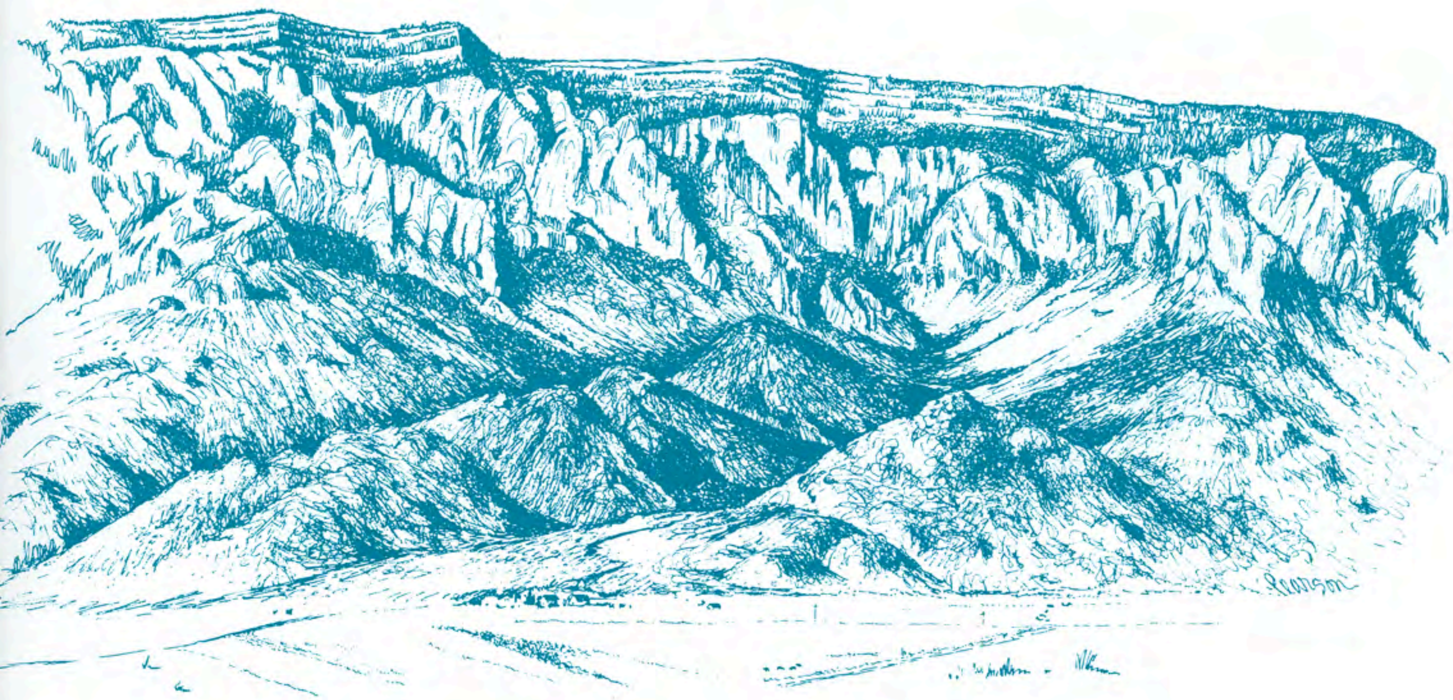
Geology of Sandia Mountains and Vicinity, New Mexico

by VINCENT C. KELLEY and STUART A. NORTHROP



MEMOIR 29 New Mexico Bureau of Mines and Mineral Resources 1975

A DIVISION OF

NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY

Geology of Sandia Mountains and Vicinity,
New Mexico

"The great tilted orogenic block composing the Sandia range, lying east of Albuquerque, is regarded as classic in this extraordinary type of mountain modeling."

—*Fayette A. Jones,* 1904, p. 1. President of State School of Mines at Socorro, 1898-1902, 1913-1917. Also, Director of Mineral Resources Survey of New Mexico which he initiated in 1915.

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Foreword

Several years ago, when the idea for this memoir was but a gleam in Vincent Kelley's eye, I allowed that, somewhere down the road, we would present the citizens of New Mexico with a worthwhile document on a most significant area. Happily, the finished product has exceeded even those expectations. The document is more than worthwhile—it is unusually important, a storehouse of geologic information. Those who seek to understand the geologic framework of their environment will be consulting this memoir for many years.

During the initial stages of writing, Vin simply wasn't satisfied with the scope of the manuscript. Typescripts shuttled back and forth, even laid idle for weeks. Paleontology and stratigraphy were important parts of the story, yet not getting the treatment needed. Then one day, he wondered out loud whether Stuart Northrop might be persuaded to come aboard as coauthor. We thought so. That idea turned out to be inspirational. It ensured the teamwork required for the success of this endeavor: Vin, the indefatigable producer and field geologist—experienced in structural geology, regional tectonics, reconnaissance mapping, mineral property evaluation, and resource development; Stu, the meticulous researcher and editor—experienced in paleontology, stratigraphy, geologic history, mineralogy, and seismology.

About a year after arriving in New Mexico, I spent a couple of weeks afield with Vin, preparing road logs for an annual field conference of the New Mexico Geological Society. From that occasion and many contacts subsequently, I have come to know him as one of the most dedicated men in our profession. (The sameness of our names is merely coincidental; we are not related.)

The coauthors are uniquely qualified to unfold the geologic record of the Sandias terrane. Their combined expertise on New Mexico geology totals 85 years, a considerable portion devoted to the Sandias and vicinity—all in association with the University of New Mexico. Both have chaired the Department of Geology; both have had a long association with the U.S. Geological Survey. No other two professors in the state have directed so many graduate theses. Their influence on the science of geology, and in the education of geologists, has been tremendous. Between them their published contributions to the literature of geology total 223 papers and books; more are in preparation. Their accomplishments, the honors conferred on them, and their professional credentials are far too numerous to list here.

The Sandia Mountains dominate the daily scene for more than a third of the population of New Mexico; the upper ridges are only 15 miles east of downtown Albuquerque. But these mountains are much more than a landmark. They contain a variety of valuable resources—geological, historical, archeological, recreational. Much of the area is in national forest with trails, campsites, picnic spots, a ski area, a stream, a scenic road to the crest, a tramway to the summit, and magnificent wildlife.

As the population of the Albuquerque region expands, so, too, will the use of the Sandia Mountains. Problems involving resources and land use are inevitable. Factual information on the geological resources is a prerequisite in solving those problems. Although this book was prepared mostly for persons interested in the earth sciences, much of the content (including the large maps in the pocket) has value for anyone concerned with either the development or conservation of the area—most particularly those who live, work, or visit there.

Robert W. Kelley
Editor and Geologist
New Mexico Bureau of Mines & Mineral Resources

Socorro
May 5, 1975

Preface

This report is in many respects a culmination of our studies of the geology of the Sandia Mountains and adjoining areas during the past 35 to 45 years. Interest in the area came easily. Its nearby location was ideal for teaching University of New Mexico field classes and directing more than a dozen thesis studies in the area. The great variety of rocks, type formations, fossils, structures, mineral deposits, and physiographic features makes the area unusually attractive.

In 1963 at the request of the Water Resources Branch of the U.S. Geological Survey, V. C. Kelley prepared a geologic map of the area, and it was published as Geologic Map 18 of the New Mexico Bureau of Mines and Mineral Resources. The immediate need for the map in water resources investigations precluded issuing an accompanying report.

During the present work Map 18 has been revised with some additions, changes, corrections, and deletion of a strip along the bordering Estancia Valley. Furthermore, the geologic map has been supplemented with a separate topographic map, a structure contour map, and a structure sections plate.

The text and map draw freely on the reports of many students who have worked under us. In particular we wish to single out Jerome E. Anderson, Bert N. Brown, John J. Bruns, Paul A. Catacosinos, Thomas A. Fitzgerald, Earl P. Harrison, Phillip T. Hayes, Richard B. Lodewick, Howard Milligan, Charles H. Phillips, Charles B. Reynolds, John W. Shomaker, Arthur H. Stukey, Jr., Ernest Szabo, Tommy B. Thompson, Donald F. Toomey, and Gordon H. Wood, Jr. Those whose works were guided by others are credited in the text where appropriate.

In the University Department of Geology J. Paul Fitzsimmons is acknowledged for discussions concerning the Sandia Granite and the orbicular rocks, Wolfgang E. Elston for certain points regarding the mineral deposits, and Douglas G. Brookins for information on radiometric dates obtained on the Sandia Granite. Francis C. Koopman gave us specimens of the orbicular granites and allowed us to photograph large slabs. During preparation of the maps and numerous line drawings William E. Hale of the U.S. Geological Survey made certain facilities and equipment available. Very special appreciation is due our long-time friend, Charles B. Read of the U.S. Geological Survey. Mr. Read did or supervised much of the first modern work on the stratigraphy of the area, and we have benefited from not only his work and publications but also from association and many conversations with him. Up-to-date generic assignments of many fossil species were kindly provided by William A. Cobban, Donald A. Myers, Norman F. Sohl of the U.S. Geological Survey, and Erle G. Kauffman and Leo J. Hickey of the U.S. National Museum. A. K. Armstrong of the U.S. Geological Survey provided information on the Mississippian in advance of publication.

Sergius H. Mamay of the U.S. Geological Survey supplied information on both the fauna and flora of the Kinney clay pit, as did Sidney R. Ash of Weber State College. Jiri Zidek of the University of Oklahoma let us see a manuscript on fishes in advance of publication. Frank M. Carpenter of Harvard University sent information on insects; Frederick R. Schram of Eastern Illinois University provided data on two shrimps and a myriapod in advance of publication. Robert C. Burton of West Texas State University made a special study of conodonts.

Howard J. Dittmer of the University Biology Department assisted with popular names of Upper Cretaceous plants. George A. Agogino of Eastern New Mexico University provided references and comments on the age of Sandia points.

U.S. Forest Service officials have been helpful in several ways, and in particular we wish to acknowledge Wallace L. Lloyd, Jack R. Miller, and Tom Smiley. Others who have helped in various ways are Gilbert R. Griswold of Chapman, Wood & Griswold, Inc., Harry J. Javernick and Walter J. Ames of Ideal Cement Company, Edward E. Kinney of Kinney Brick Company, William Vanderslice of Southern Union Production Company, and Edward C. Beaumont. Charles H. Lembke and Clark M. Carr provided some recollections concerning events in the Hagan area. Ruben Cobos of the University Modern Language Department provided some critical help with derivation and spelling of a Spanish name.

As in many instances in the past, the University Research Allocations Committee granted funds for typing, supplies, photography, and minor field expenses. Most importantly, however, this report would likely not have been undertaken or completed without considerable encouragement and financial assistance by the New Mexico Bureau of Mines and Mineral Resources. Bureau draftsmen also prepared the illustrations and made numerous minor revisions on the new geologic map accompanying this memoir.

Vincent C. Kelley
Stuart A. Northrop
Professors Emeriti
University of New Mexico

Albuquerque
September 1974

Contents

(*Tables and Figures follow*)

TABLES

FIGURES

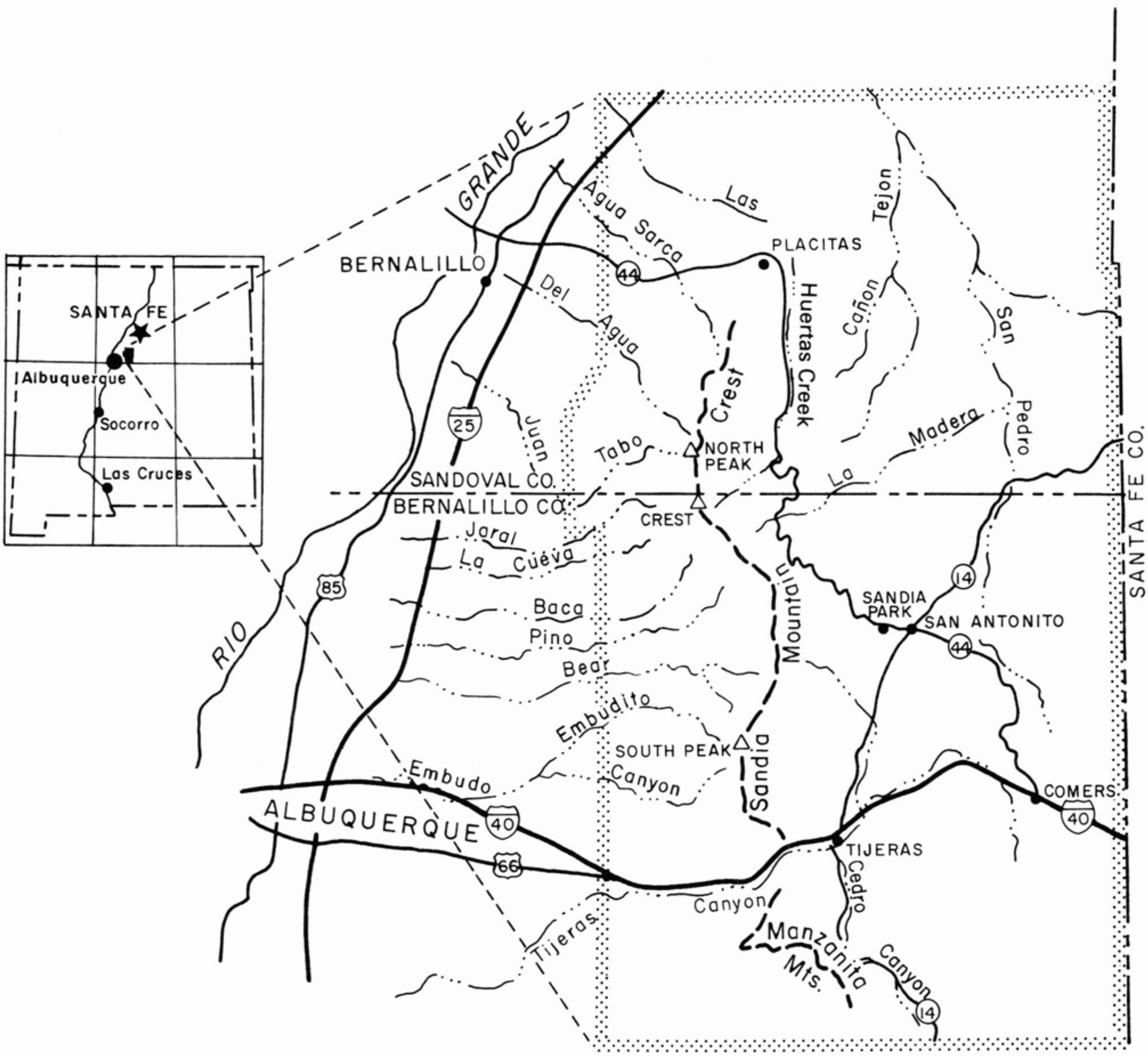


FIGURE 1—LOCATION MAP

Abstract

The Sandia Mountains area is dominated by an eastward-tilted fault block that stands imposingly above the deep Rio Grande trough on the west. Structural relief from uplift to trough is as much as 6 miles; into the basins to the east and northeast relief is 2.5 to 5 miles. The most unusual structure of the area is the Tijeras rift belt bounding the uplift on the southeast. This belt, 2 to 3 miles wide, 16 miles long, and trending northeastwards, consists mainly of two longitudinal parts: a southwestern folded graben and a northeastern horst. Tijeras rift belt is principally a Laramide feature as are a few other faults along the eastern flank of the late Tertiary Sandia uplift.

Precambrian rocks, prominent in the bold western fault scarp, consist of granite, gneiss, schist, quartzite, and greenstone. Sedimentary rocks range in age from Mississippian to Cretaceous within and immediately flanking the mountains. Thick sequences of early and late Tertiary sediments lie in order above the Cretaceous in the Hagan basin northeast of the uplift. The section is 16,000 ft thick exclusive of the late Tertiary and Quaternary trough-filling Santa Fe Formation.

The long east- to northeast-tilted homocline from the Sandia uplift into the Hagan basin contains most of the formations of central New Mexico, and is the most complete sequence in the state. Stratigraphic units consist of 1) marine Mississippian and Pennsylvanian shelf beds, 2) continental Permian, Triassic, and Jurassic red beds formed under flood-plain, evaporitic, lacustrine, and eolian environments, and 3) intertonguing marine and flood-plain Cretaceous beds of the Rocky Mountain geosyncline.

Introduction

LOCATION AND AREA

The Sandia Mountains area covers 400 square miles within six 7.5-minute quadrangles east and northeast of Albuquerque (fig. 1). The Sandia Range is the dominant feature, but part of the Manzanita Mountains south of US-66, Tijeras basin, Monte Largo (east of the Sandias), Hagan basin (northeast of the Sandias), and an edge of the Rio Grande depression are all included in the geologic map (map 1, pocket) and text. Two principal highways, Interstate 40 (including US-66) and NM-14 roughly quarter the area. Additionally, NM-44 crosses the northern part of the mountains and provides access to the crest.

The area contains most of the significant Paleozoic to Cenozoic stratigraphic units and a varied representation of the Precambrian rocks of central New Mexico; important stratitectonic relationships are observable there that bear on the understanding of the origin of the Rio Grande depression and of the Sandia Mountains. The area is particularly important to Albuquerque, the major city of New Mexico, with respect to environment, recreation, urban development, and esthetics.

PHYSIOGRAPHY

The Sandia Mountains are an eastward-tilted fault block with large and spectacular outcrops of Precambrian crystalline rocks exposed along the steeper western side (fig. 2). The crest and eastern slope of the range are capped by Paleozoic sedimentary rocks. This difference in the nature of the rocks, together with the youthful fault scarp, have given rise to numerous physiographic features for the eastern and western slopes. Furthermore, due to structural differences in the terminations of the range, the northern and southern areas have markedly different physiographic features (map 2, in pocket, and fig. 3). Altitudes along the crest vary from about 9,200 ft to 10,678 ft. Altitudes along the western base vary from about 5,800 ft near Four Hills to about 7,000 ft near Juan Tabo; along the eastern side the range is from about 6,300 ft near Tijeras to about 6,900 ft near San Antonio and La Madera. For a summary of the climate and vegetation see Anderson (1961).

DRAINAGE

Drainage of the Sandia Mountains area is semiradial westward to the Rio Grande. Three major stream systems, Las Huertas, San Pedro, and Tijeras, drain the eastern or backslope area (fig. 4). Las Huertas drains the backslope northward from Sandia Crest; San Pedro, the slope between the crest and a point on the ridge divide east of Bear Canyon; and Tijeras, the southern back-slope including the Manzanita Mountains. Ten principal stream networks drain the western face and adjoining mesa or bajada. These are from north to south: Agua Sarca, Del Agua, Juan Tabo, La Cueva, Baca, Pino, Bear, Embudito, Embudo, and Tijeras.

Tijeras drainage is unique because its tributaries

Photo by Donald A. Myers

FIGURE 2—Airview of tilted Sandia uplift, looking south. Estancia Valley in far distance. Crest is capped by strongly ledged Madera Formation (Pennsylvanian), beneath which is Sandia Formation (also Pennsylvanian) forming brush-covered slope above bold Precambrian granite cliffs.

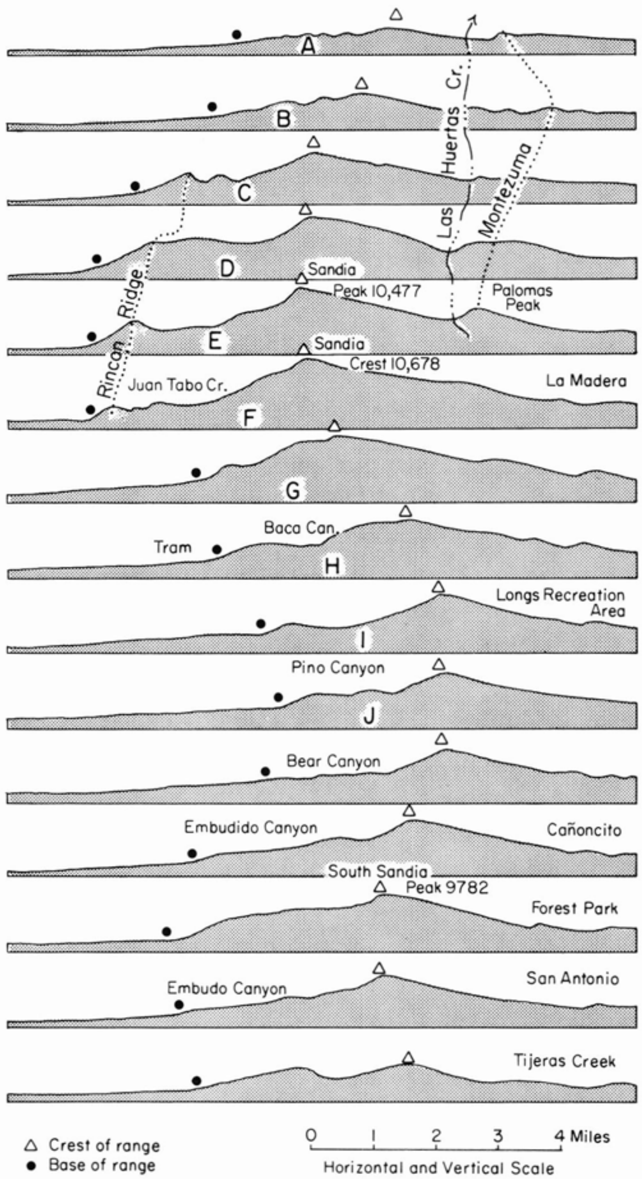


FIGURE 3—SERIES OF 15 PROFILES OF THE SANDIA MOUNTAINS, EACH ABOUT 1 MILE APART, FROM 1 MILE SOUTH OF PLACITAS TO NEAR TIJERAS.

drain both the front and back sides of the mountains. Its course was either established before mountain-building began, or early during uplift along a low, weak structural zone across the axis of the uplift. Not draining the Sandia Mountains is a portion of the Estancia Valley drainage in the southeastern part of the map area. Landforms within these drainage basins have distinctive features based upon structure, rock composition, precipitation, vegetation, and altitude.

WEST SIDE CANYONS

The 9 other west side drainages form contiguous, steep and short canyon systems. Their sharpness and vigorous erosion is in response to the rising fault escarpments, and their erosive power has largely determined the position of the crest of the range. Each canyon system (for example, Embudo) consists of numerous short tributaries which funnel out of the mountain front onto the alluvial piedmont plain along the base of the range. As the piedmont is mostly on the downthrown subsiding basin west of the fault, the gradient of the stream decreases abruptly and the canyon no longer confines it. As a result the tributary collecting system of canyons turns into a distributary system or alluvial fan on the piedmont. Each of the S canyons has an alluvial fan and the coalescence of these has formed the piedmont. This feature is locally referred to as East Mesa or the East Heights. Some of the complications of this surface are discussed in connection, with the landforms of Tijeras Canyon.

A canyon such as Bear or Embudo, when followed mountainward, branches into right and left tributaries each dividing into successively smaller subtributaries with the result that the whole system is eroded intc slopes. Farther into a canyon system the subcanyons become smaller, steeper, and higher in elevation. In the lower reaches of a canyon system the spurs apd ridges tend to be rounded; weathering is deeper; and the granitic rock which predominates weathers into large rounded or spheroidal residual boulders (fig. 5). In the higher and steeper areas more severe weathering by frost action creates a more angular, craggy terrain will fewer rounded residuals.

The mouths of the 9 principal canyon systems that dissect the western escarpment are spaced from 1 to 4 miles apart. The lower part of the escarpment between canyon mouths shows little, and in places no, dissection These less dissected areas with straight range fronts formed by youthful or actively rising fault blocks, are *triangular fault facets* (fig. 54). Such landforms may be noted between Embudo and Embudito Canyons (be. tween the eastern ends of Candelaria and Menaul Boulevards). The triangular fault facets are best seen during the winter in morning light. The best or freshest of these remnant fault facets is east of Juan Tabc Canyon, north of La Cueva Canyon and near the La Luz trail (fig. 53).

The great cliff faces of the high part of the range epitomize the grandeur of the Sandias. The greatest array of faces occurs from Pino Canyon northward; outstanding is the great *Shield* (fig. 6) jutting westwarc near the divide between Juan Tabo Canyon (south) and Del Agua Canyon (north). Of almost equal prominence are the great walls west of the crest, where several knobs of granite such as the *Needle* and the *Thumb* surmount the great faces. They are well known to mountain climbers; excellent photographs and descriptions of these features as well as approaches to them have been given by Kline (1970). Only a few granitic faces occur in the lower Pino Canyon-Bear Canyon section of the range, although thick Madera limestone ledges form strong cliffs. Around South Sandia Peak the granite again forms bold cliff faces surmounted by small knobs, locally approaching the magnificence of the northern area.

TIJERAS CANYON

Tijeras Canyon bounds the Sandia uplift on the south and the lower Manzanita Mountains on the north. Like most of the other west side canyons, Tijeras enters eastward into the mountains in granitic terrain. About halfway through the range the canyon passes into and follows, a northeast-trending fault and weak-rock zone

FIGURE 4—DRAINAGE BASINS OF SANDIA MOUNTAINS AREA.

to the back side where the canyon splits into two principal forks along fault zones. Where Tijeras Canyon first encounters the weak structural zone an anomalous side fork branches acutely backward to the southwest on line with the main canyon running northeast. This sharp fork, coupled with an on-line fork on the east side of the mountains forms an acutely crossed or scissor-shaped canyon system. Early explorers, noting this arrangement, applied the Spanish word *Tijeras,* meaning scissors.

FIGURE 5—SANDIA GRANITE, FRESH AND WEATHERED OUTCROPS. ABOVE ROADCUT ALONG I-40, SEC. 25, T. 10 N., R. 5 E.

Erosion of the Tijeras system on the east side of the Sandias is into formations of diverse composition and hardness along with faults and folds. As a result the canyon system is marked by straight and curved alternating hogback ridges and valleys with erosion corresponding closely to structure and rock composition. North of 1-40, where folds are present, landforms resemble the Ridge and Valley country of middle Pennsylvania; south of 1-40 where beds dip more gently, as in the Cedro Canyon area, landforms resemble parts of the Allegheny Plateau of western Pennsylvania.

SAN PEDRO CREEK AREA

The northeastern side of the Sandia Mountains is drained by San Pedro Creek. The large system of tributaries of San Pedro Creek includes everything north of a low divide about one mile south of Antonito; all the country along NM-14 north to Golden; the northern side of Monte Largo; the east slope of the Sandias between Armijo and La Madera Canyons; and the Hagan coal basin area. As in the northern part of the Tijeras drainage, landforms are mainly ridges and valleys adjusted to the composition and structures of the stratified bedrock, except in the eastern Hagan basin

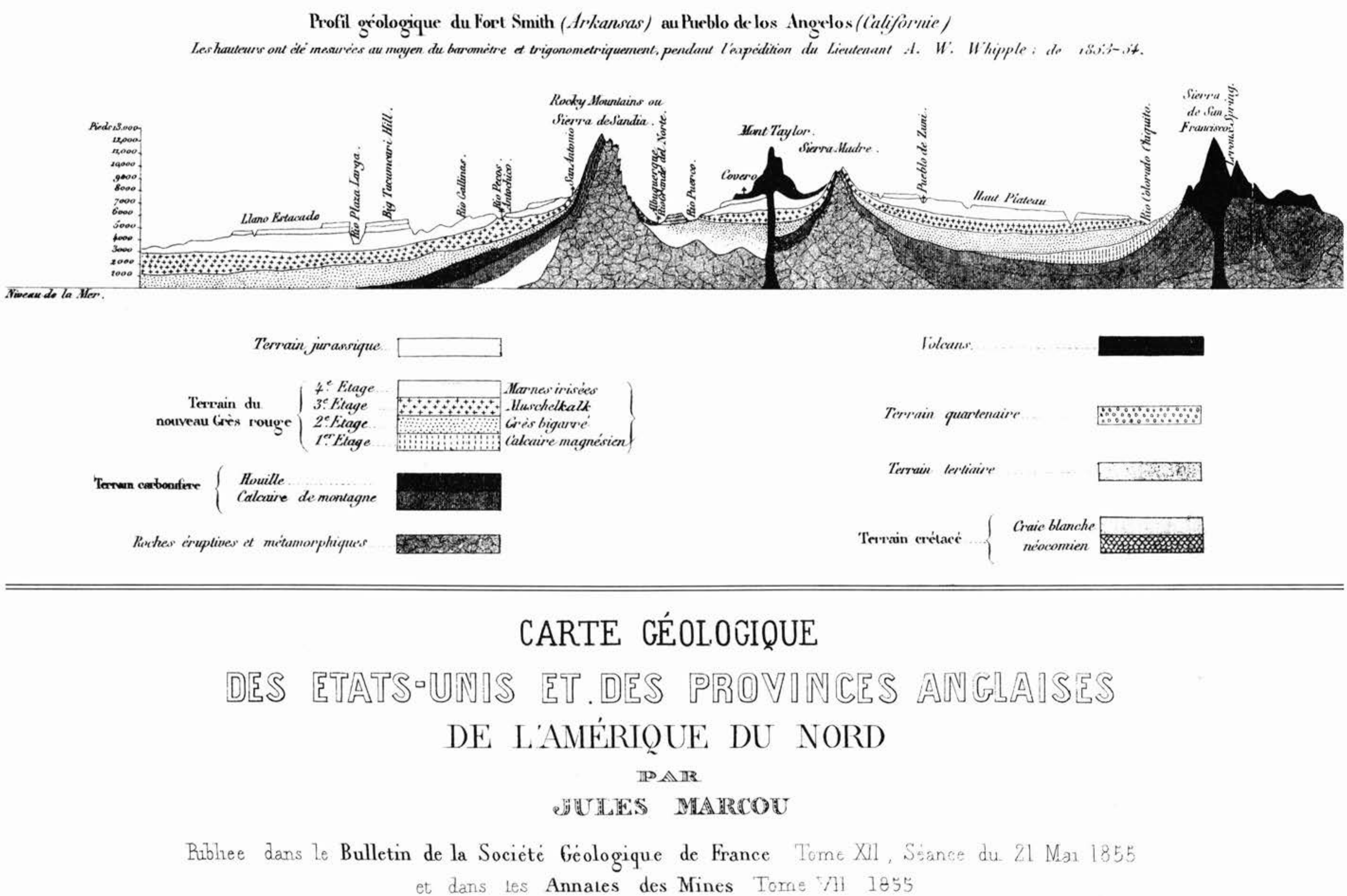


FIGURE 7—CENTRAL PART OF MARCOU'S GEOLOGIC PROFILE (1858 COLOR LITHOGRAPH). TEXAS ON LEFT (EAST), ARIZONA ON RIGHT (WEST). *Eruptive and metamorphic rocks*, PRECAMBRIAN; *carbonifère* IS PENNSYLVANIAN; *nouveau Grès rouge* IS NEW RED SANDSTONE, OR TRIASSIC; *jurassique* IS JURASSIC AND, IN PART, LOWER CRETACEOUS; *crétacé* IS UPPER CRETACEOUS.

FIGURE 6—THE GREAT GRANITE *Shield* AND *Thumb* SURMOUNTED BY CRESTAL PENNSYLVANIAN BEDS. YOUTHFUL JUAN TABO CANYON CUT THROUGH RINCON RIDGE OF MICACEOUS QUARTZITES IN FOREGROUND.

and in some of the eastern tributaries of the system. In this area and extending to NM-14 the folded Mesozoic beds were covered in early Pleistocene time by the expansive Ortiz pediment gravel. Subsequent erosion of this homogeneous blanket resulted in a partially dendritic canyon system superposed across the underlying beds, uninfluenced by structure or rock character.

LAS HUERTAS CANYON

Las Huertas Canyon enters the northern end of the mountains and follows a south-trending fault zone between the uplifted Montezuma Mountain block (east) and the main Sandia block (west). The canyon is long and narrow and abruptly terminates against Capulin Peak ridge near Palomas Peak. Tributary canyons east of Las Huertas are steep and short; those to the west are long and relatively shallow up the dip slope toward Sandia Crest.

SANDIA RIDGE AND DIP SLOPE

The Sandia crest line is 13 miles long from Tijeras Canyon to its plunging northern terminus near Placitas. Two principal eminences stand out on the ridge profile, Sandia Crest (10,678 ft) including the adjoining high Sandia Peak (10,447 ft) and South Sandia Peak (9,782 ft). The ridge line is broadly convex eastward in the vicinity of the Pino Canyon-Bear Canyon embayment which appears to be due to a frontal fault jogging into the uplift. As a result the same erosional slope up the escarpment intersects lower elevations on the uniform dip slope of the east side of the Sandias. However, the Pino Canyon-Bear Canyon reentrant is not the only contributing factor. The high ridge line at Sandia Crest is due partly to the protection from erosion afforded by the jutting Rincon Ridge west of Juan Tabo. Additionally a number of cross faults concentrate in the reentrant area, and fracturing related to them may aid erosion.

SANDIA PIEDMONT

This surface consists of two principal parts. Next to the mountain front is an irregular border cut on the uplifted Precambrian bedrock. At the mouths of canyons, these rock surfaces are referred to as rock fans (Johnson, 1932) because often they are the apices of the more extensive alluvial fans. The bare rock surfaces have local patches or narrow strips of alluvium that is being swept across the bedrock to the alluvial plain. The outer margins of the bare rock pediment are gradational into the alluvial fans by thin veneers of sand and gravel that are temporarily resting during their transport down the slope. West of the bedrock border the surface is underlain by a blanket of sand and gravel which thickens away from the uplift. Where the sand and gravel is tens of feet thick erosion only rarely exposes bedrock; this part of the piedmont is largely formed by aggradational deposition. The entire surface outward from the mountain including the aggradational outer part as well as the near-mountain rock fans and alluvial fans is referred to as a *bajada*. Commonly, truncated faults related to the uplift or the margin of the subsiding basin lie beneath the bajada. West of these faults the thickness of gravel may suddenly increase to tens, hundreds, or, in some instances, thousands of feet.

Coalescing alluvial fans along the base of the Sandias have built a piedmont plain that descends toward the axis of the Rio Grande valley. Normally the drainage would consist of a system of partly braided distributaries, flowing to the Rio Grande, but this system has been modified considerably by late Pleistocene cutting of an inner valley by the Rio Grande. As a result the distributary streams leading to the Rio Grande have been incised, especially near the inner valley. Tijeras Creek which has a larger volume of runoff than the others has been incised all the way to the mountain front and well into the mountains.

The incision process results in interlocking of new tributaries as they erode headward into the older distributary system. During the process there are numerous diversions and captures by the younger system.

MARCOU'S 1853 SURVEY

In 1853 the Congress authorized explorations for a railroad route to the Pacific coast. Several parties were sent out in the spring of 1853 by the Secretary of War, Jefferson Davis. According to Northrop (1962, p. 36),

> . . The French-Swiss geologist, Jules Marcou, accompanied Lieut. A. W. Whipple on his expedition along the 35th parallel, which left Fort Smith, Arkansas on June 16, 1853, traveled across the Texas Panhandle, and reached Tucumcari Sept. 22. Here Marcou found an abundance of oysters, noting "I have seen there myself at least two or three thousand," which he took to be a variety of *Gryphaea dilatata*, a characteristic species of the Upper Jurassic Oxford Clay of England. He later named his new variety *Gryphaea dilatata tucumcarii* and in a paper read before the Societe Geologique de France claimed to have discovered the first Jurassic rocks and fossils in all of North America. (Ironically, we now regard the Tucumcari outcrops as Lower Cretaceous, not Upper Jurassic.)
>
> The expedition continued westward, reached Cerrillos Oct. 3, Albuquerque (population of 2,500 in the town and its environs) Oct. 5, and Tijeras Canyon, Oct. 8. Marcou and Dr. John Bigelow, the botanist of the expedition, started the ascent of the east slope of the Sandia Mountains Oct. 8 and achieved the crest on Oct. 10. Marcou collected Pennsylvanian and Cretaceous fossils from several localities in the Albuquerque-Galisteo-Pecos area. In 1854 Marcou became ill and decided to take all his fossils, minerals, and rocks to France and work up his report there. He packed up and prepared to sail. This proposal displeased Jefferson Davis, who insisted Marcou stay

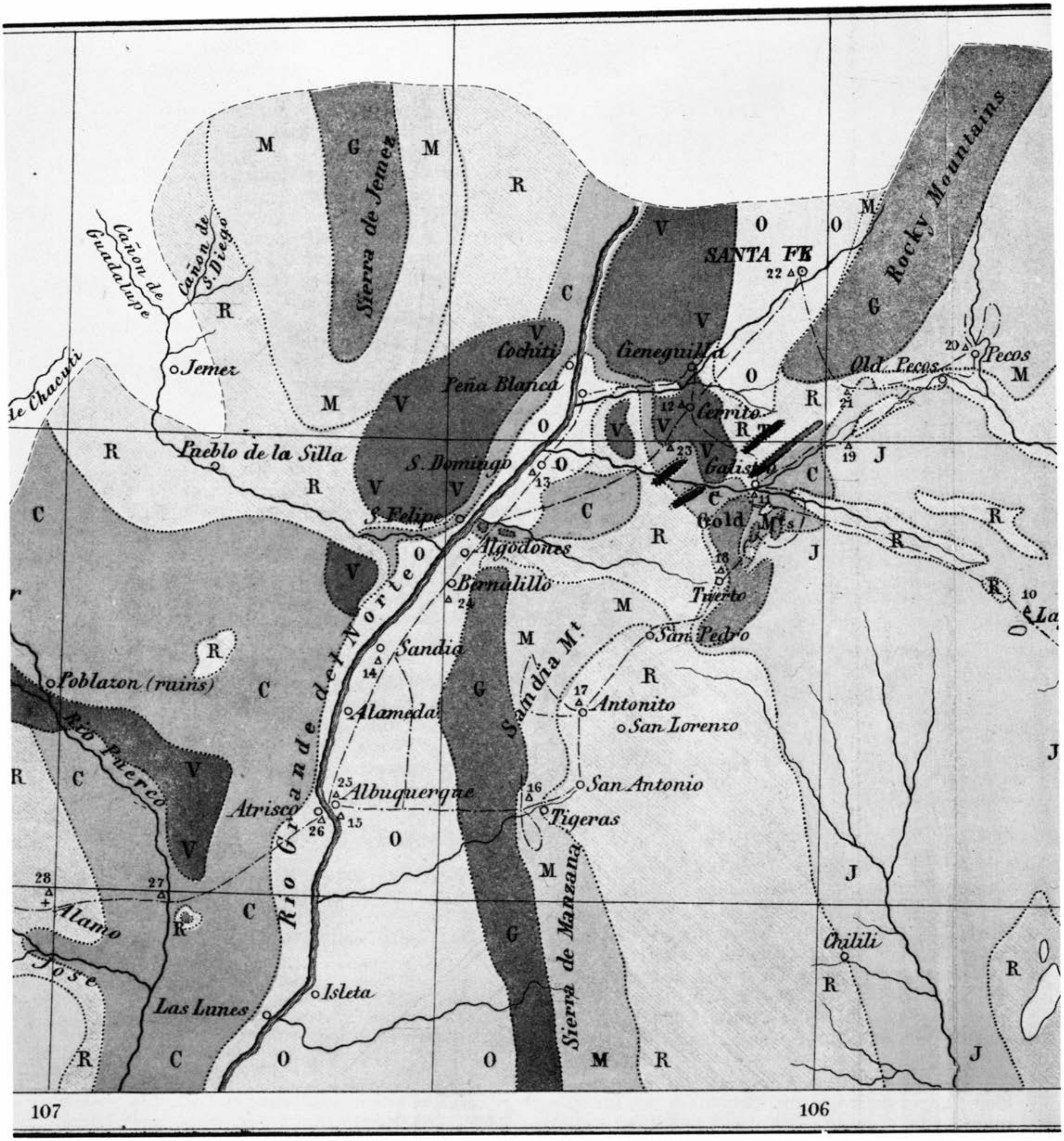
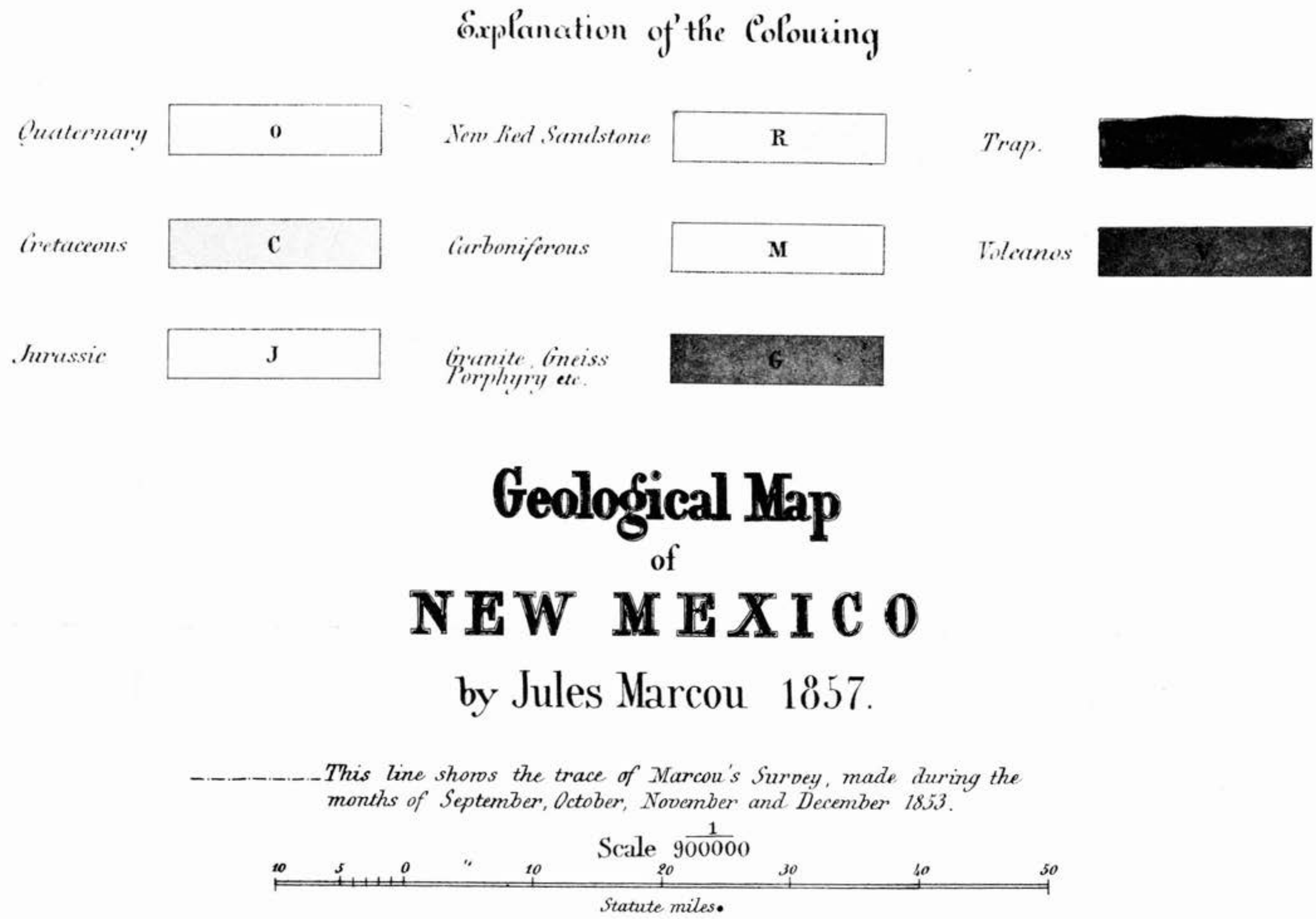


FIGURE 8—Part of Marcou's geologic strip map of New Mexico between lat. 35° 00′ and lat. 35° 30′ (1858 color lithograph). Triangles represent campsites; dashed lines, the route traversed.



in this country until he had completed and submitted his report. But Marcou sailed and was then ordered to turn his collections over to the U.S. Ambassador in Paris. This he eventually did only in part; *some* of the fossils and apparently *most* of the rocks were returned to Washington and given to [W. P.] Blake, who studied the rocks and sent the fossils to James Hall at Albany for identification. Hall appears to have received *part* of the collections from Pecos but not those from Tijeras Canyon or the Sandia Mountains. In 1856 the WhippleBlake-Marcou report was published as a Congressional Document; Marcou's field notes in French are given in left-hand columns and a translation by Blake in right-hand columns.

Marcou published several papers written in French [and German] in various journals during the period 1854-1857 and, in 1858, a book written in English, modestly entitled *Geology of North America* and containing a chapter, "Geology of New Mexico." The book was printed in Zurich and contains hand-colored maps and descriptions and excellent lithographed illustrations of a number of new species of Pennsylvanian and Upper Cretaceous fossils.

William P. Blake (1856) prepared a report on the geology of the route, based on Marcou's field notes and collections. Accompanying that report is a geological strip map, 36 inches long and lithographed in several colors, between latitudes 34° and 36°N, extending from the Mississippi River near longitude 91°W to Los Angeles and the Pacific Ocean near longitude 118°W. The map is entitled

> "Geological map of the route explored by Lieut. A. W. Whipple, Corps of Top) Eng.rs near the parallel of 35° north latitude from the Mississippi River to the Pacific Ocean, 1853-1854; Prepared in the office of Pacific Rail Road Explorations and Surveys War Dept.mt, From the notes and collections of the geologist of the expedition, M.[r] Jules Marcou, by William P. Blake."

The scale of the map is 1 inch = 47 miles. Camps shown in our area include 57, south of Galisteo; 58, San

Antonio; 59, Albuquerque, but curiously this name is omitted.

Blake's report was also accompanied by a geological cross section from the Mississippi River to the Pacific Ocean, 32 inches long and lithographed in several colors, prepared by Marcou; a quaint feature of this cross section is that tiny U.S. flags are used to designate campsites.

Better maps and cross sections were published by Marcou in 1858.

The complete title of Marcou's (1858) book is

> Geology of North America; with two reports on the prairies of Arkansas and Texas, the Rocky Mountains of New Mexico and the Sierra Nevada of California, by Jules Marcou, professor of geology in the Federal Polytechnic School of Switzerland; formerly United States geologist; and ex-geologist of the "Jardin des Plantes" of Paris.

The frontispiece of the book is a color-lithographed geologic map of the United States entitled

> Carte géologique des Etats-Unis et des provinces anglaises de l'Amerique du Nord, par Jules Marcou, publiée dans le Bulletin de la Societe Geologique de France, Tome XII, Seance du 21 Mai 1855, et dans les Annales des Mines, Tome VII, 1855.

At the top of this map is a 20-inch long, east-west geologic cross section, entitled *Profil geologique du Fort Smith (Arkansas) au Pueblo de los A ngelos (Californie),* also lithographed in several colors. The central part of the cross section, showing New Mexico, is reproduced here as fig. 7.

Plate 8 of Marcou's (1858) book is *Geological map of New Mexico,* dated 1857, lithographed in several colors except one color (dark brown) was applied by hand. This strip map, 23 inches long and 5 inches high, extends along latitude 35°N from longitude 103°W (east of Tucumcari) westward nearly to 109° (near Zuni and Fort Defiance). The scale is 1 inch = nearly 15 miles, which is three times larger than the scale of the map mentioned above that was published by Blake (1856). A dashed "line shows the trace of Marcou's Survey, made during the months of September, October, November and December 1853." The central part of the map is reproduced here as fig. 8. Small triangles indicate campsites, numbered 1 to 38. Note camps 14 and 15 at Albuquerque, 16 at Tijeras, 17 at Antonito, 18 at Tuerto (Golden), 19 east of Galisteo, and 20 at Pecos. At camp 17, note the side trip to Sandia Crest.

Marcou (1858, p. 20-22) wrote about the expedition heading westward through Tijeras Canyon,

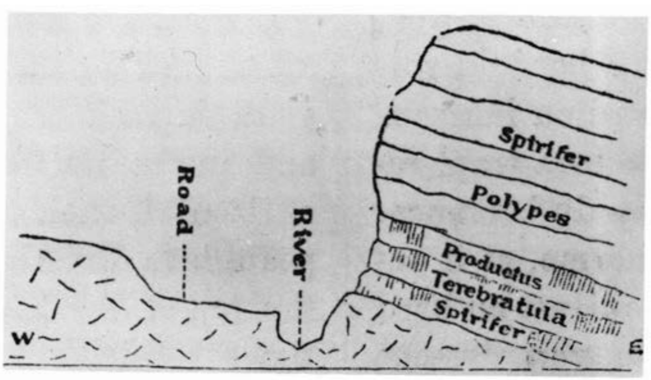
> Immediately on leaving the village of Tigeras [sic], which is situated in the middle of the Pass that crosses the Rocky Mountains, called here Sierra de Sandia, also Albuquerque Mountains; black schistose clay is seen, belonging to the *Coal-measures,* then grayish blue limestone, containing a great quantity of fossils. These last strata of schist and limestone are very much upheaved, dipping to the East at an angle of 30 or 40 degrees; they rest on metamorphic rocks. The principal fossils found in the limestone, which belongs to the *Mountain Limestone* or *Lower Carboniferous, are: Productus semi-reticulatus, P. cora, P. Flemingii, P. punctatus, P. pustulosus* and *P. pyxidyormis; Terebratula plano-sulcata; Spinier lineatus, S. striatus; Amplexus coralloides; Zaphrentis Stans-buryi;* all fossils very characteristic of the *Mountain Limestone* of Arkansas, Missouri, Iowa, Illinois, Indiana, Kentucky, Tennessee, Virginia and Pennsylvania, as well as in Europe, and even in Asia, Australia and South America. . . . On quitting the last beds of limestone that rest upon the *Quartzose Metamorphic Rocks, we* find *Serpentine;* then we come upon masses of *Granite,* which form the centre of the line of dislocation of the Rocky Mountains.

In a lengthy footnote (p. 20-21), Marcou adds:

> Having reached Albuquerque, New Mexico, the 5th October 1853, the expedition remained there until the 10th November, to recruit the strength of the party and prepare for crossing the Californian desert. I profited by this interval to explore the country comprised between Albuquerque, San Antonio, Pecos and Santa Fe; and the 8th October I started with my friend Dr. John Bigelow, the botanist of the expedition. to ascend the highest peak of the Sierra de Sandia. . . .
>
> In this exploration, which continued until the 20th October, I studied with attention the rocks of San Antonio Pass, of Antonito and of the Summit of the Sierra de Sandia, also those of the environs of the villages of San Pedro, Tuerto, Galisteo and Pecos. The ascent of one of the most elevated Summits of the Rocky Mountains,—which after all is not a very easy matter, considering the wilderness, the difficulty of the roads and the fear of the Apache Indians—was effected by Dr. Bigelow and myself the 10th of October 1853. We chose the most elevated point of the Sierra de Sandia seen from Albuquerque, which attains the height of 12,000 feet above the level of the sea. The culminating points of all this Sierra are composed of *Carboniferous Limestone,* which here merits most truly its name of *Mountain Limestone,* for it is the only limestone of any importance met with in the Rocky Mountain region. From the five or six upper beds, I collected the following fossils: *Productus Cora, P. scabriculus, P. Flemingii; Zaphrentis cylindrica, Z. Stansburyi* and *Orthoceras NovaMexicana.*
>
> In going from Albuquerque to San Antonio, in the middle of the Pass or Cañon of San Antonio, 10 minutes from the village of Tigeras, there is a bluff of *Mountain Limestone* on the right of the road, forming a grand perpendicular wall. [This was at Seven Springs.] Fossils abound in the strata of this bluff, and I collected the following species: *Productus semireticulatus, P. Cora, P. Flemingii; P. punctatus, P. pustulosus, P. pyxidformis; Terebratula plano-sulcata, T. subtilita; Spinier lineatus, S. striatus, S. Rockymontani; Amplexus coralloides* and *Zaphrentis Stansburyi. . . .*
>
> The mean thickness of the *Mountain Limestone* of the Rocky Mountains in the region environing Santa Fe and Albuquerque is 700 feet.

Marcou's field notes, translated by Blake (1856, p. 141-143), read:

> *October 8.—From Albuquerque to Camp A, below Tejera.* — On going easterly from the Rio Grande, we travel ten miles on the alluviums of the Rocky mountains; then, before entering the cañon of San Antonio, we found outcrops of blackish-grey granite, with hornblende and large crystals of white feldspar, sometimes yellowish. These exposures of granite are three miles wide. Then, after passing the inhabited ranchos, we have a rose-colored granite, with but little feldspar, and dykes of rosy-white quartz; finally, a green serpentinoid trap, containing strata of metamorphic limestone of Devonian age, and, in contact with this green rock, the Mountain limestone or Lower carboniferous. At Camp A we have the following section:



The serpentinoid trap is in contact with the limestone of the inferior carboniferous, which dips to the east at an angle of from thirty-five to forty degrees, the heads of the beds turning towards the west. The trend is north and south, or from three to five degrees E. of N. This limestone is greyish-blue, sometimes black; very compact, with a conchoidal fracture, and sometimes breaks easily when it contains a lumachelle of fossils. Some strata of very thin and black clay shales are intercalated. This limestone has a thickness of three hundred feet. It is said that a short distance further south it contains beds of bituminous coal. The fossils are not very abundant or well preseved. I gathered principally the *Productus giganteus* and *punctatus, a Spirifer,* and two *Terebratulae* and *Polypi;* fragments of the stalks of encrinites forming marble--[?]; and many small *Producti,* the species *Cora.* From the camp at Tejera we have constantly on our right, for the distance of a mile, this carboniferous limestone, then in the village we again meet the Trias with all its divisions. Behind San Antonio, near Antonitto [sic], we have white gypsum of the Trias; all the beds dip to the east at angles of from twenty to forty-five degrees.

October 9.—From Camp A, Humboldt, to Camp B, Douglas, or Antonitto.—We have the inferior Carboniferous as far as Tejera village, where, as the Trias, the coal has been too much compressed and does not appear. The carboniferous has a thickness of two thousand feet (2,000,) the Trias four or five thousand (4,000 or 5,000.) Behind San Antonio we find white gypsum, and all our route, as far as Camp Douglas, is on the Trias. Alluvium from the mountains, and without striated pebbles. We have immense erratic blocks.

October 10.—We ascended the Albuquerque mountains *(Sandia mountains)* 10,000 feet high. They are surmounted by the limestones of the inferior carboniferous. The direction is N. and S., and the rocks dip to the eastward at an angle of from twenty-five to thirty degrees. Gold mountain is less elevated than Albuquerque mountain. From Camp Douglas we followed for one and a half miles a cañon in the upper Trias; then we commenced with the greyish-white, blackish limestone of the carboniferous formation; the coal does not appear—it has been too much compressed. In these carboniferous rocks we found the following fossils: *Productus, giganteus* and *punctatus; Terebratulae, Spiriferae, Orthocera, Zaphrentis* and Crinoids; the *Zaphrentis* was very abundant. Coal is found further to the south, in the Manzana mountains. Several beds of black shales, four to six feet in thickness, and very thinly stratified, are found between the beds of compact limestone. Kidney-shaped masses of black silex are present in the limestone, and at the summit it is a little marly, with silex, like the limestone of Fort St. Andre. There are no visible traces of glaciers in the canons. The section is much like that seen yesterday. Some beds of very hard and rose-colored sandstone are interposed in the limestone. One of these beds is of coarse rolled grains. The limestone is the predominating rock.

Among discrepancies between the field notes made by Marcou in 1853, as translated by Blake (1856), and Marcou's (1858) account, the following may be noted. The height of the Sandia Mountains is reported to be 12,000 ft in one account and 10,000 ft in another; actually it is 10,678 ft. Apparently elevations were determined both by aneroid barometer and by surveying methods. The thickness of the *Mountain Limestone* is given as 700 ft in one account and that of the *carboniferous* as 2,000 ft in another. In the field notes Marcou cited *Productus giganteus,* but by 1858 he had decided that this form was not present.

The "Camp A, below Tejera," or Humboldt of the field notes is camp 16 (triangle) on the map; "Camp B, Douglas, or Antonitto" of the field notes is camp 17 (triangle) at Antonito on the map. "Tejera" of the field notes became "Tigeras" in 1858; modern spelling is Tijeras.

Marcou's fossils are described and illustrated in our discussion of Pennsylvanian stratigraphy.

GEOLOGICAL SOCIETY OF AMERICA ANNUAL MEETING 1907

In 1907 the Geological Society of America, joined by the Cordilleran section, held its annual meeting in Albuquerque (Northrop, 1966, p. 10, 11). W. G. Tight gave a paper on the geology of the Sandia Mountains, and a field trip was held in the Sandia-Manzanita Mountains area between Tijeras and Hell Canyons. For the occasion Dr. Tight prepared a "Sketch Map, Sandia Mountains Excursion, G.S.A., 1907" (fig. 9), showing the geology, the route, two structure sections, and a brief mileage log. The participants went from Albuquerque into Tijeras Canyon to about Seven Springs. They then returned to near Carnuel where the route followed the old trail from Santa Fe to Socorro through Garcia Canyon to Coyote Canyon, with a side trip up Coyote Canyon. They continued southward along the mountain front to about Hell Canyon before returning across the mesa to Albuquerque, a trip distance of 51 miles.

The geologic map reveals a considerable understanding of the principal geologic features. Of interest is the fact that the Cibola Gneiss is mapped as "Fine granite," the Tijeras Greenstone as "Intrusive," and the East Mesa alluvial fan and pediment gravel as "Mesa Marls." The spelling of "shist" is also curious.

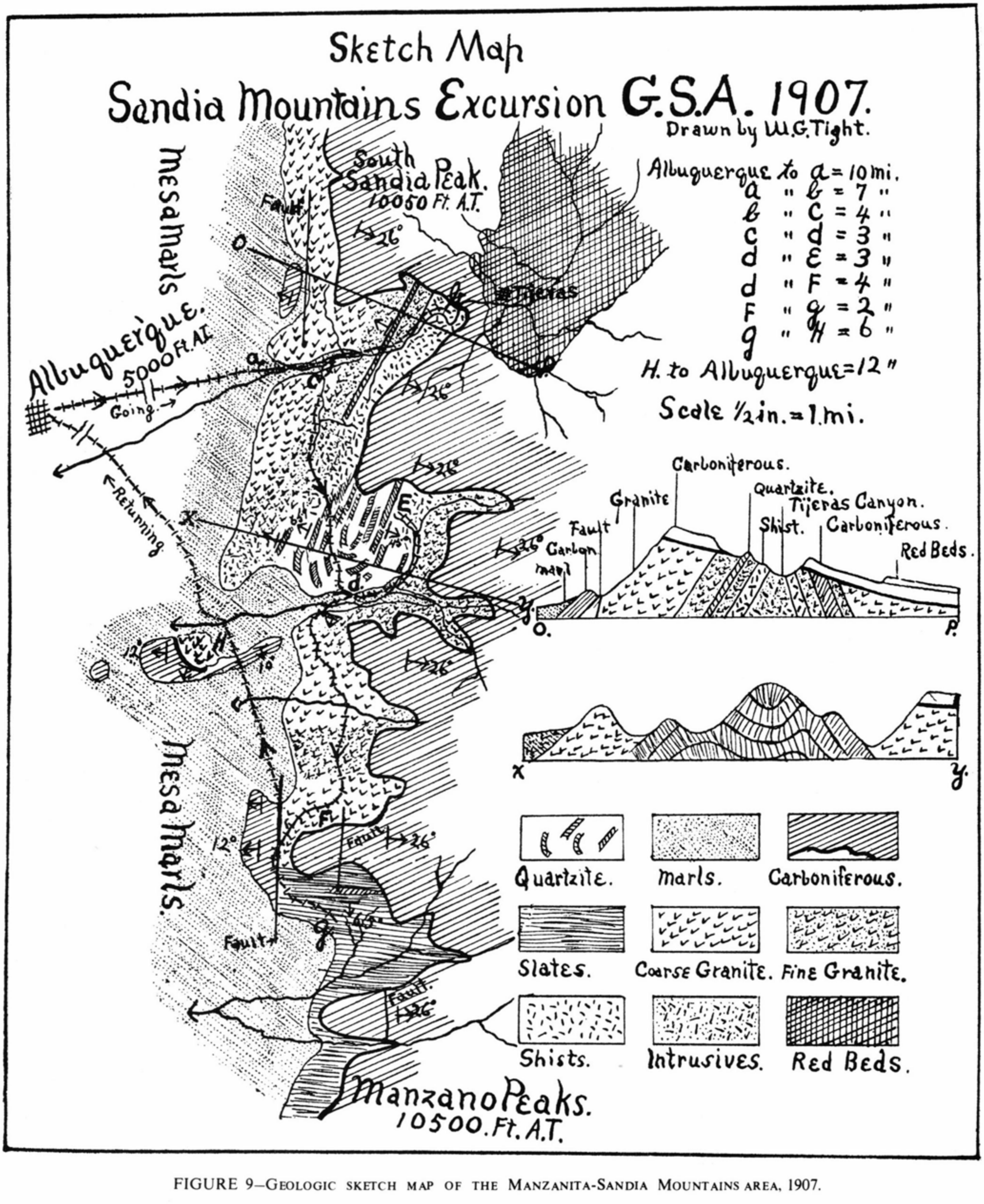


FIGURE 9—Geologic sketch map of the Manzanita-Sandia Mountains area, 1907.

Rocks and Formations

Rocks within the area range in age from Precambrian to Holocene, and include an array of igneous, metamorphic, and sedimentary lithologies. However, lower and middle Paleozoic rocks, so well represented 150 miles to the south, are completely missing in the Sandia area. Among the igneous rocks are basic to acidic types of plutonic and hypabyssal origins. Both thermal and dynamic metamorphic rocks of all the common types are represented. The sedimentary rocks are rather evenly proportioned among shale, sandstone, and limestone and are marine and continental in origin. Among the continental types are flood-plain, paludal, eolian, lacustrine, piedmont, and bolson environments. There is also considerable intertonguing of continental and marine types. Lithology and age are summarized in the stratigraphic table (fig. 10).

PRECAMBRIAN

Precambrian rocks of the Sandia Mountains and environs are scattered and diverse. The most extensive exposed unit is the Sandia Granite which predominates in the uplift. Metamorphic rocks lie in three principal areas, Tijeras Canyon and vicinity, Monte Largo, and Rincon Ridge west and northwest of Sandia Crest.

TIJERAS CANYON METAMORPHICS

Most of the lower part of Tijeras Canyon is eroded into Sandia Granite, but beginning in the NE 1/4 sec. 30, T. 10 N., R. 5 E. a northeast-trending belt of metamorphic rocks appears and occupies the Canyon nearly to Tijeras where it passes beneath Paleozoic beds. The Tijeras belt is prominent in Cerro Pelon Ridge and into Coyote Canyon along the southern edge of the area. The metamorphic sequence south of Tijeras Canyon extends southward in a nearly continuous belt along the western side of the Manzanita and Manzano Mountains (Reiche, 1949; Stark, 1956). Gneiss, schist, quartzite, and greenstone occur in distinctly separate masses except for some of the quartzite that lies within the gneiss along Tijeras Canyon. Only the petrology of the rocks is considered here. Some of the complex structural relations are explained in the chapter on structure.

The northwesternmost unit of the belt is here referred to as the Cibola Gneiss. It forms an outcrop strip up to about 0.75 mile wide by 5 miles long between the Sandia Granite on the northwest and the Tijeras fault and Tijeras Greenstone on the southeast (fig. 11). The gneiss is distinctly foliated, dipping 40 to 65 degrees northwestward toward the granite contact. Midway in the northwestern part are narrow strips of quartzite. Where present the quartzite holds up a ridge in the gneiss as seen from 1-40 just west of the big turn in Tijeras Canyon. The quartzite is as much as 200 ft thick and trends left diagonally across the belt and is truncated by the Tijeras fault. The gneiss is generally light pinkish and medium grained, and the parts either side of the quartzite are not greatly different in appearance. However, the southeastern part is slightly finer grained and Lodewick (1960, p. 13-14) noted that it contains more quartz than the feldspathic part to the northwest of the quartzite strip. Part of the difference may be due to magmatic replacements from the Sandia Granite. In order of abundance the gneiss consists of quartz, microcline, microperthite, oligoclase, and biotite with accessory magnetite, ilmenite, zircon, and sphene. The texture is uniformly gneissic and homogeneous but locally layered biotite foliation is present (fig. 12).

As the Sandia Granite is approached the gneiss becomes irregularly coarser grained and develops more

ERA	SYSTEM	SERIES	GROUPS, FORMATIONS	MEMBERS
CENOZOIC	Quaternary	Holocene and Pleistocene	Landslides Valley alluvium Terraces and pediments	
	Tertiary	Pliocene Miocene Oligocene Eocene Paleocene	Santa Fe Formation Espinaso Volcanics Galisteo Formation	
MESOZOIC	Cretaceous	Upper	Mesaverde Formation Mancos Shale Dakota Sandstone	
	Jurassic	Upper	Morrison Formation Todilto Formation: Gypsum and Limestone members Entrada Sandstone	
	Triassic	Upper	Dockum Group: Chinle Formation Santa Rosa Sandstone	
PALEOZOIC	Permian	Guadalupian	Bernal Formation	
		Guadalupian / Leonardian	San Andres Formation	Fourmile Draw Member Bonney Canyon Member Rio Bonito Member Glorieta Sandstone Member
		Leonardian	Yeso Formation	San Ysidro Member Meseta Blanca Member
		Wolfcampian	Abo Formation	
	Pennsylvanian	Virgilian Missourian Desmoinesian	Magdalena Group: Madera Formation	Arkosic limestone member Lower gray limestone member
		Atokan Morrowan	Magdalena Group: Sandia Formation	
	Mississippian	Osagean	Arroyo Peñasco Formation	
PRECAMBRIAN	*Gneiss, schist, quartzite, greenstone, granite*			

FIGURE 10—STRATIGRAPHIC TABLE.

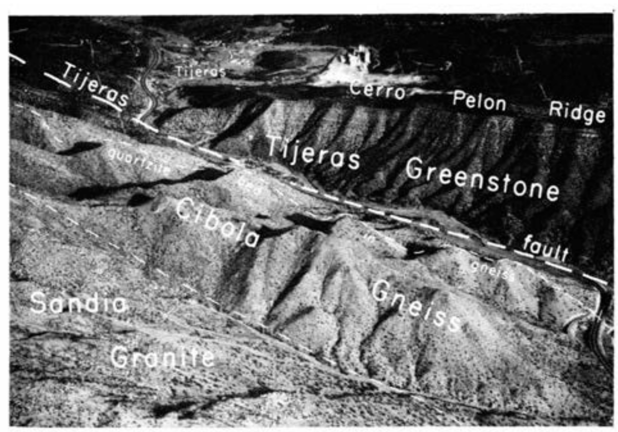


Photo by Donald A. Myers

FIGURE 11—PRECAMBRIAN BELTS ALONG TIJERAS CANYON. PENNSYLVANIAN BEDS CAP CERRO PELON RIDGE. VILLAGE OF TIJERAS AND IDEAL CEMENT PLANT BEYOND.

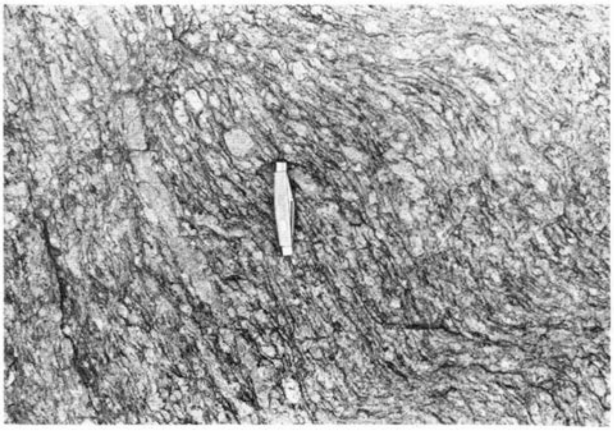


FIGURE 12—CIBOLA GNEISS OUTCROP. NEAR US-66 AND SANDIA GRANITE TRANSITIONAL CONTACT.

wavy foliation and feldspar augen (fig. 13). Some minor migmatitic structures occur locally nearing the contact; Lodewick (1960, fig. 4) delineated sillimanite gneiss near the contact. The contact with the granite is generally gradational through widths of 100 to 300 ft. Lodewick (p. 25-30) compared zircons in the gneiss and the granite and based on their differences, together with the field structural and petrographic relationships, concluded that the gneiss belt was derived from arkosic sandstone, pure sandstone (quartzite), and siltstone.

The greenstone of Tijeras Canyon is here named the Tijeras Greenstone. It occurs in a belt about 1 mile wide and 5.5 miles long between the Tijeras fault and Cibola Gneiss on the northwest and Cerro Pelon ridge on the southeast (fig. 14). Bruns (1959) mapped the greenstone and recognized several metaigneous and metasedimentary types within the belt. The greenstone is typically dark green, its texture ranging from nonfoliated to highly schistose. Foliation is generally parallel to the elongation of the belt and dips 60° to 70° SE, although there is considerable local variation from this attitude. Foliated greenstone is generally either hornblende or chlorite schist; either may predominate but they commonly occur together. Epidote, quartz, plagioclase, and calcite are also common along with lesser quantities of biotite, sericite, actinolite, and opaque minerals.

FIGURE 13—CIBOLA GNEISS SAMPLE. NEAR GRANITE CONTACT, CENTER OF SEC. 20, T. 10 N., R. 5 E. DARK STREAKS ARE BIOTITE; MEDIUM-GRAY BANDS ARE AUGEN OF POTASH FELDSPAR; WHITE STREAKS ARE PLAGIOCLASE; QUARTZ IS NOT READILY DISTINGUISHABLE.

Photo by Donald A. Myers

FIGURE 14—TIJERAS GREENSTONE BELT ALONG TIJERAS CANYON (LOOKING NORTHEASTWARD). SANDIA AND MADERA FORMATIONS ALONG CERRO PELON RIDGE ON RIGHT. FAULTED RIDGE OF QUARTZITE IN CIBOLA GNEISS CROSSES TIJERAS CANYON WEST OF TRACE OF TIJERAS FAULT.

Although the greenstone is mostly schistose there are large masses distributed along the belt of nonschistose mafic metaigneous rocks. Bruns (1959, p. 25) recognized metapyroxenite, metadiorite, metadiabase, metabasalt, and metarhyolite interspersed with the hornblende and chlorite schists. Some parts of these rocks are nearly unaltered and recognition by composition and texture is not difficult. Epidotization, sericitization, and chloritization in veinlets or in fine granular mosaics are the common metamorphic effects. Why some masses have escaped conversion to schists is not clear. A few masses resemble residual plugs; others, sills or flows. Original form, texture, or primary structure may have determined the development or lack of development of schistosity. Perhaps the nonschistose bodies were massive or dense and the schistose rocks were thin bedded, less dense, or tuffaceous.

The metasedimentary rocks associated with the greenstone occur mostly next to Tijeras fault in secs. 29, 31, 32, T. 10 N., R. 5 E., but also in small masses elsewhere in the greenstone. They consist of mica schist, quartzite, quartz-mica schist, phyllite, marble, and banded epidote marble resembling ricolite, a variety of verde antique. Quartz-mica schist is concentrated along the border of the metarhyolite and mica schist (mostly muscovite) and is commonly intercalated with nonschistose metaigneous layers. Quartzite occurs as a band along the boundary between the metasediments and the typical greenstone near the bottom of Tijeras Canyon in sec. 29, T. 10 N., R. 5 E. There are marble lenses in the greenstone locally; one particularly good occurrence bears sulfide ore at the York mine in sec. 10, T. 10 N., R. 5 E.

A small area of the Tijeras Greenstone is exposed in Cedro Canyon in sec. 35, T. 9 N., R. 5 E., where faults and erosion have combined to produce an inlier surrounded by Pennsylvanian rocks..

Quartzite and schist bound the greenstone belt on the south and southeast. Quartzite holds up Cerro Pelon and extends southward and southwestward to Coyote Canyon and into the edge of the Four Hills area west of Tijeras fault in sec. 14, T. 9 N., R. 4 E. In this metamorphic sequence white and grayish-white quartzite, about 2,000 ft thick, forms the lower part; schist, phyllite, and slate form the upper. The principal part of the sequence occurs between Cerro Pelon and Madera Canyon where a northeast-plunging set of isoclinal folds is overturned and thrust northwestward over the green-stone belt. In the Four Hills area the folded sequence is intruded by the Sandia Granite.

MONTE LARGO METAMORPHICS

The Monte Largo Precambrian area is exposed in a narrow northeast-trending horst between the Tijeras fault and the Gutierrez fault. Pennsylvanian rocks nonconformably overlie the Precambrian at both ends of the horst, and a low, broad northwest-trending cross anticline has uplifted Precambrian in a rectangular area of about 7 square miles to form Monte Largo.

The Precambrian is generally foliated in the direction of the elongate horst. The metamorphic rocks consist principally of quartz-feldspar gneisses, hornblende and biotite gneisses, some muscovite and hornblende schists, and quartzite. All these rocks were thought by Huzarski (1971) to have formed from sediments and metamorphosed synkinematically to an amphibolite facies. The metamorphics are locally intruded by small bodies of granite and local aplite and pegmatite dikes. Lambert (1961, fig. 1) discovered small bodies of carbonatite and quartz-tourmaline-calcite rock in the southwestern corner of the Monte Largo complex in association with breccia plugs. The carbonatite consists largely of dolomite, apatite, phlogopite, and magnetite, with local or minor quantities of chlorite and possibly nepheline and pyroxene in the form of melteigite (Lambert, 1961, p. 68-70). Analysis of the carbonatite by Chapman, Wood, and Griswold (personal communication) showed 0.295 Nb_2O_5.

RINCON RIDGE METAMORPHICS

One of the more prominent features of the Sandia Mountains is Rincon Ridge (8,201 ft) which stands as a large jutting corner from the northern part of the range. The existence of the ridge is due largely to its makeup of resistant quartzite and quartz-mica schist. Hayes (1951, p. 7, 8) referred to the rocks as the Juan Tabo sequence and believed that the thickness could be in excess of 7,000 ft. Within the sequence there is much gradation between quartzite and schist. Pure quartzite such as dominates the terrane at Cerro Pelon is not the rule; Hayes estimated that 75 to **80** percent of the rock is either micaceous quartzite, which is more abundant and contains much detrital feldspar, or micaceous quartz schist.

Some feldspar and sillimanite schists occur near the Sandia Granite. Greenstone and chlorite schist occur in patches along the northwestern part of the Rincon in secs. 22, 14, T. 12 N., R. 4 E. Green and Callender (1973, p. 643) described a contact aureole in the regionally metamorphosed sedimentary and volcanic rocks formed by the Sandia Granite intrusion. The aureole, more than 1,000 m wide, ranges from sillimanite- and garnet-bearing gneisses to andalusite schist. The sequence at the Rincon is not as white as that at Cerro Pelon, and the rocks tend more to light gray, even to dark brownish gray. The two sequences lying on opposite sides of the Sandia Granite pluton can hardly be correlative.

A small outlier of the Rincon metamorphics is exposed at the base of Montezuma Mountain in the southeastern part of the San Antonio de Las Huertas Grant.

SANDIA GRANITE

The escarpment of the Sandia Mountains is dominated by the distinctive light-colored porphyritic pluton known as the Sandia Granite. It extends for 20 miles in outcrops along the front of the mountains from the tip of the Four Hills in T. 9 N. to near Placitas. Its principal outcrop belt is bounded on the west by alluvial outwash or locally downfaulted Tertiary Santa Fe sand and gravel and on the east in Tijeras Canyon by the Cibola Gneiss. Along the crest of the range it is bounded by the overlying Pennsylvanian rocks (fig. 15). Several inliers of the granite are exposed east of the crest in canyons eroded through the Pennsylvanian dip slope. Overall, the Sandia pluton appears to trend northeastward across the range between the Rincon Ridge metamorphics on the northwest and the Tijeras Canyon metamorphics on the southeast; the exposed pluton width is about 9 miles. The length is not known in the subsurface but might be several times its projected 20-mile outcrop length. It is of interest that its projected extent to the southwest beneath the Rio Grande trough is on line with similar granite in the Ladron Mountains some 50 miles away.

The Sandia Granite is homogeneous throughout its exposures. Perhaps its most distinctive aspect is its porphyritic texture—microcline phenocrysts in a granitoid groundmass of quartz, feldspars, and micas. In weathered outcrop the rock has a distinctive nubby surface owing to more rapid disintegration of the granular matrix relative to the microcline (fig. 16). Some microcline phenocrysts are as much as three inches across (Fitzsimmons, 1961, p. 91) but are most typically about one inch. The fresh granite is most commonly light gray, but colors range through medium gray,

FIGURE 15—North wall of upper part of La Cueva Canyon. Shows diverse jointing in Sandia Granite, much of which dips at low angles here.

FIGURE 16—SANDIA GRANITE SHOWING TYPICAL WEATHERED SURFACE. RESISTANT MICROCLINE PHENOCRYSTS AND SMALL INCLUSIONS.

pinkish, and light reddish brown. Fitzsimmons has noted that the reddish tints are primarily in the microcline and that color variations appear to be more common near the unconformity with the overlying Pennsylvanian rocks, implying a pre-Pennsylvanian weathering effect. However, this is not a consistent relationship because the reddish coloration is evident for 300 to 400 ft below the unconformity around the head of La Cueva Canyon.

The most common minerals of the Sandia Granite are microcline, quartz, oligoclase, and biotite. Accessory minerals generally consist of sphene, magnetite, and apatite, with rare occurrences of hornblende, muscovite, tourmaline, or pyrite. The rock is a porphyritic biotite granite in which the essential minerals commonly average about: quartz, 35 percent; microcline phenocrysts, 15 percent; albite and oligoclase, 35 percent; biotite, 10 percent; microperthite, 5 percent. However, considerable variations from these proportions occur locally and Feinberg (1969, p. 10) has noted as much as 51 percent quartz and 43 percent biotite; Shomaker (1965, p. 10) has estimated a range in quartz content from 18 to 36 percent. He also estimated sphene as high as 5 percent, and magnetite 4 percent. Through areas of several acres, biotite reaches concentrations of 50 percent appearing to be primary or early magmatic concentrations; and in some areas the microcline phenocrysts amount to 20 to 25 percent of the granite.

Late magmatic, deuteric or perhaps hydrothermal alteration has modified considerable volumes of the granite. Such alteration occurs in local patches but is related to primary fracture systems. It is later than the aplite and pegmatite dikes associated with the granite. Shomaker (1965, p. 20-22) has carefully described the alteration product consisting of hematite, chlorite, and epidote as follows:

> Long bands of granite that has been highly altered by hydrothermal hematite, epidote, and chlorite are very common throughout the area. Apparently the introduction of material follows well-defined fractures, for a definite lateral progression of alteration is visible. The outer zone consists of granite whose phenocrysts are pink, probably due to small amounts of hematite, or to iron in solid solution. This granite appears no different in thin section from unaltered material. Closer to the axis of the band, fine fractures begin to appear, and finally, along the axis, the granite may be altered entirely to a mass of epidote, chlorite, and hematite. Only some fragments of hematite-stained potassium feldspar remain.
>
> In general, oligoclase is altered to epidote and quartz and biotite to chlorite. Sphene, magnetite, and apatite remain nearly unaltered, and microcline is not much altered except to sericite, as is usual throughout the granite. The highly altered material is actually slightly more resistant to weathering than fresh granite, and forms low ridges and knobs. On the other hand, these altered rocks seem to be zones of structural weakness, and more often than not are followed by faults. Slickensides on altered material show that at least some of the movement along the faults has occurred since alteration took place. Alteration does not extend into the overlying Pennsylvanian limestone, even though the faults do continue into it.
>
> Where aplite dikes are crossed by the fractures along which the altering fluids moved, they are altered in the same way as the granite. Faults are so often associated with the altered rocks that degree of alteration proved to be a mapping guide.
>
> The alteration must have occurred after emplacement of aplites and pegmatites, but before the main periods of faulting, for some intensely altered bands show no evidence of shear or displacement. In addition, veins and stringers of epidote associated with the alteration phase are displaced by faults, and spessartite dikes cut by faults along altered zones are not altered. It is possible, however, that some faults were active before alteration, and that slickensides on altered rock were created by later movement.

Magmatic inclusions are common in the Sandia Granite (fig. 17). They range in size from tiny blebs to bodies several feet in length. Flattened, elongate, and rounded shapes occur usually with no systematic arrangement. They are not uniformly distributed in the granite and are more abundant in some areas than others. Shomaker (1965, p. 15) found four petrologic types: 1) melanocratic [dark-colored] granitoid, 2) leucocratic [light-colored] granitoid, 3) gneissic, and 4) quartzitic. Dark-colored granitoid inclusions are most abundant and, except for being fine or medium grained and slightly foliated, are of very nearly the same composition as the granite. The light-colored types differ only in containing less biotite and more quartz. Shomaker noted them to be in spherical, ellipsoidal, or bladed shapes. The gneissic types are smaller, banded in variations of biotite, quartz, and feldspar. Quartzite inclusions are the least common, small, and less rounded. All inclusions show some suggestion of digestion by the magma, and reaction halos, especially of biotite, are common within the granitic types. Microdine porphyroblasts similar to the smaller phenocrysts in the granite are common in the inclusions. Nearly all the inclusions probably come from the country rock and are considered xenoliths.

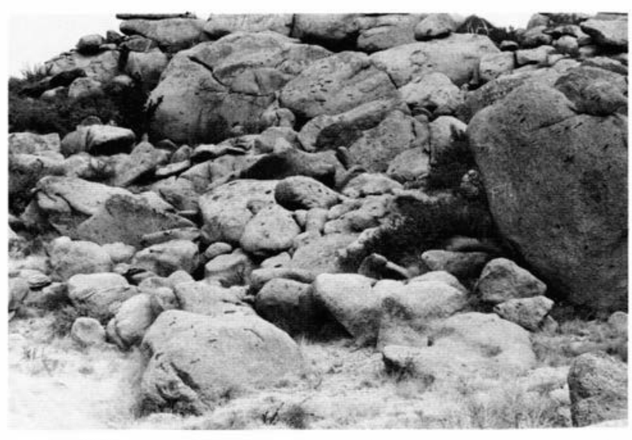


FIGURE 17—OUTCROP OF SANDIA GRANITE WITH NUMEROUS INCLUSIONS. RESIDUAL SPHEROIDAL BOULDERS ALONG US-66 IN TIJERAS CANYON.

Small masses of orbicular rock have been found in the northern part of the Sandia Granite, and these have been described briefly by Fitzsimmons (1966) and Feinberg (1969), and in more detail by Daugherty and Asquith (1971), and Thompson and Giles (1974), and Enz (1974). The principal known deposits occur just south of the ridge spur along which the lower new La Luz trail ascends. The orbicular mass is described in more detail than the Sandia Granite and some other Precambrian rocks because of its unusual and striking character. New Mexico is one of 11 states from which only 19 occurrences are known; 8 of these are from California (Leveson, 1966).

The main mass on which a small cut face has been dug is 500 ft south of the Sandoval County line at an altitude of about 7,800 ft. It is reached by a short hike from the next to the upper north switchback on the lower end of the La Luz trail. The principal outcrop trends S. 75° E. up the ridge, and is about 40 ft long. A maximum of 7 feet is exposed more or less midway. The upper smaller occurrence is about 65 ft higher and 150 ft in a S. 65° E. direction up the ridge. The two deposits may be continuous with one another, but much hillside debris prevents complete tracing between.

In the small cut face at the principal exposure, the northern contact of the body is exposed against the typical pinkish, porphyritic Sandia Granite. The upper, hanging wall contact is sharp and dips N. 5° E. at 60° to 65°; the lower contact is not well exposed, but appears in places to be gradational. In part, the footwall granite is richer than normal in biotite, and feldspar phenocrysts are more abundant and slightly more euhedral. A gradation is further suggested by thin wraps of biotite around some phenocrysts.

The northern 5 ft of the mass is almost completely orbicular with no more than 20 to 30 percent granitoid matrix. The southern 2 ft consists of 60 to 70 percent light-colored granite with rounded floating orbicules 1 to 1.5 inches in diameter (fig. 18B). The highly orbicular main body contains more coarse crystalline biotite, whereas the floating orbicules of the footwall zone have less biotite and are finer grained. Orbicules in the main mass are larger than those in the footwall zone and commonly attain maximum diameter of 4 to 5 inches. A few orbicules adjacent to the hanging wall are nearly 1 ft in greatest diameter, but most are granite autoliths with thin wraps of biotite.

Nearly all the orbicules in the main mass are triaxial ellipsoids, with major axes roughly parallel to the tabular form of the body. However, some are of oblique orientation as by slight swirling or plastic distortion. Within the dominant alignment there are also many individual orbicules of aberrant crosswise orientation. The following are axial dimensions (in inches) of 8 orbicules measured in the outcrop.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	(inches)							
Near-strike axis	2	4.2	3	3	2.7	3	9	7.5
Near-dip axis	1.2	3	2	2.2	2.2	3	6.2	5.7
Near-width axis	1	2.6	1.5	1.5	1.3	1.5	5.5	3

In all examples the width axis is the shortest, and in 7 or 8 orbicules the strike dimension is longer than the dip direction. No. 6 is oblate discoid. Growth was easiest in the strike direction; the principal stress axis appears to have been north-south in the magma during growth. A considerable number of centers or cores of the orbicules lie loose in the weathered surface float near the cut face. The axes of about 40 of these have been measured. Prolate and oblate triaxial ellipsoids are about equal in number; a lesser number are more or less equidimensional. In the group, the long axes ranged from 1 to 1.8 inch; the intermediate axes, 0.6 to 1.4 inch; and the short axes 0.6 to 0.9 inch. Sawed equatorial sections of the cores are commonly slightly squarish or obtuse rhombic in outline.

Cross-sections of the ellipsoids reveal numerous minor distortions away from bilateral symmetry due to irregular growth but also in part to some deformational warping by plastic flow. Slabbed surfaces of the rock show some fracturing of orbicules. In other surfaces orbicules appear to protrude into adjacent ones, as though by force of growth, with development of individual orbicules apparently beginning at different times. In such instances, growth around later nucleation centers seems to have destroyed or thinned outer shells of previously formed orbicules nearby.

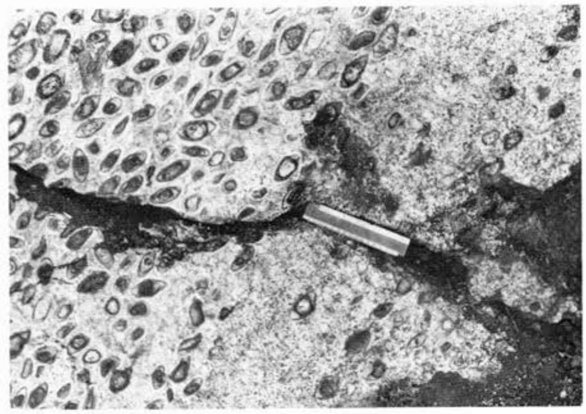
The concentric bands consist predominantly of oligoclase and biotite. These are usually wrapped around a granitoid core which in many samples resembles the normal Sandia Granite, although not with as large phenocrysts as in the typical porphyritic granite. Some cores are quite light colored consisting of orthoclase, oligoclase, and to a lesser extent, quartz. Some slabbed surfaces of the rock show biotite at the center, but nearly all equatorial sections would probably show granitoid feldspar. Thompson and Giles (1974, p. 911) found the cores to be biotite monzonite. However, the cores are likely a facies of the regular granite. Sections that are not equatorial may be misleading in making the core texture appear either slightly gneissic or nonconcentric. Nevertheless, the concentric zones exhibit some regularity and the following consistency of order:

1) Core zone of weakly concentric-banded or unbanded granitoid rock
2) Intermediate zone dominated by biotite
3) Outer shell of radiate oligoclase

The intermediate zone typically consists of wrappings of biotite alternating with several thin concentric oligoclase or oligoclase and biotite bands. The biotite is usually tangential in growth but may be radial or random in orientation. Outside the core the predominant feldspar is oligoclase forming radiate columns and needles in each concentric layer. In numerous places radiate oligoclase is transected by tangential biotite. Accessory minerals that are common in the typical granite also occur in the orbicules; these include apatite, zircon, and opaque minerals such as magnetite, pyrite, chalcopyrite, and ilmenite. Some malachite staining exists in the cut face. Deuteric epidote and chlorite are present locally and sericite is widespread, especially in the oligoclase of the orbicules.

The upper smaller occurrence of the orbicular rock is 150 ft east of the main body and only 50 to 60 ft down the ridge from a prominent cliff. This smaller body is poorly exposed, roughly on line with the lower body; it

A—Main outcrop cut face showing hanging wall of granite.

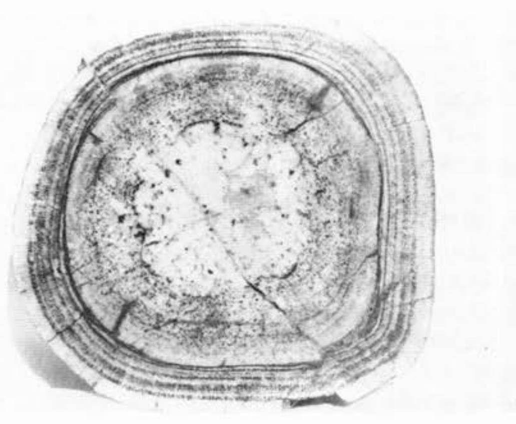


B—Main outcrop cut face showing floating orbicules of footwall side of the tabular mass. About 6 inches intervenes on cut face between A and B.

C—Sawed slab of typical orbicular part of A. Note different cores, some granite, some feldspar, and some biotite; difference may merely be apparent because slice did not go through center of the orbicule. Note also light-colored matrix which is finer grained than granite autholithic cores.

D—Fine-grained orbicules characteristic of hanging wall zone and upper outcrops. Pencil line on face is 2 inches. *Francis Koopman's specimen*

E—Orbicule cores; center-sawed. Note rectangular shape and first biotite wrap; second wrap around coarse feldspar core is shown on halves lying face-down.



F—Center-sawed, round orbicule from upper exposures. Horizontal diameter is 4 inches; core diameter is 1.5 inches. Note convex outward bulging of core shown by first biotite wrap.

FIGURE 18—Orbicular structures in Sandia Granite

appears to extend for about 35 ft with a maximum width of 4.5 ft. The orbicules are more rounded than in the main deposit and are largely floating in granite in a similar manner to the footwall zone at the lower cut face. No sharp contact with the adjacent nonorbicular pinkish Sandia Granite is observable. The enclosing and surrounding granite is slightly more biotitic than the average granite; the texture is more ragged and less porphyritic. Up the ridge the Sandia Granite becomes quite dark colored in a 20- to 30-ft zone that extends nearly to the top. Biotite content becomes as high as 50 percent, indicating that the rock is a basic magmatic segregation. Like the normal granite, it contains sparse small inclusions of gneiss, schist, and quartz.

Maximum diameter of the rounded orbicules ranges from 2 to 5 inches. These orbicules are finer grained than those with prominent biotite intermediate shells of the main body. Concentric banding is usually well developed and visible because of biotite bands across the radial oligoclase. Biotite consists of subhedral grains arranged radially and tangentially. As many as 15 biotite bands may be counted on equatorial cuts of the larger orbicules. Individual bands are less than 0.04 inch thick with average biotite grains running 0.004 to 0.01 inch. Magnetite is also concentrated with biotite in some bands. Feldspar is dominant in all the orbicules. In addition to forming pure or nearly pure bands of radiate oligoclase up to 0.1 inch in the concentric shells, the feldspar pervades the biotite bands and occurs in nonradiate coarse subhedrons and anhedrons in the feldspathic cores. The oligoclase is greatly sericitized but numerous unaltered crystals are common. Biotite makes up less than 10 percent of the average orbicule, but in some it is less than 1 percent, or essentially absent.

The nonconcentric cores range from 1 to 2 inches in diameter and consist of oligoclase, orthoclase, and quartz, minor biotite, and the usual accessories. Orthoclase and quartz tend to be more abundant in the central part of the core. A few cores contain irregular inclusions of what Thompson and Giles concluded are hornfels.

Thompson and Giles recognized three orbicular structures: type I, the principal kind with alternating biotite- and plagioclase-rich shells (fig. 18C); type II, plagioclase with or without a continuous biotite shell near the periphery (fig. 18E); and type III, plagioclase cores surrounded by thin concentric shells of fine-grained biotite (fig. 18D, 18F). Autoliths of biotite granite or monzonite shown by Thompson and Giles (1974, fig. 2c) and in fig. 18A (near the hammer) might be another type.

General paragenesis consists of the following principal stages:

1) Early magmatic crystallization to form autolithic blobs of unbanded granitoid crystals
2) Orbicule formation involving principally oligoclase and biotite in repetitions of concentric bands with both radiate and tangential crystal orientations
3) Post-orbicule formation, nonorganized, fine- to medium-grained or normal granitoid matrix crystallization (fig. 18C)
4) Deuteric or hydrothermal alteration forming epidote, chlorite, and sericite

Thompson and Giles believed that the rare presence of hornfels xenoliths in cores, along with other considerations, indicated that orbicule development was metasomatic, seemingly implying late magmatic development. However, it is difficult to imagine that orbicules of the kind shown in fig. 18D, F are replacements to any great extent, hence our conclusion that they are of early magmatic origin.

Except for late magmatic aplite, pegmatite, and lamprophyre dikes the Sandia Granite is the youngest Precambrian rock in the area, and this is generally shown by field relationships. The first radiometric analysis of biotite and muscovite from the granite (Aldrich, Wetherill, and Davis, 1957, p. 656) yielded K-Ar and Rb-Sr ratios suggesting ages of 1,340 and 1,350 m.y. (million years). Since 1957 some 50 dates determined using U, Th-Pb, Pb-Pb, K-Ar, Rb-Sr (whole-rock and mineral), and fission-track data suggest a best age of crystallization of the granite of 1,500 ± 100 m.y. (Douglas G. Brookins, written communication; Brookins, 1973). The Sandia Granite has been age-dated most often of any rock in North America; some of the recent papers including data on the possible age of the Sandia Granite are by Wasserburg and Steiger (1967), Aldrich and others (1957), Aldrich and others (1958), and Tilton and Gruenenfelder (1968).

Naesser (1971, p. 4980) cites French geochemist Poupeau (1969) for a Sandia Granite apatite fission-track date of 50 m.y., which is thought to indicate a Laramide geothermal perturbance effect during that orogeny.

DIKES RELATED TO SANDIA GRANITE

Large areas of the Sandia Granite are intruded by thousands of aplite and pegmatite dikes. Map 1 shows the distribution of most of these. They range in thickness from an inch or so to as much as 50 ft, and some are nearly 1 mile long. Most of the mapping of the dikes has been done by Hayes (1951), Shomaker (1965) and Feinberg (1969). Numerous thin and short dikes either go undetected or are hardly mappable at the working scale; most dikes mapped are between 500 and 1,500 ft in length. The dikes generally occur in irregular single sets, although in places a lesser set crosses the dominant one. The dominant set trends eastward followed by lesser sets of northwestward or northeastward trend. Individual dikes tend to be slightly or, in rare instances, sharply curved. Dikes and well-defined faults rarely coincide and many dikes terminate at faults. As noted by Shomaker (1965, p. 20) the greatest concentration of dikes is in the central area of the granite body. Relatively few dikes occur in the Cibola Gneiss on the southeast, but numerous dikes and sills occur in the Rincon metamorphic complex on the northwest. Hayes (1951, p. 20) observed that dikes are numerous in the Rincon Ridge country rock but are sparse in the border of the granite batholith.

The small intrusions related to the Sandia batholith fall into four principal categories: 1) composite aplite-pegmatite, 2) aplite, 3) pegmatite, and 4) quartz (silexite). Most are dikes or dikelets but in places are pod- or finger-like bodies. Composite aplite-pegmatite dikes are most abundant, but the proportion of aplitic or pegmatitic texture may range considerably in individual dikes. The composition may also range considerably locally or even across the dikes. Microcline-microperthite, quartz, and oligoclase are the predominant constituents with only minor biotite, muscovite, and very minor apatite, pyrite, tourmaline, beryl, magnetite, and ilmenite.

Aplite is most abundant in the thin, small dikes. It is typically sugary textured, consisting of quartz and orthoclase with accessory muscovite. Some aplite dikes bear garnet in amounts of as much as 5 to 10 percent. It also occurs in circular bodies which may be bulbous or fingerlike beneath the surface. Feinberg (1969, fig. 3) mapped several such bodies up to 500 ft in diameter in the Bear Canyon-Pino Canyon reentrant.

Pegmatites occur as short dikes, pods, lenses, or small fingerlike masses. The composition is simple for the most part, with sparse development of mica, garnet, or black tourmaline. Only few small masses occur in the granite, but they are the dominant rock of the dikes in Rincon Ridge (Hayes, 1951, p. 20) (fig. 19). The pegmatite dikes, forming a swarm across the schist in the western escarpment, are up to 3,000 ft long and 10 ft wide. Many show crude zoning consisting of borders, 1 to 3 inches wide, of fine-grained feldspar and quartz with fine-grained muscovite. The border zones grade inward to the wall zone, which is coarser and locally graphic in texture with small muscovite books up to about 1 inch in diameter. In many dikes the central parts are quartz cores, but these are absent in most dikes where wall-zone textures and composition occupy all but the fine-grained borders of the dike (Hayes, 1951, p. 23). Pegmatites, like the other dikes, range considerably in mineral proportions. The approximate mean of 40 percent for quartz may range from 20 to 60 percent and the 50 percent mean for feldspar from 25 to 75 percent.

Quartz dikes (silexite) occur locally, are generally short and pod-shaped. In places dikes contain black tourmaline. The dikes are identical in many respects to the quartz cores of the pegmatite or aplite-pegmatite dikes. Quartz forms late in the dikes and crosscuts dikes in other places. Quartz dikes are not to be confused with quartz veins which may be banded or crusted and associated with fluorite, barite, calcite, or base metals. Silexite dikes never occur in sedimentary rocks as the quartz veins commonly do.

MISSISSIPPIAN

ARROYO PEÑASCO FORMATION

Recognition of Mississippian rocks in northern New Mexico—Mississippian strata are the oldest known Paleozoic rocks of definite age in the Sandia Mountains area. By contrast, considerable thicknesses of Cambrian to Mississippian strata occur in southern New Mexico.

A detailed summary of investigations on the Mississippian rocks of northern New Mexico was given by Northrop (1961a, p. 105-106):

FIGURE 19—PEGMATITE DIKE SWARM IN RINCON RIDGE. COUNTRY ROCK IS MICACEOUS QUARTZITE. NOTE HOLOCENE FAULT SCARP AT BASE OF RIDGE.

Prior to 1951, no diagnostic fossils—with the exception of a foraminifer, *Endothyra baileyi*—had been found in pre-Pennsylvanian strata in New Mexico north of Ladron Peak, between Socorro and Belen. More than a century ago Marcou (1856; 1858) misidentified Pennsylvanian fossils from Pecos, the Sandia Mountains, and Tijeras Canyon as Mississippian species. He concluded that the Madera or Magdalena limestone was "calcaire du carbonifere inferieure" or limestone of the Lower Carboniferous. Later he called it the "Mountain Limestone" and stated that the Sandia rim was "composed of *Carboniferous Limestone,* which here merits most truly its name of *Mountain Limestone,* for it is the only limestone of any importance met with in the Rocky Mountain region." Within a few years other workers assigned this limestone to the Upper Carboniferous or Pennsylvanian.

Apparently, the first recognition of pre-Pennsylvanian Paleozoic strata in New Mexico north of Ladron Peak was in 1940, when the 7,407-foot well in the Rattlesnake field was completed; Needham and Bates (1942) assigned 215 feet of strata in this well to the Mississippian. This same year Thompson (1942) found 106 feet of pre-Pennsylvanian rocks at the north end of the Sandia Mountains near Placitas. Above the Precambrian he measured 16 feet of conglomerate and sandstone overlain by 90 feet of unfossiliferous limestone and hazarded the opinion that these rocks might be "of lower Paleozoic age" (Thompson, 1942, p. 19). During the period 1942-1947 it was suggested by several members of the U.S. Geological Survey that such scattered remnants of pre-Pennsylvanian strata might be Mississippian or older (Read and Henbest, 1942; Henbest, Read, and others, 1944; Read and others 1944; Henbest, 1946a, 1946b; Kelley and Wood, 1946; Wood and Northrop, 1946; Northrop and others, 1946; Read and Wood, 1947). On the basis of *Endothyra,* Henbest 1946a, 1946b) correlated this unit in the Sangre de Cristo and Sandia Mountains with the Leadville of Colorado.

It remained for A. K. Armstrong, an undergraduate student at U.N.M., to discover the first diagnostic megafossils in the pre-Pennsylvanian rocks. Early in 1951 Armstrong was engaged in a field problem under the direction of J. Paul Fitzsimmons. He was examining Precambrian rocks at the south end of the Nacimiento Mountains west of Jemez Pueblo, when *he* found fossils in small patches of limestone faulted down into the Precambrian basement. The first two slabs of this limestone Armstrong submitted to me early in 1951 contained *Conularia* sp. and *Eumetria* sp. Recognizing the latter as a Mississippian form, I suggested that Armstrong make further search for fossils. Fitzsimmons concurred and the emphasis of the problem shifted from Precambrian to Mississippian, Further collections were made by Armstrong and some were made by Fitzsimmons and myself. On May 21, 1951, I submitted to Armstrong a memorandum on all the material, tentatively identifying a variety of brachiopods and representatives of five other classes of invertebrates. I wrote as follows:

> "The age of these fossils is Mississippian. I had anticipated that any Mississippian strata of northern New Mexico would prove to be older Mississippian, that is, Kinderhook or Osage, because these strata extend farther north in southern New Mexico than do younger Mississippian strata, such as Meramec and Chester. Again, in southern Colorado the Leadville or Madison limestone is chiefly Kinderhook or Osage in age.
>
> "However, the *Eumetria* in your collections seems close to *Eumetria verneuiliana,* which is found in the Middle Mississippian Meramec of the Mississippi Valley region (Salem limestone and St. Louis limestone) and ranges up into the Upper Mississippian Chester series."

I suggested to Fitzsimmons that, because these were the first pre-Pennsylvanian megafossils ever found in northern New Mexico in a distance of 200 miles between Ladron Peak, New Mexico, and Piedra River Canyon, Colorado the fossils should be submitted to Mackenzie Gordon, Jr., a Mississippian specialist of the U.S. Geological Survey.

It was decided to name the formation the Arroyo Penasco formation. Gordon's report on the fossils, listing 39 species, corroborated my determination of a Meramec, possibly St. Louis age. A paper by Fitzsimmons, Armstrong, and Gordon (1956) was submitted in June 1955 and published in August

1956. Meanwhile Armstrong (1955) had published independently a report that included observations on Mississippian rocks in the Sangre de Cristo, Sandia, Manzano, and Ladron Mountains. Chiefly on the basis of microfossils, he concluded that the upper part of the "Arroyo Penasco" of the Sangre de Cristos is Meramec in age but that the lower unfossiliferous strata might be equivalent to the Leadville of Colorado or the Caloso of Ladron Peak. In this connection it may be noted that Baltz and Read (1960) collected Early Mississippian fossils at several localities in the Sangre de Cristos; they named two new formations, the Tererro of Early Mississippian (Kinderhook and Osage) age, and the Espiritu Santo of possible Devonian age. In view of the fact that the Meramec fossils of the Arroyo Penasco at the type locality of that formation occur in the upper part, it is possible that the unfossiliferous lower part of the Arroyo Penasco may be Lower Mississippian and equivalent to the Tererro formation.

In the Placitas area at the north end of the Sandia Mountains, Toomey (1953) measured ten sections of pre-Pennsylvanian strata, ranging from 20 to 81 feet in thickness. The only determinable fossils he found were poorly preserved *Euomphalus* sp., two high-spired gastropods, and a cephalopod. Later, in the Placitas area, Armstrong (1955) measured one section of 102 feet of pre-Pennsylvanian rock and cited poorly preserved *Siraparolus? [Euomphalus?] sp., Stegocoelia?* sp., *Goniatites* sp., and *Plectogyra* sp. Subsequently Armstrong (1958) cited *Endothyra prodigiosa.*

At the south end of the Sandia Mountains in Tijeras Canyon, Szabo (1953) measured ten sections of the pre-Pennsylvanian sequence, ranging from 8 to 48 feet in thickness. However, in his thickest section, as much as 32 feet of red shale may be Pennsylvanian in age. If the questionable red shale that appears in most of his sections *be* assigned to the Pennsylvanian, the remaining pre-Pennsylvanian strata range from 8 to 27 feet in thickness. Armstrong (1955) measured only one section in Tijeras Canyon, 16 feet thick. Some of my colleagues hold the opinion that, in the absence of diagnostic fossil evidence, the so-called pre-Pennsylvanian rocks in Tijeras Canyon should be assigned to the Sandia formation. Certainly, along much of the Sandia crest, the pre-Pennsylvanian seems to be missing. On the other hand, Toomey (1953, p. 12) observed that the basal unit of the Sandia formation in the vicinity of the Sandia crest "contains numerous, large, reworked fragments of pre-Pennsylvanian limestone."

At Bosque Peak in the southern Manzano Mountains, east of Los Lunas and a few miles southwest of Mosca Peak, Armstrong (1958) found 22 feet of limestone that may be Mississippian. He observed also a few isolated remnants of limestone, 20-30 feet thick, at several places in the Manzanita and Manzano Mountains between Tijeras Canyon and Bosque Peak.

It now seems likely that all of the pre-Pennsylvanian rocks of the Sandia-Manzanita-Manzano area should be assigned to the Tererro (or Tererro and Espiritu Santo formations). As Baltz and Read (1960, p. 1768) have well said, "Further paleontologic studies and studies of the physical stratigraphy must precede correlation, firm assignments of age, and adjustments in the terminology of the Espiritu Santo, Tererro, and Arroyo Penasco formations."

After the above summary was written, Catacosinos (1962) examined the Precambrian-Pennsylvanian contact at 6 places along the Sandia Rim but did not find any Mississippian rocks intervening. Armstrong published several papers on the Mississippian of southwestern and west-central New Mexico during the period 1958-1965.

Lithology and Fossils—Armstrong and Holcomb (1967) described and illustrated the Placitas section. Armstrong's (1967) paper, entitled "Biostratigraphy and carbonate facies of the Mississippian Arroyo Periasco Formation, north-central New Mexico," includes annotated sections of the Placitas section (fig. 40, p. 49) and of the Tijeras Canyon section (fig. 41, p. 50), and photomicrographs of various rocks (pls. 2, 5, 7); calcispheres, ostracods, and foraminifers are illustrated.

In 1972 and 1973 Armstrong re-examined and made additional collections from Mississippian outcrops in northern New Mexico. Armstrong and Mamet (1974, p. 148-149) note that

> "The knowledge of Mississippian microfossils has greatly increased, and more refined zonation is now possible since the publication of Armstrong's 1967 paper. Taxonomic changes have been rapid, and more than 60 new generic taxa have been proposed in 5 years."

They raise the Arroyo Peñasco Formation to group rank and include in it two formations, the Osagean Espiritu Santo and the Meramecian Tererro of Baltz and Read (1960).

At the north end of the Sandia Mountains near Placitas, 33 miles southeast of the type locality of the Arroyo Peñasco Formation, the Arroyo Peñasco Group is represented by 73 ft of the Espiritu Santo Formation (Osagean). At the base, Armstrong and Mamet (1974, p. 155) recognized 6.6 ft of the Del Padre Sandstone Member, followed upward by 33 ft of stromatolitic dedolomites, followed by lime mudstones and dolomites and minor amounts of wackestones. They report well-preserved microfossils in the nodular dark-gray cherts in the lower part of the section, as well as microfossils in the lime mudstones in the upper parts of the section.

They list calcareous algae and foraminifers from three levels: 1) near the base of the section (12.2 to 15.2 ft), 2) middle part of the section (42.2 ft), and 3) upper part of the section (69.3 ft). A combined list follows.

Calcareous Algae
- *Calcisphaera laevis*

Foraminifera
- *Earlandia clavatula*
- *Endospiroplectammina?* sp.
- *Endothyra* sp.
- *Inflatoendothyra* sp.
- *Latiendothyra* of the group *L. parakosvensis**
- *L.* sp.
- *Palaeocancellus* sp.
- *Parathurammina* of the group *P. cushmani*
- *P.* of the group *P. suleimanovi*
- *P.* sp.
- *Radiosphaerina*
- *Septaglomospiranella* sp.
- *Septatournayella* sp.
- *Spinoendothyra* sp.
- *Tournayella* sp.
- *Vicinesphaera* sp.

*Includes *Endothyra skippae* of Armstrong (1967). In 1967 Armstrong had also reported *Septabrunsiina parakrainica* and fragments of echinoderms and ostracods.

Armstrong and Mamet note further that the age is Early Mississippian Osagean, upper Keokuk, and not Late Mississippian Meramecian. The earlier report by Armstrong (1967, fig. 40) of *Endothyra prodigiosa, E. irregularis,* and *E. macra* must be discarded.

There are two principal occurrences of these pre-Pennsylvanian strata in the northern Sandia Mountains. One section, studied by Armstrong, is in duplicated faulted strips 1 mile east of Placitas at the base of

Montezuma Mountain (fig. 20). The other occurrence is about 3 miles west-southwest of Placitas in sec. 12, T. 12 N., R. 4 E.; the section there consists of 20 ft of cherty gray limestone and 10 ft of white dense marble overlying Precambrian greenstone. The Mississippian beds are overlain directly by a thinned section of Madera limestone with the clastic Sandia Formation missing. The contact with the overlying Madera may be a low-angle fault which has cut the Sandia or the area may have stood as a high during Sandia time.

At the southern end of the Sandia Mountains Szabc (1953) measured ten sections of what he considered tc be pre-Pennsylvanian beds, ranging from 8 to 48 ft in thickness. About half of the material may belong to the overlying Sandia Formation. Armstrong (1955) did not find fossils in the single 16-ft section he measured in Tijeras Canyon.

Read and others (1944) had mapped these Mississippian beds as a Lower limestone member of the Sandia Formation, suspecting that they might be Mississippian or in part older. The same procedure was followed in the southern Sangre de Cristo Mountains in the Las Vegas area (Northrop and others, 1946) and in the Jemez-Nacimiento Mountains (Wood and Northrop 1946).

Our geologic map shows Mississippian rocks only in the Placitas area at the north end of the mountains instead of using Espiritu Santo Formation of the Arroyc Peñasco group we prefer the name Arroyo Peñasco Formation. The few feet of strata between the Precam. Brian and Pennsylvanian Sandia Formation in Tijeras Canyon at the south end of the mountains are no shown on the map.

PENNSYLVANIAN

The Pennsylvanian rocks of central New Mexico and the Sandia Mountains consist of the Magdalena Group, a term proposed by Gordon in 1907 (p. 806-812) for all the beds in the Magdalena Mountains between the Mississippian Kelly Limestone and the Permian Abo Formation. The group generally has been divided into the basal Sandia Formation, named by Herrick (1900a)

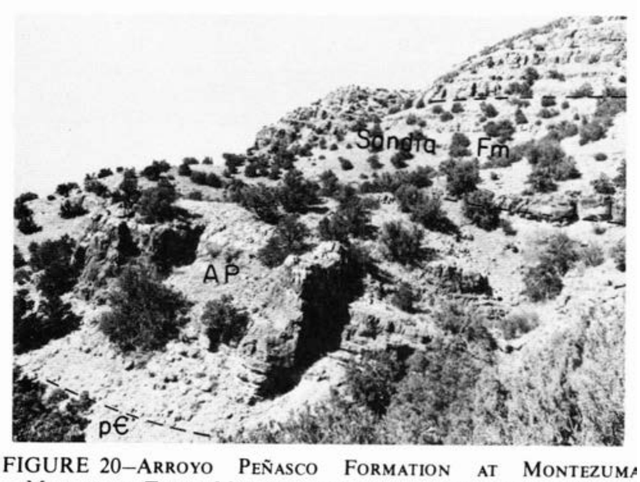


FIGURE 20—ARROYO PEÑASCO FORMATION AT MONTEZUMA MOUNTAIN. THICK MADERA LIMESTONE LEDGES OVERLIE SANDIA SANDSTONE, SHALE, AND THIN LIMESTONE IN SLOPE ABOVE LEDGED ARROYO PEÑASCO (AP). A WHITE QUARTZITE CONGLOMERATE, 3 FT THICK, MARKS BASE ON PRECAMBRIAN SCHIST (p€).

and Herrick and Bendrat (1900) for exposures at the southern end of the Sandia Mountains (actually in the Manzanita Mountains) and the Madera limestone named by Keyes (1903), presumably for exposures neat the old village or canyon of La Madera on the eastern side of the mountains. An intriguing point here is that a Madera Canyon is tributary to Coyote Canyon in the Manzanita Mountains; could this have been the source of Keyes' name?

In the first modern mapping of the Sandia Mountain: and adjoining areas Read and his associates (Read and others, 1944) subdivided the Madera into the Lowe' gray limestone member and the upper Arkosic lime. stone member. This mapping was based partly upon distinct lithologic differences between the lower and upper halves of the Madera and partly upon physic). graphic breaks which arose out of stratigraphic differ. ences between the two members. Northrop and other: (1946) used these same members in the Sangre de Cristc Mountains near Las Vegas, and Wood and Northrop (1946) used them in the Jemez-Nacimiento Mountains The fact that lithology and stratigraphy change regionally, and that the contact between the two is in places transitional or indefinite, has prevented the twc members from being extended widely in New Mexico.

Other informal subdivisions of the Madera have beer made locally, such as the Coyote sandstone (Herrick 1900a; Herrick and Bendrat, 1900; Herrick and Johnson, 1900, pl. 22 of U.N.M. Bull. 23), a 40-ft bec within the Lower gray limestone member. Students ai the University of New Mexico mapping in field geology) courses commonly mapped a thin unit at the top of the Madera that consists of mixed continental and marine deposits. In areas to the south and west this unit hat been given several formal names, such as Red Tank: Member (Kelley and Wood, 1946); Bursum Member (Wilpolt and others, 1946); and Agua Torres Member (Stark and Dapples, 1946, p. 1154).

Based on mapping and studies in the Manzanc Mountains since 1962, Myers (1973) elevated the Madera to group status and defined it to include all the beds between the Sandia Formation below and the Abo Formation above, which is essentially what Kelley and Wood (1946) did in the Lucero uplift west of the Ric Grande depression. Myers (Myers, 1969; Myers and McKay, 1970) has been able to map several divisions of the Madera rather widely through the Manzano and Manzanita Mountains in units formally named as follows:

- Madera Group
  - Bursum Formation (100+ ft)
  - Wild Cow Formation
    - La Casa Member (280+ ft) Pine
    - Shadow Member (240+ ft) Sol
    - se Mete Member (210+ ft)
  - Los Moyos Limestone (600+ ft)

The Wild Cow Formation is probably roughly equivalent to the informal Arkosic limestone (upper) and the Los Moyos Limestone to the informal Lower gray limestone of Read and others (1944). In this memoir the Madera unit will be referred to as Madera Formation rather than Madera Group or Madera Limestone.

SANDIA FORMATION

Definition—Except in few small areas where thin Mississippian strata are present the Sandia nearly everywhere overlies the Precambrian and is overlain gradationally by the Madera Formation. The Precambrian surface upon which the Sandia deposits were spread was a peneplain and relief appears to have been no more than a few tens of feet. Relief on the surface was principally in the form of monadnocks or low ridges of quartzite. Along Cerro Pelon ridge in the northwest corner of sec. 5, T. 9 N., **R.** 5 E. a quartzite hill about 50 ft high on the Precambrian surface rises into onlapping Sandia beds nearly to the base of the Madera. A similar small buried ridge occurs high along Tijeras Canyon north of Seven Springs in sec. 16, T. 10 N., R. 5 E. Elsewhere the surface has little or no relief beyond the few feet of buried residual boulders or small pinnacles (figs. 21, 22). For detail of this nature few exposures surpass those in the old roadcut above the present NM-44 in Tejano Canyon about half a mile southeast of Tree Springs.

The top of the Sandia Formation is transitional and is typically chosen at the base of the first massive limestone ledge of the Madera. Because of the difference in the erosional resistance of the thin-bedded sandy or

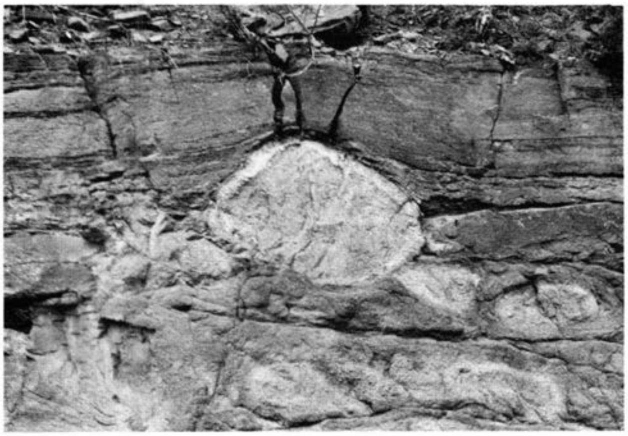


FIGURE 21—Basal Sandia Formation resting on spheroidal boulder in Sandia Granite. Exposure is in old NM-14 roadcut 0.5 mile southeast of Tree Springs. Note deformation of coarse-grained calcareous sandstone around ancient spheroidal residual boulder.

FIGURE 22—Knob of Sandia Granite buried beneath basal Sandia Formation sandstone. Note spheroidal weathering formed in Pennsylvanian time.

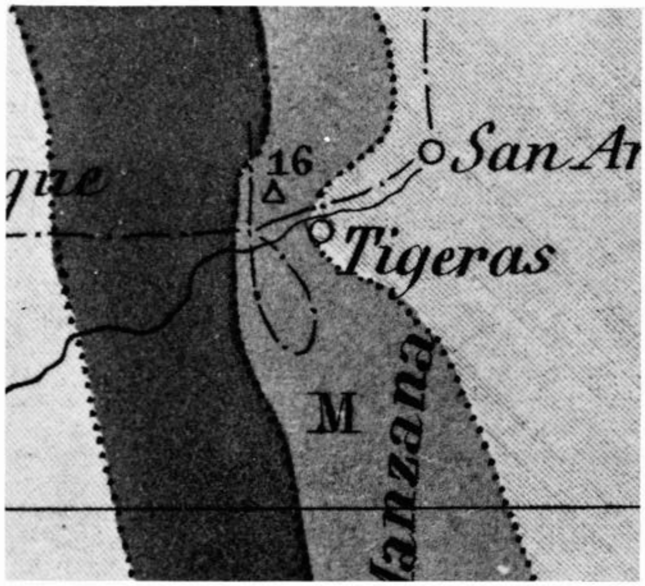


FIGURE 23—Marcou's camp A, October 8, 1853, at Tijeras. Campsite was at triangle numbered "16." Enlargement of part of our Figure 8; see also pages 18-19 of this memoir for Marcou's description of the rocks and fossils.

shaly Sandia beds as compared to the Madera limestone ledges, the top is commonly mapped at the top of a slope or the base of the cliffy outcrops. Limestone is also common in the Sandia Formation in thin- to medium-bedded ledges. In many places these ledges increase in number and thickness near the top of the Sandia, just as thin shale and sandstone beds occur near the base of the Madera. Because of these variations at the upper boundary and because the contact zone is commonly not well exposed, the boundary is not chosen or mapped uniformly from place to place. The variability of lithology and surface expression of this boundary is as much (or more) responsible for differences in apparent thicknesses of the Sandia as irregularities on the Precambrian at the base.

The Log Springs Formation—This unit was named by Armstrong (1955, p. 5, 9) for Log Springs in Peñasco Canyon, near the south end of the Nacimiento Mountains. There the Log Springs Formation consists of 10 to 75 ft of ferruginous shales, sandsones, and conglomerates.

> The immediately underlying part of the Arroyo Peñasco Formation is brecciated and contains numerous solution cavities that are filled with the basal ferruginous shales from **the** overlying Log Springs Formation. The basal shale of the Log Springs Formation is highly ferruginous, with numerous oolites of hematite, and is followed by a medium-bedded series of deep-red shales, sandstones, and conglomerates. The sandstones tend to form small prominent ledges. It is interesting to note that the lower beds of this formation contain sporadic rounded pebbles of Mississippian chert; but the higher conglomerate beds contain angular pebbles of Mississippian chert and limestone as well as of Precambrian gneiss and green schist. No fossils *have* been found in the Log Springs Formation.

At Placitas, according to Armstrong and Mamet (1974, p. 155),

> **The** Espiritu Santo Formation is uncomformably overlain by 2 to 3 m of red shale and siltstone of the Log Springs Formation, which are unconformably overlain by the coarse-grained cross-bedded sandstones of the Sandia Formation.

In Tijeras Canyon, Armstrong (1955, p. 29 and fig. 19) found 16 ft of Mississippian strata, "overlain by 23 feet of ferruginous red shales tentatively assigned to the Log Springs formation." We include this Log Springs in our basal Sandia Formation.

Originally Armstrong (1955) believed that the Log Springs Formation was of Early Pennsylvanian age. Later, he (1967, p. 32) concluded that it might be Late Mississippian and/or Early Pennsylvanian. At present, Armstrong and Mamet (1974, figs. 1, 2; p. 150) consider it to be Late Mississippian (Chesterian) rather than Early Pennsylvanian.

Distribution—The Sandia Formation crops out mostly on the high western face of the mountains (figs. 24, 25) and extends in a nearly continuous narrow band from Coyote Canyon at the southern edge of the geologic map (map 1) to the northern end of the Sandia Mountains around Placitas. It also occurs in several inliers on the east slope of the mountains from near the head of Las Huertas Canyon south to Sulphur Canyon. Some of the best exposures are found in these areas. The Sandia also crops out north and south of Monte Largo in the eastern part of the area, and there is one small inlier east of Cedro Canyon in sec. 35, T. 10 N., R. 5 E.

Photo by Donald A. Myers

FIGURE 24—Airview of northern part of Sandia ridge. Sandia Formation underlies brush-covered slope above precipitous granite cliffs. Crest is held up by resistant Madera limestone ledges. Palomas Peak, upper left margin. Tijeras syncline in valley near top is shown by arcuate outcrops of tree-covered Dakota Sandstone ridge and grass-covered Mancos Shale valley.

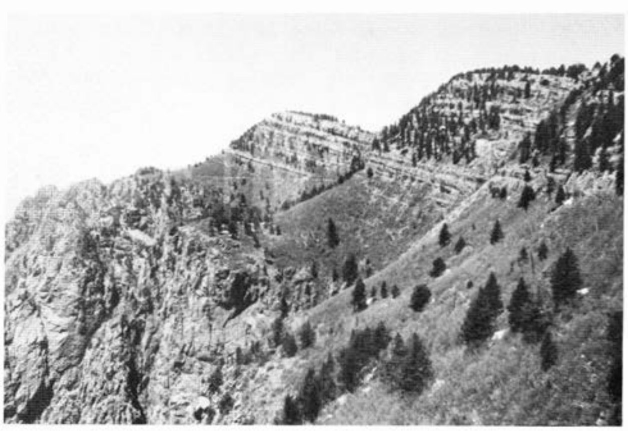


FIGURE 25—Pennsylvanian beds near Sandia Crest. Sandia Formation underlies brush-covered slope and is overlain by thick-ledged limestone of Madera Formation. View north from Sandia Peak Tramway.

Thickness—At the northern end of the Sandias Toomey (1953, p. 53-64) measured 6 sections of Sandia ranging from 49 to 85 ft in thickness above the Arroyo Peñasco Formation. Szabo (1953, p. 28-29) measured 116 ft above 38 ft of presumed pre-Pennsylvanian beds or a total of 154 ft below the Madera Formation. Phillips (1964, p. 63-71) measured 6 Sandia sections at inliers on the east side of the mountains ranging from 113 to 138 ft in thickness. Reynolds (1954, p. 76-77) measured 159 ft of Sandia above his Las Huertas limestone (Arroyo Penasco Formation) at Montezuma Mountain. Harrison (1949, p. 21) measured 172 ft at the same location. At Palomas Peak, Johnson (1948, pl. 1) measured 200 ft of Sandia. Catacosinos (1962, p. 27-36) measured 6 poorly exposed sections of the Sandia along the high western escarpment between North Sandia and South Sandia Peaks and his thicknesses range from 175 to 300 ft. These thicknesses are in excess of all other measured sections; as he could directly observe the contacts in only the thinnest section, because of the extensive talus and heavy plant cover, his upper contacts were probably chosen too high. The thicknesses measured by Harrison, Reynolds, and Phillips agree reasonably well, averaging about 150 ft, but those of Toomey do not agree, averaging only 60 ft.

Lithology—The Sandia is dominantly a siliceous clastic unit consisting of sandstone, shale, limestone, conglomerate, and siltstone (abundances in general in the order given). Considerable variation occurs laterally as shown comparatively in graphic sections of figure 26. In some sections sandstone is dominant; in others shale, limestone, and siltstone are more abundant with thin coal or coaly shale seams present. Conglomerate occurs mostly at the base but is present in higher parts. Sandstone occurs in unusual thicknesses around the head of Las Huertas Canyon, in Osha Canyon, and especially in Capulin Canyon in sec. 34, T. 12 N., R. 5 E., where thicknesses of 50 to 60 ft of thick-bedded, coarse-grained, grayish sandstone are well exposed. In contrast, considerably more black shale is present in Barro Canyon and in the Tijeras Canyon sections.

In general the Sandia sandstone varies from thin to thick bedded, white, yellowish, brownish, or light gray, medium to coarse grained, locally conglomeratic, and rather commonly contains shaly or silty partings. Cross and lenticular bedding is not uncommon. Carbonized and silicified wood or other plant remains occur locally. The sandstone is commonly micaceous and locally arkosic. Rock fragments are angular to subrounded and consist mostly of quartzite with lesser quantities of schist, gneiss, greenstone, or granite depending upon the underlying Precambrian rocks. Locally limestone fragments are present. Conglomerate in the Sandia is mostly pebbly and only locally bouldery or granulitic; conglomerate beds, present primarily in the basal section, are not thick, and are usually lenticular.

Limestone is widely distributed throughout the Sandia section, even at the base, although most of the limestone occurs in the upper part. Beds range from thin to thick with the thicker ledges being hackly, dense, and gray. Chert occurs in many beds but is not as common as in the Madera Formation. Textures range

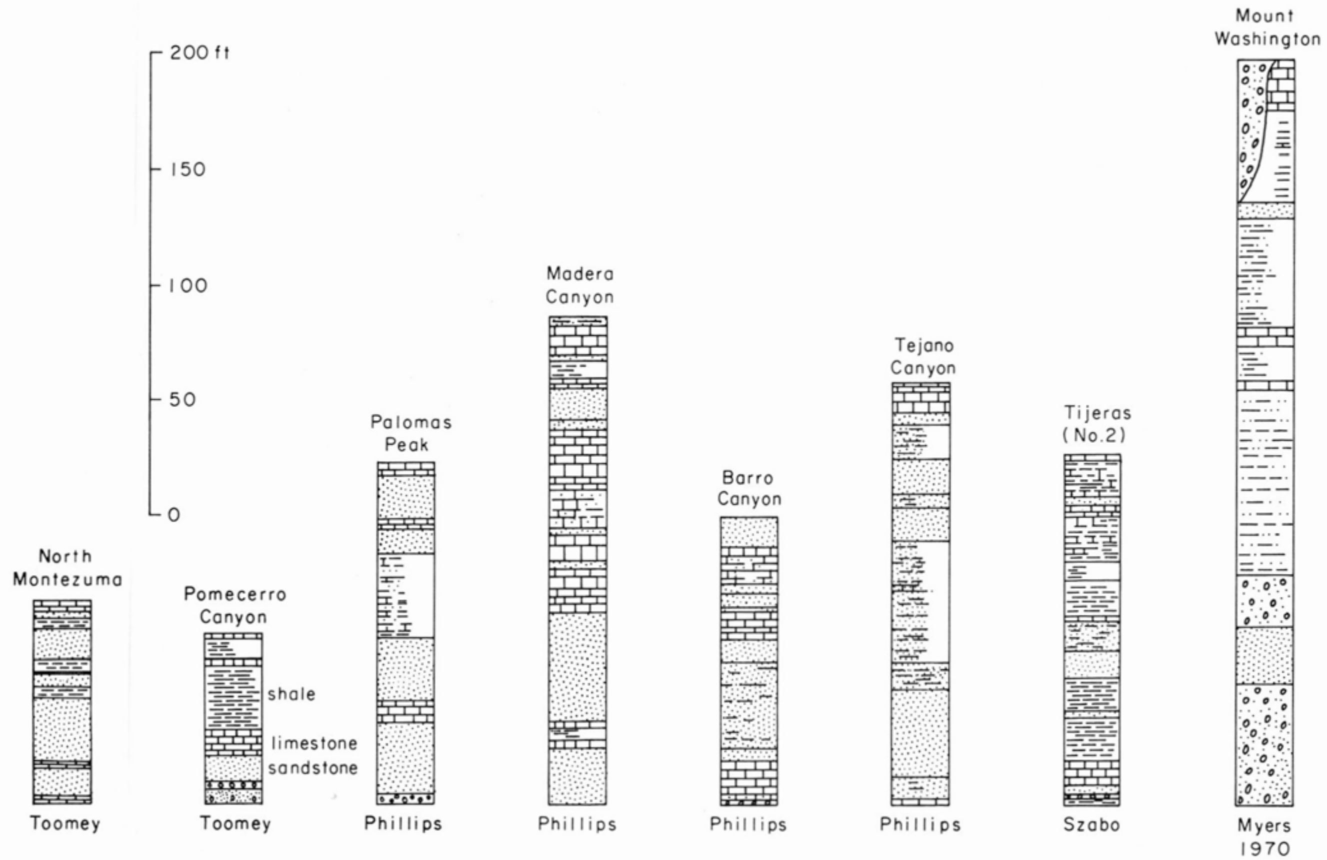


FIGURE 26—GRAPHIC SECTIONS OF THE SANDIA FORMATION.

from micritic to arenitic. Many limestones are sandy and gradations between sandstone and limestone appear to occur laterally as well as vertically. Some limestone beds are conglomeratic with either or both quartz and feldspar fragments. The thin and medium-thick beds are commonly dark yellowish brown or black and they may be nodular and locally shaly. Limestone also occurs as lenses or concretions in the shale units.

Shale in the Sandia is black, olive drab, and gray. It is commonly silty or sandy and commonly calcareous with local thin coal seams in the shale or siltstone units. Shale units are probably more prevalent in the middle part of the Sandia Formation. Locally reddish residual soil-type shale or claystone occurs in the Sandia and has been compared to the red Molas sediments of Colorado or put in a pre-Pennsylvanian category as Szabo (1953, p. 22) did in Tijeras Canyon.

Age—Fossils and age of the Sandia Formation are discussed at the end of the section on the Pennsylvanian.

MADERA FORMATION

Definition—The base of the Madera Formation is transitional and hence completely conformable with the underlying Sandia Formation. In most places the top of the Madera is also transitional or gradational with the overlying continental Permian Abo Formation. The first red-bed Abo-type strata appear near the top of the Madera, below the uppermost marine limestone that customarily is used to map the top of the Madera.

Distribution—The Madera is the most widespread outcropping formation in the Sandia area, capping the crest and forming the eastern dip slope of the Sandia Mountains. Its outcrop area (exclusive of Cenozoic deposits) is more than twice that of either the remaining pre-Cenozoic stratified rocks or the Precambrian exposures. The Sandia uplift is surfaced by Precambrian or Pennsylvanian rocks (in approximately equal western and eastern halves). The largest expanse of Madera is in the flat-lying beds of the Manzanita Mountains area south of Tijeras Canyon and US-66, where the unit is quite thick and relatively resistant. The Lower gray limestone member forms the crest of the Sandias and some of the upper eastern dip slope of the mountains. It also occurs along the western faces of the northern end of the Manzanita Mountains and in the deeper canyons of the eastern side of the mountains. Elsewhere the Madera shown on the geologic map (map 1) is surfaced by the upper Arkosic limestone member.

Lithology—The Madera Formation is dominantly a gray marine limestone sequence, but with variable interbeds of black, gray, reddish-brown, or purplish shale, sandstone, and conglomerate. The formation consists of a lower part comprising thick ledges of gray or black cherty limestone and an upper part of limestone in which arkosic sandstone, conglomerate, and reddish-brown shale or mudstone beds are common. The lower part has been termed and mapped by Read and associates as the Lower gray limestone member and the upper part, the Arkosic limestone member (Read and others, 1944).

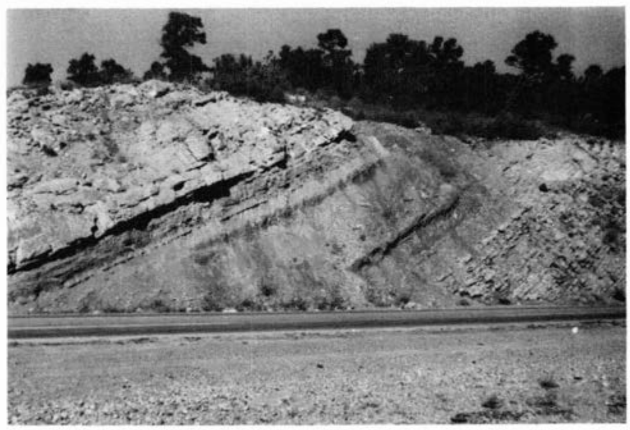
The name of the upper member was chosen not so much because the limestone beds are arkosic (micaceous *and* feldspathic) but because abundant feldspathic and micaceous sandstones and mixed conglomerates are interbedded with the typical Madera limestone.

The Lower gray limestone member constitutes 40 to 45 percent of the thickness of the Madera and is dominated by limestone ledges from 10 to 60 ft thick. In the lower and upper parts of the member black shale, micaceous siltstone, or shaly limestone partings up to 10 ft thick are present. A few thin light-gray to yellowish sandstone beds and very rare conglomerate lenses are present. Many thick limestone ledges are hackly weathering arenite. Many others are cryptocrystalline or lithographic micrite; others are finely crystalline. White, gray, black, and brown chert is abundant in the limestone as nodules, lenses, thin layers, or irregular stringers and masses. In parts of the section chert may constitute 50 percent or more of thick ledges composed of alternating thin layers of chert and limestone. Occasionally chert forms beds up to 2 or 3 ft thick; chert is commonly found along cross fractures or joints.

A section measured across the northern end of Montezuma Ridge, modified from Harrison (1949, p. 31-33), is given in Appendix 1.

The Arkosic limestone member makes up 55 to 60 percent of the Madera section. The quantity of clastics in the member differs greatly and is in general about twice that in the Lower gray member. The lower member clastics consist of more black shale and siltstone and cleaner sandstone, whereas the upper member elastics are muddier, arkosic, and more conglomeratic with reddish-brown, greenish, and yellowish colors prevailing over grays or blacks (fig. 27). Upper member limestone beds are somewhat less cherty than those of the lower member, and they are more commonly argillaceous, arenaceous, or arkosic. However, there are many nearly pure limestone units, and the limestone quarried by the Ideal Cement Company at Tijeras is in the upper part of the member.

A—ROADCUT along US-66 WEST OF TIJERAS. REDDISH-BROWN SHALE BEDS ALTERNATE WITH GRAYISH ARKOSIC SANDSTONE. GRAY LIMESTONE ON RIGHT.



B—ROADCUT ALONG US-66 EAST OF ZUZAX. GRAY THICK LIMESTONE ON LEFT OVERLIES DEEP MAROON MUDSTONE WITH THIN-BEDDED LIMESTONE AND SHALE ON RIGHT.

FIGURE 27—ARKOSIC LIMESTONE MEMBER (UPPER) OF MADERA FORMATION.

Limestone in the Arkosic limestone member is thin to thick bedded, light gray to black, and fine to very fine grained. Limestone occurs in intervals up to 30 ft thick and these may aggregate in units up to 60 to 70 ft thick with little or no sandstone or shale, but some intervals split and alternate or intertongue with thin units of shale, siltstone, or sandstone. Gray, black, and olive drab shale units are as much as 30 to 40 ft thick and are commonly calcareous, many units containing nodular limestone concretions. Much of the shale contains admixtures or intercalations of micaceous siltstone or fine-grained sandstone, or is in places just arenaceous. Sandstone units are up to 40 ft thick and are generally buff, tan, or reddish brown, medium to coarse grained, and locally conglomeratic. Conglomerate in the member is most variable, occurring in local lenses or channels that may reach several tens of feet in thickness with fragments consisting of limestone, chert, or quartzite.

Variability is a characteristic of the upper member especially within individual units. However, groups of beds may be followed using overall lithologies, fossils, and geomorphic expressions. Brown (1962, p. 29-31) followed zones of beds in the northern Manzanita Mountains around Cedro Peak in an effort to obtain a thickness for the Madera. Stukey (1967, fig. 1) mapped several alternating clastic and carbonate intervals in part of the upper member over a distance of some 10 miles during an effort to place the highly fossiliferous shale and limestone beds at the Kinney clay pit with reference to the top of the Madera Formation. His descriptions and stratigraphic sections (Stukey, fig. 1) reveal much about the lithologic variability within zones of beds.

Thickness—The thickness of the Madera generally ranges from about 1,300 to 1,400 ft. Read and others (1944, fig. 1, nos. 14, 15) measured two complete sections within the Sandia area as follows:

	Monte Largo	Tejano Canyon
Arkosic limestone member	780 ft	855 ft
Lower gray limestone member	495 ft	450 ft
Totals	1,275 ft	1,305 ft

In the southern part of the area around Cedro Peak, Brown (1962, p. 36) was able to piece together a thickness of 875 ft for the Arkosic member and about 500 ft for the Lower member for a total Madera thickness of 1,375 ft. Harrison (1949, p. 33) and Reynolds (1954, p. 16) measured sections of the Madera at Montezuma Mountain of 1,261 and 916 ft, but Reynolds believed Harrison had measured some strata twice in crossing a tight fold. Read and others (1944, fig.

1, no. 14) measured 985 ft at Montezuma Mountain, allowing for an estimated interval of interruption in the section.

Two sections of the Sandia and Madera Formations were measured by R. B. Johnson (1948) for a study of the lithology and insoluble residues, one at Palomas Peak and one at Seven Springs.

		Palomas Peak	Seven Springs
Madera Fm.	Upper arkosic limestone mem.	140 ft	40+ ft
	Gray limestone mem.	316 ft	300 ft
		(456)	(340+)
Sandia Formation		203 ft	20+ ft
		659 ft	360+ ft

Johnson recognized 8 "lentils" in the Gray limestone member and was able to recognize them in the section at Monte de Belen, 56 miles southwest of the Seven Springs section. In most cases, fossils were identified only generically.

A decade later, Perkins (1959) studied the lithogenesis of the Madera Formation at Palomas Peak. He measured two sections 660 ft apart.

	1	2
Upper Madera Formation	111 ft	149 ft
Lower Madera Formation	432 ft	481 ft
	(543)	(630)
Sandia Formation	32+ ft	40+ ft
	575+ ft	670+ ft

Johnson's thickness of his Upper arkosic limestone member (140 ft) agrees with Perkins' thickness of his Upper Madera (149 ft), but note the discrepancy between Johnson's thickness of his Gray limestone member (316 ft) and Perkins' thickness of his Lower Madera (432 ft in one section and 481 ft in the other).

Major rock types of the Madera Formation, according to Perkins (1959), include calcarenite, calcirudite, micrococquina, recrystallized calcisiltite, sandstone, coquina, and shale. Fossils were identified only by phylum.

Perkins (1959, fig. 5) noted rhythmic deposition evidenced by alternating clastic and bioclastic limestone units; he recognized 6 clastic and 6 bioclastic units in the Lower Madera. He also suggested that a high percentage of silica occurring as chert, chalcedony, opal, and quartz probably had a syngenetic origin.

Good complete sections of the Madera are difficult to find in the Sandia Mountains area owing to faults, spreading of outcrops across dip slopes, or cover by soil and vegetation. The Montezuma section is difficult because of dip-slope extension of beds and faulting at the top. The Tejano Canyon section is well exposed in nearly continuous roadcuts along NM-44 but is complicated by longitudinal faults which may both lengthen and shorten the section. The Monte Largo section is the least disturbed but is much covered by trees and is somewhat spread out down slopes. The Manzanita area is much covered and complicated by a number of faults as well as considerable spread between the base and top.

FOSSILS

Several thousands of years ago the prehistoric inhabitants of New Mexico occasionally collected fossil shell, bone, and wood. The buttonlike segments or columnals of Pennsylvanian crinoid stems were used in making bracelets and necklaces. Early Spanish explorers and colonists must have seen and collected fossils of various ages, but we have never seen any mention of fossils in the several chronicles and narratives of the early expeditions beginning with Coronado in 1540 and extending through the Pueblo Revolt in 1680. This is rather surprising in view of the many references to ores of silver, copper, and lead; to minerals, such as turquoise, gold, silver, copper, salt, garnet, peridot, alum, sulfur, azurite, malachite, lodestone, selenite, mica, jet, etc.; and to various rocks (Northrop, 1959, 1962).

Lieut. J. W. Abert (1848) was in the territory between September, 1846 and January, 1847. He visited both the Old and New Placers near Golden and submitted his collections of Pennsylvanian and Upper Cretaceous fossils to Prof. J. W. Bailey, who prepared a 2-page report entitled

> Notes concerning the minerals and fossils, collected by Lieutenant J. W. Abert, while engaged in the geographical examination of New Mexico, by J. W. Bailey, professor of chemistry, mineralogy, and geology at the United States Military Academy.

which was appended to Abert's 130-page report, published in 1848 as a Congressional Document. The Abert-Bailey report is accompanied by 24 unnumbered lithographed plates; the 24th plate illustrates "fossils from the lead mine at Tuerto [Golden]," including two views of a brachiopod, labeled "Terebratula" (now *Composita)*, and one of a shark's tooth. These are the earliest known illustrations of any New Mexico fossils.

The next description and illustration of fossils from New Mexico was by Lieut. J. H. Simpson (1850), of Upper Cretaceous petrified wood between the Rio Puerco and Rio Chaco, with the remark: "Do not these petrifactions show that this country was once better timbered than it now is?" His plates bear the notation: "Printed in colours at P. S. Duval's Steam lith. Press Establ. Phila." and constitute the second illustration of New Mexico fossils and the first in color.

The next important description and illustration of Pennsylvanian fossils was by James Hall (1856). As noted previously in Marcou's 1853 Survey, some of the fossils collected by Marcou at Pecos village were returned to Washington and given to Blake, who in turn submitted them to James Hall for identification. (However, it is obvious that Marcou retained some of the Pecos specimens, as well as all of the specimens from the Sandia Mountains and from Tijeras.) Hall (1856) described and illustrated 1 new species and 6 referred species: *Productus rogersi* Norwood and Pratten, *P. semireticulatus Martin, Spirifer cameratus* Morton (which, according to Hall, includes *S. triplicatus* Hall), *S. Kentuckensis* Shumard, *S. lineatus Martin, Terebratula millepunctata*, n. sp. (= *Beecheria millepunctata)*, and T *subtilita* Hall. It is interesting that Hall correctly dated these fossils from Pecos as coming from "the coal measures, or upper carboniferous limestone" or Pennsylvanian. In his report, two years later, Marcou (1858) still dated all the fossils from Pecos, the Sandia Mountains, and Tijeras as Mountain Limestone or Lower Carboniferous or Mississippian.

One of Hall's forms, *Productus rogersi*, deserves special comment. This seems to be what Marcou (1858) identified and figured as *Productus scabriculus* Mart. According to Dunbar and Condra (1932, p. 269), *P. rogersi* of Norwood and Pratten "is an ordinary specimen of *Juresania nebrascensis* (Owen)." However, Sutherland and Harlow (1973) did not find any *Juresania* at Pecos. Comparing Hall's (1856) and Marcou's (1858) figures with those of Sutherland and Harlow (1973), it seems likely that *Productus rogersi* and *P. scabriculus* are identical with *Buxtonia* n. sp. **B** of Sutherland and Harlow, described by them from Pecos and recognized by them at Tijeras.

Marcou (1858) described and illustrated a number of Pennsylvanian fossils from the Sandia Mountains area and from Pecos, not far to the northeast. He thought that they were of Lower Carboniferous or Mississippian age and called the Madera Formation the Mountain Limestone. Because his book, published in Zurich, is quite rare and not generally available in libraries, we present his account of these fossils in some detail. Weller's (1898) bibliographic index of Carboniferous invertebrates was useful in checking certain of Marcou's (1858) species. In addition, Shimer and Shrock's (1944) *Index fossils of North America* and various volumes of the *Treatise on invertebrate paleontology*, **R.** C. Moore, ed. (not included in References) were consulted in checking the status of many generic names.

Of the 22 species, 5 were new; 1 was identified only generically, and 16 were referred to previously named forms. Of the 16 referred species, Marcou identified 13 with English and European species with which he was more familiar, and only 3 with American species. In the introduction to his chapter 3, Paleontology, Marcou (1858, p. 32) states that "the greater part of these fossils have been submitted to Messieurs Agassiz, de Verneuil, de Koninck, d'Archiac, Jules Haime, Pictet and ***De***shayes, who were kind enough to aid me in their determination."

Thus Marcou cited 15 species form Tijeras, including 1 new species; 11 species from Sandia Crest and vicinity, including 1 new species; and 15 species from Pecos, including 3 new species. Some species were rare but others occurred in abundance.

Some pertinent comments by Marcou concerning rarer species are as follows:

Orthis Pecosii—only one specimen at Pecos village
Orthoceras Nova-Mexicana—a single specimen, "in a deep ravine near the summit of the Sierra de Sandia"
Productus pustulosus—"only one specimen well preserved at Tigeras"
P. scabriculus—"not very abundant"
Spirifer lineatus—"not very common"

Marcou's comments concerning some of the more common species are even more interesting, as follows:

Productus Cora—"I found several dozen specimens in the course of four or five hours exploration, at Tigeras canon of San Antonio, at Pecos village, and lastly at the

List of Marcou's (1858) fossils from the Mountain Limestone or Lower Carboniferous (Mississippian) of New Mexico, now known to be of Pennsylvanian age, with suggested current status (page, plate, and figure references are to Marcou (1858); for illustrations, see our figs. 28 and 29; T=type(s)).

	Tijeras	Sandia Crest	Pecos
Amplexus coralloides? Sow. (p. 53) = status uncertain	X		X
Bellerophon sp. (p. 44) (in last chamber of *Orthoceras Nova-Mexicana*)		X	
Myalina Apachesi, n. sp. (p. 44-45, pl. 7, figs. 6, 6a) = *Septimyalina apachesi* (Marcou)			T
Orthis crenistria Phill. (p. 49) = *Derbyia* sp.			X
Orthis Pecosii, n. sp. (p. 48-49, pl. 6, figs. 14, 14a-b) = *Cleiothyridina pecosii* (Marcou)			T
Orthoceras Nova-Mexicana, n. sp. (p. 44, pl. 7, fig. 1) = generic assignment uncertain		T	
Productus Cora d'Orb. (p. 45, pl. 6, figs. 4, 4a, from Pecos) = *Linoproductus platyumbonus* or *L. prattenianus*	X	X	X
Productus Flemingii Sow. (p. 47, pl. 6, fig. 7, from Tijeras) probably = *Sandia santafeensis* Sutherland and Harlow	X	X	X
Productus punctatus Mart. (p. 48, pl. 6, fig. 2, from Tijeras) probably = *Echinaria* sp.	X		X
Productus pustulosus Phill. (p. 48, pl. 6, fig. 1) probably = *Echinaria* sp.	X		
Productus pyxidiformis de Kon. (p. 48, pl. 6, figs. 3, 3a) = status uncertain; possibly *Antiquatonia* sp.	X		
Productus scabriculus Mart. (p. 47-48, pl. 5, figs. 6, 6a, from Pecos) = *Buxtonia* n. sp. B of Sutherland and Harlow		X	X
Productus semi-reticulatus Mart. (p. 46, pl. 5, figs. 4, 4a, from Pecos; not pl. 6, fig. 6, from Arizona) = *Antiquatonia* sp.	X	X	X
Spirifer lineatus Mart. (p. 50, pl. 7, figs. 5, 5a-b, from Pecos; 5c, from Tijeras) = *Phricodothyris perplexa* (McChesney)	X		X
Spirifer Rocky-Montani, n. sp. (p. 50, pl. 7, figs. 4, 4a-e) includes two species: *Anthracospirifer rockymontanus* (Marcou) = figs. 4c-e; and *A. curvilateralis chavezae* Sutherland and Harlow = figs. 4, 4a-b	T		
Spirifer striatus Mart. (p. 49, pl. 7, figs. 2, 2a, from Pecos) = *Neospirifer* sp.	X	X	X
Spirifer striatus triplicatus Hall (p. 49-50, pl. 7, fig. 3, from Pecos) = *Neospirifer dunbari* King	X	X	X
Terebratula plano-sulcata Phill. (p. 52, pl. 6, figs. 8, 8a-b) = *Composita* cf. *ovata* Mather	X		
Terebratula Rocky-Montana, n. sp. (p. 50-51, pl. 6, figs. 13, 13a-c) = *Leiorhynchoidea*? *rockymontana* (Marcou)			T
Terebratula subtilita Hall (p. 52, pl. 6, figs. 9, 9a-f, all from Pecos) = *Composita subtilita* (Hall)	X	X	X
Zaphrentis cylindrica Milne-Edwards and Jules Haime (p. 53, pl. 7, fig. 8, from Sierra de Sandia) = status uncertain	X	X	
Zaphrentis Stansburyi Hall (p. 52-53, pl. 7, fig. 7, from Tijeras) = possibly *Caninia*?	X	X	X

In addition to the above, Marcou noted crinoid columnals ("fragments of the stalks of encrinites") at Tijeras and "several unpublished *Bryozoa*" at Tijeras, Sandia Summit, and Pecos.

summit of the Sierra de Sandia, at 12,000 feet above the sea-level."

P. Flemingii—"is found in great abundance at Tigeras . . . near the summit of the Sierra de Sandia . . . also at Pecos village"

P. pyxidiformis—"quite common . . . near the village of Tigeras"

P. semi-reticulatus—"very abundant at Tigeras . . . [and] at the very top of the Sierra de Sandia"; at Pecos, "in an hour or two several hundred specimens in good preservation might easily be collected."

Spirifer Rocky-Montani—"I found this beautiful species in the Mountain Limestone of Tigeras, Canon of San Antonio, New Mexico; where it is not rare."

S. striatus triplicatus—"abundant"

Terebratula plano-sulcata—"I have met with it at Tigeras, New Mexico, where it is quite common."

T. subtilita—"I have seen several thousand specimens of this species at Tigeras, at Pecos village, [and] on the summit of the Sierra de Sandia . . ."

Zaphrentis cylindrica—"This gigantic species of coral, so common in the Mountain Limestone of England, Belgium, and France, had not been found previously in America. I saw a great number of specimens in ascending the Sierra de Sandia from Antonito, and several limestone beds were full of them. I also found it at Tigeras."

Z. Stansburyi—"Some specimens of the coral are quite large and sometimes much curved, having a semi-circular form . . . I saw a great many at Tigeras, on the summit of the Sierra de Sandia, and at Pecos village. The limestone in which it is found is so hard, that it is difficult to obtain well-preserved and complete specimens." The figured specimen is a "fragment showing the interior of the turbine."

It may be noted that Sutherland and Harlow (1973) make reference to some of the species described from Pecos and Tijeras by Hall (1856) and Marcou (1858) but do not mention all of them.

Pennsylvanian fossils of the Sandia Mountains area and some nearby areas are listed in tables 1, 2, and 3: Table 1—Foraminifera, Table 2—Brachiopoda, and Table 3—Fossils exclusive of Foraminifera and Brachiopoda.

Table 1, *Foraminifera in the Sandia Formation and Madera Group, Sandia Mountains, Manzano-Manzanita Mountains, and adjoining areas,* presents the complete foraminiferal fauna of the Sandia Mountains area (Column 3) and of the Manzano-Manzanita Mountains area (group of 6 columns to the right of Column 3).

Prefatory Remarks to Table I (page 42)

1. Identical or related species occurring in the Jemez-Nacimiento Mountains area are listed in this column. Note that this is not the complete fauna of that area; many species reported from that area have not yet been reported from the Sandia and Manzano-Manzanita areas. Chief sources for Column 1 include a list by Northrop (1974), which is based on an earlier list (Northrop, 1961a), compiled from Wood and Northrop (1946), which included identifications by Henbest, Read, and others (1944); and Armstrong and Mamet (1974).

2. Identical or related species occurring in the southern Sangre de Cristo Mountains area are listed in this column. Note again that this is not the complete fauna of that area; many species reported from that area have not yet been reported from the Sandia and Manzano-Manzanita areas. Chief sources for Column 2 are Needham (1937) and Sutherland and Harlow (1973, p. 10, identified by D. E. Waddell).

3. This column is for the Sandia Mountains area, principally Tijeras and Cedro Canyons. Sources are Needham (1937), Werrell (1961), and several theses.

4. The remaining 6 columns present the fauna of the Manzano-Manzanita Mountains area, based on Myers (1973) and six U.S.G.S. Geologic Quadrangle Maps published 1966-72 (Myers, 1966, 1967, 1969; Myers and McKay, 1970, 1971, 1972). A complete chart compiled by Northrop was kindly checked by Donald A. Myers. For purposes of mapping, Myers and Myers and McKay used units designated Sandia Formation and Madera Limestone. The latter was subdivided into a Lower part, followed upward by Units B, C, and D.

Later, Myers (1973) raised the Madera Limestone to group rank. He concluded that the Sandia Formation is of Atokan age and that the Madera Group ranges from earliest Desmoinesian through Missourian and Virgilian to Early Permian or Wolfcampian age. He named two new formations, the Los Moyos Limestone and the Wild Cow Formation; the latter was subdivided into three members: Sol se Mete, Pine Shadow, and La Casa. The Los Moyos Limestone is the "lower part of the Madera Limestone" of the six maps; age is Desmoinesian and earliest Missourian. It is what had been called the Lower gray limestone of the Madera by earlier workers.

The Wild Cow Formation is the Arkosic limestone member of the Madera and includes units B, C, and D of the upper part of the Madera. The basal part of the Wild Cow Formation is the Sol se Mete Member; it is unit B of the upper part of the Madera; age is Missourian. The middle part of the Wild Cow Formation is the Pine Shadow Member; it is unit C of the upper part of the upper Madera; age is early Virgilian. The upper sequence of the Wild Cow Formation is the La Casa Member; it is unit D of the upper part of the upper Madera; age is middle and late Virgilian.

The uppermost formation of the Madera Group is the Bursum Formation, of Early Permian Wolfcampian age. The Bursum is present in the southern part of the Manzano Mountains; the top of the Bursum Formation is the top of the highest marine limestone that underlies the Abo Formation. Myers (1973, p. 11-12) notes that "northward . . . the formation either becomes thinner or is replaced by the overlying Abo Formation . . . In the northern half of the Manzano Mountains, the Bursum is absent in most places. Field evidence suggests that north of Pine Shadow Spring many of the red beds of the Bursum have been replaced by gray shale and limestone. If such replacement has occurred, then the uppermost beds of the La Casa Member include Bursum equivalents in the northern Manzano Mountains."

Table 2, *Pennsylvanian Brachiopoda in the Sandia Mountains and other New Mexico areas,* presents the complete brachiopod fauna of the Sandia Mountains area in 8 columns and partial brachiopod faunas of nearby areas in 3 additional columns.

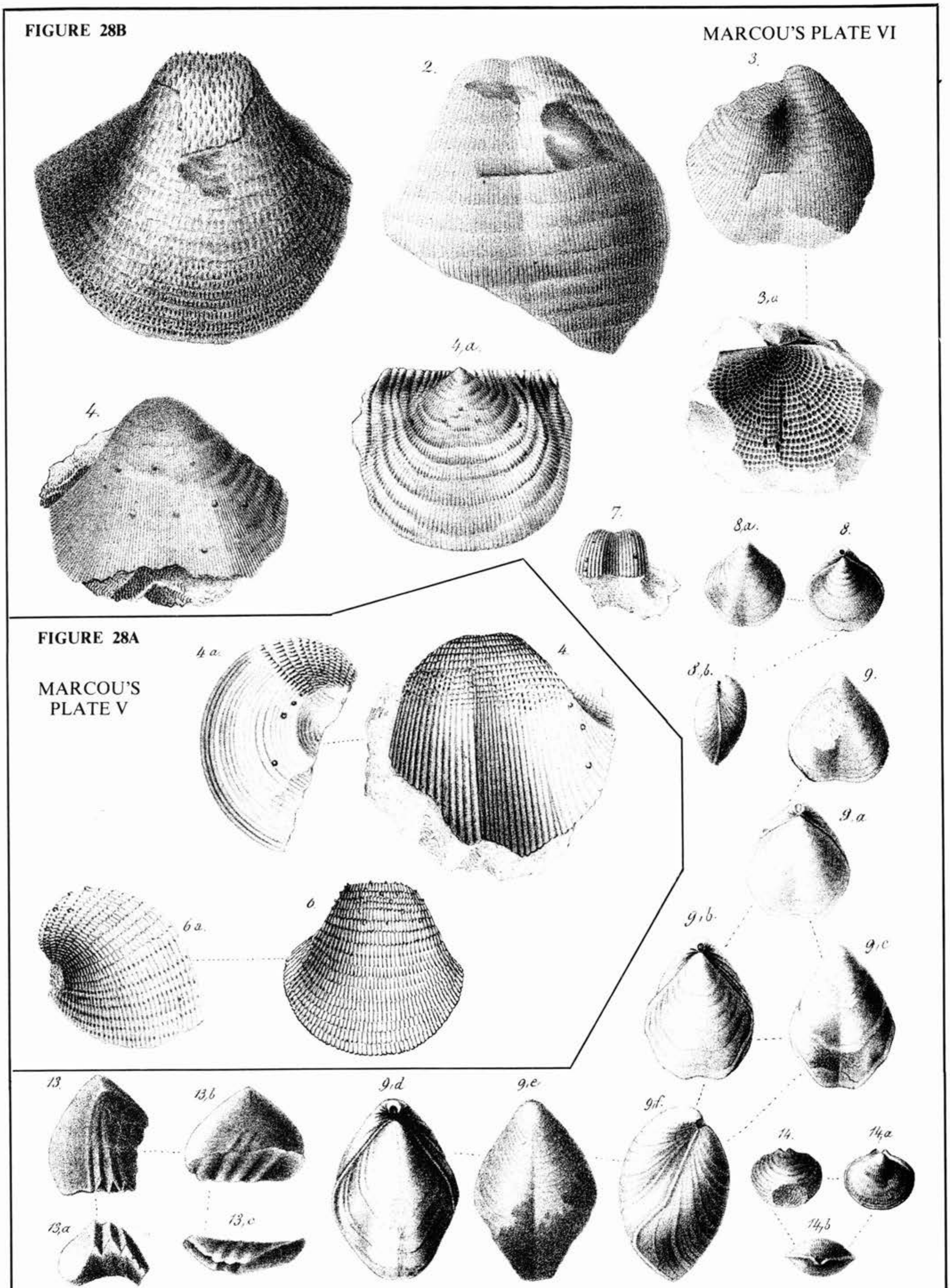


FIGURE 28—EXCERPTS FROM MARCOU'S PLATES V AND VI (1858).

Prefatory Remarks to Table 2 (page 43)

1. In Column 1, identical or related species occurring in the Jemez-Nacimiento Mountains area are listed. Note that this is not the complete fauna of that area; a number of species reported from that area have not yet been reported from the Sandia Mountains. Sources for Column 1 are a list by Northrop (1974), which is based on an earlier list (Northrop, 1961a, p. 109-111) compiled from Wood and Northrop (1946), and Sutherland and Harlow (1967).

2. In Column 2, identical or related species occurring in the southern Sangre de Cristo Mountains are listed. Again, note that this is not the complete fauna of that area; many species reported from that area have not yet been reported from the Sandia Mountains. Sources for Column 2 are Marcou (1858) and Sutherland and Harlow (1973).

3. For the Placitas area, at the north end of the Sandia Mountains, there are two columns, one for the Sandia Formation and one for the Madera Formation. Chief source for this area is Toomey (1953).

4. For the crest or rim of the Sandia Mountains, there are likewise two columns, one for the Sandia Formation and one for the Madera Formation. Chief source is Catacosinos (1962); a few species were cited by Marcou (1858).

5. For the Tijeras-Cedro Canyons area, at the southern end of the Sandia Mountains, four columns are given, one for the Sandia Formation and three for the Madera Formation; the Madera is subdivided into Desmoinesian, Missourian, and Virgilian. Sources are principally Marcou (1858), Szabo (1953), and Stukey (1967).

6. In this last column, for the Coyote Canyon, Manzanita Mountains area, species cited by Herrick and Bendrat (1900) are given. Coyote Canyon lies south of Tijeras Canyon and currently is considered to be part of the Manzanita Mountains, although Herrick and Bendrat regarded it as being in the Sandia Mountains; other workers, not recognizing the Manzanita Mountains, would place Coyote Canyon in the northern end of the Manzano Mountains.*

Herrick and Bendrat's paper is entitled *Identification of an Ohio Coal Measures horizon in New Mexico.* In 1887 Herrick had published an annotated list of fossils from the shale immediately above the cannel coal at Flint Ridge, east of Newark, Ohio. Herrick and Bendrat (1900) are rather vague as to the precise locality and horizon at which they discovered a number of fossils in the Sandia Mountains; their list is entitled "List of fossils from the Sandia Mountains of New Mexico, found in a band of shale supposed to correspond to the Flint Ridge Shales of Ohio." In the Coyote Canyon area, Herrick and Bendrat found 34 species, of which "24 are also found at Flint Ridge, Ohio." The Flint Ridge shale of Ohio is in the lower Mercer limestone (Pottsville or Atokan). However, it appears that the *Flint Ridge* of the Manzanita Mountains area must be in the Los Moyos Limestone of Myers (1973), which is dated by him as Desmoinesian, not Atokan.

Herrick and Bendrat's *Flint Ridge shale* is apparently about 150 ft above the base of the Madera Formation (compare right-hand columnar section given by Herrick

*In 1900, Herrick, first professor of geology and second president of the University of New Mexico, along with colleagues and students, generally referred to Coyote Canyon as being in the Sandia Mountains, probably because it was more accessible from Albuquerque than Tijeras Canyon was. A bit of evidence in this connection is that W. G. Tight—second professor of geology and third president of U.N.M.—led a field excursion into the Manzanita Mountains in 1907 for the annual meeting of the Geological Society of America, held in Albuquerque Dec. 30-31. For this excursion he prepared a geologic sketch map (fig. 9) with cross sections, entitled *Sandia Mountains Excursion G. S. A. 1907* (Northrop, 1966, p. 10, II; see discussion, p. 19 of this memoir).

FIGURE 28A—EXCERPTS FROM MARCOU'S (1858) PLATE V. (On page 32 Marcou noted: All the specimens are represented of the natural size exactly as they are; and I have not attempted to restore the imperfect portions, as has been done by many paleontologists, from a fear of making too fantastic additions to nature, which are very difficult to avoid in such cases.)

Figures

4 Productus semi-reticulatus MART.
4) FRONT VIEW WITH TUBERCLES, FROM PECOS; *4a*) SAME, SIDE VIEW. PROBABLY *Antiquatonia.*

6 Productus scabriculus MART.
6) FRONT VIEW, FROM PECOS; *6a*) THE SAME, SIDE VIEW. PROBABLY *Buxtonia.*

FIGURE 28B—EXCERPTS FROM MARCOU'S (1858) PLATE VI:

Figures

1 Productus pustolosus PHILL.
FRONT VIEW, FROM TIJERAS. PROBABLY *Echinaria.*

2 Productus punctatus MART.
FRONT VIEW, FROM TIJERAS. PROBABLY *Echinaria.*

3 Productus pyxidiformis DE KON.
3) FRONT VIEW, FROM TIJERAS; *3a*) SAME, "NOT WELL DRAWN." STATUS UNCERTAIN, POSSIBLY *Antiquatonia.*

4 Productus Cora D'ORB.
TWO SPECIMENS FROM PECOS: *4*) FRONT VIEW, SHOWING TUBERCLES; *4a*) DORSAL VALVE, FLATTENED BY VERTICAL PRESSURE. CERTAINLY *Linoproductus,* CF. *platyumbonus* OR *prattenianus.*

7 Productus Flemingii SOW.
FRONT VIEW, FROM TIJERAS. PROBABLY *Sandia santafeensis,* SUTHERLAND AND HARLOW.

8 Terebratula plano-sulcata PHILL.
8, 8a, 8b) DIFFERENT VIEWS OF SPECIMEN FROM TIJERAS. PROBABLY *Composita* CF. *ovata* MATHER.

9 Terebratula subtilita HALL
THREE SPECIMENS FROM PECOS: *9, 9a*) SPECIMEN SHOWING THE SINUS ON BOTH VALVES; *9b, 9c*) LARGER SPECIMEN, MORE ELONGATED; *9d, 9e, 9f*) VERY GIBBOUS AND ELONGATED SPECIMEN. *Composita subtilita* (HALL); PROBABLY OTHER SPECIES REPRESENTED.

13 Terebratula Rocky-montana, N. SP.
TWO IMPERFECT SPECIMENS FROM PECOS: *13, 13a*) IMPERFECT SPECIMEN; *13b, 13c*) ANOTHER SPECIMEN LATERALLY COMPRESSED. *Leiorhynchoidea*? *rockymontana* (MARCOU). SUTHERLAND AND HARLOW (1973, P. 60-61, PL. 13, FIG. 19) CHOSE THE SPECIMEN FIGURED BY MARCOU AS HIS FIGS. *13, 13a* AS THE LECTOTYPE (BRITISH MUSEUM OF NATURAL HISTORY B79165), AND CHOSE THE OTHER SPECIMEN FIGURED BY MARCOU AS HIS FIGS. *13b, 13c* AS THE PARATYPE (BMNH B79166). SUTHERLAND AND HARLOW (1973, P. 61) STATE THAT THIS "IS THE TYPE SPECIES FOR THE NEW GENUS *Corrugatimedio-rostrum* PROPOSED BY SARTENAER (1970, P. 23). WE REJECT THE USE OF THIS GENERIC NAME UNLESS VALID UNCRUSHED TOPOTYPES COULD BE COLLECTED TO DETERMINE THE INTERNAL CHARACTER OF THE TYPE SPECIES."

14 Orthis Pecosii, N. SP.
MARCOU HAD ONLY THIS ONE SPECIMEN FROM PECOS: *14*) VIEW OF DORSAL VALVE; *14a*) SAME, VIEW OF VENTRAL VALVE; *14b*) SAME, VIEW OF BEAK. *Cleiothyridina pecosii* (MARCOU). THE HOLOTYPE IS BMNH B79168, ACCORDING TO SUTHERLAND AND HARLOW (1973, P. 67-68, PL. 14, FIG. 24).

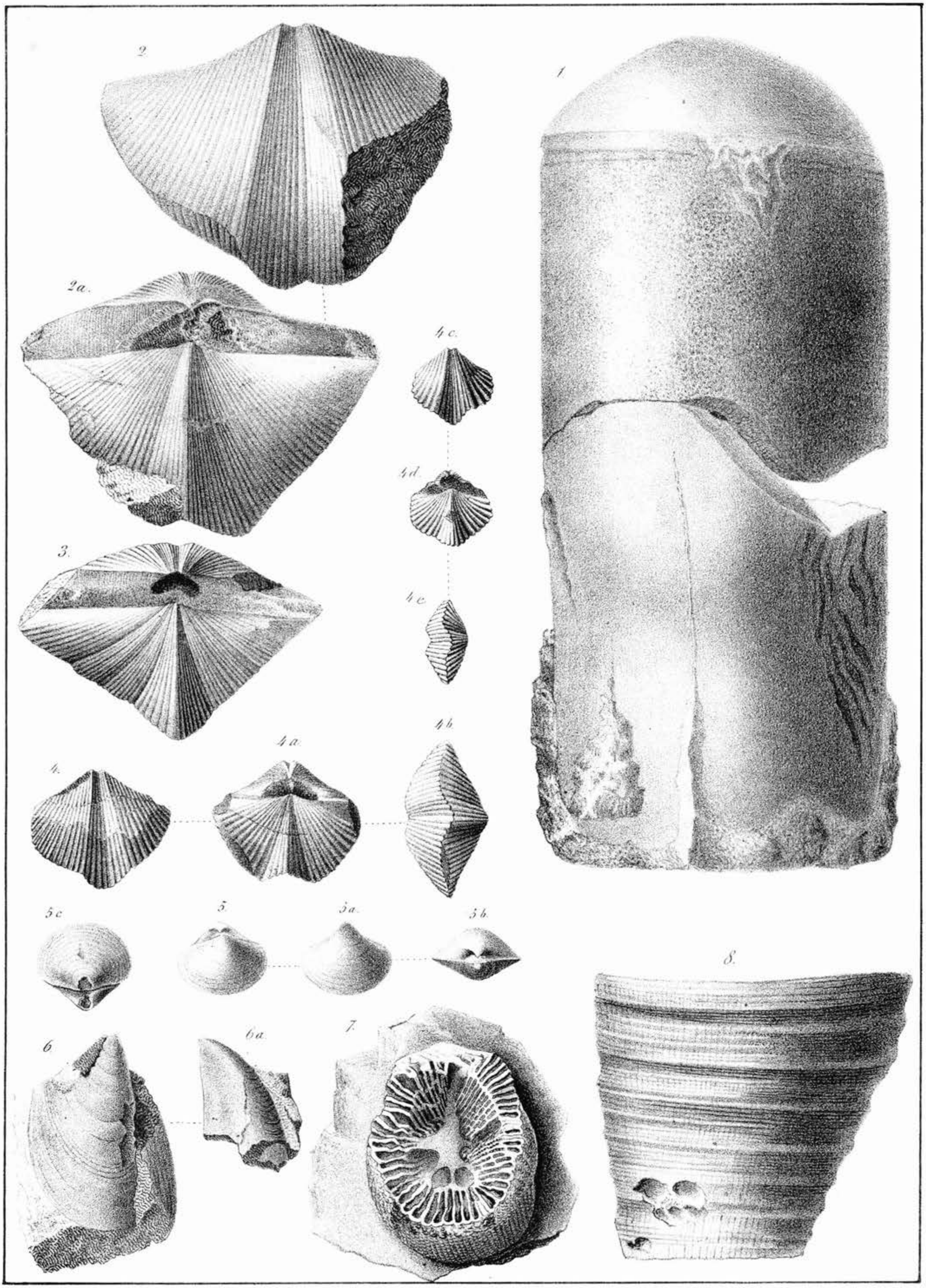


FIGURE 29—MARCOU'S PLATE VII (1858).

and Johnson, 1900, pl. 22, with Herrick and Bendrat, 1900, p. 3-4).

Older generic and specific names are given in parentheses and quotation marks. Type specimens are indicated by T. Additional information is noted at the bottom of the table.

Contrasts between the Pennsylvanian brachiopod faunas of the Sandia Mountains area and other areas in northern New Mexico are as follows.

Genera reported from the Sandia Mountains but not yet reported from the southern Sangre de Cristo Mountains include *Cancrinella,* * *Enteletes, Hystriculina,* * *Juresania,* * *Lissochonetes,* and *Retaria.* Those designated by asterisks (*) are found in the Jemez-Nacimiento Mountains.

Genera in the Sandia Mountains not yet reported from the Jemez-Nacimiento Mountains include *Buxtonia,* * *Enteletes, Lissochonetes, Mesolobus,* * *Retaria, Reticulatia,* * *Rhynchopora,* * and *Sandia.* * Those designated by asterisks (*) are found in the Sangre de Cristos.

Genera in the Sangre de Cristos not yet reported from the Sandias include *Calliprotonia, Crania, Horridonia?, Isogramma, Krotovia,* Leiorhynchoidea?, Leptalosia,* Orthotetes, Plicochonetes? *, Pulchratia? *, Rhipidomella, Spirifer,* Spiriferellina, Tesuquea,* * and *Zia.* * One reason that so many of these genera have not been found in the Sandia Mountains is that 7 of them, designated by asterisks (*), are found only in the Morrowan. So far Morrowan strata have yielded few fossils in the Sandias.

Genera in the Sangre de Cristos not yet reported from the Jemez-Nacimientos include *Buxtonia,* * *Calliprotonia, Horridonia?, Krotovia, Leiorhynchoidea?, Mesolobus,* * *Orthotetes, Plicochonetes?, Reticulatia,* Rhipidomella, Rhynchopora,* * *Sandia,* * *Spirifer, Spiriferellina, Tesuquea,* and *Zia.* Those designated by asterisks (*) are found in the Sandia Mountains.

Genera in the Jemez-Nacimientos not yet reported from the Sandias include *Crania, Isogramma, Leptalosia,* and *Pulchratia.* All occur in the Sangre de Cristos.

Genera in the Jemez-Nacimientos not yet reported from the Sangre de Cristos include *Cancrinella, Hystriculina, Juresania,* and *Schuchertella.* All occur in the Sandias.

Table 3, *Pennsylvanian Fossils of the Sandia-Manzanita Mountains area (excluding Foraminifera and Brachiopoda),* presents the complete Pennsylvanian fauna and flora of the Sandia-Manzanita Mountains area (excluding the Foraminifera and Brachiopoda, which were given above in Tables 1 and 2) in 9 columns. Note that the Jemez-Nacimiento and southern Sangre de Cristo areas are not included.

Prefatory Remarks to Table 3 (page 45)

1. For the Placitas-Tejon area, at the north end of the Sandia Mountains, there are two columns, one for the Sandia Formation and one for the Madera Formation. Chief sources are Toomey (1953) and Lee and Girty (1909). Under the heading, Sandia Mountains, Lee and Girty (1909, p. 19) give a columnar "section of a part of the beds exposed at the north end of the Sandia Mountains, near Tejon." This section ranges from "Magdalena Limestone" through Abo, Yeso, and Morrison? to Upper Cretaceous. Above the Madera limestone there is 40 ft of "sandstone, red, conglomeratic, with limestone pebbles at the base," overlain by 2 ft of "limestone, granular, earthy." This is overlain by 700 ft of Abo red beds, followed by 400 ft of Yeso. Ten species of mollusks are listed at about the middle of the Yeso. This is an error; these ten species should have been designated as coming from the 2 ft of limestone near the base of the Abo, which fact can be confirmed by checking Lee and Girty's faunal table (p. 48-49) and the register of three localities (p. 120, U.S.G.S. localities 3796, 3797, 3798). We suspect that the entire fauna of 20 species, including 10 bivalves, 7 gastropods, 2 brachiopods, and 1 scaphopod, came from the top of the Madera Formation, not from the Abo, and certainly not from the Yeso. The three localities were given as Ojo de San Francisco, road between Ojo de San Francisco and Tejon, and two miles south of Tejon. Unfortunately, a number of padlocked gates make these localities inaccessible today.

2. For the crest or rim of the Sandia Mountains,

*(continued on page **44**, right column)*

FIGURE 29—MARCOU'S (1858) PLATE VII:

Figures

1 Orthoceras Nova-Mexicana, N. SP.

A SINGLE SPECIMEN FROM A DEEP RAVINE NEAR THE SUMMIT OF SIERRA DE SANDIA. GENERIC ASSIGNMENT UNCERTAIN; PRESUMABLY THE HOLOTYPE IS IN THE BRITISH MUSEUM OF NATURAL HISTORY.

2 Spirifer striatus MART.

2) SPECIMEN FROM PECOS, VIEW OF DORSAL VALVE; *2a)* SAME, VENTRAL VALVE. *Neospirifer,* PROBABLY.

3 Spirifer striatus VAR. *triplicatus* HALL

FRONT VIEW OF SPECIMEN FROM PECOS. PROBABLY *Neospirifer dunbari* KING.

4 Spirifer Rocky-Montani, N. SP.

TWO SPECIMENS FROM TIJERAS: *4, 4a, 4b)* DIFFERENT VIEWS OF A LARGE SPECIMEN (NOW *Anthracospirifer curvilateralis chavezae* SUTHERLAND AND HARLOW); *4c, 4d, 4e)* YOUNG SHELL A LITTLE COMPRESSED (NOW *Anthracospirifer rockymontanus* (MARCOU)).

ACCORDING TO SUTHERLAND AND HARLOW (1973, P. 82-84, PL. 17, FIG. 10), MARCOU'S (1858) SPECIMEN SHOWN AS HIS FIGS. *4, 4a, 4b* IS BMNH B79154, AND IS *Anthracospirifer curvilateralis chavezae;* SUTHERLAND AND HARLOW'S FIG. 11 IS A CAST OF THE SAME SPECIMEN.

GIRTY'S LECTOTYPE OF *Anthracospirifer rockymontanus* IS BMNH B79155; SEE SUTHERLAND AND HARLOW (1973, P. 86, PL. 17, FIG. 7) AND COMPARE WITH THEIR FIG. 8, WHICH IS A PLASTOTYPE OF THE LECTOTYPE.

5 Spirifer lineatus MART.

5, 5a, 5b) DIFFERENT VIEWS OF SPECIMEN FROM PECOS; *5c)* SPECIMEN FROM TIJERAS, SHOWING TO THE NAKED EYE THE RETICULATION OF ITS SURFACE. THIS IS NOW *Phricodothyris perplexa* (MCCHESNEY).

6 Myalina Apachesi, N. SP.

FROM NEAR THE RANCHOS OF PECOS VILLAGE. *6)* SIDE VIEW OF A SPECIMEN WITHOUT THE BEAK OR THE CARDINAL BORDER; *6a)* SIDE VIEW OF THE BEAK. PRESUMABLY THE HOLOTYPE IS IN THE BRITISH MUSEUM OF NATURAL HISTORY. NOW *Septimyalina apachesi* (MARCOU), ALTHOUGH NEWELL (1942, P. 67-68) DOUBTFULLY PLACED THIS SPECIES IN THE SYNONYMY OF *S. burmai* NEWELL, A PERMIAN FORM; WE THINK MARCOU'S ORIGINAL NAME SHOULD BE REVIVED.

7 Zaphrentis Stansburyi HALL

FRAGMENT OF A SPECIMEN FROM TIJERAS, "SHOWING THE INTERIOR OF THE TURBINE." MAY BE *Caninia.*

8 Zaphrentis cylindrica MILNE-EDWARDS AND JULES HAIME

FRAGMENT OF A LARGE SPECIMEN FROM SIERRA DE SANDIA. STATUS UNCERTAIN.

TABLE 1—Foraminifera in Sandia Formation and Madera Group, Sandia Mountains, Manzano-Manzanita Mountains, and Adjoining Areas

(Superscripts at heads of columns refer to prefatory remarks in text; numbers in table refer to notes at bottom of table)

				Manzano-Manzanita Mts.[4]					
					Madera Group				
						Wild Cow Fm.			
							Virgilian		
	Jemez-Nacimiento Mts.[1]	Southern Sangre de Cristo Mts.[2]	Sandia Mts.[3]	Sandia Fm. (Atokan)	Los Moyos Ls. (Desmoinesian)	Sol se Mete M. (Missourian)	Pine Shadow Member	La Casa Member	Bursum Fm. (Wolfcampian)
Apterrinellids	X		X						
Beedeina aff. *arizonensis* (*"Fusulina"*) (Note 1)					X				
B. cf. *bowiensis*					X				
B. *euryteines*		X	X						
B. aff. *euryteines*	X								
B.? aff. *insolita*				X					
B. *novamexicana*		X			X				
B. cf. *novamexicana*					X				
B. aff. *pattoni*			X						
B. *rockymontana*			X		X				
B. aff. *rockymontana*					X				
B. *socorroensis*		X	X						
B. cf. *sulphurensis*					X				
B. *taosensis*		X							
B. aff. *taosensis*			X						
B. spp.	X	X	X		X				
B.? sp.				X					
Biseriella of the group *B. parva*	X		X						
Bradyina spp.	X		X			X	X	X	
Climacammina sp.	X					X	X		
Dunbarinella? sp.							X		
Endothyra sp.	X								
E.? sp.	X		X						
Eoschubertella aff. *bluensis*					X				
Eowaeringella aff. *ultimata*					X				
Fusulinella devexa		X							
F. aff. *devexa*					X				
F. *famula*		X							
F. cf. *famula*					X				
F. spp.	X			X					
F.? spp.	X		X	X					
Globivalvulina s.s.	X		X						
Millerella sp.	X								
M.? sp.			X		X				
Schwagerina pinosensis									X
S. sp.									X
Tetrataxis sp.	X		X						
Textularia? sp.			X						
Textulariidae	X								
Triticites aff. *cameratoides*								X	
T. aff. *creekensis*								X	
T. cf. *cuchilloensis*						X	X		
T. *fresnalensis*			X				X		
T. cf. *fresnalensis*							X		
T. aff. *fresnalensis*			X				X		
T. *irregularis*	X	X	X			X			
T. aff. *irregularis*	X		X			X			
T. *nebraskensis*	X		X						
T. cf. *nebraskensis*						X			
T. aff. *pinguis*			X						
T. cf. *plummeri*								X	
T. aff. *plummeri*	X								
T. aff. *secalicus*							X	X	
T. *ventricosus*	X		X						
T. *ventricosus*, var.	X		X					X	X
T. cf. *wellsi* (Note 2)						X			
T. aff. *wellsi*						X			
T. aff. *whetstonensis* (Note 3)	X		X						
T. spp.	X	X	X			X	X	X	X
Wedekindellina ellipsoides					X				
W. *euthysepta*	X	X	X						
W. *excentrica*	X	X	X						
W. cf. *henbesti*					X				
W. aff. *henbesti*					X				
W. spp.	X	X	X		X				

NOTES

1. Donald A. Myers (letter, Feb. 21, 1974) writes: "With regard to my use of *Beedeina,* I am following Ishii, 1957 (Proc. Jap. Acad., v. 23, p. 652-656) and 1958 (Jour. Inst. Polytechnics, Osaka Univ. ser. G, v. 4, p. 29-70). In these articles, Ishii restricted *Fusulina s.s.* to the group of *F. cylindrica*. . . . As thus defined, most of what has been called *Fusulina* in this country is now referrable to Galloway's genus *Beedeina."*

2. The type locality for *T. wellsi* Needham (1937, p. 12, loc. 8; 37-38) is about 1.5 miles east of the east edge of our map (map 1), about a mile east of Barton, along 1-40. Barton is just off the map.

3. Triticites aff. whetstonensis was identified by D. E. Waddell in a limestone of the Jemez Springs Shale Member of the Madera Formation 29 ft below the base of the Abo Formation red beds, just west of Battleship Rock 4 miles above Jemez State Monument near Jemez Springs (Sutherland and Harlow, 1967, p. 1068), and regarded as late Virgilian in age. Again, *T. aff. whetstonensis* was identified by D. A. Myers (letter, June 12, 1974) in a collection made by us and J. F. Callender from the Arkosic limestone member of the Madera Formation, in abandoned railroad cuts along the west side of San Pedro Creek, about 6.5 miles NNE of San Antonito and about 6.7 miles S of Hagan. Myers reported that the form is close to material that he has from the upper part of his La Casa Member of the Wild Cow Formation of the Madera group (late Virgilian).

TABLE 2—PENNSYLVANIAN BRACHIOPODA IN SANDIA MOUNTAINS AND OTHER NEW MEXICO AREAS

(T=type(s); superscripts at heads of columns refer to prefatory remarks in text; numbers in table refer to notes at bottom of table)

	Jemez-Nacimiento Mountains[1]	Southern Sangre de Cristo Mountains[2]	SANDIA MOUNTAINS: Placitas[3] Sandia Fm.	SANDIA MOUNTAINS: Placitas[3] Madera Fm.	SANDIA MOUNTAINS: Crest[4] Sandia Fm.	SANDIA MOUNTAINS: Crest[4] Madera Fm.	SANDIA MOUNTAINS: Tijeras-Cedro Canyons[5] Sandia Fm.	SANDIA MOUNTAINS: Tijeras-Cedro Canyons[5] Madera Fm. Desmoinesian	SANDIA MOUNTAINS: Tijeras-Cedro Canyons[5] Madera Fm. Missourian	SANDIA MOUNTAINS: Tijeras-Cedro Canyons[5] Madera Fm. Virgilian	Coyote Canyon Manzanita Mts.[6]
Anthracospirifer curvilateralis chavezae Sutherland and Harlow ("*Spirifer Rocky-Montani,*" in part) (Note 1)		T						X			
A. *matheri* (Note 2)		X						X			
A. *occiduus* ("*Spirifer occidentalis*")	X	X	X	X	X	X	X	X			
A. cf. *occiduus*	X				X						
A. *occiduus,* var.								X			
A. *opimus*	X	X	X	X			X	X			X
A. *rockymontanus* (Marcou) (Note 3)	X	X	X	X	X		X	T			
A. cf. *rockymontanus*	X					X					
A. spp.	X				X	X					?
Antiquatonia coloradoensis ("*Productus,*" "*Dictyoclostus*")	X	X				X					
A. *crassicostata*	X			X					X		
A. *portlockiana*	X	X		X			X	X	?		
A. spp.	X	X	X			X					
Beecheria bovidens ("*Dielasma*")	X			X				X	X	X	
Buxtonia scabricula ("*Productus;*" an English Mississippian sp.)		X				X					
B. n. sp. B of Sutherland and Harlow		T				?		X			
Cancrinella boonensis ("*Productella pertenuis*")	X							X	X		?
Chonetinella crassiradiata ("*Chonetes,*" "*Chonetina*")				X							
C. *flemingi*									X		
C. cf. *flemingi*						X					
C. *flemingi alata*	X										
C. *verneuiliana*									X		
Cleiothyridina pecosii ("*C. orbicularis*") (Note 4)	X	T		X				?	X		
Composita argentea ("*Terebratula,*" "*Athyris*")		X						X			X
C. *elongata*		X	X	X		X		?	X		
C. cf. *elongata*	X										
C. *magna*				X					X		
C. cf. *magna*	X										
C. *ovata*	X	X	X	X				X			
C. cf. *ovata*										X	
C. *subtilita*	X	X	X	X		X	X	X	X	X	X
C. *trilobata*	X			X					X		
C.? sp.					X						
Crurithyris planoconvexa ("*Ambocoelia*")	X	X						X	X	X	
Derbyia crassa ("*Derbya*")	X	X		X				X	X	X	X
D. sp.	X						X				
Desmoinesia missouriensis ("*Marginifera*")		X						X			
D. cf. *missouriensis*	X					X					
D. *muricatina* ("*Rudinia*")		X	X	X			X	X			
D. cf. *muricatina*						X					
D.? sp.						X					
Echinaria knighti ("*Productus,*" "*Echinoconchus*")								X			
E. cf. *knighti*		X									
E. *semipunctata*	X			X		X			X	X	
E. cf. *semipunctata*	X	X									
E. spp. See several species listed below under "*Productus.*"											
Enteletes hemiplicatus									X		
E. *hemiplicatus plattsburgensis*									X		
Hustedia mormoni ("*Terebratula*")	X	X		X		X		X	X	X	
Hystriculina wabashensis ("*Marginifera*")	X			X					X		
Juresania nebrascensis ("*Productus,*" "*Pustula*") (Note 5)	X			X				?	X	X	X
Kozlowskia splendens ("*Marginifera*")	X			X		X		X	X		
K.? sp.						X					
Lingula carbonaria										X	
L. cf. *carbonaria*		X									
L. *tighti*											X
L. spp.	X	X								X	
Linoproductus insinuatus ("*Productus*")								X			
L. *oklahomae*									X		
L. cf. *oklahomae*	X										
L. *platyumbonus*	X					X			X		
L. cf. or aff. *platyumbonus*	X	X		X				?			
L. *prattenianus* ("*Productus cora*")	X			X		?		?	X	X	X
L.? sp.						X					
Lissochonetes sp.										X	
Meekella striatocostata	X			X					X		
M. cf. *striatocostata*	X	X									
Mesolobus decipiens ("*Chonetes*")				X							
M. *striatus* ("*M. mesolobus*")		X		X				X			X
Neochonetes granulifer ("*Chonetes*")	X			X					X		X
Neospirifer alatus ("*Spirifer*") (Note 6)	X	X		X		X			X		
N. *cameratus*		X						X			X
N. *dunbari* ("*Spirifer striatus triplicatus*")	X	?				X		X	X	X	?
N. *gibbosus*	X			X					X		
N. spp.	X						X			X	
Orbiculoidea capuliformis ("*Discina convexa*")								?	?	?	?
O. *missouriensis*				X				X			
O. *nitida* ("*Discina nitida,*" an English sp.)											X
O. spp.	X	X				X					
Phricodothyris perplexa (Note 7)	X	X		X	X	X	X	X	X	X	X
"*Productus Flemingii*" of Marcou; an English sp., probably *Sandia* sp.		X				?	X	?			
"*P.* *punctatus*" of Marcou; an English sp., probably *Echinaria*		X						X			
"*P.* *pustulosus*" of Marcou; an English sp., now *Pustula pustulosa*								X			
"*P.* *pyxidiformis*" of Marcou; an English sp., now *Pustula;* possibly *Antiquatonia*								X			
Punctospirifer kentuckyensis	X			X				X	X		
P. cf. *kentuckyensis*	X	X									
Retaria lasallensis ("*Marginifera*")				X					X		
R.? aff. *lasallensis*										X	
Reticulatia sp. ("*Productus semireticulatus,*" and "*Dictyoclostus americanus*") (Note 8)		X		X		?		?	X	X	X
Rhynchopora magnicosta		X				X					
Sandia santafeensis (age probably Atokan)		T				?	X	?			
Schizophoria oklahomae	X	X									
S. cf. *oklahomae*	X		X								
S. *resupinoides*									X		
Schuchertella pratteni				X							
S.? sp.	X										
"*Spirifer fultonensis*" of Herrick and Bendrat (1900) may be *Anthracospirifer*											X
Wellerella immatura	X	X		X							
W. *osagensis*	X			X					X		
W.? sp. ("*Rhynchonella* sp.")											X

NOTES TO TABLE 2

1. Marcou's types of *Spirifer Rocky-Montani* include at least two species: *Anthracospirifer rockymontanus* (Marcou) and *A. curvilateralis chavezae* Sutherland and Harlow; see Sutherland and Harlow (1973, p. 3-4, 83, 86-87). Marcou (1858, p. 50, pl. 7; our fig. 29) collected his specimens from the "grand perpendicular wall" of "Mountain Limestone of Tigeras, Cañon of San Antonio," which is near Seven Springs, west of Tijeras. Sutherland and Harlow (1973, p. 83) believe that the larger of the two specimens (Marcou's figs. 4, 4a-b) is a variant of *A. curvilateralis chavezae.* Also placed by them in synonymy are *Spirifer boonensis?* Girty (not Swallow), 1903, and *Spirifer occidentalis* of Dunbar and Condra (not Girty), 1932. Weller's (1898, p. 589) synonymy of *Spirifer rockymontanus* for the period 1858-79 included 18 citations and included some of *S. opimus* and *S. subventricosa.* Girty (1903, p. 383-384) had 22 citations for the period 1858-99; Mather (1915, p. 181-183) had 19 citations for the period 1858-1911. Girty (1903, p. 384) proposed restricting the name *S. rockymontanus* to the smaller of Marcou's two specimens and thought the larger specimen might be a variety of *S. cameratus.* Mather (1915, p. 184) argued that the larger specimen was \`the first of the two to be mentioned in his [Marcou's] text as well as in the legend to the plate and therefore the type of the species." Dunbar and Condra (1932, p. 319) disagreed, noting that Girty's selection had precedence by 12 years, and proposed a new name, *S. matheri,* for Mather's species from the Morrowan.

2. In discussing *Anthracospirifer matheri,* Sutherland and Harlow (1973, p. 86-87) state

> "We believe Dunbar and Condra were incorrect in referring Marcou's (1858, pl. 7, figs. 4, 4a-b) larger specimen of *Spirifer rocky-montani* to this species. That specimen, apparently from Desmoinesian strata, is a larger form (with a shallower sulcus) we consider closely related to *Anthracospirifer curvilateralis chavezae."*

See Mather (1915, p. 181), Dunbar and Condra (1932, p. 322), and Sadlick (1960, p. 1212).

3. See Marcou (1858, p. 50, pl. 7, figs. 4c-e; our fig. 29). This is the smaller of the two specimens figured by Marcou and is the one selected by Girty (1903, p. 384) as the lectotype. It had long been believed that Marcou's specimens were lost, but Sutherland and Harlow (1973, p. 86) note that both are preserved in the British Museum of Natural History. Also worth noting is the following abstract, entitled *"Spirifer rockymontanus* Marcou from the type area," by James Steele Williams (1946):

> "Marcou described *Spirifer rockymontanus* from \`Tigeras, Canyon of San Antonio, New Mexico.' Bed-by-bed collections made in 1946 from the type locality show that this species has a much greater range in variation than is generally attributed to it and that certain forms now considered separate species from *S. rockymontanus* should be more logically considered as mere varieties having little stratigraphic significance."

4. Marcou (1858, p. 48, pl. 6, figs. 14, 14a-b) named this *Orthis Pecosii* for Pecos village. Girty (1915) and Dunbar and Condra (1932) referred it to *Cleiothyridina orbicularis* (McChesney) 1859. Marcou's name has priority by one year (Sutherland and Harlow, 1973, p. 67).

5. It is surprising that Sutherland and Harlow (1973) did not find *Juresania* in the southern Sangre de Cristo Mountains, although earlier they (1967) had found it near Jemez Springs. Similar genera, such *as Pulchratia?* and *Buxtonia are* each represented by several species in the Sangre de Cristos.

6. In 1932 Dunbar and Condra described two species, *Neospirifer triplicatus alatus* and *N. latus.* According to Sutherland and Harlow (1973, p. 75), the former represents the young and the latter the adult, respectively, of the same species.

7. Many different names have been applied to this species: *Spirifer lineatus* Hall (not Martin), 1856, and Marcou, 1858; *Spirifer perplexa* McChesney, 1860; *Squamularia perplexa,* of Mather, 1915, and of Dunbar and Condra, 1932. The species has been referred to *Martinia, Reticularia,* and *Condrathyris.*

8. According to Blake's (1856, p. 142) translation of Marcou's field notes, the latter found *Productus giganteus* near Tijeras. *(Productus giganteus,* of J. Sowerby, 1822, is now *Gigantoproductus giganteus* of the British Mississippian.) In his 1858 paper, Marcou (p. 56) does not mention *Productus giganteus,* but does cite *Productus semi-reticulatus.* Some forms of the latter species were given a new name, *Dictyoclostus americanus,* by Dunbar and Condra (1932, p. 218); this in turn was changed to *Reticularia*by Muir-Wood and Cooper (1960, p. 284).

(continued from page **41)**

there are two columns, one for the Sandia Formation and one for the Madera Formation. Chief source is Catacosinos (1962), but Marcou (1858) cited a dozen species from "the summit of the Sierra de Sandia," "near the summit," "at the very top of the Sierra de Sandia," etc. The holotype of *"Orthoceras Nova-Mexicana"* came from "a deep ravine near the summit of the Sierra de Sandia."

3. For the Tijeras-Cedro Canyons area, at the southern end of the Sandia Mountains, 4 columns are given, 1 for the Sandia Formation and 3 for the Madera Formation; the Madera is subdivided into Desmoinesian, Missourian, and Virgilian. Principal sources are Marcou (1858), Szabo (1953), Werrell (1961), and Stukey (1967). A few citations are from Herrick (1900a), Herrick and Johnson (1900), and Bisbee (1932). Herrick (1900a) illustrated 10 species of "Upper Carboniferous," "Permo-Carboniferous," or "Permian" fossils-probably all of Pennsylvanian Virgilian age. Four of the fossils came from the Sandia Mountains; one came from the east side of the Sandias; and five were "from base of section near adobe smelter east of Sandia Mountains at the base of the Permian." A difficulty in connection with recognizing the last locality is that there were at least 2 smelters in the area, 1 near La Madera and 1 near Tijeras. We have credited these fossils to the Virgilian of the Tijeras-Cedro Canyons area.

4. For the Coyote Canyon, Manzanita Mountains area, see Prefatory Note 6 to Table 2 (Brachiopoda) for a fuller explanation of Herrick and Bendrat's (1900) list of "Flint Ridge" shale fossils. A few records are from Herrick and Johnson (1900) and Bisbee (1932).

Northrop's (1961a, p. 109-111) list for the entire Sandia-Manzanita Mountains area might also be cited.

Older generic and specific names are given in parentheses and quotation marks. Type specimens are indicated by T. Additional information is noted at the bottom of the table.

CORRELATION

As Northrop (1961a, p. 111) wrote some years ago,

> The first significant attempt to correlate the Pennsylvanian strata of New Mexico with standard sequences in other regions was by Needham (1937) in his bulletin on New Mexico fusulinids. In 1940 he published a short paper entitled "Correlation of Pennsylvanian rocks of New Mexico." Using about twenty-five species of fossils, chiefly brachiopods and a few fusulinids, *he* suggested that the oldest Pennsylvanian strata of central New Mexico are younger than Bend, Morrow, or lower Pottsville. Two years later, Thompson (1942) proposed the term Derry series for the essentially pre-Desmoinesian Pennsylvanian rocks of central to south-central New Mexico, and correlated the Deny with the Atoka of Oklahoma, Cheney's Lampasas of Texas, and the basal part of the Des Moines of some areas in the Mid-Continent region. He did not believe that the New Mexico Pennsylvanian sequence included any part of Morrowan time.
>
> Thompson correlated the Sandia formation of the Sandia Mountains with his Elephant Butte formation of the Armendaris group of Desmoinesian age. According to him, a section at the northern end of the Sandia Mountains includes rocks of Desmoinesian, Missourian, and Virgilian age, while sections at Jemez Springs include rocks of Derryan age as well. However, in the same year, Read and Henbest (1942) stated that the Pennsylvanian of northern New Mexico includes rocks of

(continued on pare 48. bottom)

TABLE 3—Pennsylvanian Fossils of Sandia-Manzanita Mountains Area, Excluding Foraminifera and Brachiopoda

(T=type(s); superscripts at heads of columns refer to prefatory remarks in text; numbers in table refer to notes at bottom of table)

	SANDIA MOUNTAINS								
	Placitas[1]		Crest[2]		Tijeras-Cedro Canyons[3]				Coyote Canyon, Manzanita Mts.[4]
						Madera Fm.			
	Sandia Fm.	Madera Fm.	Sandia Fm.	Madera Fm.	Sandia Fm.	Desmoinesian	Missourian	Virgilian	
SCYPHOZOA (Extinct jellyfish-like forms)									
Conularia sp.						X	?		X
ANTHOZOA (Corals)									
"*Amplexus coralloides*?" (an English sp.; status uncertain)				X		X			
Aulopora? *anna*							X		
Caninia torquia					X	X	X	?	
C.? sp.		X						X	
Chaetetes milleporaceus		X				X			
C. cf. *milleporaceus*									X
Dibunophyllum valeriae						?	X	X	
D. sp.		X							
Lophophyllidium proliferum						X	X	X	
Michelinia sp. ("*Pleurodictyum*")		X							
Neozaphrentis sp.		X							
Syringopora multattenuata							X		
S. cf. *multattenuata*						X			
S. sp.		X							
"*Zaphrentis cylindrica*" (an English sp.)				X		X			
"*Z.* *Stansburyi*" (may be *Caninia*)				X		X			
Tetracorals, undet.			X	X					
BRYOZOA (Moss animals)									
Fenestella albuquerqucana Herrick and Bendrat (Note 1). Syntypes									T
F. *limbata*									X
F. *norwoodiana*									X
F. spp. ("*Fenestrellina*")		X	X	X		X	X	X	
Fistulipora incrustans						X	?	?	
F. *nodulifera*							X		
Megacanthopora sp.								X	
Penniretepora trilineata ("*Pinnatopora*")									X
P. cf. *whitei*									X
P. spp.		X					X		
Polypora coyotensis Herrick and Bendrat. Holotype (Note 2)									T
P. *elliptica*						X	X	X	
P. *fastuosa*									X
P. sp.		X							
Prismopora sp.	X					X			
Rhombopora lepidodendroides							?	X	
R. cf. *lepidodendroides*				X					
R. sp.		X							
R.? sp.			X	X					
Septopora (*Synocladia*) *biserialis*									X
S. sp.						X			
Sulcoretepora aff. *carbonaria* ("*Cystodictya*")									X
Tabulipora heteropora							X	X	
T. sp.		X							
Bryozoans undet.			X	X		X		X	
BIVALVIA (Pelecypods, clams, scallops)									
Acanthopecten carboniferus		X					X	X	
Annuliconcha interlineata							X		
Astartella concentrica							X		
A. *newberryi*									X
A. *varica*									X
Aviculopecten basilicus		X							
A.? *coreyanus* ("*Deltopecten*")		X							
A. *occidentalis*							X		?
A. spp.		X						X	
Bakevellia parva								X	
Cypricardinia carbonaria ("*Macrodon*")									X
Dunbarella knighti							X		
Edmondia aspinwallensis						X	X		
E. *gibbosa*		X					X		
E. *nebrascensis*								X	?
E. sp.								?	
Fasciculoconcha scalaris ("*Aviculopecten*")									X
Myalina (*Myalina*) *wyomingensis*							X	X	
M. (*Orthomyalina*) *subquadrata*								X	
M. sp. and *M.*? sp. (Note 3)	X							?	
"*Nuculana*" *bellistriata*		X						X	
"*N.*" *bellistriata attenuata*								X	
Monopteria marian		X							
Palaeolima retifera ("*Lima*")									X
Paleyoldia glabra ("*Yoldia*")							X	X	
Parallelodon obsoletus							X	X	
P. *tenuistriatus*								X	
Permophorus mexicanus? ("*Pleurophorus*")		X							
P. *subcuneatus*								X	
P. aff. *taffi*?		X							
P. *tropidophorus*							X	X	
Promytilus swallovi ("*Myalina*")						?	?	?	?
Pseudomonotis equistriata							X	X	
P. *hawni*								X	
Pteria? *longa* ("*Gervillia*")						?	?	?	?
Pteronites nebraskensis ("*Aviculopinna*")		?					X		
P. *peracutus*		?					X	X	
Schizodus wheeleri		?					X	X	
Septimyalina apachesi ("*Myalina*") (Note 4)		X							
S. *perattenuata*								X	
S.? sp.								X	
Streblochondria? *tenuilineata* ("*Crenipecten foersti*")									X
Wilkingia terminale ("*Allorisma*," "*Allerisma*")		X					X	X	
SCAPHOPODA (Tusk-shells)									
Plagioglypta canna		X							
P. sp. ("*Dentalium*")		X							
GASTROPODA (Snails)									
Amaurotoma subsinuata ("*Yunnania*")							X		
A.? sp.		X							
Ananias manzanicum? ("*Phanerotrema*")		X							
Anomphalus rotulus						X			
Bellerophon crassus							X	X	?
B. *majusculus*		X							
B.? sp.		X		X					
Donaldina? sp.								X	
Euconospira missouriensis							X		
E. *turbiniformis*								X	

continued

TABLE 3—PENNSYLVANIAN FOSSILS OF SANDIA-MANZANITA MOUNTAINS AREA, EXCLUDING FORAMINIFERA AND BRACHIOPODA (cont'd)

(T=type(s); superscripts at heads of columns refer to prefatory remarks in text; numbers in table refer to notes at bottom of table)

continued from page 45

	Sandia Mountains: Placitas[1] Sandia Fm.	Placitas[1] Madera Fm.	Crest[2] Sandia Fm.	Crest[2] Madera Fm.	Tijeras-Cedro Canyons[3] Sandia Fm.	Tijeras-Cedro Canyons[3] Madera Fm. Desmoinesian	Madera Fm. Missourian	Madera Fm. Virgilian	Coyote Canyon, Manzanita Mts.[4]
Euphemites carbonarius ("*Euphemus*")							X	X	
E. nodocarinatus							X		
E. subpapillosus?		X							
E. vittatus		X							
Goniasma lasallensis							X	X	
Ianthinopsis primogenius ("*Strobeus*")							X	X	
Knightites (Cymatospira) montfortianus ("*Bellerophon*")							X	X	
Murchisonia? *terebra*?		X							
Naticopsis deformis		X							
N. remex							X		
N. scintilla		X					X		
N. sp.								X	
Palaeostylus (Pseudozygopleura) perversus							X		
"*Patellostium* aff. *nodicostatum*" of Girty		X							
Platyceras (Orthonychia) parvum	X	X		X		X	X		
Straparollus (Euomphalus) plummeri							X		
S. (E.) reedsi						X			
S. (E.) sp. b of Girty		X							
Worthenia speciosa							X	X	
CEPHALOPODA (Nautiloids)									
Metacoceras cornutum						X			
M. perelegans							X		
Mooreoceras sp.						X	X		
"*Orthoceras Nova-Mexicana*" Marcou (Holotype)				T					
TRILOBITA (Crustaceans)									
Ameura major ("*Phillipsia*")								?	
A. sangamonensis							X	X	
Ditomopyge olsoni		X				X	X	X	
D. spp.		X		X					
"*Phillipsia*, sp. n." of Herrick and Johnson (Note 5)									X
"*Phillipsia*, sp. n." of Herrick and Johnson (Note 6)									X
EURYPTERIDA (Extinct arachnoids, "sea scorpions") gen. and sp. undet. (Note 7)								X	
OSTRACODA (Crustaceans with a bivalved carapace) (Note 8)									
Amphissites sp. A of Werrell							X	X	
A. sp. B aff. *irregularis*							X	X	
Bairdia chaseae								X	
B. sp. A aff. *conilata*							X		
B. sp. B aff. *auricula*								X	
B. sp. C aff. *geisi*						X			
B. sp. D aff. *ventricosa*							X		
B. sp. E aff. *summa*								X	
B. sp. F aff. *beedei* and *garrisonensis*								X	
B. sp. G							X		
Bairdiacypris cf. *acuminata*						X	X	X	
Bythocypris procera								X	
B. aff. *tumidus*						X	X	X	
Cytherella aff. *emaciata*							X	X	
C. aff. *footei*								X	
Kellettina binoda var. A							X		
K. binoda var. B							X		
Kirkbya aff. *canyonensis*							X		
K. aff. *permiana varica*							X		
Paraparchites claytonensis						X			
Silenites sp.								X	
MALACOSTRACA (Shrimps, etc.) (Note 9) n. gen., n. sp. (order uncertain)								X	
Syncarid, gen. and sp. undet.								X	
MYRIAPODA (Centipedes, millepedes) (Note 9) gen. and sp. undet.								X	
INSECTA (Insects) (Note 10)									
Madera mamayi Carpenter (Holotype)								T	
Pseudobiella fasciata Carpenter (Holotype)								T	
Blattarian, gen. and sp. undet.								X	
Thysanuran, gen. and sp. undet.								X	
CRINOIDEA (Sea-lilies)									
Cibolocrinus punctatus						X			
C. tumidus						X			
Delocrinus cf. *verus*							?		
D.? n. sp.							?		
Ulocrinus sp.		X							
Crinoid calyx, plate, columnals, undet.				X				X	
Columnals, undet.			X						
ECHINOIDEA (Sea-urchins)									
Archaeocidaris sp. plates and spines ("*Echinocrinus*")		X					X		
CONODONTS (Extinct problematical organisms) (Note 11)									
Hibbardella cf. *acuta*								X	
Hindeodella delicatula								X	
H. megadenticulata								X	
Idiognathodus acutus								X	
I. delicatus								X	
I. humerus								X	
I. meekerensis								X	
Ligonodina sp.								X	
Ozarkodina cf. *curvata*								X	
O. delicatula								X	
Spathognathodus minutus								X	
Streptognathodus cancellosus								X	
S. elegantulus								X	
S. simulator								X	
S. tenuis								X	
Synprioniodina microdenta								X	
FISHES (Note 12)									
Acanthodes aff. *bronni*								X	
Acrolepis aff. *sedgwicki*								X	
Cladodus sp.								X	
Ctenoptychius sp.								X	
Listracanthus sp.								X	
Orodus sp.								X	
Petalodus sp.				X					
aff. *Platysomus*? n. gen., n. sp.								X	
Proceratodus hlavini Zidek (Holotype)								T	
Family Coelacanthidae, gen. and sp. indet.								X	
Shark tooth, undet.						X			

TABLE 3—PENNSYLVANIAN FOSSILS OF SANDIA-MANZANITA MOUNTAINS AREA, EXCLUDING FORAMINIFERA AND BRACHIOPODA (cont'd)

(T=type(s); superscripts at heads of columns refer to prefatory remarks in text; numbers in table refer to notes at bottom of table)

	SANDIA MOUNTAINS								
	Placitas[1]		Crest[2]		Tijeras-Cedro Canyons[3]				Coyote Canyon, Manzanita Mts.[4]
						Madera Fm.			
	Sandia Fm.	Madera Fm.	Sandia Fm.	Madera Fm.	Sandia Fm.	Desmoinesian	Missourian	Virgilian	
AMPHIBIA (Note 13)									
Lafonius lehmani Berman (Holotype)								T	
PLANTS (Note 14)									
Asterophyllites equisetiformis								X	
Calamites aff. *suckowi*								X	
C. sp.								X	
Callipteris conferta								X	
C. cf. *lyratifolia*								X	
Cardiocarpon sp. 1 (seed on *Cordaites* foliage)	X								
C. sp. 2 (seed on *Cordaites* foliage)	X								
C. sp.						X			
Cordaites sp.	X					X			
Ginkgophyte n. gen., n. sp.								X	
Lebachia sp.								X	
Lepidodendron sp.	X								
Neuropteris cf. *clarksoni*								X	
N. ovata								X	
N. scheuchzeri	X					X	X		
N. tenuifolia	X					X			
Pecopteris pseudovestita								X	
Plagiozamites n. sp.								X	
Sigillaria sp.							X		
Walchia gracillima								X	
W. piniformis								X	
Petrified wood, logs				X		X	X		
Poorly preserved pollen of a primitive coniferous type (Bradbury, 1963; cited by Stukey, 1968, p. 51)								X	
Calcareous algae are widespread in marine strata									

NOTES

1. Described as a new species but not illustrated by Herrick and Bendrat (1900, p. 7-8). Fragments of 3 specimens were "found in the black limestone below 'Flint Ridge' [shale] in Carboniferous exposures 'in the corners,' three miles about south of Coyote Springs, Sandia [Manzanita) Mts., N.M." This horizon would have been in the lower 75 ft of the Madera. The syntypes and all University of New Mexico collections of the early days were presumably lost in the fire May 23, 1910 that destroyed the Hadley Climatological Laboratory. Coyote Spring is about a quarter of a mile north of the southern edge of the geologic map (map 1).

2. Described as a new species by Herrick and Bendrat (1900, p. 7) and illustrated by Herrick and Johnson (1900, figs. 8, 8a). From the "Flint Ridge shale near Coyote Springs." The horizon was apparently about 150 ft above the base of the Madera, and in Myers' (1973) Los Moyos Limestone, dated by him as Desmoinesian.

3. Fragments of a large ***Myalina*** are abundant in the Sandia Formation (Toomey, 1953). ***Myalina?*** was recorded by Herrick (1900a) from "Permo-Carboniferous east side of Sandia Mountains."

4. ***"Myalina Apachesi"*** was described as a new species by Marcou (1858, p. 44-45, pl. 7, figs. 6, 6a) from "near the ranchos of Pecos village." Girty (Lee and Girty, 1909, p. 81-82, pl. 9, figs. 6-7) identified this species from about 50 ft above the base of the Abo sandstone at Abo Canyon, south end of the Manzano Mountains; he also recorded it from about 40 ft above the base of the Abo at the north end of the Sandia Mountains. Newell (1942, p. 67-68, pl. 12, figs. 1-6) thought "Girty was not justified in reviving Marcou's ***Myalina apachesi*** for this species," and doubtfully placed Marcou's species in the synonymy of Newell's new species, ***Septimyalina burmai,*** based on a form occurring in the Lower Permian of Kansas. We disagree with Newell's assignment and suggest that Marcou's species be revived as ***Septimyalina apachesi*** (Marcou), which seems rather different from Newell's species. Compare Girty's figures with those of Marcou and of Newell; note also that in our opinion the specimens from Abo Canyon, from the north end of the Sandias, and from Pecos are all Virgilian in age.

5. ***"Phillipsia,*** sp. n." was illustrated by Herrick and Johnson (1900, pl. 21, fig. 9) but not described or named. Horizon and locality were given as "Flint Ridge shales near Coyote Spring." This would be in the Madera Formation about 150 ft above the base. It is worth noting that Herrick and Bendrat (1900, p. 10) stated: "A small trilobite is represented by pygidia alone and although it is undoubtedly new it does not seem to us desirable to name forms in this genus upon pygidial characters only."

6. Another ***"Phillipsia,*** sp. n." was illustrated by Herrick and Johnson (1900, pL 21, fig. 11) but not described or named. This specimen came from the "Sandia limestone near Coyote Spring" (our Sandia Formation).

7. A eurypterid, found by Sergius H. Mamay (letter, Nov. 21, 1974) at the Kinney clay pit, was sent to Leif Stormer, of Oslo, Norway for identification.

8. The ostracods from Tijeras and Cedro Canyons were described and illustrated by W. L. Werrell (1961) in an unpublished thesis.

9. Arthropods collected at the Kinney clay pit by S. H. Mamay were submitted to F. **R.** Schram for study. According to the latter (letter, Feb. 25, 1975), there are 2 shrimps, 1 a new genus and new species, and an undetermined syncarid. There is also a poorly preserved myriapod.

10. Apparently the first fossil insect found in the Sandia Mountains area was collected by Sidney R. Ash at the Kinney clay pit on Oct. 6, 1961 but this specimen has been misplaced. While collecting fossil plants at the same locality in 1967 and again in 1969, Mamay found a number of insects which he submitted to F. M. Carpenter. Two new genera and species were named by Carpenter (1970).

Order Palaeodictyoptera (extinct, dragonfly-like)
  Family Lycocercidae
    Madera mamayi Carpenter
Order Caloneurodea (extinct)
  Family Permobiellidae
    Pseudobiella fasciata Carpenter
Order Blattaria (cockroaches)
    gen. and sp. undet.
Order Thysanura ("silverfish")
  Suborder Monura
    gen. and sp. undet.

An interesting and significant aspect is that both the fore wings and hind wings of ***Madera*** and ***Pseudobiella*** show traces of original color patterns in conspicuous transverse bands of dark pigmentation. Because of the difficulty of making taxonomic assignments of Paleozoic cockroaches, 2 specimens were not described formally but Carpenter (1970, fig. 7) published an excellent photograph of one of them. Another cockroach wing, found by Kenneth Kietzke in 1972, was donated to the Field Museum of Natural History. The thysanuran will be described by Carpenter (letter, Jan. 14, 1975) in a forthcoming paper.

11. Apparently the first conodonts reported from the Pennsylvanian of New Mexico were found in 1964 by Robert C. Burton. In an unpublished study of the paleoecology of the Kinney clay pit, he

illustrated several specimens belonging to 7 genera. Recently he separated approximately 500 specimens from 2 kilograms of rock and now reports 16 species in 8 genera (Burton, letter, Jan. 10, 1975). In his opinion the age is Virglian. Sutherland and Harlow (1973, p. 11) report a few conodonts from Morrowan, Atokan, and lower Desmoinesian rocks of the southern Sangre de Cristo Mountains; none were reported from Missourian or Virgilian strata of that area.

12. In 1963, while collecting fossil plants from the upper Madera Formation at the Kinney clay pit, John P. Bradbury discovered fossil fishes. David H. Dunkle collected a large number of specimens in 1964; additional material was collected in 1967 and 1969 by Sergius H. Mamay. The combined collections have been studied by Jiri Zidek (1975), whose paper includes most of the fish fauna except for the Palaeonisciformes, to be described in a later paper. *Orodus* was recorded by Yale (1964, p. 23) in the Arkosic limestone member near Los Pinos on Sedillo Hill. A large tooth of *Petalodus* was collected by Northrop from the rim at Sandia Crest in the early 1930's. All other specimens are from the Kinney clay pit.

Taxonomy of the fishes is changing rapidly. For example, Romer (1945) had placed the acanthodians in the class Placodermi; in 1966 he transferred them with a query to the class Osteichthyes; now they constitute a class, Acanthodii. Current classification of the fishes from our area is as follows, according to Zidek (letter, Jan. 21, 1975).

Class Chondrichthyes (sharks and rays)
  Subclass Elasmobranchii
    Family Edestidae
      Orodus sp.
    Family Petalodontidae
      Ctenoptychius sp.
      Petalodus sp.
    Incertae sedis
      Cladodus sp.
      Listracanthus sp.
Class Acanthodii (spiny "sharks")
  Order Acanthodiformes
    Family Acanthodidae
      Acanthodes aff. bronni
Class Actinoptergyii (ray-fmned fishes)
  Subclass Chondrostei
    Order Palaeonisciformes
      Suborder Palaeoniscoidei
        Family Acrolepididae
          Acrolepis aff. sedgwicki
      Suborder Platysomoidei
        Family Platysomidae
          aff. *Platysomus?* n. gen., n. sp.
Class Dipnoi (lungfishes)
  Order ?Ceratodontiformes
    Family ?Ceratodontidae
      Proceratodus hlavini Zidek
Class Crossopterygii (fringe-fmned or lobe-finned fishes)
  Order Coelacanthiformes
    Suborder Coelacanthoidei
      Family Coelacanthidae
        gen. and sp. indet.

13. Described by Berman (1973) as a new genus and species of labyrinthodont amphibian—"the first Pennsylvanian tetrapod to be reported from New Mexico." This specimen, a juvenile, was collected at the Kinney clay pit in 1971 by Neal LaFon and Thomas Lehman. Classification is as follows.

Class Amphibia
  Subclass Labyrinthodontia
    Order Temnospondyli
      Suborder Rhachitomi
        Superfamily Trimerorhachoidea
          Family Trimerorhachidae
            Lafonius lehmani Berman

14. Most of these plants were determined over a period of years by Charles B. Read, as acknowledged by Toomey (1953, p. 9-10), Northrop (1961a, p. 109, 111), and Stukey (1967, p. 8, 51-52). Well-preserved specimens were found at the Kinney clay pit in 1961 by S. R. Ash, C. J. Felix, and G. D. Glover, according to Ash (letter, Oct. 3, 1974). More were collected by J. P. Bradbury in 1963. S. H. Mamay, of the U.S. Geological Survey, made extensive collections in 1967 and 1969 which yielded a new genus of ginkgophyte, not yet described. There is some doubt concerning the reported occurrence of *Callipteris* at the Kinney clay pit. Stukey (1967, p. 51) noted that Read had identified *C. conferta* and earlier Burton (1964, p. 10) stated that Read had identified *C.* cf. *lyratifolia.* On the other hand Mamay (letter, Nov. 21, 1974), after carefully examining many tons of material, states he has never seen any species of *Callipteris at* the clay pit.

Calcareous algae, although undoubtedly widely distributed in marine strata, have not been mentioned by most writers. Yale (1964, p. 27, fig. 15; p. 28, fig. 16; p. 31, fig. 18B) noted algal nodules in the Arkosic limestone member of the Madera near Los Pinos and Sedillo Hill. One of his thin sections was submitted to J. Harlan Johnson, who reported "an algal felt made by the blue-green algae." Stukey (1967, p. 13, 26, 29, 38, 49) also noted algal nodules 1-2 inches in diameter, which he referred to the Spongiostromata.

(continued from bottom of page 44)

Morrowan *age*. In 1944 Henbest and Read recognized the *Millerella* zone in the Jemez country near Jemez Pueblo and again at the Soda Dam, and concluded that it is of probable Morrowan age. (See also Read and Wood, 1947.) Northrop and Wood (1945), and Wood and Northrop (1946) assigned a Morrowan age to certain strata in the Jemez country, citing especially the large and distinctive brachiopod *Schizophoria cf. oklahomae* (ranging up to 73 mm across), which occurs in the Wapanucka and Morrow of Oklahoma. We collected this striking brachiopod near the base of the Sandia formation at two localities in Guadalupe Canyon, about 7 and 9 miles, respectively, north of Jemez Pueblo. Later, Armstrong (1955) found an abundance of good specimens of this species in Penasco Canyon, about 7 1/2 miles west of Jemez Pueblo.

In 1946 Northrop *[in* Wood and Northrop] reported for the Jemez-Nacimiento area a total of about 185 species, based on a preliminary study of nearly 100 collections from 33 stratigraphic sections, and proposed five faunal zones—designated A, B, C, D, and E (from oldest to youngest)—"each of which is characterized either by species having short stratigraphic ranges, by the earliest appearance of longer-ranging species, by a notable abundance of certain long-ranging species which range through more than one zone, or by a combination of these." Faunal zone A = Morrowan; B = late Morrowan, Lampasan, and early Desmoinesian; C = late Desmoinesian and earliest Missourian; D = remainder of Missourian; and E = Virgilian.

The *Schizophoria oklahomae* zone of Morrowan age in the Jemez-Nacimiento area has been informally named the Osha Canyon formation by DuChene (1973, 1974). His section of Mississippian and Pennsylvanian strata at Guadalupe Box north of Jemez Pueblo is as follows:

		ft
Pennsylvanian	Madera Limestone	760
	Sandia Formation	225
	Osha Canyon formation	56
Pennsylvanian or Mississippian	Log Springs Formation	2-5
Mississippian	Arroyo Peñasco Formation	25-26

In the southern Sangre de Cristo Mountains, Sutherland (1963) was unable to delineate the Sandia and Madera Formations and therefore proposed two new formations: 1) La Pasada (equivalent to the Sandia Formation plus the Lower gray limestone member of the Madera Formation), overlain by 2) the Alamitos

Formation (equivalent to the upper Arkosic limestone member of the Madera Formation). Farther north, in the Rio Pueblo valley, Sutherland described the Flechado Formation as the northern equivalent of the La Pasada Formation. The La Pasada and Flechado Formations range in age from Morrowan through Atokan to middle Desmoinesian. The overlying Alamitos Formation ranges from middle Desmoinesian through Missourian to Virgilian in the southern part of the Sangre de Cristos near Pecos (Sutherland and Harlow, 1973, fig. 8).

Toomey (1953, p. 47-49) concluded that the few fossils he had collected from the upper part of the Sandia Formation at the north end of the Sandia Mountains indicated early Desmoinesian age, and (in his pl. 4 and again in fig. 10) suggested that the lower part of the Sandia Formation is of Morrowan and Atokan age. Catacosinos (1962, p. 24) concluded that the Sandia Formation along the western scarp below Sandia Crest ranges from Atokan to Desmoinesian. Szabo (1953) regarded the Sandia Formation at the south end of the mountains as ranging from Atokan to Desmoinesian. In the Manzanita-Manzano Mountains, Myers (1973) believes that the Sandia Formation is Atokan in age.

Morrowan strata are present in the Santa Fe-Pecos area to the northeast, as well as in the Jemez-Nacimiento area to the northwest, and it seems likely that better evidence may eventually be found in the northern Sandia Mountains for Morrowan-age strata. However, Morrowan may be lacking in the central Sandia Mountains and in the Tijeras area.

The Madera Formation was divided by Toomey (1953) into three members (ascending): 1) Clastic limestone member (Desmoinesian), 2) Chert armor member (Missourian), and 3) Arenaceous limestone member (Virgilian?). Catacosinos (1962) reported that the lower part of the Madera Formation exposed along the western scarp of the mountains is of Desmoinesian age. Szabo (1953) concluded that the Madera at the south end of the mountains ranges from Desmoinesian to Virgilian.

In 1973 Sutherland and Harlow, in their memoir on the brachiopods of the southern Sangre de Cristo Mountains, reported on their brief examination of the area near Tijeras that Marcou had visited on October 8, 1853. They did not specifically mention the Sandia Formation, but observed that the lowermost Pennsylvanian rocks cropping "out on a steep hillside just west of the great cliff" [Marcou's "grand perpendicular wall" at Seven Springs] "are poorly fossiliferous, but we collected specimens of *Sandia santafeensis*, suggesting an Atokan age. Fossils of definite Morrowan age are lacking."

On the other hand, a limestone knob rising above the alluvium west of the mountains and only 4.6 miles west of Seven Springs (secs. 14, 23, T. 10 N., R. 4 E.) contains a sparse microfauna that suggests a possible Morrowan age (A. K. Armstrong, letter, May 10, 1974) but the Madera elsewhere in the area is not older than Desmoinesian. This small mass of limestone, several tens of feet thick, seems to resemble some part of the Lower gray limestone member of the Madera Formation rather than any limestone of the Sandia Formation. A few inches of conglomerate occur at the base. The only megafossils seen are indistinct outlines of brachiopod: and crinoid columnals.

Stukey (1967), working chiefly with the Arkosic limestone member (upper), attempted to correlate the Late Pennsylvanian rocks between the Kinney clay pit and the sequence that Yale (1964) had studied along US-66 at Sedillo Hill. He reviewed the faunal and floral evidence and concluded that as much as 400 ft of the upper part of the Arkosic limestone member (upper; might be Permian. The plants and particularly the fishes at the Kinney locality seem to indicate a Permian age even though the fusulinids are regarded as being of Late Pennsylvanian age. Some part of these beds undoubtedly equivalent to the Agua Torres Formation in the Los Pinos Mountains dated as Permian by Stark and Dapples (1946, p. 1154) or to the Permian Bursuni Formation in the Manzano Mountains (Wilpolt and others, 1946).

In the Manzanita Mountains, Myers and McKay (1970) divide the Magdalena into 1) Middle Pennsylva. nian, including the Sandia Formation (Atokan) and a "lower part" of the Madera, and 2) an Upper Pennsyl. vanian, including the remaining exposed Madera. 01 the 1,300 to 1,400 ft of Madera in the Manzanitas, 700 ft may be equivalent to the Arkosic limestone member (upper), all Upper Pennsylvanian. Myers (personal communication) has identified Virgilian-type *TriticiteJ* above the fish-bed horizon in the upper part of the Madera. As the situation now stands, the age of about 300 ft of the upper Madera is in doubt. However, it still likely that an uppermost transitional zone between the Madera and the Wolfcampian Abo may be equivalent to the Wolfcampian Bursum Formation.

PERMIAN

The Permian beds of central New Mexico are of two types: 1) the continental Abo Formation built across the surface left by the regressing Pennsylvanian sea, and 2) the Yeso, San Andres, and Bernal Formations deposited successively on the Abo flood plain in arid back-reef seaways or restricted lagoons. The Abo beds are fluvial subaerial deposits whereas the later formations are evaporitic, marine, and in part littoral and eolian in origin.

ABO FORMATION

Definition—The Abo Formation was named by Lee (Lee and Girty, 1909, p. 12) for exposures at Abo Pass at the southern end of the Manzano Mountains. The Abo rests either disconformably on or with probable conformable intertonguing with the underlying Madera Formation. It has been the custom to map the basal contact just above the last marine fossil-bearing beds, and higher limestone beds yielding no marine fossils are included in the Abo. Selection of the boundary on this basis is workable although not completely satisfactory, as marine beds are not everywhere fossiliferous. The highest fossil-bearing bed in one outcrop may pinch out in another area, requiring that the contact be shifted stratigraphically downward in order to follow the highest recognizably marine bed. Of course, the converse situation is also encountered. In most instances the stratigraphic interval involved is a few tens of feet or less; where beds dip appreciably as in the Sandia area few mapping problems result, as the contact line may nearly cover the intertonguing strip at the map scale used. Abo-type red beds as described for the upper part of the Madera may be found hundreds of feet below the top of the Madera, but those considered to be in the transition zone are commonly more purplish red-brown in color as compared to the brick-red browns of the Abo.

The top of the Abo is conformable with the overlying Yeso and the contact is fairly sharp. In places, however, the highest sandstone of the Abo and the basal sandstones of the Yeso are of very nearly the same texture and color, making selection of the boundary somewhat difficult. Abo sandstone beds are usually deeper reddish brown, lenticular, and in places intercalated with reddish-brown mudstone. The basal Yeso beds by contrast are more tan and in places include a white sandstone. The sandstone is even bedded, nonlenticular, and is not intercalated with mudstone.

Distribution—Abo outcrops are scattered. One belt extends from near Tijeras Canyon northward along the low eastern flank of the Sandias in a curving and broken belt to a termination against the Rio Grande trough north of Montezuma Ridge. Also at the northern end of the Sandias several miles west-southwest of Placitas a short, east-west strip of Abo dips northward from the uplift. One of the best exposures of the formation occurs at Tijeras and extends northeastward in a 6-mile strip followed by Tijeras Creek and US-66. Lesser outcrop areas also occur around the Monte Largo horst block, around the base of South Mountain, and in the San Pedro Mountains.

Lithology—The Abo Formation consists of an alternating sequence that is dominated by reddish-brown mudstone and sandstone with minor beds of conglomerate and limestone, especially in the basal part. ***Where*** exposures are reasonably good, as in the north-south outcrop band north of Montezuma Ridge, it may be observed that the lower part is marked by some variegation of lavender, purple, and gray in the prevailing red-brown colors, whereas the upper sandstone and mudstone is more uniformly reddish brown (fig. 30).

Sandstone occurs in sequences as much as 100 ft thick consisting of thin to thick beds that are commonly cross-bedded, and in thin-bedded sequences mixed with mudstone ranging from 50 to 200 ft thick. Locally white to light-gray sandstone ledges as much as 60 to 70 ft thick are present. Sandstone beds range from fine to coarse grained and locally are conglomeratic. White or light-gray sandstone tends to be fairly free of clay or mica, whereas the reddish-brown varieties are commonly argillaceous. Both types of sandstone are commonly feldspathic and calcareous. Mudstone is about equal in abundance to sandstone and probably consists of siltstone or silty and arenaceous claystone. Limestone beds are uncommon, mostly in beds less than 5 or 6 ft thick in the lower 100 ft of the formation. It is commonly nodular and dark gray to purplish gray. Thin conglomerate beds occur locally in the Abo and are usually composed of limestone pebbles. A 3-ft black shale, possibly marine, is exposed about midway in the sequence in the northern part of projected sec. 23, T. 13 N., R. 5 E.

A section modified from Harrison (1949, p. 42-44) measured across San Francisco Creek 2 miles north of Montezuma Mountain is given in Appendix 1.

Thickness—Most sections of the Abo in the Sandias are faulted, covered in large part, or exposed in ways that make measurement difficult or uncertain. However, calculations based on width of outcrop, together with average dip, indicate thicknesses of 700 to 900 ft.

Fossils—It is curious that so few fossils have been found in the Abo of the area. Some wood, in places partly replaced by copper minerals, is found in the Abo east of Tijeras. By contrast, plants, amphibians, and reptiles have been found in the formation near Jemez Springs and again in the Chama country farther north. Plants and reptiles are also found at the south end of the Manzano Mountains near Abo Pass.

YESO FORMATION

Definition—Lee (Lee and Girty, 1909, p. 12) named the Yeso from Mesa del Yeso about 12 miles northeast of Socorro, but as measured the unit included the Glorieta Sandstone and part of the San Andres Formation. Needham and Bates (1943, p. 1658) redescribed the type section but in doing so began the section too high thus omitting the Meseta Blanca part of the formation. This part was later recognized and the section redefined (Bates and others, 1947, p. 27). Wood and Northrop (1946), mapping in the Nacimiento Mountains, subdivided the Yeso into the lower Meseta Blanca Sandstone Member and an upper San Ysidro Member, and these two members are recognized and mapped in the Sandia area, despite Baars' (1961a, p. 196; 1961b, p. 115) contention that the term Meseta Blanca Member should be supplanted by De Chelly Sandstone.

The Meseta Blanca Sandstone Member appears to be conformable on the underlying Abo Formation. It is distinguished from the Abo principally by its even beddedness, tan color, and finer clean sandstone. The upper contact with the San Andres Formation is conformable to disconformable, and there is no intertonguing or transition zone.

Distribution—Yeso distribution is similar to that of

FIGURE 30—REDDISH-BROWN ABO SANDSTONE BEDS. ROADCUT ALONG US-66 BETWEEN JUNCTIONS NM-14 SOUTH AND NORTH. WHITE BLEACH SPOTS ARE CHARACTERISTIC.

the Abo Formation with the principal outcrops in interrupted exposures along the lower eastern base of the Sandias. Owing to its friability and low resistance to erosion, it forms poor outcrops except for the basal Meseta Blanca beds. The best exposures are in the sparsely vegetated terrain of the Town of Tejon Grant northeast of Montezuma Ridge. There are also reasonably good exposures along Gonzales Canyon in secs. 13, 24, T. 12 N., R. 5 E., 3 to 4 miles northeast of Palomas Peak. There are also reasonably good exposures in both flanks of the San Pedro syncline east and west of NM-14 in the central part of the San Pedro Grant.

Lithology—The Yeso typically contains gypsum, tan-brown sandstone, light reddish- or orange-brown siltstone, and limestone or dolomite. In the Sandia area, however, gypsum is not evident. However, as many weathered veneers on sandstone or siltstone are gypsiferous, it may be that gypsum beds have been dissolved at the surface. In any event gypsum beds, if present, were probably few and thin. The Meseta Blanca Sandstone Member consists of thick, even-bedded, tan-brown, light-orange, and white sandstone, which is fine to medium grained and somewhat friable, with loose calcareous or argillaceous cement. Parallel cross-bedding is common.

The upper San Ysidro Member is thinner bedded than the Meseta Blanca and is friable, affording poor exposures. It consists mostly of alternately fine- and medium-grained sandstone, although some beds are of very fine or even silt-sized grains. All the sandstone is clean and lacks argillaceous or arkosic debris. In the middle of the section some sandstone is gypsiferous. Limestone beds from 3 to 8 ft thick are present, especially in the middle of the section. The limestone is commonly crinkly and contorted. It is light gray, finely crystalline, and cavernous owing to ground-water solution. Considerable chert is found in some beds. Current and oscillation ripple marks are not uncommon.

Thickness—The Meseta Blanca varies in apparent thickness in part depending upon the degree of cementation; cementation results in massiveness and resistance to erosion of the Meseta Blanca sandstones, which in turn affects the San Ysidro thickness. However, the evidence of this is inconclusive owing to paucity of good exposures. The thickness of the Meseta Blanca appears to range between about 70 and 150 ft and that of the San Ysidro between 250 and 400 ft. The total Yeso thickness in the area averages about 500 ft.

Age—No fossils have been found in the Yeso of the Sandia area. Based on evidence principally in southeastern New Mexico the Yeso is probably of Leonardian age.

SAN ANDRES FORMATION

Definition—The San Andres was named by Lee (Lee and Girty, 1909, p. 12, 29) for occurrences in the San Andres Mountains, and Needham and Bates (1943, p. 1664) designated a type section at Rhodes Pass in the same mountains. Read and associates (Read and others, 1944) divided what they thought to be the San Andres Formation into three members, in ascending order: 1) Glorieta Sandstone Member, 2) Limestone member, and 3) Upper member. The Glorieta Sandstone was first named by Keyes (1915, p. 257, 262) for exposures on Glorieta Mesa in San Miguel County. Darton (1922, p. 181) subsequently lumped the Yeso, Glorieta, and San Andres Formation (all the beds between the Abo Formation and the Santa Rosa Sandstone) into the now-abandoned term Chupadera Formation. He did this principally on the basis of exposures in the southern part of Chupadera Mesa in Socorro County, which suggested to him that the three formations named by Lee intertongued or changed lithologies laterally to such an extent as not to be distinct sequences superposed one above another. In central New Mexico the three formations are everywhere distinct, and workers before and after Darton have mapped them. An important relationship that Darton had seen was intertonguing of the San Andres and Glorieta, and this relationship has been defined by recent mapping in southeastern New Mexico (Kelley, 1971, p. 9-12).

It has developed that Read (Read and others, 1944) was right when he designated the Glorieta of the Sandia country as part of the San Andres Formation. It is now known to be a facies of the lower (Rio Bonito Member) part of the San Andres Formation in southeastern New Mexico (Kelley, 1972b, p. 73). The San Andres Limestone member of Read is probably the Bonney Canyon Member of southeastern New Mexico.

Not long after Read's early work in New Mexico he began to suspect that the upper member of the San Andres, as he and his associates had mapped it, was likely a post-San Andres unit, and he was instrumental in its later being formalized as the Bernal Formation (Bachman, 1953). It was not without planning that he labelled the outcrops around the Sandias, and at Bernal, "Pb" on U.S.G.S. Oil and Gas Inv. Prelim. Map 21 (Read and others, 1944). Read also actively encouraged the Roswell Geological Society (Tait and others, 1962, p. 504-505) to venture equivalency of the Bernal with some part of the Artesia Group. Recent mapping in east-central New Mexico has shown this to be true (Kelley, 1972a, p. 15,), and that the Bernal Formation should be used in the Sandia Mountains as a post-San Andres sequence.

The Glorieta Sandstone Member of the San Andres Formation rests conformably, or disconformably without gradation or intertonguing, on the Yeso Formation in the Sandia area. The top of the San Andres is in disconformity with the base of the Bernal. The Bernal is too thin to be shown at the scale of the geologic map (map 1) and has been included with the San Andres Bonney Canyon Member. Also owing to map scale limitations the Glorieta and Bonney Canyon Members are mapped as one unit where dips are steep and the outcrops narrow, as along the prominent north-south ridge through the Town of Tejon Grant and also in the east-west hogbacks west of Placitas.

Distribution—The San Andres, including the Glorieta, crops out around the Sandia Mountains in strips closely parallel to those of the Abo and Yeso. The Glorieta and Bonney Canyon are resistant to erosion, both supporting prominent ridges. For example, in the north-south ridge in the western part of the **Town** of Tejon Grant the Bonney Canyon limestone holds up the crest, with the underlying Glorieta down slope to the west and the Triassic Santa Rosa Sandstone down slope to the east.

Lithology—Two distinct lithologies characterize the San Andres Formation in the Sandia area. The first is that of the Glorieta Sandstone, which is a clean, white, medium-grained sandstone. The bedding is usually massive but with both parallel laminae and cross beds internally, resulting primarily from minor grain size, cementation, and sorting differences. Texture varies from friable to well cemented; grains are mostly subrounded.

The San Andres Bonney Canyon Member is composed of gray to black, very fine to fine-grained limestone with some intercalated sandstone beds similar to those of the Glorieta. The limestone is thin to medium bedded and locally cavernous. Chert is not uncommon, and the limestone is locally dolomitic. A few undeterminable fossils have been seen in the San Andres.

The Bernal Formation consists principally of tan-brown, fine- to medium-grained sandstone with local thin limestone beds, and is generally similar to the Yeso, although gypsum is probably absent in the Sandia area.

Thickness—The Glorieta varies in thickness throughout the area from about 65 to 125 ft. Thickness of the San Andres, on the other hand, varies greatly owing to erosion of its upper surface prior to deposition of the Santa Rosa Sandstone, but the maximum thickness where Bernal is still present may be 180 to 200 ft. The Bernal has been removed in many places by pre-Santa Rosa erosion. Remaining outcrops are up to 75 ft thick.

Age—On the basis of age determinations for San Andres- and Artesia-equivalent units in southeastern New Mexico the San Andres may range in age from late Leonardian to Guadalupian, and the Bernal would most likely be Guadalupian. Inasmuch as the thick Fourmile Draw Member of other parts of New Mexico is absent in the Sandia area the remaining part may be only Leonardian. Locally, the limestone of the Bernal contains small brachiopods.

TRIASSIC

The only Triassic beds of central New Mexico and the Sandia Mountains are of Late Triassic age. The sequence is thick and divided into a thinner lower part referred to as the Santa Rosa Sandstone and a thicker upper part termed the Chinle Formation. The Santa Rosa Sandstone was named for the beds at Santa Rosa, east-central New Mexico (Darton, 1922, p. 183). The Chinle Formation was named for exposures near Chinle in northeastern Arizona (Gregory, 1915, p. 102). Both formations are continental red-bed sequences of fluvial, flood-plain derivation similar in most respects to the Abo Formation described above.

SANTA ROSA SANDSTONE

Definition—The Santa Rosa rests unconformably on Permian San Andres or Bernal beds in the Sandia area; local and regional relief on the pre-Santa Rosa surface of deposition is several tens to several hundreds of feet. Missing at this erosional and nondepositional surface are most Guadalupian and all Ochoan and Early Triassic beds; the Permian is well represented in southeastern New Mexico and the Early Triassic in Arizona beneath the Santa Rosa or its equivalent Shinarump in Arizona. The top of the Santa Rosa is gradational and intertongues with the Chinle.

Distribution—The Santa Rosa crops out in several separate areas around the Sandias. One of these is an interrupted elliptical belt around the Tijeras basin area with the best outcrops in the ridge west of Cañoncito. Also in part of this belt are narrow slices preserved along the Gutierrez fault bounding the southeast side of the Tijeras graben. On the northeastern side of this belt outcrops cross the graben in the Sandia Knolls area (2 to 3 miles east of San Antonito along Frost Road). The other large area of Santa Rosa outcrops is around the south and west sides of the Hagan basin. Because of the sparse vegetation these outcrops are particularly well exposed, extending from the southern part of T. 12 N., R. 6 E., westward and then northward through the western half of the Town of Tejon Grant to the Rio Grande trough fault boundary near Arroyo de San Francisco. A small outcrop occurs southwest of Placitas in the downfaulted segment or ramp of the northern end of the Sandia Mountains.

Lithology—The Santa Rosa typically consists of white, light-gray, buff, and reddish-brown sandstone that is thin to thick bedded. Slabby and flaggy bedding is common and such sandstones have been quarried, especially near Cañoncito. Lenticular bedding and irregular cross bedding are common. Grain size ranges from fine to coarse with medium-grained sandstone dominant. The formation is also locally and variably conglomeratic. Conglomerate lenses and beds occur principally in the lower part, and pebbles consist mostly of limestone, sandstone, and chert (Appendix 1). Weathering commonly produces rusty and yellow-colored sandstone and conglomerate, and both sandstone and conglomerate beds are purplish or lavender locally.

Although sandstone is dominant, reddish-brown mudstone partings and intervals up to several tens of feet thick are interspersed within groups of sandstone ledges or elsewhere intercalated with thin-bedded, reddish-brown sandstone units; mudstone intervals become prevalent higher in the formation. The boundary with the overlying Chinle is not everywhere an alternating transition of mudstone and sandstone; in the Tejon area, for example, the boundary is fairly abrupt. Elsewhere the contact is more difficult to choose because of the gradational zone and because local sandstone units are present in the basal Chinle.

Petrified wood, probably coniferous, is present locally in the Santa Rosa.

Thickness—The thickness of the Santa Rosa varies considerably due partly to intertonguing, partly to variations in the gradation from sandstone to shale at the top, and partly to the presence of some broad swales or channels at the base. Thicknesses range from less than 100 ft in some places on the Tejon Grant to more than 400 ft, as near Cañoncito.

CHINLE FORMATION

Definition—The Chinle Formation is completely conformable and intertongues or is gradational with the underlying Santa Rosa Sandstone. The top is disconformable with the overlying Entrada Sandstone (Jurassic). In Arizona, northwestern New Mexico, and in east-central New Mexico the Chinle is subdivided into several members but no such divisions are apparent in the Sandia area.

Distribution—Chinle outcrops for the most part parallel those of the Santa Rosa. However, because of its greater thickness and less resistant lithology it forms poor outcrops and underlies a number of wide valleys. Good exposures are seen along NM-14 between Cañoncito and San Antonio, and the broad, much cultivated alluvial valley north and east of San Antonito is underlain by a wide expanse of flat-lying Chinle in the broad San Pedro syncline (map 1). It also underlies broad valleys along San Pedro and Gonzales Creeks in the northern part of T. 12 N. in R. 5, 6 E. Farther north down Gonzales Creek, the unit is greatly restricted and cut out by faulting, but still farther north in the Tejon Grant and San Felipe Indian Reservation the outcrop widens and the soft Chinle is well exposed in dissected badlands.

Lithology—The Chinle consists predominantly of reddish-brown mudstone with numerous local thin sandstone units within the sequence. Across the badland exposures in the Tejon Grant there is a slight color difference between the mudstone of the lower and upper parts of the formation. The lower part is characterized by variegations of lavender, blue, light gray or greenish gray, and reddish brown. The upper part (about two-thirds) of the sequence is more uniformly tan brown to reddish brown. However, it is not uncommon to find olive-drab and greenish-gray mudstones in many places. Thin nodular limestone beds are present locally in the upper part of the formation. In the Tejon Grant area there is also a flaggy sandstone unit, 20 to 30 ft thick, at the top of the formation. Although the lithology is somewhat different the position is equivalent to the Correo Sandstone Member mapped by Kelley and Wood (1946) along the base of Mesa Gigante north of Correo on the Santa Fe railroad (Appendix 1).

Thickness—The Chinle thickness is difficult to determine because of poor exposures from which attitudes must be measured and the broad expanse of outcrops. The fine exposures in the northern part of the Tejon Grant (map 1) are complicated by faults which both thicken and thin the section. Based on dips and on width of outcrop along San Pedro Creek in secs. 9, 16, T. 12 N., R. 6 E. and across Frost Creek in sec. 28, T. 11 N., R. 6 E., our calculations indicate that the Chinle is about 1,300 to 1,400 ft thick.

Apparently no fossils have been reported from the Chinle Formation in the area. Elsewhere in New Mexico Upper Triassic strata have yielded numerous plants, freshwater bivalves *(Unio),* amphibians, and reptiles of several types, including small dinosaurs.

JURASSIC

The Jurassic rocks of the Sandia area consist, in ascending order, of the Entrada Sandstone, Todilto Formation, and Morrison Formation. They are well developed and exposed in several places. The three are of contrasting lithologies and origins. The Entrada is a massive-bedded sandstone; the Todilto is a lacustrine or lagoonal carbonate and an evaporitic or possibly partly eolian gypsum; and the Morrison consists of arkosic and tuffaceous variegated mudstone and sandstone of mixed lacustrine and flood-plain origins.

The term Entrada Sandstone, at one time more properly referred to as the Wingate Sandstone (Dutton, 1885, p. 136), was applied mistakenly by Gilluly and Reeside (1926) in a press bulletin to Wingate beds at Entrada Point in the San Rafael Swell, Utah. When the error was finally discovered the U.S. Geological Survey (Baker, Dane, and Reeside, 1947) ruled against the prior name Wingate for what is probably New Mexico's grandest formation.

Only shortly prior to the change to Entrada U.S. Geological Survey geologists had extended the Wingate nomenclature to strata near Tucumcari, New Mexico (Dobrovolny and Summerson, 1946), to beds which only miles away in Union County had been named Exeter by the Survey (Lee, 1902, p. 45-46). Recently Mankin (1972, p. 91) recommended the abandonment of the term Entrada in northeastern New Mexico in favor of the earlier, long-established term Exeter, and this move has the concurrence of the New Mexico Bureau of Mines and Mineral Resources (Kelley, 1972a, p. 8, 22, pl. 2). The term Exeter could with much justification be applied also to the old Wingate unit in central New Mexico including that in the Sandia Mountains.

The Todilto (Gregory, 1916) was named from exposures at Todilto Park, McKinley County, New Mexico. Although first applied to the limestone lower part it has been extended to include the thick overlying gypsum which is widespread in northwestern New Mexico. As used in much of New Mexico it is equivalent to the Wanakah Formation (Baker, Dane, and Reeside, 1947).

The type Morrison is at Morrison, Colorado (Eldridge, 1896). The unit has been traced widely throughout the Rockies from Montana to New Mexico and from the Colorado Plateau to the High Plains. Lee (1902) first traced the Morrison into northeastern New Mexico.

ENTRADA SANDSTONE

Definition—In the Sandia area the Entrada lies disconformably on the Chinle Formation and in places with minor erosional irregularity. It is overlain disconformably to conformably by the Todilto Formation. In the central Colorado Plateau it overlies the Carmel Formation and underlies the Curtis Formation, both of which can be dated as Late Jurassic on the basis of marine fossils. Elsewhere in Arizona and New Mexico it may rest on the Navajo Sandstone, Kayenta Shale, or Wingate Sandstone as has been suggested for exposures at the great Wingate cliffs east of Gallup. In the northeastern part of the San Juan basin the Entrada is overlain by Summerville beds included in the Morrison. In central eastern New Mexico the Entrada rests on a Wingate-like sequence of red beds which is referred to as the Redonda Formation (Dobrovolny and Summerson, 1946).

Distribution—The Entrada crops out in three places in the Sandia area, the largest and best exposure lying in a long curving strip around the southwest side of the

Hagan basin. A second exposure is a short east-west strip in the downfaulted end of the Sandia uplift west of Placitas. The other exposure is around the northeast end of Tijeras basin, south and east of San Antonito. The best exposures are those in the Tejon Grant and the San Felipe Indian Reservation (fig. 31) along Tongue Arroyo at the northern edge of the mapped area. The unit is also readily seen in the gully just west of the old Ideal Cement Plant gypsum quarry and along NM-14 one-half mile east of Cañoncito.

Lithology—The Entrada is predominantly a buff, tan, or bleached white sandstone. It is typically massively bedded and commonly holds up cliffs. It is fine to medium grained, consisting almost entirely of fairly well sorted subangular to subrounded quartz. In places "floating" rounded coarse grains are present. Large-scale eolian cross bedding is common. One or two thin reddish-brown mudstone units occur locally in the lower part of the unit. The white or light yellowish colors are found in the upper part and appear to be a groundwater bleaching effect, as the white-to-tan color contact in places runs across inclined crossbeds. The sandstone is slightly to highly cemented, and cement consists mostly of calcite.

Thickness—The thickness ranges from about 60 to 120 ft in the Sandia area with the greater thicknesses in the vicinity of Hagan basin. Thicknesses in wells drilled by Southern Union Production Company along the southern part of Tijeras anticline ranged from 70 to 90 ft. Differences are partly due to irregularities both on the Chinle surface and, in some instances, at the top of the Entrada. Where the Todilto is absent, thinner sections are due to pre-Morrison erosion.

Age—The Entrada can be accurately assigned to the Late Jurassic owing to gradation with the fossil-bearing Todilto in New Mexico and the marine fossils of the underlying Carmel and overlying Curtis on the Colorado Plateau.

TODILTO FORMATION

Definition—The term Todilto was first applied to the distinctive limestone outcrops at Todilto Park, New Mexico. However, through northwestern New Mexico, adjoining Colorado, and in the Sandia area a thicker gypsum unit overlies the limestone and in places either intertongues with the limestone or contains similar thin beds of limestone. Current usage of the term includes both lithologies. The contact of the Todilto with the underlying Entrada is sharp, although some alternation of sandstone and limestone laminae through 1 or 2 ft is common. The Todilto is overlain by the Morrison, in places disconformably, and in places by intergradation with the lowest Morrison sandstones through a few inches to 1 or 2 ft.

Distribution—The Todilto outcrops in the Sandia area are the same as those of the Entrada described above. Along the northern side of the Tijeras basin in sec. 19, T. 11 N., R. 6 E. a round sinkhole has formed over a poorly exposed gypsum outcrop. As the formation is thin in most places, especially where the Gypsum member is absent, it has been included with the Entrada on the geologic map (map *1).*

Lithology—The Todilto in most places comprises a thin lower Limestone member and a thicker upper Gypsum member. The Limestone member consists of fissile, papery thin laminations of gray to dark-gray limestone, especially in the lower part. Distinctive features of the limestone are the laminated bedding and the petroliferous or fetid odor from freshly broken surfaces. The lower few feet is usually a transitional mixture of Entrada-like sandstone and Todilto laminations. The upper contact with the gypsum is usually sharp. In places the Limestone member consists of 4 distinct parts as shown in a well exposed section in the NW 1/4 of projected sec. 6, T. 12 N., R. 6 E. It is underlain by massive white Entrada Sandstone and overlain by a 50-ft section of the Gypsum member (fig. 33).

Bed No.	Description	Thickness ft
4	Limestone: gray, massive breccia of laminae and irregular algal forms; porous with fragments up to nearly 0.5 inch	11
3	Limestone: gray, crinkly laminations	6
2	Limestone: gray to black, very even laminae	1.5
1	Sandstone and limestone: buff to gray, even parallel laminae; sandstone is dominant and fine-grained	2.5

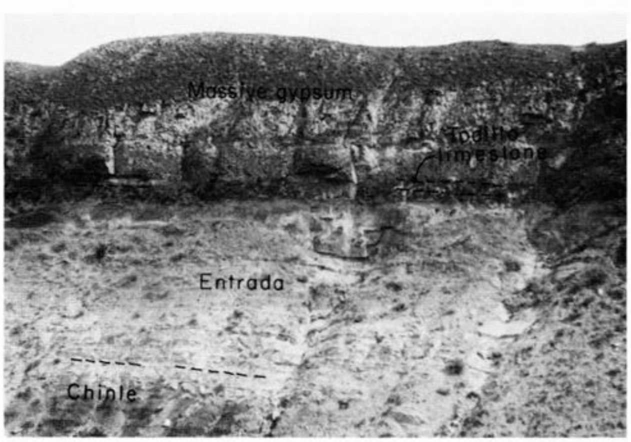
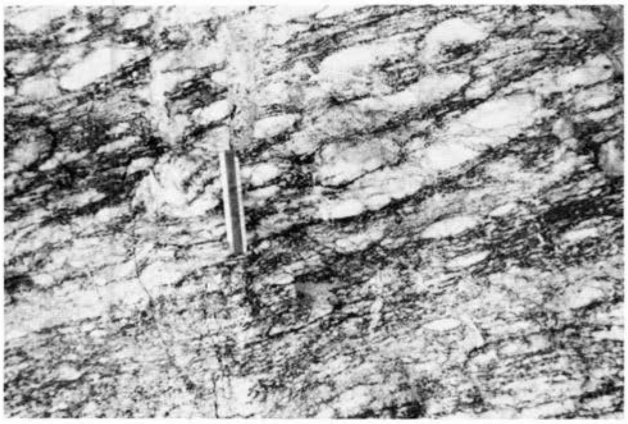
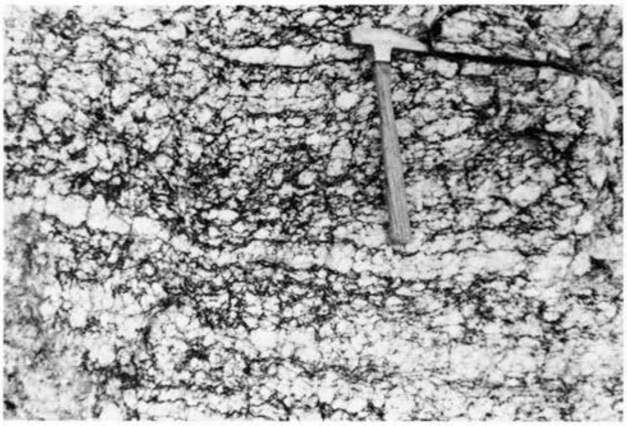


FIGURE 31—ENTRADA SANDSTONE AND TODILTO FORMATION. TELEPHOTO VIEW FROM WEST SIDE OF TONQUE ARROYO. WHITE MIDDLE ENTRADA, ABOUT 80 FT THICK. CHINLE SHALE IS REDDISH BROWN. TODILTO LIMESTONE IS FLAGGY 10-FT INTERVAL.


FIGURE 33—TODILTO OUTCROP ALONG GONZALES CREEK. EXPOSURE IN NW SEC. 6 (PROJECTED), T. 12 N., R. 6 E. UNDERLYING WHITE ENTRADA SANDSTONE, LOWER LEFT; PICK IS ON CRINKLY LIMESTONE BED; PITTED, KNOBBY OUTCROP IS LOCAL ALGAL LIMESTONE MOUND.

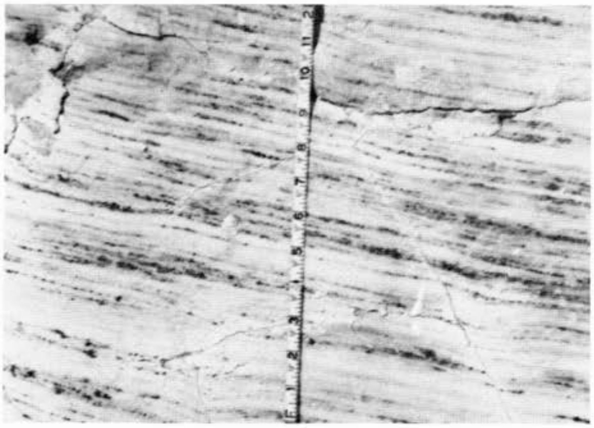


A—UNIT NO. 2 OVERLAIN BY UNIT NO. 3. SOUTHWEST WALL OF PIT AS EXPOSED OCTOBER, 1972.



B—UNIT NO. 2. WEST WALL NEAR ENTRANCE TO PIT.

C—UNIT NO. 2. EAST WALL NEAR ENTRANCE TO PIT.



D—UNIT NO. 4. EAST WALL OF PIT.

FIGURE 32—TODILTO GYPSUM AT SAN FELIPE QUARRY, TONQUE ARROYO.

The lower 3 beds are widely present in the member, but the upper one is local and occurs in low, broad mounds. In the above exposure the outcrop length is about 100 ft.

The Gypsum member consists almost entirely of massive gypsum with limestone beds 1 to 4 inches thick, especially in the upper part or locally at the top. The gypsum in good exposures is both thin bedded and lenticular or nodular, producing a "chicken-wire" mottled pattern with distorted gray limestone. Small grains of carnelian chalcedony may also be found in the gypsum, particularly near the top.

The following section (fig. 32) was measured across the gypsum quarry on the San Felipe Indian Reservation at Tongue Arroyo (SW 1/4 sec. 1, T. 13 N., R. 5 E.).

Anderson and Kirkland (1960, p. 38-40) have shown that the laminations in the gypsum beds form annual sets or varves consisting of "repetitions of three laminae: light-brown microcrystalline limestone, thin straw-colored organic material, and a discontinuous layer of clastic grains. These three laminae constitute a cycle that is repeated an average of 2,200 times per foot of section." At the transition into the overlying gypsum a "lamina of gypsum is added to the three-fold varved sequence" and "the four-fold cycle persists for several feet." Laminae of dark-brown bituminous limestone persist throughout the gypsum unit but are greatly distorted by recrystallization. Clastic grains are greatly diminished in the gypsum, but in many places carnelian jasper grains can be found, and these are probably a chemical precipitate accompanying evaporitic precipitation of gypsum.

Bed No.	Description	Thickness ft
	Morrison Formation	
	Todilto Formation (Total thickness)	189
6	Gypsum: white and pink; large-scale mottling; intercalated with two or three, 2- to 3-inch gray limestone beds; 4- to 6-inch carnelian bed at top.	16
5	Gypsum: white, mottled with spider-web limestone lines through large nodules, spindles, and cannon-ball-sized gypsum masses; most limestone lines are inclined more steeply eastward than the parallel beds, as though they were foresets.	45
4	Gypsum: white; parallel-banded gypsum and limestone couples; gypsum layers 0.1 to 5 inches; limestone layers 0.01 to 0.6 inch; 40 to 50 couples per ft (fig. 32D).	57
3	Gypsum: white; nodular with crude banding averaging about 2.0 to 2.5 inches thick, but ranging from 1 to 6 inches; "chicken-wire" pattern of reticulated black limestone 0.02 to 0.2 inch thick; some diagonal limestone laminae cross the banding (fig. 32A).	44
2	Gypsum: white; with limestone laminae more regular than in no. 3; limestone laminae 0.01 to 0.1 inch thick; gypsum wavy bands 0.25 to 1.0 inch but averaging about 0.5 inch; 20-25 couples per ft (figs. 32B, C).	22
1	Limestone: black and gray laminated; overlies the Entrada Sandstone.	5

The Todilto basin was a large lake which may have had connections across subaqueous bars with the Upper Jurassic Curtis sea to the northwest. Calcium sulfate for the evaporitic gypsum may have come partly from the sea but mostly from streams from surrounding uplands (Anderson and Kirkland, 1960, p. 45).

Fossil fish have been found in the limestone member in peripheral parts of the basin and Anderson and Kirkland (p. 44) believe that they likely lived in streams or areas of nearly fresh water near the mouths of streams feeding the lake.

Thickness—The Todilto Limestone member ranges in thickness from 5 to 20 ft. The Gypsum member where present ranges up to about 190 ft. The thickest gypsum sequence occurs along Tongue Arroyo in sec. 12, T. 13 N., R. 5 E. This thickness is greater than any other known outcrop in the surrounding region. The top of the Todilto is commonly eroded, and it may be that the Tongue exposure is one of the very few original full sections. Several miles to the southeast the Gypsum member thins markedly and the outcrops along Gonzales and San Pedro Creeks, although poorly exposed, appear to be 50 ft thick or less. Around the Tijeras basin the gypsum is only locally present; soil and vegetation cover are heavy in the area and the only known surface occurrence is the short outcrop, 50-75 ft thick, at the old Ideal Cement Company gypsum quarry just east of NM-14 in NW, SW sec. 36, T. 11 N., R. 5 E. However, Southern Union Production Company in 1964 drilled at least one well through the Todilto in which the total thickness of both members was 150 ft. Gypsum outcrops in the Tijeras basin are near the southern terminus of the gypsum as it is known west of the Rio Grande and in the Colorado Plateau, and they are the southernmost Todilto gypsum outcrops in eastern New Mexico, there being none in the Todilto outcrops of the Tucumcari basin.

Although the prevailing concept for the origin of the Todilto gypsum is by evaporation in a desiccating lake, Tanner (1972, p. 58) has made strong points for a more complex derivation. He favors a combination origin as a subaqueous bar and dunes, possibly with alternations of the two conditions. However, he believes that some of the forms as observed today may have been modified by ground-water solution. Certainly units 3 and 5 at the Tongue quarry differ so markedly from unit 4 as to require quite different modes of origin.

Algae have been the only reported fossils from the Todilto of the area; elsewhere in New Mexico, this formation has yielded at least two genera of fishes, ostracods, and aquatic insects.

MORRISON FORMATION

Definition—Between the lacustrine Todilto or the Entrada Sandstone and the Dakota Sandstone in New Mexico there is a diverse sequence of mudstone, sandstone, and conglomerate of variegated reds, browns, greens, and grays that is generally referred to as the Morrison. However, in some places and especially in surrounding regions a number of units both at the bottom and the top have been removed from the Morrison as separate formations. Chief among these at the base have been the Summerville and Bluff; at the top are such units as the Purgatoire (Stole, 1912), Cedar Mountain (Stokes, 1944, p. 966) and Dead Mans Peak (Swift, 1956, p. 43). All these units possess lithologies characteristic of the Morrison and in places they may grade into or intertongue with the Morrison. Also, in places they or their equivalents have been included in the Morrison.

In recent years the Morrison of west-central New Mexico has been divided (in ascending order) into the Recapture Shale Member, Westwater Canyon Sandstone Member, and Brushy Basin Shale Member lying between the Summerville Formation and Bluff Sandstone below and the Dakota above (Hilpert, 1963, p. 7). In the Sandia area, especially in the Hagan basin, representatives of all the above, down to the Summerville beds, may be present, but they have not been effectively separated, thus the Morrison is mapped and described as a unit between the Todilto at the base and the Dakota at the top.

Distribution—The Morrison outcrops closely parallel those described above for the Entrada and Todilto. There are especially good exposures east of Tongue Arroyo in sec. 12, T. 13 N., R. 5 E., but a number of good exposures are found throughout the outcrop belt around the west and south sides of Hagan basin. Somewhat different and significant exposures may be found around the northwest side of Tijeras basin, particularly in the ridge east of the abandoned Ideal Cement Company gypsum quarry in sec. 36, T. 11 N., R. 5 E. A small questionable outcrop with some Chinle shale and sandstone lies west of the Sandias in sec. 10, T. 11 N., R. 4 E. near the Juan Tabo road. This outcrop and the associated Chinle beds were thought to be all Chinle by Read and others (1944) and Galisteo by Kelley (1963). Although Galisteo beds have lithologies of all these beds in various parts we believe designation of this inlier as fault slices of Morrison and Chinle is more likely.

Lithology—Morrison lithology in the Sandia area is variable. Matching units of the Hagan basin (Appendix 1) with those in the Tijeras basin is impossible. The sequence consists dominantly of greenish, reddish, lavender, and light-gray mudstone, claystone, and siltstone interbedded with white, buff, and orange sandstone. Variable thin beds of limestone and conglomerate are found in the middle and upper parts. Much of the claystone is slightly arenaceous and commonly bentonitic. The sandstone is friable and consists of subangular to subrounded medium to coarse grains of quartz and lesser feldspar. The conglomerate is in irregular lenses and beds with fragments of quartz, chert, dense limestone, and altered fine-grained or vitric rhyolitic volcanic rocks. White kaolin fragments and kaolin cement are common especially in sandstone of the upper part of the formation. The limestone is light to medium gray, fine grained, and nonfossiliferous. Occasionally in the middle mudstone or claystone units are thin, dense, silicified beds that may be silicified air-fall tuff. Many of the sandstone beds could be tuff or reworked water-laid tuff.

The top of the Morrison is an erosional disconformity, and it appears that there was some mild broad warping and accompanying erosion after Morrison deposition and before the laying down of the basal Dakota sands (fig. 34). This accounts for most of the considerable differences in thickness observed in the Hagan area, and in the Gonzales Creek area divergence of a few degrees can be observed between some high Morrison ledges and the Dakota basal beds (fig. 35). Some of this disturbance and erosion appears to have occurred in latest Morrison time, and the uppermost sandstone beds show some internal discordance, as in the prominent exposures on the west side of San Pedro Creek.

Thickness—Harrison (1949, p. 100-102) measured 730 ft of Morrison east of Tongue Arroyo in sec. 1, T. 13 N., R. 5 E. It is about 500 to 550 ft thick in the Placitas area. In the Tijeras basin exposures are usually poor with either the top or bottom obscured. Furthermore, the upper part consists of sandstone beds that have been confused with those of the overlying Dakota. On the basis of wells drilled by Southern Union Production Company on Tijeras anticline, and allowing for some thicknesses excluded into the Dakota, we estimate a thickness for the Morrison of at least 760 to 915 ft.

Age—The Morrison of the area has not yielded determinable fossils. Elsewhere in New Mexico, several genera of dinosaurs have been found, especially west of Albuquerque near Correo and Mesa Gigante, near Acoma, and near Grants; some of the bones are impregnated with uranium minerals; both permineralized wood and dinosaur bones have been found in some of the uranium mines (Northrop, 1972, p. 61-62). Although age of the Morrison has generally been considered to be Late Jurassic, it was earlier thought to be Early Cretaceous (?) (Darton, 1928). In places, at least, the Purgatoire seems to have been separated from the Morrison on the grounds that it is Early Cretaceous in age rather than on lithology. In the Tucumcari basin this certainly appears true, even though the Mesa Rica sandstone beds are similar to those in the Morrison, and the overlying Pajarito claystone and sandstone are all typical of the Morrison. At least part of the uppermost Morrison may be Early Cretaceous in the Hagan basin.

CRETACEOUS

The Cretaceous rocks of the Sandia area consist of the Dakota Sandstone, Mancos Shale, and Mesaverde For

FIGURE 34—DISCONFORMABLE CONTACT OF DAKOTA SANDSTONE LEDGES ON FRIABLE, PEBBLY WHITE SANDSTONE OF MORRISON FORMATION. MORRISON CONTAINS MANY FRAGMENTS OF BLEACHED OR KAOLINIZED FELDSPAR. IN SW SEC. 31 (PROJECTED), T. 13 N., R. 5 E. NEAR GONZALES CREEK.

FIGURE 35—MASSIVE UPPER MORRISON BEDS CAPPED BY DARK LEDGES OF DAKOTA SANDSTONE. SAN PEDRO CREEK, SEC. 5, T. 12 N., R. 6 E.

mation. Their combined thickness is nearly as great as the combined thickness of all the previous Mesozoic and Paleozoic formations. They are marine and inter-tongued marine and nonmarine flood-plain beds deposited in the Rocky Mountain geosyncline during Middle and Late Cretaceous time. The sediments consist mostly of shale and sandstone, some coal, and minor conglomerate. The total thickness is about 4,700 ft.

DAKOTA SANDSTONE

Definition—The Dakota type locality is near Dakota, Nebraska (Meek and Hayden, 1862, p. 419-420). This unit has been mapped and extended widely through the High Plains, Rockies, and Colorado Plateau from Montana to New Mexico. Winchell (1875, p. 32) designated it a group. Later several sandstone units separated by shales were included. Some of the lower units had varied lithologies more characteristic of the Morrison (Lee, 1927, p. 17-23) and were subsequently (Waage, 1955, p. 15-49) separated from the Dakota. Nevertheless, there are many places where several Dakota sandstone units separated only by thin intervals of gray or black shale justify inclusion in the Dakota. Elsewhere, especially if the intervening shale is thicker, the second and successive units may be given separate names or referred to as Tres Hermanos Sandstone (Herrick, 1900c) and included as members of the Mancos Shale or the Graneros Shale.

Owing to transgressive spreading over so wide an area, the basal sandstone unit and the age of the formation are not everywhere the same; because of local changes in near-shore sediment from mud to sand, coupled with minor seaward-landward shifts of the shoreline, the Dakota sandstone is not a continuous sheet or layer. In some places the intervening shale units of the Dakota rest on the Morrison and Morrison shales then are included with at least the first succeeding shale unit in the Dakota proper, as in the Galisteo basin not far northeastward of the Hagan basin (Stearns, 1953b, p. 965).

The Dakota overlaps the Morrison on a broad regional scale in the Sandia area, but to the south it gradually oversteps formations as old as the Abo in southern New Mexico. The upper contact is gradational, the Dakota intertonguing with the Mancos Shale.

Distribution—Dakota Sandstone outcrops follow closely those of the Morrison along the south and west sides of the Hagan basin. The formation is especially prominent around the northeast end of the Tijeras basin and in a short, steep, faulted hogback along the southwestern border of the Tijeras graben, just east of San Antonio. In the Placitas area thin units of Dakota occur as small outcrops in three separate fault blocks.

Lithology—The Dakota consists dominantly of sandstone but contains smaller beds of black shale, especially in the upper part. Sandstone beds are thin to thick or massively bedded with local small cross beds. It varies from white to light grayish or buff and is commonly stained yellowish to rusty brown on blocky weathered outcrops. The sandstone ranges from medium to coarse grained and contains thin beds of conglomerate at places in the basal part. Beds are well cemented, weathering out in angular ledges or hillside scree; surfaces of weathered outcrops are also commonly rough and pitted. The angular aspect of its weathered outcrops is in marked contrast with the rounded, somewhat spheroidal, outcrops and boulders of the underlying friable Morrison sandstone beds.

Thickness—The Dakota Sandstone in the Hagan basin and at Placitas is unusually thin but variable. It may be as thin as 5 to 10 ft or as thick as 40 to 50 ft in local areas, but most commonly it is 20 to 25 ft thick. The top part is difficult to measure owing to stripping in hogbacks where dips are 25 to 35 degrees. Lee (Lee and Knowlton, 1917, p. 203) observed variation between 15 and 50 ft, and Stearns (1953b, p. 964) found a range of 6 to 25 ft. The variation probably results from normal differences of accumulation on a uniform surface, from some filling of swales in the Morrison surface, or from apparent local additions of the basal sand of the overlying Mancos. Around Placitas the Dakota is similarly thin. In the Tijeras basin area, on the other hand, the Dakota is considerably thicker, probably because of sandstone additions at the top. Thicknesses appear to approach 150 to 200 ft. Massive sandstone of the Morrison, which immediately underlies the Dakota, may be mistaken for the Dakota; in picking of some well-log tops in the Tijeras anticline the Morrison appears to have been picked 150 to 200 ft low, thus adding as much as 150 to 200 ft to the Dakota.

Fossils and Age—A peculiar and distinctive feature of the Dakota Sandstone is the presence in many places of warty or tuberculate cylindrical concretions known as *Ophiomorpha* (fig. 36). The cylinders are generally nearly normal to the bedding and range from 0.25 to 0.5 inch in diameter and nearly a foot in length. *Ophiomorpha* was originally named *Halymenites major* by Lesquereux more than a century ago; see Lee and Knowlton (1917, p. 242) for description and synonymy. "One of the most abundant and widely distributed fossil organisms known in the Rocky Mountain region," it was interpreted as a form of algae or seaweed. It was early thought to indicate marine conditions, and generally to indicate shallow-water and near-shore conditions. It is most abundant in the higher beds of the Upper Cretaceous but is found in the Colorado Group as well as in the Montana Group. *Halymenites major* has been reported in our area from sandstones of both the Mancos Shale and Mesaverde Formation of the Hagan basin and also from the Cerrillos-Madrid area.

Roland W. Brown (1939, p. 253-254, pls. 62-63) was the first to suggest that these warty or tuberculate structures were not seaweeds but burrows of some organism and that the tubercles were droppings of the animal that inhabited the burrow. The tuberculate appearance gave rise to the colloquial name "fossil corn cob." Weimer and Hoyt (1964) described the burrows of the living ghost shrimp, *Callianassa major* Say. They note that this decapood crustacean is about 4 inches long and 0.5 inch in diameter; it is a permanent inhabitant of its burrow, rarely being seen on the surface, which may explain the common name "ghost shrimp." The burrows are 0.1 to 0.4 inch in diameter near the surface and enlarge downward to as much as 0.6 to 0.9 inch in diameter. Some burrows extend downward 3 to 6 ft; most are normal to the surface but some are diagonal, and some horizontal; burrows may branch.

The Dakota Sandstone burrows are somewhat smaller than those of the Mancos and Mesaverde Formations (Table 4, Trace Fossils). It is an interesting coincidence, regarding the specific name, that Say in 1818 named the shrimp he collected near Jacksonville, Florida, *Callianassa major* and that Lesquereux more than half a century later (1872) named the supposed fossil seaweed *Halymenites major*. Currently the trace fossil is known as *Ophiomorpha major*.

Cobban and Reeside (1952, p. 1028, note 9) wrote:

> The relations of the sandstone designated "Dakota" in this [New Mexico] and many other areas to the typical Dakota sandstone on the Missouri River near Sioux City, Iowa, are not well understood. Such usage of the name may cover beds of both Early and Late Cretaceous ages, though it was apparently the intent originally to include in the Dakota beds no older than the European Cenomanian. There is much doubt that any part of the typical exposures are Late Cretaceous.

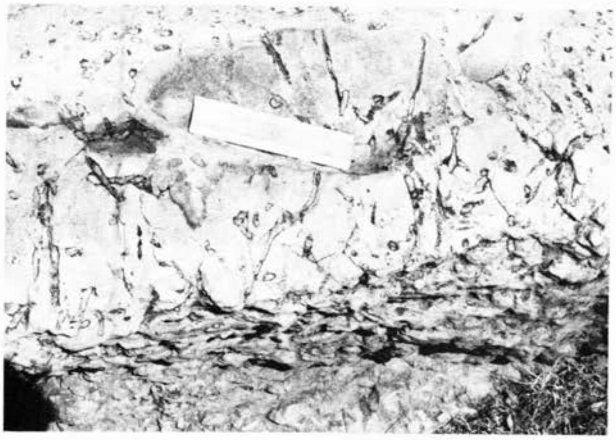
However, several years later, in discussing the Dakota Sandstone of the eastern side of San Juan basin, Dane (1960, p. 67) stated that

> In so far as known to the writer, fossils closely diagnostic of age have not been found in the Dakota of the eastern San Juan Basin . . . It seems likely that most of the Dakota sandstone of the eastern San Juan Basin is of Late Cretaceous age and may be entirely younger than any part of the Dakota sandstone of northeastern New Mexico and southeastern Colorado, much, if not all, of which is of Early Cretaceous age . . . The two areas may well have been separated by an erosional barrier 15 to 25 miles wide trending southward along the 106° meridian toward central New Mexico.

Thus, the Sandia Mountains area is critically located; the 106° meridian lies only a few miles east of our map area, between Cerrillos and Galisteo.

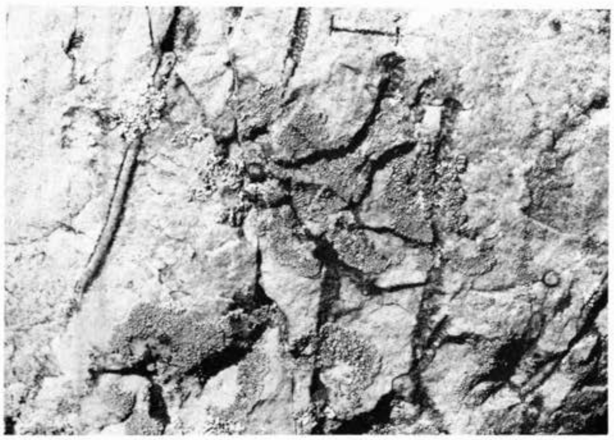
MANCOS SHALE

Definition—The Mancos Shale was named by Cross (1899) for exposures near Mancos in southwestern Colorado. It is typically a thick black marine shale between the Dakota (below) and Mesaverde (above). The lower and upper boundaries are conformable, being both gradational and intertonguing from place to place. Tongues of sandstone from the western sources or limestone from eastern sources in places have made it possible to divide the marine Mancos into members. Few persistent sandstones and only one or two thin



A—LONGITUDINAL AND TRANSVERSE SECTIONS (SCALE, 6 INCHES).

B—TUBERCULATE MOLD (KNIFE, 3¼ INCHES).



C—MOLDS AND CORE, NUMEROUS LICHEN (HORIZONTAL LINE SEGMENT NEAR TOP CENTER, 1 INCH).

D—MOLDS AND CORES SHOWING BIFURCATION (VERTICAL LINE SEGMENT NEAR TOP CENTER, 1 INCH).

FIGURE 36—*Ophiomorpha* BURROWS IN DAKOTA SANDSTONE. OUTCROPS LOCATED IN NORTHEAST PART OF TIJERAS COAL BASIN IN SE SEC. 32, T. 11 N., R. 6 E. SOME BURROWS ARE PARALLEL OR DIAGONAL TO BEDDING, BUT MOST ARE NORMAL TO BEDDING. NOTE WARTY OR TUBERCULATE APPEARANCE.

limestones are traceable in the Mancos of the Sandia area and, therefore, no members or subdivisions are designated. However, equivalents of such units as the Graneros, Tres Hermanos, Greenhorn, Carlile, Juana Lopez, and Niobrara are present and recognizable, especially in the Hagan basin area (Stearns, 1953b, p. 966-969; Lee and Knowlton, 1971, p. 203). The lower part of the Mancos, including the Graneros Shale, Tres Hermanos tongues, Graneros Shale, and Greenhorn Formation, is considered transgressive (Coates and Kauffman, 1973, p. 965-966). The highest Greenhorn and Carlile Shale are considered regressive in origin, but the Juana Lopez, which is well developed in the Hagan area where exposures are good, and the upper Mancos shales are transgressive.

Distribution—The Mancos occurs in a wide belt curving from westward to northward trend through the Tejon Grant (fig. 37), but much of it is covered by terrace gravel and valley alluvium. In the Tijeras basin the Mancos underlies a nearly circular valley around the basin between the Dakota or other resistant beds on the outer side and the Mesaverde ridges on the inside. It is mostly covered by alluvium and the only outcrops of note are on slopes up to the overlying Mesaverde or in a few small gullies cut into the Mancos valley near Tijeras Creek. The best partial outcrops occur around the amphitheater valley eroded in the Tijeras anticline in secs. 11, 12, T. 10 N., R. 5 E. Some additional narrow outcrops are present along NM-14 near San Antonio.

Lithology—The Mancos Shale is predominantly black to gray and, locally, brown. The shale is calcareous to varying degrees and locally carbonaceous or siliceous. It is quite fissile and commonly laminated with siltstone or fine-grained sandstone. Secondary gypsum in the form of selenite or satin spar is locally present (Appendix 1).

The Mancos sequence of the Hagan basin area differs from that of Tijeras basin in having more thin sandstone beds or sandy zones and in intertonguing more with the Mesaverde Formation. At Tijeras, Mancos underlies a smooth valley in which there are essentially no low ridges or knolls to indicate the presence of sandstone tongues. A few thin sandstone units interbedded with shale occur just above the main Dakota ledges, but these are easily included in the Dakota Sandstone. The upper 50 to 75 ft of the Mancos consists of intercalated thin sandstone and shale beds which grade into the thick basal Mesaverde ledges. Exposures in the Tijeras basin are by no means as good as in the Hagan basin, but gullies do expose parts of the section, especially along the southeast side; no consistent sandstone units are seen. Locally a thin limestone bed is exposed in the lower part of the Mancos which may or may not be a Greenhorn equivalent.

In the Hagan basin where exposures are better several thin sandstone horizons are observable and two of these have been mapped (Harrison, 1949, pl. 1). One of these, about 135 ft above the base of the Mancos, is 25 to 50 ft thick and such sands have been termed Tres Hermanos. Elsewhere, as along Gonzales Creek, Tres Hermanos-type sandstone beds are thin or absent. Local exposures show them to be no more than 5 to 10 ft thick or only thin-bedded intercalations with siltstone or shale. Another sandstone, 650 to 700 ft above the base, is 18 to 20 ft thick and may be the Juana Lopez Sandstone (Rankin, 1944, p. 19-20). A sandy limestone unit about 8 ft thick crops out about 480 ft above the base. A very fossiliferous concretionary brown silty calcareous zone 1 to 2 ft thick was noted about 480 ft above the base by Harrison. The two thin sandstone units are tongues which locally divide the Mancos into three shale units, especially south and west of Hagan. To the north in the Tejon Grant the sandstone beds either die out or are covered and not mappable.

The calcareous bed which Harrison (1949, pl. 1) noted at about 480 ft above the base of the Mancos may be the Greenhorn zone which Stearns (1953b, p. 966, 967) stated was represented by "no more than one limestone" bed less than 1 ft thick in the Tongue area, but Stearns gave only 200 to 250 ft for the underlying Graneros Shale.

The upper sandstone horizon at 650 to 700 ft above the base of the Mancos is probably the Juana Lopez, and Stearns (1953b, p. 968) has suggested member status and usage of the term, Juana Lopez Member, because of variations in lithology including limestone and shale as well as sandstone. Rankin (1944, p. 12) believed that the Juana Lopez is very near the top of the Carlile. However, as is common in central New Mexico the boundary of the Carlile with the overlying Niobrara Shale is not readily identified.

Harrison (1949, pl. 1) chose the top of the Mancos at the base of the prominent sandstone which Stearns (1953b, pl. 1) termed Cano member and used as the base of his "Upper Mancos shale" near Hagan. Stearns did not cite Harrison's thesis and probably was not aware of it, although he did cite his own unpublished manuscript. The Cano and the thick shale interval above contain marine fossils; perhaps the Mancos top should be chosen at the base of the next higher sandstone ledges that consist of terrestrial coal-bearing shale beds and in so doing increase the thickness of the Mancos by about 500 ft (Harrison, 1949, pl. 1).

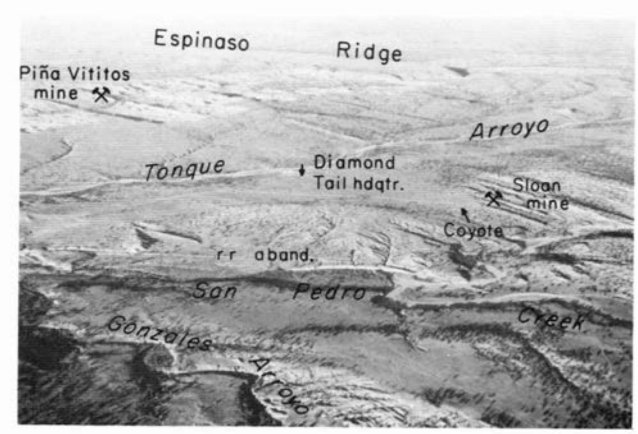


FIGURE 37—AIRVIEW NORTHEAST ACROSS HAGAN BASIN NEAR DIAMOND TAIL RANCH HEADQUARTERS.

Thickness—Definite thicknesses for the Mancos are difficult to obtain for either the Tijeras or Hagan basins, owing to poor exposures and to indefinite or intertongued boundaries, particularly with the Mesaverde Formation. In the Tijeras basin lack of outcrops and change of attitude across the formation make measurement or calculation uncertain. Along the northern side of the basin, averaging of available dips at the top of the Dakota and base of the Mesaverde ledges yields a calculated thickness for the Mancos of 1,400 to 1,500 ft. In the Tijeras anticline along the southern side of the basin, a well spudded in the middle of the Mancos gives a depth to the top of the Dakota of 887 ft. Surface measurements from the well collar across the east limb of the anticline to the base of the Mesaverde yield the remaining thickness, and these two measurements-887 and 573 ft, respectively—suggest a total thickness for the Mancos of 1,460 ft.

West of Hagan, Harrison (1949, p. 118-119; pl. 1) measured a section across an outcrop width of about 0.5 mile which totaled 1,304 ft in thickness between the top of the Dakota and the base of a sandstone about 512 ft below the Cano Sandstone of Stearns (1953b, p. 971), and this left his Mancos thickness thinner by 512 ft. If adjusted to the base of the Cano, Harrison's measured Mancos would be 1,816 ft. Based on cursory inspection of fossils in the Hagan Mancos Reeside thought the section to be thickened by faulting (C. B. Read, personal communication).

Fossils found in Mancos Shale are listed in Table 4 and are discussed with other Cretaceous fossils after Mesaverde Formation.

MESAVERDE FORMATION

Definition—The sedimentary sequence known as Mesaverde gets its name from exposures at Mesa Verde near Mesa Verde National Park in Colorado (Holmes, 1877, p. 245-248). He divided the formation into three parts: 1) a massive sandstone sequence at the base termed the *Lower Escarpment,* 2) a middle coal-bearing shale sequence, and 3) a massive sandstone sequence at the top termed the *Upper Escarpment.* Later Collier (1919, p. 296) proposed the now widely used formal names Point Lookout Sandstone, Menefee Formation, and Cliff House Sandstone for Holmes' units. The term Mesaverde is widely used as either a group or formation depending upon the ability to recognize or use the Collier formation names, or it is used to bracket within a group other formation names which do not correlate or fit well with the type names. The term Mesaverde has been widely extended in mapping and correlation through the Rocky Mountains from Montana to New Mexico; in places the term may be applied to beds above and below those not present at the type locality.

The Mancos grades into and intertongues with the overlying Mesaverde as described above. Southward and westward from the type locality the Mesaverde becomes much thicker by intertonguing downward at the expense of the Mancos. In the northwest, and northern San Juan basin, the Mesaverde is overlain by the thick marine Lewis Shale. Eastward across the San Juan basin the Lewis Shale thins greatly and its presence as far east as in the Hagan basin is doubtful. In the absence of the Lewis marine tongue, younger coal-bearing units would overlie the Mesaverde and would be included in the group. In the Hagan basin the Mesaverde is thick and overlain unconformably by the Galisteo red-beds sequence. It is conceivable that some of the upper part of the Hagan Mesaverde is younger than the type, or pre-Lewis, Mesaverde of the San Juan basin, and that it thus contains Pictured Cliffs, Fruitland, or younger equivalents.

Distribution—Mesaverde outcrops are found in three separate areas. The most extensive and thickest are in the Hagan basin (Appendix I) in a northward-trending belt along the Una de Gato Arroyo, from around the abandoned coal town of Hagan northward across Tongue Arroyo (figs. 38, 39). In this belt the beds dip 20 to 30 degrees eastward in the northern part, becoming northward near Hagan. Another large area of Mesaverde occupies the center of the Tijeras syncline and crops out around the rim of the adjoining Tijeras anticline. The top of the formation is not preserved in the Tijeras area. There is a small outcrop just northwest of Placitas, which is overlain by Galisteo beds as in the Hagan basin, but the section is much thinner owing to much more stripping of the Mesaverde prior to deposition of the Galisteo.

Lithology—The Mesaverde Formation consists of alternating units of sandstone and shale which form a series of parallel ridges and valleys along much of the outcrop belt. Sandstone units range from about 20 to 600 ft thick and shale from 20 to 500 ft. Some intervals consist of thin alternating beds of sandstone, shale, and shaly sandstone (Appendix 1). Sandstone is light gray through buff, to greenish gray or olive drab. Bedding ranges from thin to thick. Texture is fine to coarse grained and very locally conglomeratic. Grains are subangular to subrounded. Composition ranges from relatively clean quartz sandstone through some feldspathic types into abundant subgraywacke types exhibiting distinctive salt-and-pepper qualities which result from a mixture of feldspar and dark fragments resembling propylite.

Shale units are of two types, noncarbonaceous and carbonaceous or coal-bearing. Shale colors vary from gray to dark gray or locally black, and from brown to olive drab. Brown colors are more common in the upper part of the section. Sandy seams intercalate with many shale units.

FOSSILS AND AGE

Table 4, *Upper Cretaceous Fossils in the Sandia Mountains and adjoining areas,* presents the complete Upper Cretaceous fauna and flora of the Tijeras and Hagan basins. In addition, the complete faunas and floras of the Cerrillos-Madrid area and of the Omera mine-Galisteo-Lamy area are included, chiefly because many fossils found in these areas may eventually be found in the Sandia Mountains area. The Upper Cretaceous outcrops of the Cerrillos are are only 8-10 miles to the northeast and east of the Hagan-Tongue outcrops; Madrid is about 11 miles northeast of Hagan.

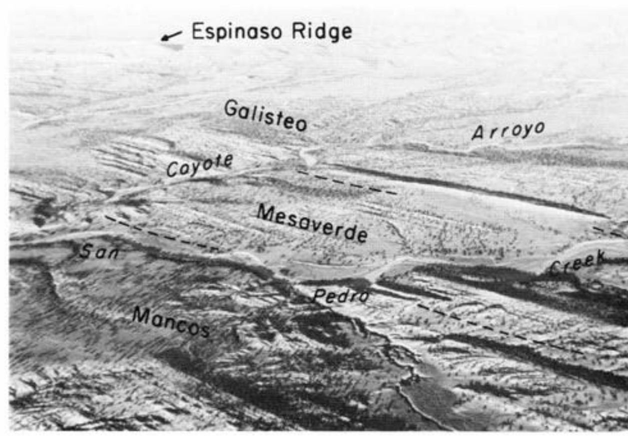


FIGURE 38—Airview northeast across Hagan basin near Coyote Arroyo. Middle left shows fork of Coyote Arroyo from San Pedro Creek which runs across the middle. In upper left corner Tonque Arroyo cuts through Espinaso Ridge.

The Omera coal mine is 17 miles east of Hagan; Galisteo is 22 miles east-northeast of Hagan; and Lamy is 27 miles east-northeast of Hagan.

Earlier workers extended the terms Mancos and Mesaverde from the San Juan basin eastward to the Tijeras and Hagan basins, and still farther eastward to the Omera coal mine in the Galisteo area. Recently, the Kansas-Colorado nomenclature of Graneros, Greenhorn, Carlile, and Niobrara has been brought into the Lamy-Galisteo-Omera mine area. See Stearns (1953b). For a discussion of differing philosophies, see Dane, Cobban, and Kauffman (1966) and Coates and Kauffman (1973). The last paper, on a coral thicket near Lamy, subdivides the Graneros Shale, Greenhorn Formation, and Carlile Shale each into several members.

Prefatory Remarks to Table 4, page 63

1. For the Tijeras basin, two columns are given, one for the Mancos Shale and one for the Mesaverde Formation. Chief source is Lee and Knowlton (1917); invertebrates were identified by T. H. Stanton, and plants by Knowlton. Several species of bivalves were cited by Stevenson (1881) from near San Pedro, which Lee and Knowlton (1917, p. 25) interpreted as having come from the Tijeras basin.

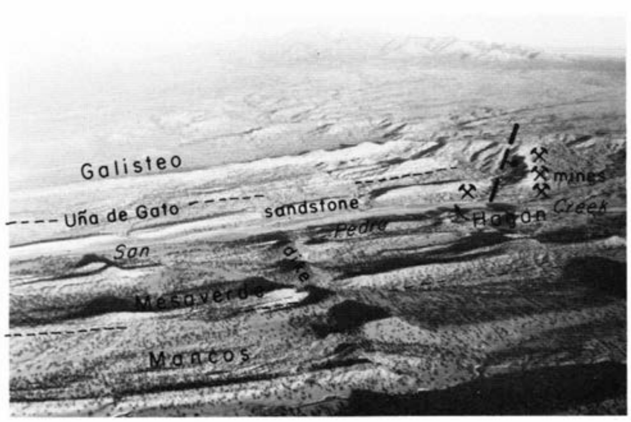


FIGURE 39—Airview east across Hagan basin near Hagan. Ortiz Mountains in background. Buildings of abandoned coal camp of Hagan, along Una de Gato Arroyo, just right of center. Note basalt dike cutting across the formations.

2. For the Hagan-Tonque basin, two columns are given, one for the Mancos Shale and one for the Mesaverde Formation. Sources include Lee and Knowlton (1917) and Stearns (1953b). In the latter paper, invertebrates were identified by J. B. Reeside, Jr. in 1942 and 1947 (see Stearns [1953b, table 2, p. 970]; for a map showing U.S.G.S. fossil localities, see Stearns [1953c, pl. 1]).

3. For the Cerrillos-Madrid area, two columns are given, one for the Mancos Shale and one for the Mesaverde Formation. Sources include Herrick and Johnson (1900), Johnson (1902-03), Lee and Knowlton (1917), and Dane, Cobban, and Kauffman (1966). A few fossil plants were reported by Lesquereux (1872) from "Placer Mountain"; there is some reason for believing that this was near Madrid.

Marcou (1858, p. 36-37, pl. 2, fig. 3) described *Inoceramus lerouxi as* a new species from the vicinity of Cerrillos,

> at the point where the road from Santa Fe to Algodones crosses the Rio [Galisteo] . . . I have dedicated this fossil to my friend and travelling companion, the celebrated guide and mountaineer Antoine Leroux, called by the Mexicans Don Joachin.

We have not included this species in the table because we are not certain of its status, nor of the exact locality from which it came.

Marcou (1858, p. 42) also identified but did not illustrate two bivalves, *Cytherea missouriana* and *Tellina occidentalis,* among

> a great number of bivalves forming a lumachella in a yellowish-gray limestone placed between the gray marls that occupy the country between Gold Mount and the villages of Galisteo and Algodones.

These species have not been included in the table; Marcou may have found them either in the Cerrillos area or in the vicinity of Tongue and Hagan.

4. For the Omera-Galisteo-Lamy area, five columns are given. Many of the earlier workers cited fossils simply from the Mancos Shale at the Omera mine. Later workers used the Kansas-Colorado nomenclature of Graneros, Greenhorn, Carlile, and Niobrara. Sources include Reeside (1927), Cobban (1951), Stearns (1953b; map in 1953c), and Coates and Kauffman (1973).

Marcou (1858) described a new species of shark tooth, *Ptychodus whipplei,* from 3 miles north of Galisteo; see footnote 4 at bottom of table.

Type specimens are indicated by T. Older generic names are given in parentheses and quotation marks. For modern generic assignments of many species of invertebrate fossils, we are indebted to W. A. Cobban (cephalopods), E. G. Kauffman (bivalves), and N. F. Sohl (gastropods). Additional information is noted at the bottom of the table.

TERTIARY

The Tertiary rocks of the Sandia area consist of two types, stratified and intrusive. The stratified rocks include the Galisteo Formation red beds, Espinaso Volcanics, and Santa Fe Formation of the Rio Grande trough. They contrast strongly in origin, sites, and extent of deposition.

GALISTEO FORMATION

Definition—The Galisteo was named by Hayden (1869, p. 40, 67, 90) for exposures along Galisteo Creek near Cerrillos. Johnson (1903, p. 332-338) reviewed at length the early literature on the "Galisteo Sand Group" in the Cerrillos area and concluded that its age was Late Cretaceous or Laramie. He noted that some workers had thought the Galisteo was Triassic. In that area the formation unconformably overlies Mesaverde and is overlain conformably or disconformably by the Espinaso Volcanics. Locally Galisteo beds appear to parallel the underlying Mesaverde in the Hagan basin, but the considerable differences in thickness of the Mesaverde beneath the Galisteo in such places as Placitas, Hagan, and in the Galisteo Creek area strongly suggest warping and erosion of the Mesaverde prior to Galisteo deposition.

Distribution—In the Sandia area the Galisteo crops out in four separate areas. The largest is a broad belt in the Hagan basin north of the abandoned coal town of Hagan (fig. 39). Most outcrops are in the drainage area of Coyote Arroyo and northward across Tongue Arroyo, where formation dips change from northeastward to eastward at about 30 degrees. West and northwest of Placitas **2** short east-west-trending outcrop strips are separated by a large fault crossing the downthrown end of the mountains. In both outcrops dips are 60 to 70 degrees northward.

Lithology—The Galisteo is a thick sequence of variegated sandstone and mudstone with lesser beds of conglomerate (Appendix I). Sandstone beds are not unlike those of the Mesaverde but the presence of pebbles and cobbles in the sandstone, lenses and thin beds of conglomerate, and petrified wood fragments and large logs distinguishes the formation. Limonite staining is prevalent. In the lower beds iron-stained sandstone concretions are common (fig. 40).

In the Hagan basin the Galisteo consists of 3 sandstone units separated by reddish-brown and variegated mudstone units (Harrison, 1949, pl. 1). Bedding is thin to massive with cross-bedding. The sandstone is generally medium to coarse grained, locally conglomeratic, and commonly friable. Quartz predominates, with minor quantities of feldspar, chert, and various rock fragments. Conglomeratic fragments are

(continued on page 66)

FIGURE 40—LOWER GALISTEO SANDSTONE NORTH OF HAGAN. NOTE ROUND LIMONITE-IMPREGNATED SANDSTONE CONCRETIONS AND PETRIFIED LOG.

TABLE 4—UPPER CRETACEOUS FOSSILS IN SANDIA MOUNTAINS AND ADJOINING AREAS

(T=type(s); superscripts at heads of columns refer to prefatory remarks in text; numbers in table refer to notes at bottom of table)

	Sandia Mts. Area: Tijeras[1]		Sandia Mts. Area: Hagan-Tonque[2]		Cerrillos Madrid[3]		Omera-Galisteo-Lamy[4]				
	Mancos	Mesaverde	Mancos	Mesaverde	Mancos	Mesaverde	Mancos at Omera	Graneros	Greenhorn	Carlile	Niobrara
FORAMINIFERA											
Dentalina? sp.									X		
Globigerina sp.									X		
Nodosaria? sp.									X		
ANTHOZOA (Corals)											
Archohelia dartoni Wells (Note 1)										T	
Solitary coral, indet.					X						
BRACHIOPODA											
Lingula subspatulata					X		X				
BIVALVIA (Pelecypods, clams, oysters)											
Anatina sp.			X		X						
Anomia sp.	X		X	X	X		X		X		
Astarte evansi					X						
A. sp.					X						
"*Aucella strongi*" Johnson (probably *Inoceramus dimidius*)					T						
Callistina? sp. ("*Callista*? sp.")		X									
Camptonectes aff. *platessa*									X		
C. sp.											X
Cardium sp. (may be *Ethmocardium*)		X	X	X	X						
Cladoceramus aff. *undulatoplicatus* ("*Inoceramus*")											X
Corbula sp. (Stevenson cited 3 sp.)	X				X						
Crassatella andrewsi ("*Crassatellites*")			X								X
C. *shumardi*				X	X		?				
C. sp.										X	
Crassatella (*Landinia*?) *fitchi* Johnson ("*Corbula nematophora fitchi*")					T						
Crassostrea glabra	?	?									
C. aff. *glabra*					X						
C. aff. *soleniscus*						X					
Cymella montanensis ("*Liopistha undata*")				X	X						
Cyprimeria sp.		X		X	X		X			?	X
C.? *sulcata* Johnson					T						
Endocostea brooksi Johnson					T						
E.? *barabini* ("*Inoceramus*")		X		X	?						
E.? *simpsoni*					?	?					
E.? *typica* ?					X						
Entolium n. sp. of Kauffman and Powell (Note 2)									X		
Ethmocardium pauperculum				X							
Exogyra columbella								X			
E. *ponderosa*					X		X				
E. *winchelli* ?				X							
Gervillia sp.											X
Idonearca? sp. ("*Cucullaea*")		X		X	X		X				
Inoceramus balchii					X						
I. "*fragilis*"			X		X					X	
I. *perplexus*					X						
I. cf. *perplexus*									X		
I.? *rutherfordi*								X			
Inoceramus (*Inoceramus*) *dimidius*					X						
I. (*I.*) aff. *flavus*									X		
I. (*I.*) cf. *pictus*									X		
I. (*I.*) aff. *tenuiumbonatus*									X		
"*Inoceramus*" *deformis*											X
"*I.*" aff. *tenuirostris*											X
"*I.*" sp. nov. of Johnson					X						
"*I.*" sp. "very large"			X								
"*I.*" spp.		X		X	X		X	X			X
Isocardia sp.			X								
Legumen aff. *planulatum*				X							
L. sp.											X
L.? sp.		X			X						
Lima utahensis									X		
L. aff. *utahensis*									X		
Liopistha? *madridensis* Johnson ("*Arca*")					T						
Lithophaga ("*Lithophagus*")				X							
Lopha lugubris ("*Ostrea*")			X		X					?	
L. aff. *lugubris*				X	X						
L. sp. ("*Alectryonia*")				X							
"*Lucina*" aff. *juvenis*								X			
"*L.*"? n. sp. of Reeside *in* Stearns									X		
"*Mactra*" aff. *alta*						X					
"*M.*" aff. *formosa*				X							
"*M.*" aff. *gracilis*				X							
"*M.*" *pulchella* Herrick and Johnson				T							
"*M.*" spp.		X		X			X				
"*M.*"? spp.			X	X	X						X
Modiolus sp. ("*Modiola*")				X							
Mytiloides labiatus s. l. ("*Inoceramus*")			X		X						
M. cf. *labiatus*										X	
M. cf. *mytiloides*									X	X	
M. *opalensis*									X		
M. "*problematicus*"					X						
M.? aff. *stantoni* ("*Inoceramus* aff. *acutiplicatus*")			X	X							
Nucula subplana					X						
N. sp.					X						
Nuculana sp. ("*Leda*")				X	X						
"*Ostrea*" *anomioides*				X							
"*O.*" *anomioides nanus* Johnson					T						
"*O.*" *beloiti*								X			
"*O.*" *elegantula*				X	?						
"*O.*" spp.		X	X	X	X			X			X
"*Pecten*" sp.			X		X						
Phelopteria gastrodes ("*Pteria*," "*Avicula*")										X	
P. n. sp. of Kauffman and Powell (Note 2)									X		
Pholadomya sp.			X								
Pinna petrina			X		?						
P. sp.				X							X
Platyceramus? aff. *proximus* ("*Inoceramus*")					X						
P.? *sagensis*					X		?				
P.? aff. *sagensis*			X								
P.? *vanuxemi*					X						
Plicatula sp.			X		X						
Protocardia rara ?					X						
Pseudoperna congesta ("*Ostrea*")					X						
Pycnodonte? *bentonensis*										X	
P.? *newberryi* ("*Gryphaea*")									X		
Solen cuneatus ?					X						
Syncyclonema n. sp.				X							
"*Tellina*" sp.				X							
"*T.*"? sp.		X									

continued

TABLE 4—Upper Cretaceous Fossils in Sandia Mountains and Adjoining Areas (cont'd)

(T=type(s); superscripts at heads of columns refer to prefatory remarks in text; numbers in table refer to notes at bottom of table)

continued from page 63

	Sandia Mts. Area: Tijeras[1] Mancos	Sandia Mts. Area: Tijeras[1] Mesaverde	Sandia Mts. Area: Hagan-Tonque[2] Mancos	Sandia Mts. Area: Hagan-Tonque[2] Mesaverde	Cerrillos Madrid[3] Mancos	Cerrillos Madrid[3] Mesaverde	Omera-Galisteo-Lamy[4] Mancos at Omera	Omera-Galisteo-Lamy[4] Graneros	Omera-Galisteo-Lamy[4] Greenhorn	Omera-Galisteo-Lamy[4] Carlile	Omera-Galisteo-Lamy[4] Niobrara
Trigonarca cf. *obliqua*				X	X						X
Volviceramus? *irregularis* Johnson ("*Inoceramus*")					T						
SCAPHOPODA (Tusk-shells)											
Dentalium sp.					X						
GASTROPODA (Snails, conchs, drills, limpets)											
Acmaea cerrillosensis Johnson					T						
A.? n. sp. of Reeside in Stearns									X		
Acteon sp.			X	X							
A.? sp.							X				
"*Admetopsis*? *elevata*" Johnson (probably Buccinid? indet.)					T						
Anchura sp.					X						
A.? sp.				X							
Anisomyon coniformis Johnson ("*Scurria*?")					T						
Aporrhais prolabiata									X		
Buccinopsis? *occidentalis* (Herrick and Johnson) ("*Harpa*?")				T							
Carota dalli ("*Rostellites*")			X								
C. wellsi (Johnson)					T						
Cerithiopsis n. sp. of Coates and Kauffman									X		
Cerithium n. sp. of Reeside in Stearns									X		
Charonia? *kanabense* ("*Tritonium*")					X						
Fasciolaria? sp.				X							
Fusus? sp.		X									
Gyrodes cf. *conradi*				X							
G. depressa											X
G. sp.		X	X	X	X		X				
Liopeplum sp.					X						
Lunatia sp.				X							
Natica sp.					X						
Odontofusus? sp.		X		X							
Pterocerella sp.				X							
Pyrifusus? sp.				X							
Pyropsis sp.		X									
P.? sp.			X	X							
Rostellaria cf. *ambigua* ("*Volutoderma*," "*Rostellites*")					X						
Tessorolax? sp.											X
Turris sp.				X							
Turritella galisteoensis Johnson					T						
T. aff. *whitei*			X								
T. sp.				X	X						
Volutoderma? sp. (may be *Rostellaria*)				X	X		X				X
Volutomorpha novamexicana Herrick and Johnson		X	X	T							
V.? *texana* ("*Rostellaria*?")					X						
V.? sp.		X			X						
CEPHALOPODA (Nautiloids, ammonoids)											
Acanthoceras alvaradoense								X			
A. amphibolum? ("*Plesiacanthoceras*")								X			
Acanthocerid? ammonite, n. sp. of Coates and Kauffman									X		
Allocrioceras annulatum? ("*Helicoceras pariense*" and "*Exiteloceras pariense*")					X						
Baculites aquilaensis ("*B. anceps*")				X	X						
B. aquilaensis separatus					X						
B. asper					X						
B. cf. *codyensis*											X
B. ovatus					X		X				
B. ovatus haresi				X			X				
B. spp.		X		X	X		X				X
B.? sp.									X		
Binneyites carlilensis										X	
Calycoceras naviculare									X		
C. spp.								X			
Calycocerid? ammonite, n. sp. of Coates and Kauffman									X		
Clioscaphites novimexicanus (Reeside) ("*Desmoscaphites*")					T						
Coilopoceras? sp. ("*Sphenodiscus lenticularis*" of Hyatt)		X				?					
Collignoniceras woollgari ("*Prionotropis*")					X						
C. 2 or more spp.			X								
Desmoceras (*Moremanoceras*) *scotti*									X		
D.? n. sp. of Coates and Kauffman									X		
Eutrephoceras alcesense				X	X		X				
E. dekayi ("*Nautilus*")				X	X						
E. sp.							X				
Glyptoxoceras novimexicanum ("*Hamites*")					X						
G. sp.					X						
"*Helicoceras*" n. sp. of Coates and Kauffman									X		
Hoploscaphites nodosus ("*Scaphites*")		X									
Kanabiceras septemseriatum									X		
K. aff. *septemseriatum* ("*Neocardioceras*")								X			
Metoicoceras whitei									X		
"*Pachydiscus*" n. sp. of Stanton in Lee and Knowlton			X		X						
Peroniceras (*Reginaites*) *leei* Reeside							T				
Placenticeras intercalare				X							
P. meeki				X	X		X				
P. placenta? (prob. *P. meeki*)					X						
P. planum		X		X	X		X				X
P. whitfieldi (prob. *P. meeki*)				X							
P. spp.			X	X	X						
P. sp. "very large"							X				
Placenticeras (*Stantonoceras*) *guadalupe* (also as "*guadalupae*" and "*guadeloupae*")					X		X				
P. (*S.*) aff. *guadalupe*				X							X
P. (*S.*) *newberryi*							X				
P. (*S.*) *sancarlosense*		X		X	X		X				
P. (*S.*) *sancarlosense pseudosyrtale*					X						
Placenticeras? *intermedium* Johnson (= *Placenticeras planum*)					T						
P.? *rotundatum* Johnson (= *P.* (*Stantonoceras*) *sancarlosense*)					T						
P.? sp.					X						
Prionocyclus macombi					X						
P. wyomingensis			X		X					X	
P. wyomingensis elegans					X						
P. n. sp. of Johnson					X						
Pseudocalycoceras dentonense									X		
P. cf. *indianense* (= *P.* cf. *dentonense*)									X		
Puebloites corrugatus ("*Helicoceras*")									X		

TABLE 4—Upper Cretaceous Fossils in Sandia Mountains and Adjoining Areas (cont'd)

(T=type(s); superscripts at heads of columns refer to prefatory remarks in text; numbers in table refer to notes at bottom of table)

	Sandia Mts. Area: Tijeras[1] Mancos	Tijeras[1] Mesaverde	Hagan-Tonque[2] Mancos	Hagan-Tonque[2] Mesaverde	Cerrillos Madrid[3] Mancos	Cerrillos Madrid[3] Mesaverde	Omera-Galisteo-Lamy[4] Mancos at Omera	Graneros	Greenhorn	Carlile	Niobrara
Scaphites ferronensis					X						
S. aff. *geinitzi*					X						
S. hippocrepis					X						
S. hippocrepis crassus							X				
S. aff. *hippocrepis*				X	X						
S. leei Reeside					T		X				
S. leei parvus				X							
S. ventricosus											X
S. warreni			X		X					X	
S. whitfieldi					X						
Sciponoceras gracile									X		
Stantonoceras, gen. nov. of Johnson (= subgenus of *Placenticeras*)											
S. pseudocostatum Johnson (= senile form of *Placenticeras (Stantonoceras) guadalupe*)					(T)						
Texanites omeraensis (Reeside) ("*Mortoniceras*")							T				
Tragodesmoceras bassi									X		
Watinoceras n. sp. of Coates and Kauffman									X		
W. sp.								X			
Worthoceras gibbosum									X		
W. vermiculum									X		
W. n. sp. of Coates and Kauffman									X		
W. sp.									X		
W.? sp.					X						
ANNELIDA (Worms) *Hamulus*? sp.					X						
CRUSTACEA *Hoploparia* sp. (lobster)					X						
TRACE FOSSILS *Crossopodia* (meandering trails of worms and/or arthropods)										X	
Ophiomorpha major ("*Halymenites*") (Note 3)			X	X	X	X					
Worm tracks and burrows			X		X						
FISHES (Note 4) *Beryx* sp.					X						
Lamna sp.				X							
L.? sp.		X									
Ptychodus whipplei Marcou								T			
P. sp.								X			
Fish vertebrae				X							
Fish bone, teeth, scales, debris					X						
PLANTS (Note 5) *Abietites dubius* (fir)						X					
"Alga"				X							
Aralia? sp. (ginseng)						X					
Brachyphyllum macrocarpum (conifer)				X							
B. cf. *macrocarpum*						X					
B. sp.				X							
Carpites spiralis ("*Carpolithes*," a fruit or seed)						X					
C. n. sp. of Knowlton				X							
Celastrus n. sp. of Knowlton (bittersweet)						X					
Cinnamomum mississippiensis						X					
Cunninghamites pulchellus (redwood)						X					
Cyperacites sp. (sedge)				X							
Dalbergia n. sp. of Knowlton				X							
Ficus eucalyptifolia (fig)				X		X					
F. leei		?		X							
F. cf. *multinervis* ("*F.* type of *F. lanceolata*" of Knowlton)				X		X					
F. praetrinervis				X							
F. rhamnoides						X					
F. rhamnoides?						X					
F. speciosissima						X					
F. speciosissima?				X		X					
F.? *starkvillensis*				X							
F. tiliaefolia						X					
F. uncata						X					
F. uncata?						X					
F. wardii?				X							
F. n. sp. of Knowlton						X					
F. spp.		X		X							
Gleichenia rhombifolia (fern)				X							
Juglans similis (walnut)				X							
Laurus? sp. (laurel)		X									
Magnolia sp.						X					
Myrica torreyi (bayberry)		?		X							
Nelumbo intermedia? (water lily)				X		X					
Palmocarpon compositum ("*Carpolithes*," fruit or seed)						X					
P. mexicanum						X					
Platanus cordata (buttonball, sycamore, plane tree; "*Quercus platania*?" of Lesquereux)						X					
P. guillelmae						X					
Populus balsamoides (poplar, cottonwood)						X					
Protophyllocladus sp. (yew)				X							
Quercus sp. (oak)				X							
Q.? sp.						X					
Sabal? *ungeri* (palm)						X					
S.? sp.						X					
Sequoia reichenbachi (redwood)						X					
Trapa? *microphylla* (water chestnut)				X							
Viburnum sp. (honeysuckle)				X							
Petrified log 10 inches in diameter			X								
Petrified wood				X							

NOTES

1. Specimens were collected at Lamy by N. H. Darton in 1914; the species was described by J. W. Wells in 1933. Corals are rare throughout the Western Interior Cretaceous. Coates and Kauffman (1973', p. 953) describe the occurrence at Lamy as "a lenticular, paucispecific thicket composed predominantly of the gregarious ahermatypic coral.... This is the first coral framework known from the entire Western Interior Cretaceous seaway."

2. To be described in a forthcoming Geol. Soc. America Special Paper by Kauffman and Powell.

3. Formerly interpreted as an alga or seaweed; now regarded as burrows with wartlike ornamentation made by a decapod crustacean similar to the shrimp, *Callianassa.*

4. A current classification of the shark teeth and fish scales, as suggested by Jiri Zidek (letter, Jan. 21, 1975), follows.

(continued on page 66)

(continued from page 65)

Class Chondrichthyes (sharks and rays)
Subclass Elasmobranchii
Cohort Selachii Euselachii)
Order Hybodontiformes
Family Ptychodontidae (shell-crushing teeth)
Ptychodus whipplei Marcou
Superorder Galeomorphii
Order Lamniformes
Family Lamnidae (flesh-cutting teeth)
Lamna sp.
Class Actinopterygii (ray-finned fishes)
Subclass Teleostei
Superorder Acanthopterygii (spiny teleosts)
Order Beryciformes
Family Berycidae
Beryx sp. (scales)

Ptychodus whipplei was described as a new species from 3 miles north of Galisteo by Marcou (1858, p. 33, pl. 1, figs. 4, 4a), who wrote

> I dedicate this beautiful species of cretaceous [sic] fish to my friend Capt. A. W. Whipple, the able and learned chief of our Exploration in the Rocky Mountains.

He added that Prof. Agassiz saw the holotype "and recognized it at once as a new species of his genus *Ptychodus."* Earlier, Romer (1945, p. 577) had assigned it to the order Batoidea (skates and rays) but later (Romer, 1966, p. 349) transferred it to the order Selachii, suborder Hybodontoidea, and (ibid., p. 43) characterized it as a mollusk-eating shark. *Lamna,* on the other hand, is one of the mackerel sharks, with long, slender, flattened teeth, suitable for cutting flesh. Scales of *Beryx* were figured by Johnson (1902, pl. 1, fig. 12a).

S. Leo J. Hickey was unable to check the present status of all these plant names, but wrote (letter, May 23, 1974):

> Most of Knowlton's assignments of fossil leaf specimens to modern living genera are incorrect. Thus the assignments to *Celastrus, Cinnamomum, Dalbergia, Ficus* (especially), *Laurus, Magnolia, Myrica, Quercus, Populus, Sequoia,* and *Trapa, are* all very likely incorrect. Recent work in Russia has shown that the genus *Platanus* did, indeed, live during the late Cretaceous and early Tertiary, thus this is probably a good assignment. In addition, *Nelumbo* is probably valid and *Juglans* is probably correct only at the familial level.

However, it was thought that a complete listing of the names would be worthwhile as a matter of record. Howard J. Dittmer, of U.N.M., assisted us with names of modern representatives, given in parentheses.

(continued from page 62)

subangular to well rounded and consist of chert, quartz, quartzite, sandstone, and limestone, and minor clay galls. Fragments of gneiss, coarse angular feldspar, and rare crystalline rocks indicate that Precambrian terranes had been exposed in Galisteo time.

Thickness—The Galisteo thickness ranges considerably, and Stearns (1943, p. 309) found it to be a northeast-trending wedge which thickens from about 1,000 ft along the eastern margin of the Rio Grande trough to about 4,000 ft along a line from Hagan to Galisteo. He also believed that the section might be still thicker to the south and southeast, but this is not known as there are no exposures in that direction. Source areas for the Hagan-Galisteo area could have been to the northwest, north, or northeast, but there is little likelihood of a source to the south, such as the Sandia Mountains.

Stearns' calculated thickness of 2,100 ft along Pinovetito Arroyo agrees well with the hand-levelled section of 2,372 ft measured by Harrison at the same place. The outcrops at Placitas are incomplete, the upper part being overlain unconformably by the Santa Fe Formation. Only 600 to 800 ft of the lower part of the Galisteo crops out south of the overlying Santa Fe.

Fossils and Age—Few fossils other than petrified wood have been found in the Galisteo Formation. Silicified logs near Cerrillos attracted much attention from early travelers and explorers. What seems to be the earliest definite reference to fossils of any age in New Mexico is by Josiah Gregg, most famous of the Santa Fe traders, who made several trips to New Mexico during the 1830's. In his diary, *Commerce of the Prairies*, published in 1844, he described beautiful specimens of silicified wood near Cerrillos on land that later (about 1900) became the Sweet ranch. He wrote that one log "lies between Santa Fe and the Placer, broken into blocks since its petrifaction, which shows every knot, crack and splinter almost as in its ligneous state. It is said that there are some of these arboreous petrifactions in the vicinity of Galisteo, still standing erect."

In the summer of 1846, Wislizenus (1848) saw "large masses of petrified wood" near Cerrillos. On September 29, 1846, Abert (1848) visited Cerrillos and noted "fragments of immense petrified trees."

The first identification, apparently, was by Knowlton; Johnson (1902, p. 217; 1903, U.N.M. Bull., p. 145) reported *?Quercus* sp. from 2 miles east of Cerrillos, noting that

> In the red sandstones above the coal measures were found numerous fossil tree trunks, many of which were from one to two feet in diameter . . . Thin sections from one of these fossil trees were examined by Mr. Knowlton [who wrote] "The wood is a dicotyledon, and while it has been somewhat distorted by fossilization, it appears to be a species of *Quercus* . . ."

Lee and Knowlton (1917, p. 185) reported that the Galisteo Formation

> contains great numbers of petrified logs, which are beautifully preserved in external form, but the cellular structure of the wood is not well retained and no specific identifications have been made. The best-known locality at which these logs occur is a few miles east of Cerrillos in the so-called petrified forest, where there are many logs 25 to 75 feet or more in length. Logs have been found in this formation in many other places in a much better state of preservation. Fossil leaves have also been found in a few places, but their preservation is poor and few have been specifically identified.

Near Rogers, 2 miles southwest of Cerrillos, Lee and Knowlton (1917, p. 212) found *Sabal? ungeri* and *Dryopteris?* sp. in the lowest 10 ft of the Galisteo Formation.

Stearns (1943, p. 312) notes that collections from 7 localities, "most of them in the upper few hundred feet of the Galisteo," were studied by W. C. Darrah, who reported that

> The bulk of the specimens belong to the conifers.—the pine *type, Pityoxylon* . . . There are several genera of flowering plants—an oak *[Quercus], a Fagus?* (beech), a woody legume related to *Acacia,* a diffuse-porous wood allied to poplar, and two indeterminate, ring-porous hardwoods.

At the Sweet Ranch Petrified Forest, 1 tree was about 6 ft in diameter and had a length estimated to be 135 ft; many years ago I. C. Sweet (oral communication to Northrop) stated that assays showed traces of both gold and silver. Woods (1947) reported a tree 4 ft in diameter and 185 ft long. Popular articles describing and illustrating this "forest" include Northrop and Popejoy (1931), Harrington (1939), and Woods (1947).

Vertebrate fossils have been collected at several localities. Theodore White made a small collection in 1939 from less than 200 ft below the top of the Galisteo Formation near the Sweet ranch that yielded *Teleodus* sp. and *Uintacyon*. The former is a titanothere (extinct perissodactyl) and the latter a primitive carnivore (Stearns, 1943, p. 310). Stearns found abundant disarticulated bones in the Arroyo Pinovetito (sec. 4, T. 13 N., R. 6 E.), in the zone of transition between the Galisteo Formation and the Espinaso Volcanics. According to White (Stearns, 1943, p. 311), both a large and a small titanothere are represented in this collection; the age was given as "Duchesnean [sic] . . . uppermost Eocene . . . [or] lowermost Oligocene."

In 1955, Robinson (1957) found an upper molar of *Coryphodon* (an archaic hoofed mammal known as an amblypod or pantodont) about 700 ft above the base of the Galisteo Formation about 2 miles northeast of Cerrillos. Robinson notes

> "*Coryphodon* is an excellent lower Eocene index fossil and indicates Wasatchian age for the lower part of the Galisteo formation . . . Both White's and Stearns' collections indicated Duchesnian age (latest Eocene) for the upper Galisteo rocks . . . The presence of *Coryphodon* in the lower Galisteo beds shows that these deposits began to accumulate in the early Eocene."

The considerable likeness of the Galisteo to the San Jose Formation (formerly Wasatch) of the San Juan basin suggests that the 2 were either once continuous or deposited at the same time on opposite sides of the Laramide Nacimiento uplift.

ESPINASO VOLCANICS

Definition—The formation was named by Stearns (1943, p. 304), as suggested by Bryan and Upson in an undated unpublished manuscript, as the Espinaso Volcanics exposed in Espinaso Ridge (fig. 37). Here the Espinaso is in near conformity with the underlying Galisteo and is overlain by white to pinkish beds that may be either the Abiquiu Formation or a lower part of the Santa Fe Formation.

Distribution—In the Sandia map area the Espinaso crops out in a north-northwestward-trending belt about 4 miles long in the north-central part of T. 13 N., R. 6 E. The relatively resistant Espinaso, compared with the adjacent, less resistant Galisteo on the west and Abiquiu on the east, holds up the prominent Espinaso Ridge. Dips are regular ranging between about 15 and 20 degrees, and the attitude of the lower part of the overlying Santa Fe beds is essentially the same. No other outcrops of the Espinaso occur in the *area*.

Lithology—At Espinaso Ridge the formation is latite and quartz latite porphyry breccia and conglomerate with considerable water-laid tuff in the lower 200 to 250 ft. For the most part the formation is well bedded resembling a fanglomerate. Some tuff-breccia beds, however, strongly suggest pyroclastic air-fall deposition. The general color of the formation is bluish gray, but brownish, purplish, and reddish grays are common. The most abundant fragments of the breccia and conglomerate range from pebbles to small boulders, but locally blocks as large as 10 ft in diameter may be found. These large particle sizes suggest mudflows or torrential deposition, but the character of the bedding and rounding of many fragments suggest a predominantly alluvial origin for the coarse material. Stearns (1953a, p. 422) describes 2 trachyte flows (10 to 50 ft thick) high in the formation at the northern end of the ridge and *a* hornblende quartz latite flow in the eastern part of the outcrop belt near Huerfano Butte (sec. 23, T. 13 N., R. 6 E.). The following is a description of a section measured by Stearns:

Bed No.	Description	Thickness ft
	Espinaso (Total thickness)	1,450
4	Breccia and conglomerate interbedded, gray, fragments up to 6 inches in diameter, water-laid Abiquiu above	150
3	Breccia and conglomerate interbedded, gray, indurated, minor amounts of water-laid tuff, fragments up to 2 ft in maximum diameter, some blocks up to 6 and 8 ft across occur in the upper half, ridge-forming	1,050
2	Tuff, blue-gray, a few beds of clay, 1 to 2 ft thick near the base, pebbly beds in upper half, water-laid	200
1	Clay, green, tuffaceous. Lenses of red clay and limonite-stained sandstone in the lower 25 ft are transitional with the underlying Galisteo Formation. Abundant fossil bone occurs in a bed 1 to 2 ft thick midway of the unit (Stearns, 1943, p. 310 and fig. 7), Galisteo below	50

Age—The Espinaso is relatively younger than the Eocene Galisteo and older than the Miocene Abiquiu Formation. The porphyry intrusions at Cerrillos deform and probably intrude the Espinaso. These geological relationships suggest at least an Oligocene age and probably a late Eocene age as maintained by Stearns (1953a, p.423).

SANTA FE FORMATION

Definition—The name "Santa Fe marls" was given by Hayden (1869, p. 60, 69) to beds exposed north of Santa Fe. The term was intended for the thick sequence in the Tesuque and Espanola Valleys. Johnson (1903, p. 313) credited Hayden for the name "Santa Fe Marl Group" and applied it to the late Tertiary gravel beds in the Cerrillos Hills area, including the gravel on the Ortiz surface of planation (p. 472). Johnson (1903, p. 313-332) reviewed at length the early literature on the Santa Fe Marl Group in the Cerrillos area and concluded that its age ranged from Loup Fork (Miocene, Pliocene, and Pleistocene?) to the present. In time the term was changed to Santa Fe Formation (Darton, 1922, p. 187). Bryan (1938a, p. 205) observed that

> The main body of sedimentary deposits of the Rio Grande depression, from the north end of the San Luis Valley to and beyond El Paso, is considered to be of the same general age and to belong to the Santa Fe Formation.

The term has been extended widely to deposits along the Rio Grande valley and also out of the valley to similar deposits, especially in southern New Mexico and to some deposits in the Puerco, Estancia, and Jornada del Muerto valleys. Kelley (1952, p. 102) suggested the term, group, again for the Santa Fe including all the trough-filling beds including the pedimental and alluvial fan beds. Later Spiegel and Baldwin (1963, p. 38-39) more formally proposed usage of the term, Santa Fe Group, to include Quaternary as well as Tertiary beds and volcanic flows in the Rio Grande trough and adjacent areas. They also proposed expanding the unit, in its group status, to include the Abiquiu Formation of Smith (1938, p. 301) and Stearns (1953c, p. 477, pl. 1). Galusha (1966, p. 4-7) defined and delineated the Zia Sand Formation in Sandoval County as separate from beds previously referred to as the Santa Fe Lower gray member (Bryan and McCann, 1937) and retained the term, Santa Fe Formation, for the overlying beds. Hoge (1970, fig. 6) included the Zia in the Santa Fe Group and used the term Tesuque Formation (Baldwin, 1956, p. 115-116) for the overlying beds exclusive of the Quaternary insets and terraces related to the present river. He recommended the substitution of Zia for Abiquiu as extended into the Santo Domingo basin area by Stearns (1953c, pl. 1).

Galusha and Blick (1971, p. 30) restricted the Spiegel and Baldwin term, Santa Fe Group, to the occurrences in the Espanola basin and described it as consisting of 2 formations, the thick and extensive Tesuque below and the lesser Chamita above. They further restricted and redefined the Tesuque Formation to include 5 members in the Espanola Valley and 2 in the Abiquiu area. The base of the Tesuque and the Santa Fe Group, as restricted, is variously on such trough units as Abiquiu and Picuris, and possibly Espinaso (p. 37-38). Galusha and Blick (p. 39) point out the inadvisability of extending the type Santa Fe outside the area and specifically recommend that a different formation name be applied to beds in the Santo Domingo Valley. On the other hand, they apply "Tesuque Formation" to the Bryan and McCann "Middle Red" unit in the Jemez Creek area while at the same time recommending that none of the other Jemez Creek and Rio Puerco units should be correlated with formations at the type locality of their Santa Fe Group (p. 40). In short, they propose that the term, Santa Fe Group, be restricted to beds of the type area or to "those that can be shown to be traceable from the type area to contiguous areas" (p. 41). Although there are cogent reasons why this proposal might be followed, in all practicality the term Santa Fe has been so widely used in the less restricted sense that the change is hardly feasible or even desirable. In our minds there is little doubt about the equivalency of some of the thick, strongly tilted Santa Fe beds northwest of the Sandia uplift with the Tesuque beds of the Espanola basin.

Regarding recent suggestions that Santa Fe Group be used in either expanded or restricted senses, it is difficult to follow either, and there are undesirable aspects to both recommendations. The ranks of formation, including member, and group are interchangeable to suit the particular needs in different areas, as in the use of "Mesaverde" to refer to either a formation or group. Therefore, in this work the long-established Santa Fe Formation is used for rocks in the Albuquerque and Santo Domingo basin areas. The term Tesuque is not used as it includes too nearly the same strata as the Santa Fe, and because it tends to displace a widely used and well-established name for what is probably the earliest recognized New Mexican formation.

Distribution—Most of the Santa Fe outcrops lie northwest of the Sandia Mountains where they are downthrown into the Rio Grande trough. In the extreme northeast corner of the map area (map 1), east of Espinaso Ridge, Santa Fe beds lie conformably on the Abiquiu (Zia?) beds of Stearns (1953c, pl. 1). No Santa Fe proper is exposed west of the main escarpment of the Sandia Mountains except along the sides of Tijeras Arroyo (secs. 26, 35, T. 10 N., R. 4 E.). However, considerable Santa Fe may lie only a few tens of feet beneath the terrace or pediment gravel veneers along the entire front of the mountains. The best exposures of Santa Fe near the mountains are in the Rio Grande trough west and north of Placitas between NM-44 and San Francisco Arroyo (figs. 41, 42). In the southeastern part of the San Felipe Pueblo Grant (sec. 4, T. 13 N., R. 5 E.) the formation is tilted as much as 45 degrees, revealing a considerable section. Excellent exposures of the coarse basal part of the formation lie across steep plicated beds of formations from the Morrison to the Galisteo. These outcrops as well as other nearby basal beds are also tilted as much as 10 to 45 degrees.

Lithology—The Santa Fe is variable in composition and texture depending upon the source of materials; in general it has had two contrasting sources. The most abundant source has been local—the adjacent uplifts along either side of the Rio Grande trough. The basal Santa Fe fanglomerate in the dissected mesas west and northwest of Placitas consists predominantly of large boulders of reddish Abo and Meseta Blanca sandstone. The source must have been the nearby mountains before the Abo was eroded from the crest. The other source during most of the existence of the trough has been axial to the basins, regardless of whether these were joined by a through-flowing river or not. Axial gravels were long ago recognized by Bryan (1938a, p. 205-206) and other workers. The local source materials differ greatly in coarseness from place to place, depending upon proximity, abruptness of uplift, and the composition of the rocks being eroded. The axial materials are a mixture of rocks derived locally and from far up the drainage system.

The influence of local sources on composition is frequently seen in the Santa Fe (fig. 42). If the source is in Cretaceous terranes the grays and olive drabs of the shales show up in the Santa Fe. If the source is largely red beds of the Permian or the Triassic, the Santa Fe is

FIGURE 41—SANTA FE FANGLOMERATE UNCONFORMABLY OVERLYING SOFT GALISTEO BEDS. WEST SIDE SEC. 31, T. 13 N., R. 5 E., 2 MILES WEST OF PLACITAS. FANGLOMERATE CONSISTS LARGELY OF ABO FRAGMENTS AND DIPS ABOUT 40°. GALISTEO DIPS 55° TO 60°.

FIGURE 42—Fanglomerate of Santa Fe Formation along Tonque Arroyo. Here it is dropped on west side of San Francisco fault against Entrada and Chinle. Fragments are diverse and include quartzite, gneiss, sandstone, and Tertiary porphyritic rocks.

reddish; if from the Madera limestone, the Santa Fe is calcareous with prominent limestone and chert gravels. Bryan and his co-workers (Stearns, 1953c, p. 472) have emphasized the coarse resistant gravels of quartzite, gneiss, and foreign volcanic rocks in the recognition of an axial throughgoing drainage. Although these are diagnostic their absence does not rule out the existence of an ancestral Rio Grande. This is evident from the present and Holocene river bed in which the material is largely sand and mud, much of which obviously has been transported from great distances.

Bryan used the term, axial gravels, and he mapped these as a narrow strip roughly parallel to the present river between the latitudes of Santa Fe and Albuquerque; he believed that the gravels came from the San Juan Mountains country via an ancestral Rio Chama (Bryan, 1938a, p. 206). His term appears to have been restricted mostly to the well-rounded cobbly quartzite gravels obviously transported from afar by high-regimen stream flow. The evidence for the source and the axial continuity is tenuous; however, there is an axial suite of gravels along the Rio Grande depression. This suite comprises more than the cobbly beds and includes sand, silt, and mud of a distant source; the term, axial facies, would be better. The distribution of the axial facies varied in response to shifts in the sag axis, influx volume from tributaries, and meandering of the river. Tijeras Arroyo has gravel foreign to the Sandias as far as 6 miles from the present Rio Grande junction, showing that at the time the foreign gravels were deposited there was an axial river within only 2 or 3 miles of the border of the trough at about the position of Sandia Laboratories.

Mixing of source types is inevitable, especially with the longer tributaries that extend into a variety of formations. Tijeras Creek is an example; when it reaches the axial area of the Rio Grande, it carries debris from every formation in the area except the Galisteo and Espinaso, having mixed it with far-off axial materials such as from the Jemez Mountains. San Pedro Creek does likewise but also transports debris from the Galisteo, Espinaso, and the laccolithic porphyries.

Dominance of local source is evident in the angular bouldery material near the base of the formation in the mesa west of Placitas where the material consists predominantly of Abo sandstone, but several hundred feet above the base Madera limestone dominates. The bulk of the Santa Fe is a mix primarily of sand, mud, and gravel from many sources. It was derived or deposited under warm and humid to savannah-type climatic conditions; thus, the subaerially weathered debris developed a characteristic pinkish terra cotta or light-gray tone. Reddish-brown shades are found mostly in muds, and their colors may in many instances reflect those of the source beds. No significant thickness of Santa Fe is exposed in the area, but exposures in nearby parts of the trough and penetrations in wells suggest thicknesses of several thousand feet.

Apparently no significant fossils have been found within the map area that have been determined to be of Oligocene, Miocene, or Pliocene age. Lambert (1968, table 7, p. 237) found a few vertebrates west of the map area on the south side of Tijeras Arroyo (sec. 15, T. 9 N., R. 3 E.). He assigned these to his upper buff formation of the Santa Fe Group, and D. E. Savage identified them as: cf. *Camelops* (extinct camel) and *Equus* cf. *plesippus* or *E. bautistensis* (zebrine horse), with a range in age from late Pliocene to early Pleistocene.

INTRUSIVE ROCKS

Tertiary intrusive rocks in the Sandia Mountains are few and widely scattered. Complex intrusions of laccoliths, stocks, and sills form a north-south-trending belt just east of the Sandia map area; a few of these extend into the edge of the map area near Monte Largo; and there are a few small intrusions elsewhere that seem to be petrologically related to porphyritic bodies. In Ferryboat Hill northeast of Monte Largo a monzonitic sill up to 60 ft thick has been intruded just above the Sandia Formation. Little contact metamorphism or mineralization is associated with the intrusion. A small sill-like exposure of monzonite also occurs near the head of Coyote Arroyo in sec. 25, T. 13 N., R. 6 E. The intrusion is mostly covered by Tuerto Gravel but at the west end it is in contact with Mancos Shale. Another small monzonitic dike crops out along San Pedro Creek 1.5 miles downstream from NM-14. Considerable alteration and metamorphic effects are observable in the surrounding area in the high beds of the Madera Formation, as though a larger intrusion may lie just below the surface. The metamorphic minerals include some epidote and, locally, garnet. One other intrusion of monzonitic porphyry is far from the porphyry belt in the Sandia uplift in NW 1/4 sec. 35, T. 11 N., R. 5 E. The intrusion is in the Yeso Formation east of the road up Cañoncito Canyon to the Cole Springs picnic area. It appears to be either a small plug or a short, thick sill with little associated mineralization or metamorphism.

In the Hagan basin there are several long dikes, several sills, and 2 thick concordant tongues. Some of these appear to be related petrogenetically to the porphyry belt rocks, but several of the dikes are basaltic and probably related to the younger Rio Grande trough eruptions. The largest dike lies north of Hagan, and is nearly 3 miles long and 20 ft wide. It strikes east-northeastward and cuts Mancos to Galisteo beds. Similar but much shorter dikes occur about 1 mile to the north and about 1 mile south of Hagan. Still farther southeast another basaltic dike, somewhat porphyritic, is intruded along a north-northeast fracture that appears to be an extension of the Perlas del Polvo fault.

The largest intrusion in the Hagan basin is a sill up to 60 ft thick near the base of the Mancos Shale (fig. 51, p. 76). It is monzonitic and extends along strike with interruptions of outcrop for 2.5 miles. Little metamorphism or mineralization is associated with the intrusion.

Several short tonguelike sills occur in the Mancos, some in positions which could have been fed from faults or other fissures. These intrusions are monzonitic and petrogenetically related to the porphyry belt. The largest tongue exposed is about 100 ft thick and 600 ft wide with apparent elongations downdip to the east-northeast.

A single basalt dike occurs northwest of Placitas in Mesaverde beds. It is up to 30 ft wide and dips 55 to 60 degrees southeastward. Three north-striking hornblende latite or andesite dikes occur east of the Sandias. Two of these are in the east limb of the Tijeras anticline (fig. 49, p. 76), and the third is in Tejano Canyon (secs. 10, 15, T. 11 N., R. 5 E.). The dike of figure 49 contains numerous hornblende phenocrysts up to about 5 mm in length.

A number of lamprophyric dikes occur in the Sandia Granite (fig. 50, p. 76). Shomaker (1965, p. 23) assigns them a Tertiary age based upon 1) the existence of similar dikes cutting much younger sediments (see above) and 2) the lack of any diaschistic field relationships with the aplites. The few lamprophyres in the granite are generally longer than the aplites and almost all of northward trend. Shomaker described the dikes as principally spessartite and vogesite varieties. They are up to 20 ft wide and extend as a swarm some 12 miles long and 2 miles wide. They are dark-green, fine- to medium-grained dikes, usually with distinct chilled margins, and they differ in many respects from the aplite dikes. Shomaker (p. 38) also found granite and aplite inclusions in the lamprophyres, which cut across the aplite dikes.

Woodward (1970) described the petrography of the dikes and presented chemical analyses of the typical hornblende spessartite and a light-colored hornblende syenite differentiate found locally in dikelets and segregations.

QUATERNARY

PEDIMENTS AND PEDIMENT GRAVEL

A pediment is an erosional surface at the base of mountains. It is covered by thin to moderately thick blankets of gravel; where thin, the gravels are in a sense the cutting tools and products of the cutting. Pediments form through prolonged erosion under stable conditions of elevation and erosional base level, to which the pediment surface grades. A widespread old pediment occurs north and east of the Sandia Mountains.

The term pediment was first used by McGee (1897, p. 92) although others (Gilbert, 1877, p. 130-131) had recognized these "planes of corrasion" (Johnson, 1903) in many places. Large and small remnants of these features are widespread at many altitudes in New Mexico; of especial interest are those around the Sandia and Ortiz Mountains, in the plains to the east, and in the Rio Grande valley. One of the highest and oldest of these is the Ortiz surface or pediment (Bryan, 1938a, p. 215) which surrounds the Ortiz Mountains and extends into the Sandia Mountains area. Johnson (1903, p. 174-175) was possibly the first to note this surface and referred to it as "the erosion plains sloping away from the Ortiz Mountains" without formally naming the pediments the Ortiz surface. About the same time Ogilvie (1905, p. 34) described the pediment surrounding the conical Ortiz porphyry-cored mountains as the "conoplain of the Ortiz." However, Bryan appears to have been the first to name the pediment and to extend it by mapping and correlation widely away from the Ortiz and Sandia area.

The Ortiz surface was eroded following deposition and subsidence of the Santa Fe Formation into the Rio Grande trough. During development of the Ortiz surface the Rio Grande or a stream at the basin axis was at a level of 400 to 500 ft higher than at present, and long erosion of the surrounding uplands formed the Ortiz surface across the Santa Fe and older rocks. Since that time uplift of the region caused canyons and valleys, including the Rio Grande and its tributaries, to dissect and largely remove the old surface. The surface has been named for preserved areas around Ortiz Mountains about midway between Albuquerque and Santa Fe (Bryan, 1938a).

Considerable areas of the Ortiz surface and its overlying Tuerto Gravel (Stearns, 1953c, p. 476-477) are shown on map 1 east of Hagan (fig. 43) to NM-14 and extending southward into the San Pedro Valley around San Antonito. Numerous remnants occur west of the lower part of San Pedro Creek between Gonzales and Arroyo Seco Creeks and extending well into Tecolote Canyon near La Madera. Some fingers of this surface extend up the eastern slope of the mountains and are preserved in a few places along low ridges, such as south of Cienega picnic area in sec. 23, T. 11 N., R. 5 E. and near Cienega and Bill Springs a short distance to the north. These remnants range in altitude from about 7,200 ft (southwest of Sandia Park) to nearly 8,000 ft (near Bill Springs). The elevation of the Tuerto Gravel near San Antonito is 6,850 ft. The higher remnants appear to represent canyon extensions of the Tuerto Gravel and the underlying pediment, as seen in San

FIGURE 43—Tuerto Gravel cap of Ortiz pediment surface NW sec. 34, T. 13 N., R. 6 E., 1 mile east of Hagan. Here gravel rests across upturned edges of reddish Galisteo mudstone and white sandstone.

Pedro Valley and farther north. Elevations of the eroded edge of the gravel and pediment are 6,100 to 6,200 ft. Remnants of this surface are also preserved north of Montezuma Mountain, 2 to 2.5 miles east-northeast of Placitas at about 6,200 ft. The high level on the gravel west and north of Placitas, mapped by Hoge (1970, pl. 19, Qpt), may also be equivalent to the Ortiz. The surface levels are at elevations from 6,000 to 6,300 ft, with the higher levels near the Sandia, Monte Largo, and Cerrillos Mountains; a broad swale probably existed in the Hagan Valley where the present dissecting drainage concentrates.

There is a pediment surface with gravel east of Monte Largo that extends into Estancia Valley. The head of this surface next to Monte Largo is at 6,900 to 7,200 ft. Across the uplift along the San Pedro Valley, side elevations are about 6,600 ft, showing that the two surfaces were graded to different bases. Two remnants of the Estancia surface are preserved on the Abo at the southwest end of Monte Largo at elevations of 6,850-6,900 ft (map 1). In later Quaternary time the San Pedro drainage extended itself along Frost Creek in the weak Triassic rocks, and it is now eroding the higher Estancia surface a few miles north of Corners.

The other large pediment in the Sandia area lies along the western base of the mountains. It formed later at elevations 200 to 300 ft lower than the Ortiz surface and has been correlated with Bryan's (1938a) La Bajada surface. The piedmont surface consists of two parts, one south of Campus Wash (an old Tijeras arroyo) referred to as the Airport surface and a younger, lower, more dissected surface extending northward along the mountain front to near Bernalillo. The older surface at the Albuquerque International Airport and south of Tijeras Arroyo is a pediment remnant. Along the north side of Tijeras Arroyo, just west of Four Hills Road, the gravel-veneered surface can be seen slightly truncating Santa Fe beds below. North of Campus Arroyo (Kelley, 1969, p. 27), Embudo, Bear, Pino, and other streams have completely dissected the Airport surface and nearly regraded the surface to the Rio Grande flood plain; the high bluffs seen west of the airport are absent here. This is especially true near the mouths of Baca and Pino Arroyos. While this late cutting was going on alluvial fans continued to build onto the old surface in places along the base of the mountains. However, the larger canyons from the mountains have adjusted rapidly to the base formed in the Rio Grande flood plain.

The Sandia pediment has been traced around the northern end of the uplift to intermediate surfaces in the Santo Domingo basin and Hagan embayment (Hoge, 1970, pl. 19), and into what has generally been thought to be the wide La Bajada surface along 1-40 to Santa Fe.

Extensions of the Sandia pediment can be traced well into Tijeras Canyon from the levels around the Western Skies Motor Hotel. Shoulders on both sides of the canyon are evident almost to the big turn in the canyon. The gradient of Tijeras Canyon through the mountains and the shoulders in the lower part of the canyon is 100 ft per mile. The Sandia surface gravels appear to be equivalent to those up the canyon at Seven Springs, Tijeras, San Antonito, and on the flats around Cañoncito. However, there are a number of still higher gravel remnants along the Sandia slopes between Cañoncito and Tijeras. Two small patches occur at 6,500 to 6,600 ft on the low hills just north of Tijeras, about 200 ft above the lower gravel along the canyon bottom. Several ridge-capping strings of gravel occur north and south of Lorenzo Canyon and south of Cañoncito. Near Cañoncito these are about 200 ft above the gullied gravel along San Antonito Arroyo. The old high gravel at Cañoncito extends up the ridge to about 7,100 ft from its lower eroded end at 6,930 ft—a rise of about 225 ft per mile. The ridge gravel remnant north of Lorenzo Canyon is about 6,000 ft long and it rises from 6,850 ft to 7,450 ft at a rate of 100 ft per mile. These are probably alluvial remnants of higher valleys, leading to an older higher pediment that may have been equivalent to the Ortiz pediment. The lower end of the Cañoncito remnant is about 50 ft lower than any of the present divides between the Tijeras and San Pedro drainage systems proving that gravels in the Tijeras drainage area did not connect with the alluvial remnants. No remnants of higher gravels are along the Sandia front. A few obscure local flats on the low part of the Sandia escarpment between Tijeras Canyon and the Juan Tabo area might, however, be remnants of cut rock surfaces at the heads of a former higher surface now completely eroded on the valley side. The flats at Juan Tabo picnic area are only about 200 ft above the heads of the pediments near La Cueva Canyon. A higher pediment of this sort might account for the anomalous cutting of Juan Tabo Canyon across Rincon Ridge. North and west of Placitas thick gravel deposits, with mountainward surface altitudes from 6,000 to 6,300 ft, appear to be above the Sandia (Bajada) surface to the west (Hoge, 1970, p1. 19, Qop) as described above.

RIVER TERRACES AND GRAVEL

River terraces have some affinities with pediments in that they are commonly surfaces cut on bedrock at the base of steep slopes along canyon sides. Like pediments they are usually capped with gravel. The two are closely related around the northwest side of the Sandia uplift.

Terrace gravels are present along the sides of Tijeras Canyon but these have already been mentioned in connection with the extension of the Sandia piedmont level into and back of the mountains.

River terraces have long been known along the Rio Grande inner valley and they have been studied by Bryan (1938a) and his associates who gave names to these levels. Several terrace surfaces are preserved in the northwest corner of the map area (J. E. Anderson, 1960, p. 79-82). Anderson described the Sile terrace 25 ft above the river which may have been' ut only a few hundred years ago. He also identified remnants of the Peña Blanca terrace, about 150 ft above the river; and a Rio Grande terrace about 95 ft above river. Long northwest-sloping pediment surfaces, extending from well up the slopes along the Sandias dissect and intersperse at their lower ends with terrace gravels.

ALLUVIAL FANS

Sand and gravel at the base of a mountain without lateral confinement by ridges or arroyo banks are alluvial fans; if small, alluvial cones; and if coalesced with adjoining fans, alluvial piedmont plains. Around the East Heights or East Mesa near the bases of the Sandias and the Four Hills are a number of fans built from the major canyons debouching onto the alluvial piedmont. The largest of these are Embudo, Embudito, and Baca. Smaller ones have formed along the base of the Four Hills, along Rincon Ridge, north and south of Monte Largo, around the south and east sides of South Mountain, and south of the San Pedro Mountains. The deposits have an arched fan shape. They are thickest and highest along a medial axis and thin in all directions from a mid-point on the axis. The alluvial fans along the Sandia front consist predominantly of granitic debris with minor quantities of limestone and sandstone. Torrential flow and rare mudflows have brought local strings of boulders and some blocks weighing up to 20 tons far out onto the fans (fig. 44).

At the mouth of La Cueva Canyon enormous granite boulders have been debouched across a fan-form rock surface eroded into disintegrated weathered granite. The boulders of the thin alluvial fan are not the products of spheroidal weathering in place because some boulders are of red granite or limestone derived from high on the mountain. Spheroidally weathered granite blocks as much as 5 ft in diameter have been found 1 to 2 miles away from the mouth of La Cueva Canyon.

The wide area of alluvium in T. 9 to 12 N., R. 6 to 8 E. is a piedmont of coalesced fans and valley alluvium that is spreading into the interior Estancia Valley. All fans are Holocene in age.

Photo by James Bollich, Louis Goldsmith, and Richard Huzarski, 1948

FIGURE 45—Steps along Las Huertas Creek near Las Huertas picnic area. Steps are formed by a series of calcareous tufa dams precipitated from the lime-rich water. Some pools are 5 to 6 ft deep behind thin dam walls.

VALLEY ALLUVIUM

Alluvial fans and valley alluvium are the youngest of deposits. Valley alluvium includes the deposits of sand and gravel along the bottoms of valleys, arroyos, and gullies and even the narrow stringers on top of alluvial fans. Only the large strips of such deposits are shown on the geological map. Notable for length and width are those in the arroyos and canyons of Las Huertas (fig. 45), Tijeras, Una de Gato, San Pedro (fig. 46), Gonzales, Juan Tomas, Coyote, and San Jose. Some of these accumulations of alluvium have been dissected during the last 100 years or so by gullies as much as 30 ft deep, and the bottoms of the gullies have floors of younger valley alluvium inset within the wider slightly older valley deposit. The most extensive deposits of valley alluvium are in the Estancia Valley, shown on the eastern part of the geological map, where stream flow from the many arroyos and sheet runoff spread sand and gravel in wide expanses.

Valley alluvium consists of central deposits transported down the canyon or valley, and marginal material contributed from adjacent hillsides and small side canyons.

Zandia Clay or Placita Marl—There has been some confusion in the literature involving the Zandia (San-

FIGURE 44—Large granite boulders and blocks on Albuquerque's East Mesa. Along Embudito Arroyo at Eubank Blvd. (shown on fig. 4), and about 1.5 miles west of base of mountains near Glenwood Hills.

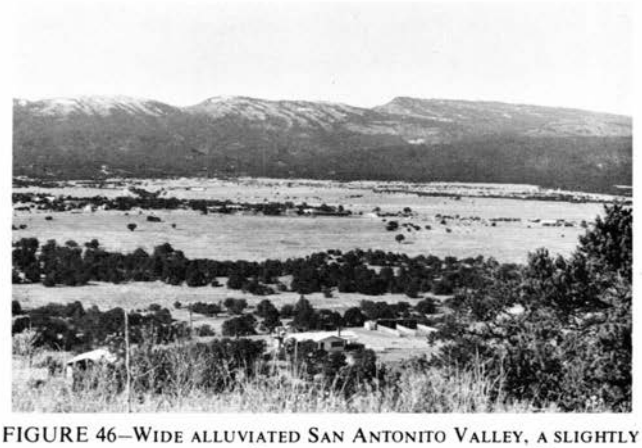


FIGURE 46—Wide alluviated San Antonito Valley, a slightly modified level of the Ortiz surface to the north. Surface is eroded largely on soft Chinle Shale along axis of San Pedro syncline. Photo taken from Sandia Knolls toward the northwest, showing distant dip slope of Sandia uplift.

known of these is Sandia Cave located in a massive limestone ledge at an elevation of about 6,980 ft and during the field-season of 1874," submitted to the Chief of Engineers, War Department, Cope (1875, p. 996-997) described his visit to Placitas and wrote:

> In the intervals between the hills there is a deposit of indurated clay of 40 feet in thickness of post-Pliocene age. I obtained teeth and other bones of *Elephas primigenius* subspecies *columbi*, from this bed, and found bones of the same species in place in the banks of the arroyo. Shells of *Planorbis, Physa, etc., indicated* the lacustrine character of the deposit, which may be known as the Zandia clay.

In his text, Cope does not mention the Placita Marl, but in an accompanying sketch (Cope, 1875, fig. 3, p. 997), reproduced here as our fig. 60, the "Placita marls" are shown, designated *p* and noted in the legend.

Two years later, Cope (1877, p. 25) wrote as follows:

> In the intervals between the hills, there is **a deposit of indurated clay of 40 feet in thickness, of Postpliocene age. I** obtained teeth and other bones of *Elephas primigenius* **subspecies** *columbi* from this bed, and found bones of **Elephants in** place in the banks of the arroyo. Shells of *Planorbis, Physa, etc.,* indicate the lacustrine character of the deposit, which I have called the Placita marl.

A footnote cites his 1875 paper. Apparently he changed his mind and decided to use Placita Marl rather than Zandia Clay.

In her lexicon, Wilmarth (1938, p. 1676) gave the age of the Placita Marl as "Tertiary? (probably Pliocene and Miocene)," and the age of the Zandia (= Sandia) Clay as Quaternary (p. 1907). In the past several writers have mentioned the Placita Marl, generally regarding it as equivalent to the Santa Fe Formation and of Miocene-Pliocene age. It seems clear that Cope meant to substitute Placita Marl for his Zandia Clay and that he, both in 1875 and again in 1877, dated it as Quaternary or post-Pliocene.

In his paper on Sandia Cave, Hibben (1941, p. 6, 7) noted that the lake in which the Placita Marl accumulated

> could never have been very large. As a result of the cutting of a large arroyo, extremely deep exposures have been made, permitting thorough study of these sediments. In the bottom of this wash or arroyo, residents of Placitas found two ungrooved Folsom-shaped points similar to those from Sandia Cave. They presumably washed out of the Placitas deposits. Fire areas, usually accompanied by sporadic chips of flint, are fairly frequent at several levels in the Placitas sediments. Most of these burned areas occur at a depth of some 9 feet below the present surface on what appears to be an old soil level or stratum darkened by vegetable material. Robert Ariss, of the Department of Geology of the University of New Mexico, has recovered a variety of Pleistocene remains from these deposits including horse (probably *Equus excelsus)* and mastodon.

CAVES, ARTIFACTS, AND FOSSILS

Several caves of Quaternary age occur in the Madera limestone along the east side of the Sandia Mountains. Embudo Cave is high (8,940 ft) in the mountains a short distance south of the Sandia Peak ski area, along a forest trail to the crest in projected sec. 4, T. 11 N., R. 5 E. (map 2). In recent years the cave has been used by the University of New Mexico Physics Department for underground measurements of cosmic radiation. The best known caves lie along the east wall of Las Huertas Canyon in sec. 22, T. 12 N., R. 5 E. (map 2). The best

dia) Clay and Placita Marl. In his "Report on the geology of that part of northwestern New Mexico examined about 80 ft above the bottom of the canyon floor. According to Hibben (1941, p. 3-5) all the caves show some degree of past human habitation, but only 2, Davis and Guano, in addition to Sandia, are of any considerable size. Hibben (p. 5) also mentions a large cave "just below the old Ellis ranch near the head of Las Huertas Canyon." Typically all the caves, when first entered for exploration, were blocked by fallen rock, washed-in debris, and calcareous tufa. The present entrances of several of the caves may have been eroded back 10 ft or so since they were originally occupied.

Sandia Cave, excavated by solution in limestone of the Madera Formation, is located high on the steep eastern wall of Las Huertas Canyon, 3.5 miles south of Placitas (fig. 47). The cave is tunnel-like, more than 450 ft long, and 7 to 10 ft in diameter. The slope is 72 ft in 453 ft "or approximately 9 degrees, somewhat less steep than the dip of the limestone beds so that the cave begins in one bed and ends in a higher one" (Bryan, 1941, p. 48). Boy Scouts from Albuquerque had explored it in 1927-28. A ground sloth claw found by Kenneth Davis aroused the interest of Frank C. Hibben and the U.N.M. Department of Anthropology began excavation in 1936; excavations continued through 1940 (Hibben, 1941). Three age levels were delineated. The oldest or Sandia level, with its Sandia points, thought by Bryan (1941, p. 58) to be somewhat older than 25,000 years B.P., contains

Bison antiquus (bison)
Camelops sp. (camel)
Elephas sp. (mammoth) [now *Mammuthus (Parelephas)* sp.]
Equus excelsus (horse)
Mastodon americanus (mastodon)

The overlying Folsom layer, containing Folsom points, was thought by Bryan to be somewhat younger than 25,000 years B.P., but possibly only 8,000 to 10,000 years B.P. (discussion by Northrop, 1959, p. 5-6; and Hibben, 1961), contains

Bison sp., near but smaller than *taylori*
Camelops sp. (camel)
Canis cf. *lupus* (wolf)
Elephas sp. (mammoth) [now *Mammuthus (Parelephas)* sp.]
Equus near occidentalis (horse)
Nothrotherium sp. (ground sloth)

The uppermost layer, possibly a few thousand to less than a thousand years old, contains

Cervus sp. (elk)
Erethizon sp. (porcupine)
Neotoma sp. (wood rat)
Nothrotherium sp. (ground sloth)
Odocoileus sp. (mule deer)
Ovis canadensis (mountain sheep)
Tadarida mexicana and other spp. (bat)
Ursus sp. (bear)

The Hibben (1941) paper, with an appendix by Bryan, illustrates points, scrapers, and other artifacts.

Charcoal specimens from fire hearths of the Sandia level were dated by Libby in 1948 (Hibben, 1955) at 17,000+ and 20,000+ years B.P. In 1952, Hibben sent

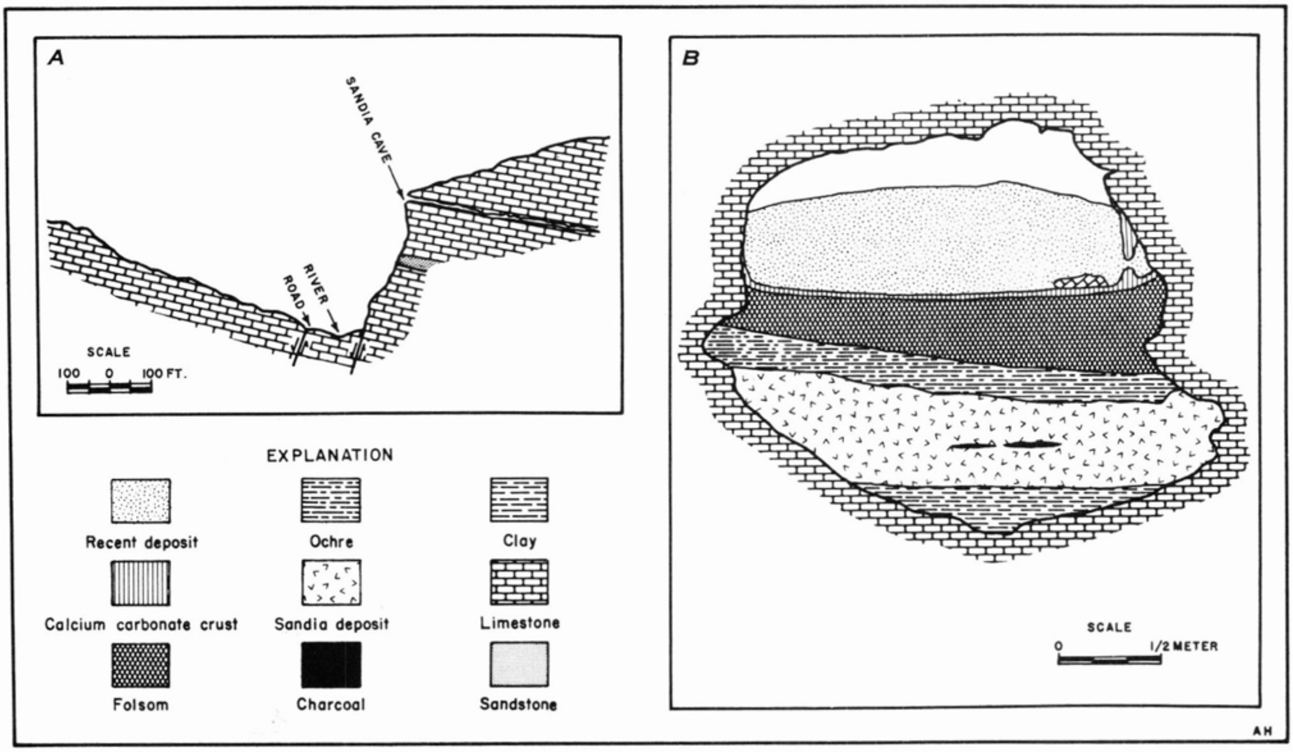


FIGURE 47—CROSS SECTIONS OF SANDIA CAVE (HIBBEN, 1961; ADAPTED FROM HIBBEN, 1941, FIGS. 5, 7). A, LONGITUDINAL EAST-WEST CROSS SECTION SHOWING GENERAL LOCATION OF THE CAVE IN LAS HUERTAS CANYON; B, TRANSVERSE CROSS SECTION OF THE CAVE, 15 M FROM THE ENTRANCE, SHOWING STRATIGRAPHY OF CAVE DEPOSITS.

two specimens of ivory (one from a mammoth tusk and one from a mastodon tusk) to H. R. Crane (Hibben, 1955; Crane, 1955) for carbon-14 dating. In 1954, a third fragment was submitted. Crane concluded that one of the Sandia tusks was at least 20,000 years old and that the others were about 25,000 years old, but noted that

> The great age of the Sandia tusk naturally raises the question whether it is contemporary with the evidence of habitation among which it was found, or whether, instead, we have discovered that among the men who inhabited the cave there were archeologists who collected and brought home tusks belonging to earlier times.

On the other hand Hibben (1955) observed that meat had been "cut from the bones, as is indicated by occasional scars on the bone surfaces. Subsequently the bones were cracked and broken lengthwise to extract the marrow."

Several workers have disputed the 25,000-year dating of Sandia points. For example, Mason (1962, p. 229) noted that

> . . . the dating of Sandia points is uncertain. Radiocarbon dates alleged to pertain to the Sandia cultural complex have been disputed, and there is little but confusion to be gained by appealing to them. All that can definitely be stated is that Sandia is earlier than Folsom by an unknown number of years, at least at the type site.

In commenting on Mason's paper, Agogino (1962, p. 247) stated that

> Shortly before his death the late E. H: Sellards informed me that Sandia points were reported from apparently the same cultural horizon as Clovis points at the Clovis type site, eastern New Mexico. The discovery had been made by a student associate and since he had not uncovered the material himself and had not seen the material "in situ" he hesitated to announce the discovery publicly.

Witthoft (1962, p. 270) commented:

> It is hard to believe that Sandia can be other than a local specialized variant or derivative of the Clovis type, comparable to a few very poorly known eccentric forms from other areas.

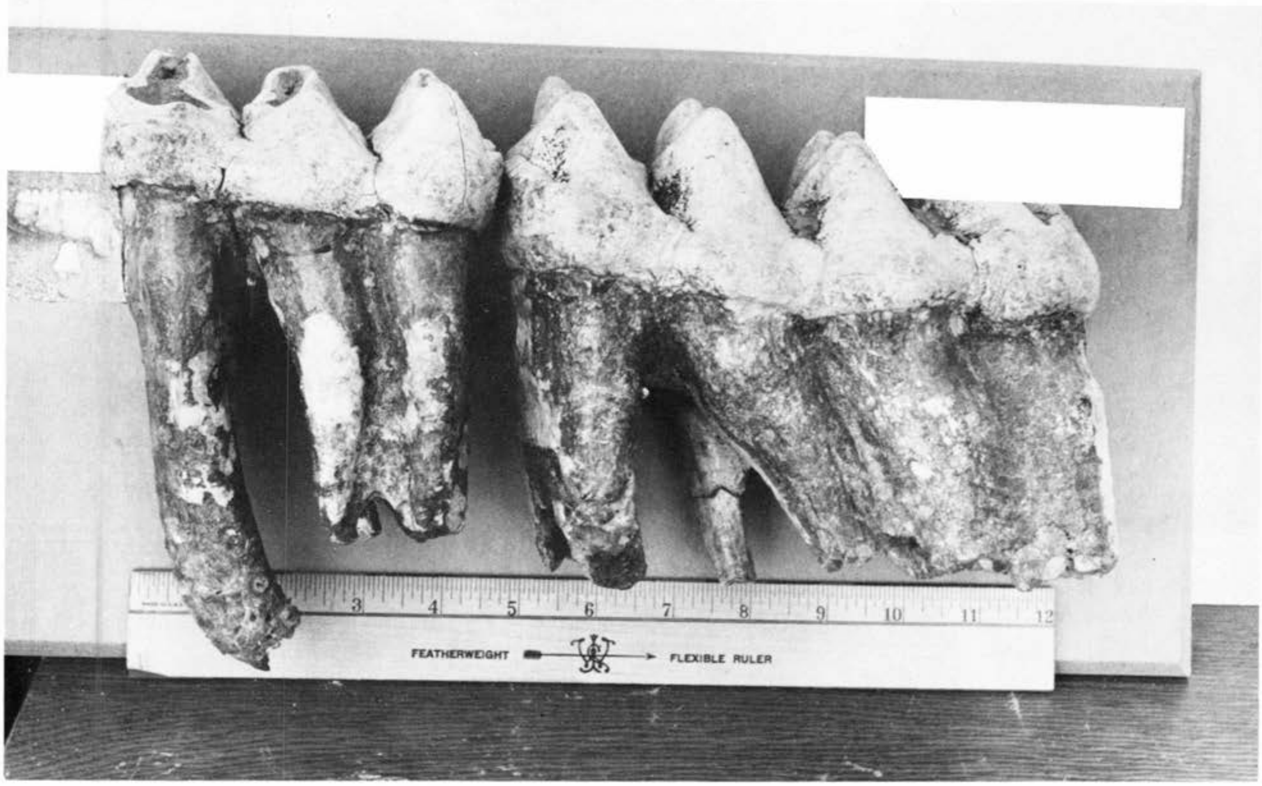
A few years later Willey (1966, p. 41) wrote:

> According to G. A. Agogino, one of the recent investigators. there is strong suggestive evidence that Sandia points, while antedating the Folsom points, may originally have lain in the same geologic stratum with them and not in the layer below the yellow ochre. Redeposition to the layer in which they were reported found was probably the result of rodent activity which carried the artifacts through the cracks and fissures into the sub-ochre layer. This reinterpretation would mean that the Sandia culture is approximately the same age as the Llano or Clovis complex.

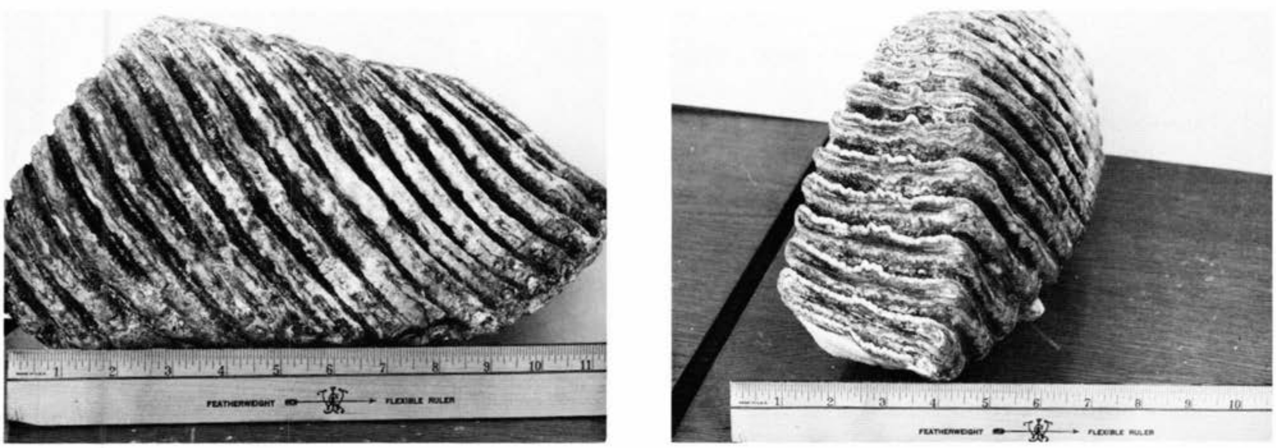
More recently, Agogino (personal communication, October 1, 1974) writes:

> Based on several years research regarding Sandia Cave, I feel that the age of the Sandia level is roughly that of Clovis, that is roughly 11,500 years old. This is based on geologic evidence plus typological characteristics of the artifacts themselves. The earlier age of more than 25,000 was based on the belief that the Pleistocene period ended roughly 25,000 years ago rather than the currently accepted age of 10,000 years ago.

In addition to the vertebrate remains found in Sandia Cave a most spectacular fossil discovery was made in 1956 by J. Nicoll Durrie, Jr., then aged 9, while hunting arrowheads near Tree Spring (on the wooded east slope of the Sandia Mountains about 3 miles northwest of Sandia Park). He found several remarkably well-preserved teeth and part of the jaw of *Mastodon americanus* (fig. 48A). This occurrence at an elevation of 8,470 ft may constitute an altitude record in New Mexico for the species. Jerry Harbour, a University of New Mexico student, excavated the left lower jaw from



A—SIDE VIEW OF TWO MOLARS (LOWER LEFT, 2D AND 3D MOLARS) OF *Mastodon americanus,* FROM NEAR TREE SPRINGS. NOTE ABRASION OF CUSPS AT UPPER LEFT. COMBINED WEIGHT IS A LITTLE LESS THAN 8 POUNDS.



B—TWO VIEWS OF A SINGLE MOLAR OF THE MAMMOTH, *Mammuthus (Parelephas) columbi,* FROM ALBUQUERQUE GRAVEL PRODUCTS COMPANY NORTH EDITH PIT, ALBUQUERQUE. AT ~~LEFT~~ R IS VIEW OF GRINDING SURFACE; AT ~~RIGHT~~ L IS SIDE VIEW. WEIGHT IS 12.5 POUNDS.

FIGURE 48—MASTODON AND MAMMOTH TEETH ON EXHIBIT AT UNIVERSITY OF NEW MEXICO GEOLOGY MUSEUM (SCALE, INCHES).

only a few inches below the surface. The teeth and jaw are not mineralized and appear to be only slightly more decomposed than some bones of modern animals found in the same area. This individual may be only a few thousand years old.

The second and third left lower molars are on exhibit in the U.N.M. Geology Museum. Mastodons were about the height of the modern Indian elephant but much stockier. They were forest-dwelling animals whose teeth were adapted for a browsing diet, eating chiefly leaves. Mammoths were larger than mastodons and were plains-dwelling animals whose teeth were adapted for grazing herbs and grasses.

Actually, proboscidean remains, including tusks and molars, are not uncommon in nearby areas, such as gravel pits within the city limits of Albuquerque, in the Estancia Valley, and in the Isleta Caves south of the city.

Lambert (1968) found *Bison, Equus,* turtle, and a poorly preserved mammoth or mastodon tusk in the Edith Formation (Late Pleistocene) at the Albuquerque Gravel Products quarry (sec. 3, T. 10 N., R. 3 E.). A mammoth molar (fig. 48B) found at the same quarry was donated to the Geology Museum by John H. Doyle. Mammoth remains have been found at the Chavez quarry (sec. 26, T. 10 N., R. 2 E.). Extinct forms of bear,

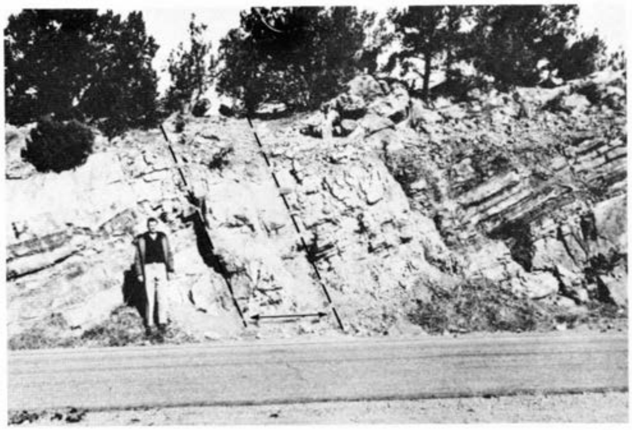


Photo by Gene Polk, Marvin Matheny, and John Lookingbill

FIGURE 49—HORNBLENDE ANDESITE DIKE IN MESETA BLANCA SANDSTONE. CUT ALONG ZAMORA RD. (OLD US-66) A SHORT DISTANCE SOUTH OF GUTIERREZ FAULT.

two genera of camels, and horse, as well as proboscideans, were found in the Isleta Caves (Harris and Findley, 1964). Camel and ground sloth are known from Manzano Cave, at the south end of the Manzano Mountains (Hibben, 1941, p. 35-36).

LANDSLIDES AND ROCK FALLS

Landslides are masses of rock that have moved along the ground under the influence of gravity. Rock falls involve free fall of rock from cliffs or steep slopes. Many landslides have occurred on the eastern slope of the mountains but none occurs on the western side because of more resistant rocks and stronger disposition of internal structures such as joints and bedding. Doubtless numerous rock falls have occurred on the western side, but they are generally so small and so scattered as to go undetected.

Landslides are common on the eastern slope where bedding nearly parallels the surface allowing individual beds, a group of beds, or weathered mantle to slide downhill on bedding planes. Eleven landslides have been mapped (map 1) and many more, either unseen or too small to show, are present. Two of the largest occur 1 to 2 miles north of Sandia Park. The largest of these, nearly 1 square mile in area, is near the head of Tecolote Canyon. The other is a long narrow mass on the east dip slope of the ridge east of Doc Long picnic area. Both of these slides are chaotic masses that have been broken and jumbled in sliding probably no more than a few hundred feet down steep eastern slopes. Another large slide occurred high on the Madera dip slope 2.5 miles south of Placitas. A thick limestone slid on a shale zone and was broken into chaotic blocks; the downward movement lowered the surface of the upper area of the slide by 30 to 40 ft. A small slide 1 mile southeast of Palomas Peak, near the head of Tecolote Canyon, has moved down the canyon about half a mile. A similar canyon slide exists near the head of Madera Canyon at the bottom of the Sandia Peak ski run. The slide broke loose from the Upper Slalom slope and

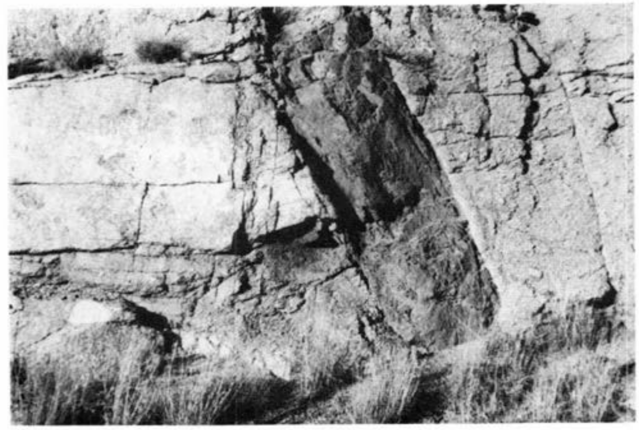


FIGURE 50—LAMPROPHYRE DIKE CUTTING SANDIA GRANITE. ROADCUT ALONG I-40, SEC. 25, T. 10 N., R. 4 E.

moved across NM-44 and into the steep part of the canyon below. There are excellent exposures of crumpled and broken beds in the roadcut just north of the entrance to the ski run. The steep part of the slalom is the pull-away face back of the slide. The lodge and the low beginners' slope is on a flattened surface of the slide. The slide has probably stabilized, but it is not out of the realm of possibility that with heavy or prolonged precipitation the slide could move again. Other hillside slides occur at Cole Springs, northwest of the Hobbies store, and at several points between.

Most of the high bare faces on Sandia escarpment are kept bare by severe weathering. Large joint blocks and slabs continually work loose, and debris of this sort occurs in many places at the bases of the cliffs. An unusual rock fall was observed in 1936 by Mr. E. W. Cottam of the Forest Service (Workman and Kelley, 1940). Lightning struck a prominent point north of the upper tower along the Sandia Peak tramway and knocked off a large joint block of granite 40 ft wide and 150 ft long, a volume of some 2,000 cubic yards. The fresh face of the slide is still visible from the tram car (Kelley, 1969, p. 73).

FIGURE 51—MONZONITE SILL IN MANCOS SHALE. HOGBACK IS ALONG SAN PEDRO CREEK AT WESTERN EDGE OF SEC. 4, T. 12 N., R. 6 E. TWO SMALL FAULTS HAVE DISLOCATED SILL. THE MONZONITE IS DENSE AND FINE TO MEDIUM GRAINED.

Structure

REGIONAL SETTING

The Sandia area consists of several structural elements; we will discuss the regional setting, then the Sandia area and its elements. Selection of structural elements of an area is difficult and somewhat subjective. However, it is desirable to describe large elements within which the details of structure may be organized for a better analysis of the mechanisms and origins.

Within a region there are usually several magnitudes of deformation; in central New Mexico the north-south structural belt of the Rockies is of the greatest magnitude. The Rockies belt can then be divided into units of second order; in the report area these are the Rio Grande trough and its two flanking belts of tectonically related uplifts. In this classification the Sandia area lies astride two second-order tectonic elements, the Rio Grande trough and the eastern flanking belt of uplifts. The eastern flanking belt includes several third-order elements such as the Sandia, Manzanita, and Manzano uplifts, and others; the Rio Grande trough consists of two basins of third order, the Albuquerque and the Santo Domingo. Thus, the structural description of this area involves a number of third-order elements and, where necessary for understanding, still lower order elements. In an area such as the Sandias any particular fault, fold, or set of joints, may be of fifth or sixth order of magnitude in the overall tectonic development.

This type of analysis may not be simple, as the several elements of structure are commonly of distinctly different ages and origins. For example, the ages of the Precambrian structures are greatly different from those of the third-order structural elements. Futhermore, the crustal depth at which the Precambrian deformation took place represents possibly three or four times the observed depth of deformation of the Sandia uplift or the Tijeras basin. Less obvious are the probable differences in age and modes of deformation between the Sandia uplift and the Hagan basin, on the one hand, and the Monte Largo-Tijeras belt or the South Mountain-San Pedro porphyry structures on the other. In view of such differences it is necessary to add to magnitude of deformation the sequence and mode of deformation in delineation of the structural elements. For older elements assignments of magnitude or designation of second or third orders are uncertain. As an example the northeast-trending structural belt including the Tijeras fault, Tijeras graben, and Monte Largo horst is probably older than the Sandia uplift. Whether it was a second-, third-, or fourth-order feature at the time of its origin is uncertain. The descriptions that follow are of geometric elements; following the descriptions the mechanics and origin of the whole structure are considered.

SANDIA UPLIFT

Johnson (1903, p. 456-457) was apparently the first to use the term Sandia uplift. In describing the Cerrillos area, he wrote:

> The movement which produced this uniform eastward dip was probably the same which resulted in the great monoclinal uplift of the Sandia Mountains . . . [and of the Manzano and more southern ranges] For this great movement I propose the name of "Sandia uplift."

EXTENT

The Sandia uplift is an eastward-tilted fault block 22 miles long and up to 12 miles wide (map 3); it is bounded on the west by faults separating the uplift from the Albuquerque basin. The boundary on the east is indefinite because in most places the tilted slope merges with the western limbs of basins or synclines that lie on the east. To the northeast the uplift merges into the west and south flanks of the Hagan basin; on the east the uplift merges into the San Pedro syncline and the Tijeras basin. On the southeast the uplift is bounded by the Tijeras fault, which sharply separates the Sandia uplift from the structurally lower Manzanita uplift (fig. 52). The Tijeras fault is the southeast boundary of a wedge that comes to a point at the southern end of the Four Hills, where the uplift dies out. This termination of the uplift is several miles south of Tijeras Canyon, which topographically separates the Sandia and Manzanita Mountains. However, uplifts and physiographic mountains are not always the same and the emphasis here is on the uplift. Where the structural boundary is absent or poorly defined, as along most of the eastern side of the uplift the boundary must be chosen arbitrarily, for the flank of an uplift is also the flank of an adjoining syncline or basin. The Tijeras fault is a good boundary to near the area where it crosses NM-14 and begins to diagonally cross the Tijeras basin with diminishing throw. Northward from there the boundary is arbitrarily chosen paralleling NM-14 on the west for about 8 miles to where the road turns east across San Pedro Creek. It is then drawn northwestward along the Madera-Abo contact to the Seco fault which drops a southwestern reentrant of the Hagan basin into the Sandia uplift. North of the Seco fault the boundary is followed to Tejon Canyon and thence along the uplifting Ridge and Frisco Springs faults to a termination with the San Francisco fault. The northwestern boundary is then chosen successively southwestward along the San Francisco, Suela, and Placitas faults to the big west side Rincon fault.

WEST SIDE FAULTS

Uplift of the Sandia block occurred primarily on faults near the western base of the mountains. In nearly all such tilted blocks the main fault is either presumed or found to be very near the base (fig. 53). In many tilted fault blocks there is a set of parallel faults which elevate the uplift by step faulting. Step faulting is difficult to detect unless there are stratified rocks that show dislocation of beds. Whether one or several faults are present their traces are commonly not exposed owing to covering alluvial deposits. The presence of one or more faults near the base of the Sandias is well indicated in one or two places by great stratigraphic displacement between the top and bottom of the uplift (map 4).

The actual exposure of a fault at the base is seen in

FIGURE 52—Aerial photomosaic of Sandia Mountains and surrounding area.

FIGURE 53—ERODED FAULT SCARP ALONG CENTRAL PART OF SANDIA UPLIFT.

only three places. One of these is at the mouth of Tijeras Canyon along the east side of Four Hills Road 0.4 mile south of the Western Skies Motor Hotel. The exposed fault surface dips westward about 55 degrees, with gravel of the Santa Fe Formation downthrown against the Sandia Granite. A second exposure is in the form of a Holocene fan scarp (fig. 57) at the base of Rincon Ridge. This exposure can be seen at the edge of the Precambrian outcrop and is traceable for about 1 mile. The other exposure of this fault occurs across NM-44 near the northern end of the mountains (sec. 1, T. 12 N., R. 4 E.). Several closely spaced faults are traceable but the best exposure is in a roadcut where Santa Fe gravel is downfaulted against Mancos Shale (fig. 58).

About 1.3 miles north of 1-40 (sec. 14, T. 10 N., R. 4 E.) is a small inselberg of Sandia Granite and Madera limestone in alluvium. The apparent vertical displacement of the limestone from equivalent beds capping the mountain 3 miles east, is nearly 3,000 ft. The trace of the Sandia fault is presumed to lie buried beneath the alluvium between the outlier inselberg and the main outcrop of the mountain granite (map 4). As illustrated by Kelley (Kelley and Read, 1961, p. 18), the limestone may be projected (without faulting) as the west limb of an anticline. However, the general evidence strongly favors a fault just east of the inselberg as shown on the geologic map (map I).

The Sandia fault appears to terminate near the entrance to Juan Tabo Canyon (fig. 54) in sec. 2, T. 11 N., R. 4 E. The termination is at a diagonal cross-ramp fault which jogs the uplift westward to the Rincon fault (fig. 54). In the reentrant there is another inselberg, in this instance, Chinle and Morrison beds. The two formations are considerably disturbed but appear to dip mostly toward the Sandia Granite and strike northward into the Rincon metamorphics. A fault separates the Chinle (west) from the Morrison (east). Vertical separation along the bounding faults must be at least 10,000 ft, and the structural implications are considerable (fig. 66). The outcrop poses puzzling structural problems not the least of which is the disparity in the age of the outcropping rocks just west of the fault at the two inselbergs described above.The third exposure is in the roadcut on NM-44 where the Rincon fault is again exposed with lowermost Santa Fe beds downthrown against Mancos Shale (fig. 58). Although not an actual fault surface exposure, the several relatively undissected triangular fault-scarp facets along the base of the uplift north and south of the mouth of La Cueva Canyon are physiographic evidence of youthful, actively uplifting fault blocks so common in the Basin and Range Province of western Nevada and eastern California.

Along the main crest of the uplift the top of the Precambrian is 9,000 to 10,300 ft above sea level (not a large difference), but along the basin margin the difference in projected downthrow between Morrison and Madera beds could amount to 5,000 to 6,000 ft. Therefore, the basin block appears relatively much more deformed internally than does the uplift bordering the fault.

In addition to the main Sandia and Rincon faults which lie very near the base of the mountains, it appears possible that parallel buried faults may lie west beneath alluvium and east in granite. It is to be noted that two faults are labeled Sandia on map 1, one near the base of the range and another buried 1 to 1.5 miles to the west in the stretch along the Pino Canyon-Bear Canyon reentrant. Perhaps the entire belt of roughly parallel faults, both in the granite and in the alluvium should be referred to as the Sandia fault zone. Because of the homogeneity of the granite, faults therein are not readily evident. Crushing and shearing along the faults have made the rocks especially susceptible to weathering and erosion. These faults, therefore, should show up physiographically as short aligned canyons, spurs, springs, or saddles. A number of such probable faults are shown on the geologic map, especially in Bernalillo County. Five are shown in T. 10 N. that could have been part of the mechanics of uplifting of the range. Another set of such faults occurs south and west of Sandia Peak in the Elena Gallegos Grant. Ellis (1922, p. 30, pl. 1) believed that a great fault zone followed the bases of the high cliffs in the granite for almost the full length of the uplift, and he pointed to a single fault scarp 1,000 to 1,500 ft high between Pino Canyon and Sandia Crest. There are a number of prominent shields and faces, orientations of which are controlled by either faults or closely spaced joints forming weak sheeted

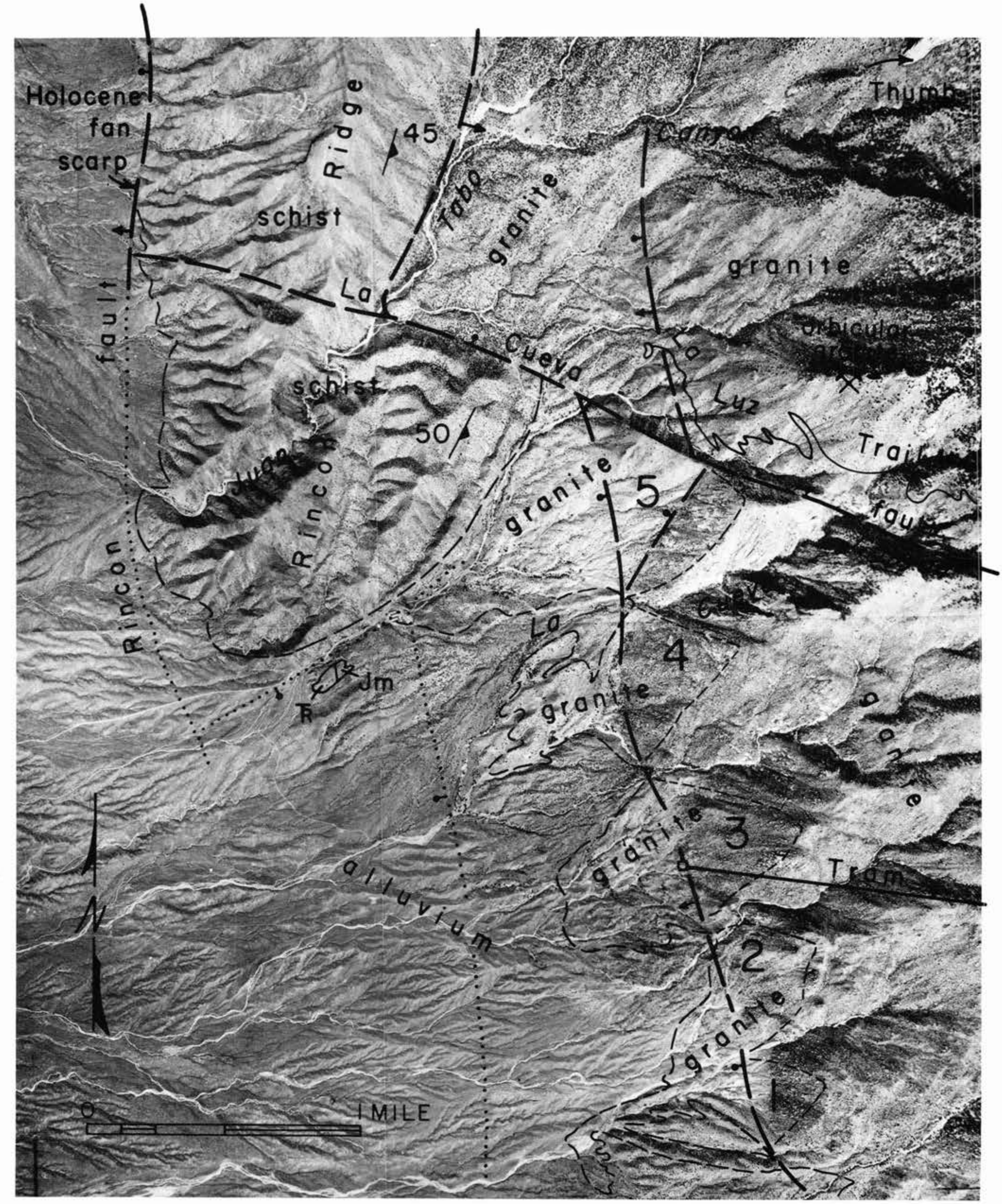


FIGURE 54—Vertical air photo of Juan Tabo area showing triangular fault facets and principal faults. Five little-dissected fault scarp facets are numbered south (1) to north (5) in sequence of increasing height. Facets 4 and 5 are best preserved.

FIGURE 55—TRIANGULAR FAULT FACETS AT MOUTH OF LA CUEVA CANYON. GRANITE *Shield* IN BACKGROUND.

FIGURE 56—FAULTED SANDIA GRANITE IN CANYON SIDE NEAR BOTTOM OF LA LUZ TRAIL. THIS FAULT FORMS THE BASE OF THE PROMINENT TRIANGULAR FAULT-FACETED SPURS NORTH AND SOUTH OF LA CUEVA CANYON.

zones, that do not follow a line or even a single zone paralleling the crest of the range. Many of the faults and sheeted zones in the granite are Precambrian but some of them may have had renewed displacement during the uplift of the mountains.

The San Andres Mountains of south-central New Mexico, a long uplift tilted similarly to the Sandias,

FIGURE 57—HOLOCENE FAULT SCARP ALONG RINCON FAULT. SHADOWED LINE ALONG THE BASE OF RIDGE ACROSS ALLUVIAL FANS IS SCARP AS MUCH AS 10 TO 15 FT HIGH CAUSED BY SUDDEN MOVEMENT PROBABLY WITHIN LAST 100 YEARS.

FIGURE 58—RINCON FAULT IN ROADCUT ON NM-44. SANTA FE FANGLOMERATE DROPPED AGAINST MANCOS SHALE.

have much more stratified limestone preserved above the Precambrian basement along the escarpment and base. These beds are displaced by both longitudinal and transverse faults that are clearly a part of the Late Tertiary uplifting of the tilted fault block. By analogy many of similarly positioned faults in the Precambrian of the Sandias probably played a part in the Late Tertiary uplifting even though evidence is not direct, owing to erosion of the once-present younger sedimentary beds.

EAST SIDE FAULTS

Faults along the east side of the uplift are different in arrangement and nature from those on the west side. There is very little extension or connection of faults of one side to the other and instead, a minor group of small cross faults along the crest of the uplift appears different from those on either side. The east side faults appear to be more numerous than elsewhere in the uplift and this is puzzling because the greater displacements have occurred on the west side. However, the smaller number of faults on the west side may be more apparent than real, as suggested previously, because of cover and difficulties of recognition.

The east side faults form a complicated and varied pattern. Overall, the system is dominated by faults of northward to north-northwestward trend which are arranged in a right echelon. The echelon is most apparent in the southern part where Abo red beds are dropped in zigzag outcrops by 4 of the 5 principal faults of the echelon. These 4 faults are Flatirons, Cañoncito, Wolf Spring, and San Antonito. The first 3 are about halfway up the dip slope and are positioned about where the dips of 10 to 15 degrees of the high part increase to dips of 15 to 30 degrees or steeper. At the southern end of the echelon set the Flatirons fault impinges on the big Tijeras fault zone and offsets several of the splays of the Tijeras fault. Some of the most severe and complex local deformation of the uplift occurs near this junction. Beds become steeply dipping to vertical and commonly overturned; they have also been severely squeezed and crushed, with some thin stratigraphic units having been locally faulted out of the normal sequence. The Flatirons, Cañoncito, Wolf Spring, and San Antonito faults probably dip westward and are downthrown on the east, with left offsets of the Abo-Madera contacts of as much as one mile. There is a possibility also of minor components of left slip, and the mechanics of deformation has a sense of counterclockwise motion.

The Barro fault contrasts with the other members of the echelon in being upthrown on the east, and in this respect it correlates with the big Ellis fault and lesser related faults northward along the eastern side. The Barro and Ellis faults bring up small tilted fault blocks in piggy back fashion and with the same motion as that for the entire Sandia tilted block. Throw on the Barro fault is as much as 1,800 ft, and that of the Ellis fault about 1,000 ft (fig. 59). The Barro fault curves broadly from a northward trend in its southern part (parallel to the Sandia uplift) to a northeastward trend and possible connection with the Seco fault (part of a transverse set of faults descending into the Hagan basin).

The Ellis fault is part of an irregular right-echelon set of about seven faults that have broken and jostled slices of the northern half of the back slope of the Sandias. In this set most of the throws are up on the east but a few are upthrown on the west. Other principal faults of the echelon are from southwest to northeast: Capulin Springs, Lagunita, Palo Duroso, Apache, and Perdiz (map 1).

High along the northern dip slope of the mountains there is a local structural terrace which extends northward in T. 12 N., R. 5 E. from section 29 into section 20 where it merges into the southern end of the Agua Sarca fault. The large landslide and springs in the area appear to be related in part to this terrace.

FIGURE 59—VIEW NORTHWEST FROM HEAD OF LAS HUERTAS CANYON. DIP SLOPE ATTITUDE OF MADERA LIMESTONE LEDGES SHOWS IN NORTH SIDE OF OSHA CANYON. MADERA IS DOWNTHROWN ON THE WEST SIDE AGAINST SANDIA GRANITE ALONG ELLIS FAULT. INNER CANYON WALLS ARE ALL GRANITE.

TERMINATIONS

The Sandia uplift terminates on the north at the right offset of the Rio Grande trough from the Albuquerque basin into the Santo Domingo basin. The termination is excellently exposed in the Placitas area (fig. 60), where it consists of a much broken nose that plunges into the Rio Grande trough as a ramp between two trough boundaries, the Rincon and San Francisco faults (fig. 63). The lower (northern) part of the ramp is covered unconformably by the trough-filling Santa Fe beds and pediment gravel along a 3- to 4-mile stretch between the northward-dying Rincon fault on the west and the southward-terminating San Francisco fault to the east of the nosing ramp. The San Francisco fault is the main boundary between the Rio Grande trough and the Hagan basin, whereas the Rincon fault is a trough boundary with the Sandia uplift.

Erosion into the Precambrian together with sharp breaking and turning of blocks by the Placitas and Agua Sarca faults have destroyed or modified what was once a more smoothly curved plunging anticline or nose. Projection of structure contours along the crest and west of Placitas depict the uplift plunging northward at a rate of about 3,000 ft in 3 miles, from Sandia Crest to the Placitas fault (fig. 62). North of the fault plunge of the ramp is much steeper, amounting to at least 10,000 ft in 3 miles (map 3).

South of the western half of the Placitas fault (fig. 61) there is a long east-west hogback held up by northward-dipping Madera beds. At the eastern end of the hogback it is only a short distance across a saddle eroded into Precambrian to a spur of the uplift capped by north-northeastward-dipping Madera. Up the spur and to the east, uplift dips curve gradually into normal eastward dips of the uplift back slope.

Within the north-dipping northern end of the Sandia uplift are several short north-trending faults which appear to have acted with the Rincon and San Francisco faults to step fault the ramped block down to the west. These are from east to west the Suela fault (just east of the village of Placitas), Pomecerro or Fish Hatchery fault, the Agua Sarca fault, Caballo fault, and a short split from the Rincon fault in secs. 1, 12, T. 12 N., R. 4 E. Downthrow to the west is indicated by left offset of several of the north-dipping formations; in the case of the Pomecerro fault the throw is more than 2,000 ft and horizontal separation of the Dakota is nearly 4,000 ft.

The large San Francisco fault has a problematical southern termination. Much of the termination is covered by alluvium at Tecolote, and beneath the valley at Tecolote the fault appears to either curve into an offset end of the Placitas fault or to continue up Las Huertas Canyon and splay into the east side echelon faults described above. The latter concept is preferred. The westward branching Placitas fault does not bound the trough so much as it contributes to the northward down-ramping of the uplift.

A special feature of this portion of the Sandia termination is the narrow southward-wedging Las

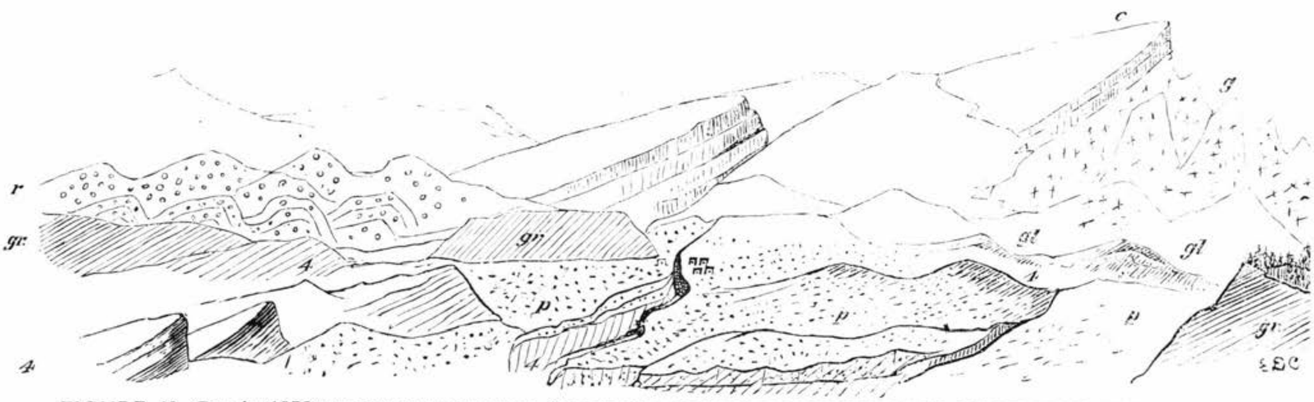


FIGURE 60—COPE'S (1875) DIAGRAMMATIC SKETCH. SITE OF VILLAGE MARKED BY HOUSES, ONE TO LEFT OF GULLY, FOUR TO RIGHT. Diagrammatic sketch of the Zandia Mountains, looking east by south across the village of Placita: *g*, granite; *c*, Carboniferous limestone; *r*, red beds, looking like *gl*, Galisteo sandstone; 4, Cretaceous Nos. 4 and 3; *p*, Placita marls; *gr*, gravel mesas.

Photo by Donald A. Myers

FIGURE 61—AIRVIEW TO THE SOUTHEAST SHOWING NORTHERN END OF SANDIA MOUNTAINS. UPPER RIGHT SHOWS BRUSH-COVERED SLOPE ERODED ON SANDIA FORMATION OVERLYING CLIFFS OF SANDIA GRANITE. STRONGLY LEDGED CREST AND EAST DIP SLOPE IS MADERA FORMATION. CENTER AND LOWER RIGHT SHARP, ERODED HOGBACK HILLS ARE CAPPED BY NORTH-DIPPING MADERA BEDS FAULTED DOWN AND ROTATED TO FORM THE NORTH RAMP TERMINATION OF THE UPLIFT. ON THE UPLIFT BACK SLOPE CAN BE SEEN PALOMAS PEAK AND OTHER SMALL PIGGYBACK FAULT BLOCKS.

Photo by Donald A. Myers

FIGURE 62—AIRVIEW EAST OF PLACITAS AREA. MONTEZUMA RIDGE, NEAR UPPER LEFT; MONTE LARGO ON SKYLINE; NORTHERN LOW DIP SLOPES OF SANDIA MOUNTAINS BACK OF THE VILLAGE; LEFT CENTER DISSECTED HILLS (SEE FIG. 41) ARE TILTED, OLD SANTA FE BEDS. TEXAS-NEW MEXICO PIPELINE, SEEN FROM TOP RIGHT TO LOWER RIGHT CORNER, TRANSPORTS PETROLEUM FROM UTAH TO TEXAS. LAS HUERTAS WASH, LOWER LEFT.

Huertas graben floored by Abo beds. The Abo and some Meseta Blanca beds are downthrown against Precambrian and Madera beds on the east side of the graben, and the throw could be 2,000 ft or more at the northern end. On the west side of the graben the Abo is stepped down by two faults, one along NM-44 and another to the west along Oso Creek. The graben is tilted eastward. Just to the west of these faults is the short Cuchilla Lupe horst which is surfaced by upthrown Madera Formation with Abo on either side. In this section of the northern end of the Sandias there is considerable breaking and jostling of small blocks up and down just south of the Placitas fault.

North of the Placitas fault jostling has affected many blocks in the northward and northeastward plunging ramp structure that descends toward the Santo Domingo basin. Additionally a disrupted monoclinal flex results in steepening of dips of 25 to 30 degrees south of NM-44 to dips of 45 to 70 degrees north of the road. The steep limb passes beneath basal Santa Fe beds with a surface of unconformity below the Santa Fe. A tectonically significant feature not heretofore recognized is that the Santa Fe beds are also considerably deformed but in a different manner and direction. Although some faulting is involved, the post-Santa Fe deformation takes the form principally of several northnorthwestward-trending anticlines and synclines that plunge down the ramp (fig. 63). Three erosional lobate forms in the Santa Fe outcrop pattern result from these folds. The anticlines are stripped into the steep pre-Santa Fe formations, and the synclines are occupied by the Santa Fe lobes which stand as mesas. The middle (Lomos Altos) syncline of the mesa, 1.5 miles west of Placitas, and the two flanking anticlines are the main elements of this post-Santa Fe deformation. The westernmost syncline is obscure and perhaps modified by the Rincon fault. The easternmost syncline northeast of Placitas is likewise obscure, possibly disturbed by the San Francisco fault, and also complicated by a fault and erosion along Las Huertas Arroyo. The southwestern limb of the Lomos Altos syncline has a dip of as much as 40 degrees, and the west limb of the Las Huertas syncline dips as much as 45 degrees. The eastern limbs of these synclines are low dipping and not easily seen.

The northern, ramp termination of the Sandia uplift is important in displaying evidence of 3 distinct periods of deformation. The first was before early Santa Fe and

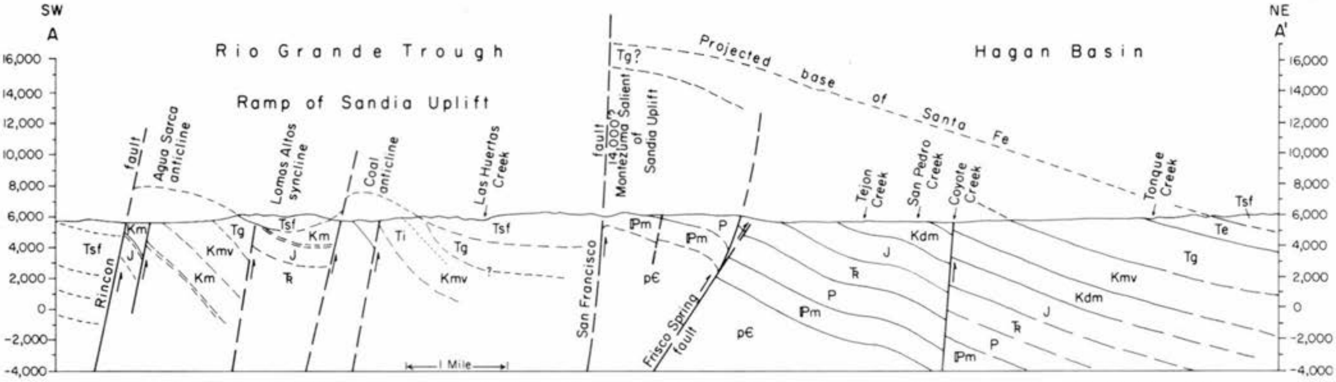


FIGURE 63—STRUCTURE SECTION *A-A'* FROM RIO GRANDE TROUGH TO HAGAN BASIN. SECTION CROSSES MONTEZUMA SALIENT AND STRUCTURAL DOWNRAMP NORTH OF PLACITAS. (LINE OF SECTION SHOWN ON MAP 1.)

the second followed early Santa Fe deposition. In sec. 36, T. 13 N., R. 4 E. a north-trending fault, which may be a splay of the Rincon fault (fig. 61), offsets the Galisteo and folded lower Santa Fe conglomerate and is younger than the first two deformations. The steep Galisteo beds near the fault show left drag, parallel with similar drag on the San Francisco fault. The basal Santa Fe fanglomerate east of the fault consists predominantly of red Abo sandstone with no Madera or Precambrian fragments, indicating that only Abo surfaced the uplift (fig. 64). West of the fault the downthrown Santa Fe fanglomerate consists predominantly of Madera fragments with minor small fragments of Abo and no Precambrian. Thus, the nearby uplift had been stripped of most of its Abo, but uplift and erosion had not yet affected the Precambrian. The Madera-bearing Santa Fe may be several hundred feet stratigraphically above the Abo-bearing Santa Fe.

In describing the extent of the Sandia uplift, the Frisco Spring fault and its branches southward along Tejon Canyon were selected as the boundary between the uplift and the Hagan basin. These curving, high-angle reverse faults dip from 60 to 90 degrees toward the west or south. Here the uplift is raised steeply and sharply against and over the edge of the Hagan basin. At the salient near Tejon, upthrusted Abo rides onto Santa Rosa Sandstone with all the Yeso and San Andres having been overridden and cut out locally. Reynolds (1954, p. 45) believed the western part of the Montezuma fault to be a left tear fault (map 1) which

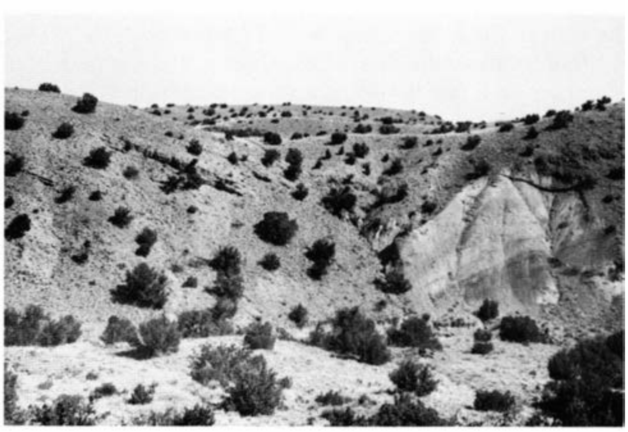


FIGURE 64—SANTA FE FANGLOMERATE (LEFT) DOWNFAULTEI AGAINST GALISTEO AND OLDER SANTA FE FANGLOMERATE. SEC. 36 T. 13 N., R. 4 E.

facilitated considerable upthrusting and overriding at the Tejon salient and along the south-trending thrusts, Kelley and Reynolds (1954) suggested that these structures might be older than the late Tertiary block faulting and possibly Laramide in age. Renewed movements may have readjusted the blocks along these faults in late Tertiary.

The southern termination of the uplift is entirely different from the northern. The boundary is the Tijeras fault which lies mostly in Precambrian terrane. The most obvious termination is in Tijeras Canyon where the trace of the fault passes from the Precambrian intc Pennsylvanian strata. To the north Pennsylvanian strata lie high along the Sandia crest and dip uniformly eastward to the canyon bottom and the fault. To the south of Tijeras fault Pennsylvanian beds are lower and strike northeastward parallel to the fault. Projection of this Pennsylvanian base upward to the fault shows (map 3) that the south side of the fault is 800 to 1,200 ft higher than the projected trace of the north side base tc the fault. Stratigraphic projections worked out in structure contouring (map 3) suggest a long southward-plunging anticline for the southern point of the uplift, from a high near Sandia Crest of about 11,000 ft on top of the Precambrian to about 7,000 ft near Four Hills in 11 miles. However, in a strict sense there may be nc termination on the south—rather, just a change of magnitude of uplift across Tijeras fault into the Manzanita uplift.

MA NZANITA UPLIFT

The Manzanita Mountains are a broad dissected plateau, which lies between the Sandia Mountains on the north and the Manzano Mountains on the south. Most of the uplift is south of the report area. The length, north to south, is about 15 miles and it extends from the western escarpment some 15 to 20 miles to the east where it merges into the Estancia Valley. The western escarpment into the Rio Grande valley is deeply indented by erosion up to an irregular crest line at altitudes of 7,500 to 8,000 ft, which is some 1,000 to 2,500 ft lower than the crests of the more strongly uplifted and tilted mountains to the north and south.

The northern boundary of the uplift is at the Tijeras fault to about the town of Tijeras, thence southward and then northeastward around the Tijeras basin along the Chamisoso and Gutierrez faults. The uplift merges gradually with the Estancia basin a short distance east of the area. The southern end of the uplift is just north of Mosca Peak of the Manzano uplift and about at the Bernalillo-Torrance county line. The western boundary is outside the area of the Sandia geologic map, but like the Sandias the Manzanitas are bounded by the Rio Grande trough. The structural descent into the trough is by both faulting and downwarping.

The Manzanita uplift is tilted broadly and rather gently eastward. Dip across the plateaulike structure probably averages no more than 1 to 2 degrees. However, very low, broad open anticlines and synclines interrupt the low eastward inclination. In the north-central part of the uplift a north-trending set of faults centers along the Cedro Canyon area. Throws on these faults generally do not exceed 400 to 500 ft and are commonly much less. The principal feature produced by these faults is the elongate Cedro Peak horst. The horst is bounded by the Otero fault on the west and the Cedro fault on the east. The Chamisoso fault, which is probably related to the overall subsidence of the Tijeras basin, crosses the Cedro Peak horst. The Chamisoso fault uplifts the horst by 100 to 200 ft to the south and brings to view a small body of Precambrian rock.

Two broad northward-plunging folds modify the northern end of the Manzanita uplift. On the west is the Apachitos syncline. The Apachitos syncline plunges generally toward the southwestern end of the Tijeras basin to which it may be related. However, the syncline terminates at the Otero fault. The western limb of the Apachitos syncline projects updip through Cerro Pelon ridge to a termination at the Tijeras fault. The east limb of the syncline is long and broken by faults, but except for local reversals near the faults, is coincident with the west limb of the Sabino anticline. The Sabino anticline extends beyond the Sandia map on the south. It dies out into homoclinal northward dips toward the Tijeras basin. The east limb extends through 2- to 3-degree dips for many miles into the Estancia basin.

In the eastern part of the Manzanita uplift, the north-trending arcuate Barton fault breaks the monotony of the long Sabino east limb. The Barton fault, shown more completely by Kelley (1963), is 10 to 11 miles long. The east side of the fault is uplifted several hundred feet, and high beds of the Arkosic limestone member of the Madera are repeated in outcrop.

HAGAN BASIN

The Hagan, or Una de Gato, basin of Stearns (1953c, p. 483), is an arcuate tilted half graben. The term Hagan basin, as applied here, is preferred because of the better known Hagan coal center, and perhaps the designation as a basin rather than half graben is justified because of the plunging syncline created by the arcuate outcrops which curve from west to north trend around the southwest side. The southwest side of the basin is against the Sandia uplift, particularly, the Madera salient, as previously described. The east side, largely buried by pediment gravel, is downthrown against a variety of Mesozoic and older Tertiary rocks and is exposed where Holocene erosion has removed or cut through the gravel (Stearns, 1953c, pl. 1). The fault system on the east is a southward extension of the La Bajada or Rosario fault (as mapped farther north); farther southward the east structural edge of the basin may be followed along the San Pedro fault and eventually along the Barro fault of the Sandia Mountains. The western side of the basin coincides in part with the northern end of Sandia uplift and with the San Francisco fault, which bounds the Santo Domingo basin of the Rio Grande trough. However, the San Francisco fault either dies out or is buried in the northern part of the basin, and Santa Fe beds merge with those in the northeastern part of the Hagan basin. In Santa Fe time the Hagan basin was a reentrant structural embayment of the Rio Grande trough (Kelley, 1954).

The Hagan structural basin has an embayment on the southwest that lies between 2 prongs of the Sandia uplift. These are the Montezuma salient on the north and the Madera salient on the south. The boundary of the basin embayment with the Madera salient is along the Seco and Barro faults. On the geologic map the embayment can be easily visualized by following the Abo-Madera contact. However, northward along the west side of the embayment, the boundary is along the north-trending high-angle faults. The embayment is structural and is cut by an array of faults mostly of northeastward trend.

Along the north-trending side of the Hagan basin, especially in the Town of Tejon Grant, there are several longitudinal faults. One is the Largo fault which may duplicate or thicken the Mancos section to some extent. However, the largest of these is the Frisco Spring fault which occurs along the eastern base of the high hogback formed by the San Andres and Santa Rosa beds. This fault, together with two branches, appears to be related to the Montezuma upthrust to which it ties at the point of the Montezuma salient. The greatest throw on the Frisco Spring fault is at the salient where the entire thick Chinle section is missing.

RIO GRANDE TROUGH

The parts of the Rio Grande trough directly related to the Sandia area are the Albuquerque and Santo Domingo basins (fig. 65) (Kelley, 1952, p. 93). The Albuquerque, or Albuquerque-Belen basin (Bryan, 1938a, p. 209) adjoins the long line of uplifts including the Sandia, Manzanita, Manzano, and Los Pinos. The Santo Domingo basin adjoins the northern tip of the Sandia uplift as well as the Hagan basin. Only the eastern margins of these two basins are of concern relative to the structure of the Sandia area.

In the Santo Domingo basin the trough-filling Santa Fe beds are dropped along the San Francisco fault against beds ranging from lower Santa Fe, north of Espinaso Ridge, to Madera beds along Montezuma Mountain. San Francisco fault appears to die in or be buried by upper Santa Fe beds north of Espinaso Ridge; vertical separation increases to more than 10,000 ft at its southern end (map 3). However, this difference is in large part due to rise of the southwestern side of the Hagan basin with respect to its northeastern part.

The upper Santa Fe beds along the western side of the fault are approximately the same age, but lower beds dip northeastward and rise structurally to the southwest in parallel with the northern end of the

Sandia uplift and the southwestern edge of the Hagan basin. Upper beds of the Santa Fe may be found to dip in some places slightly away from the uplift. The older beds of Santa Fe, as in T. 13 N., R. 5 E. and near Placitas, dip locally as much as 45 degrees northeastward.

In the Hagan embayment, east of Espinaso Ridge, lower Santa Fe beds, including the Zia or Abiquiu and underlying Espinaso volcanic beds, dip in near conformance with the Eocene and all older beds toward the eastern edge of the embayment. This edge, formed by the La Bajada fault, is also the eastern edge of the Santo Domingo basin (Kelley, 1954). Thus, it appears that the Hagan half-basin and the embayment were tilted after early to middle Santa Fe time. Inasmuch as the southwestern side of the Hagan basin is also the northeastern flank of the Sandia uplift, one may project a model (fig. 66) showing rise of the Sandia uplift in early Santa Fe time. In doing this one could also suggest that the early Rio Grande basin covered much if not all the Sandia uplift. In this instance where would the southeastern margin of the trough have been; could it have been the Tijeras fault? The Tijeras trend is parallel to the present San Francisco fault edge of the Santo Domingo basin and both are roughly parallel to the opposite trough boundary along the Jemez margin. The

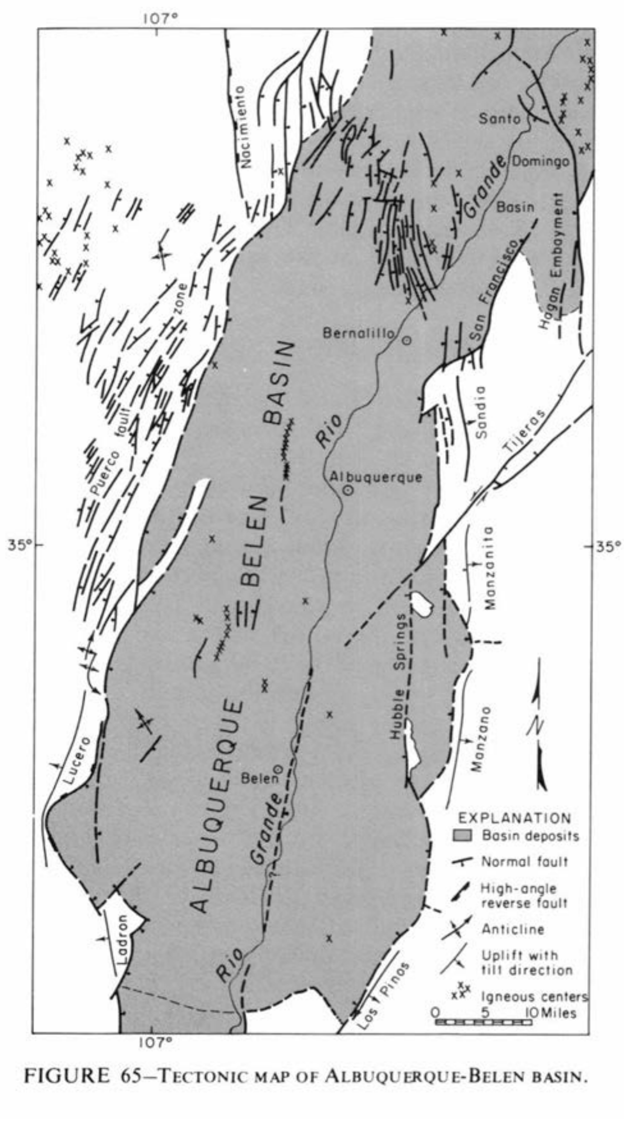


FIGURE 65—TECTONIC MAP OF ALBUQUERQUE-BELEN BASIN.

part of this early trough southeast of the San Francisco fault, if it already existed, might have been a bench of the deeper main trough along the present Rio Grande. Such a bench or step, down to the trough axis, is present west of the Manzanita and Manzano uplifts between the main fault at the base of the mountains and the Hubble Springs fault 5 or 6 miles out into the trough. Similar ones appear to be present in places along the western side of the Albuquerque basin.

The structural edge of the Albuquerque basin west of the Sandia-Manzano line of uplifts is poorly exposed and difficult to define clearly because of masking by outwash from mountains. Thus, two geomorphic features, the attitudes of the high surfaces in the valley and the alluvial fans at the base of the mountains, may be used together with subtle structures to define the basin boundary and suggest something of the nature of basin subsidence. The high surface west of the Rio Grande at the latitude of Albuquerque slopes eastward, and it may be projected across the inner valley to the high surface at the Albuquerque International Airport, which slopes at the same low rate of about 40 ft per mile. The high Airport surface, north and south of Tijeras Arroyo, is quite flat with even low swales south of the arroyo, where westward slope is less than 3 ft per mile. Beneath these surfaces in the sides of Tijeras Arroyo and in the west-facing erosional scarps of the inner Rio Grande valley, dips in the high Santa Fe beds of 0.5 to 1.5 degrees eastward may be seen in several places. Santa Fe beds in Tijeras Arroyo south of the Western Skies Motor Hotel dip about 1 degree toward the nearby upfaulted Sandia Granite even though the surface at the top of the arroyo slopes slightly westward. Elsewhere beds are nearly horizontal east of the river. Alluvial fans along the uplifts, especially along the Manzano uplift, are not wide or large; they appear to be young and built upon earlier fans which subsided into the basin.

The eastward-tilted surface and beds, and small, only slightly coalesced fans all point toward tilting of the Albuquerque basin toward the east side uplifts. Rotation downward toward the more strongly uplifted eastern side may have accompanied much of the basin subsidence creating what has been termed a vortex monocline, as described for the Triassic Newark basins of the eastern United States. In such troughs, beds increase in dip and thickness toward actively rising borders. Keyes (1908a, p. 83) long ago showed this thickening of half grabens toward the fault.

There is an axis of sagging well out in the trough. Between the northwestern end of the Sandia uplift and Santa Ana Mesa west of the Rio Grande a sag axis follows the river course. The basalt flows on the mesa and the San Felipe volcano are tilted toward the sag axis.

In late Santa Fe time the Rio Grande course in the Albuquerque area was as much as 6 miles east of its present position as evidenced by volcanic debris, derived from the Jemez area, in the beds along the sides of Tijeras Arroyo.

The evidence for late Santa Fe tilt of the basin toward the east along the eastern part of the Albuquerque basin does not assure that the entire basin is also tilted east or that the beds at depth along the eastern side might not

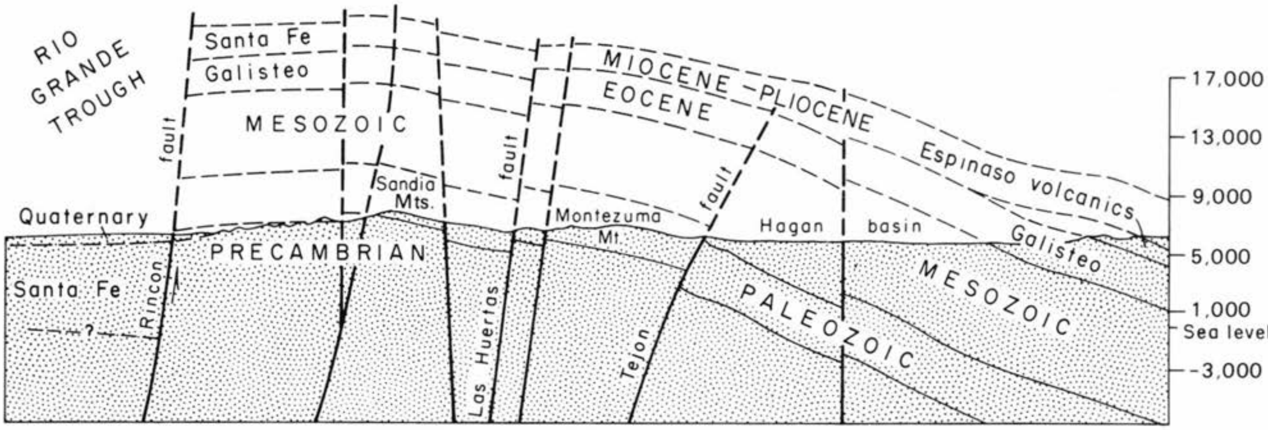


FIGURE 66—STRUCTURE SECTION ACROSS HAGAN BASIN AND NORTHERN SANDIA MOUNTAINS, SHOWING POSSIBLE EXTENSION OF SANTA FE GROUP BEDS ACROSS UPLIFT.

be tilted westward as they are in the eastern part of the Espanola basin. The structure is probably more complicated than can be observed at the surface. The uplift structure is not simple; confinement stresses should be greater in the subsiding blocks than in the uplifts where confining stresses are released as uplifts rise above the surrounding terrain. Furthermore, some Laramide deformation may have occurred along the entire length of the Rio Grande fault belt.

For the entire late Tertiary belt the trough mechanism is dominant; uplifts are the smaller, counterpart reactions to the subsidence. There is some suggestion that the greater the subsidence the greater the uplift. The high mesa surfaces are lower paralleling the greater rises such as the Sandia and Manzano uplifts. The mesa level is higher paralleling the lower Manzanita uplift from the Albuquerque International Airport south to the southern boundary of the Isleta Pueblo Grant.

Overall displacement between the Sandia uplift and the Rio Grande trough has long been a subject of interest. Just as the uplift altitudes differ along the margins of the trough so do the altitudes of the bottom of the trough, and there are reasons for believing that the trough bottom may be more irregular. On the basis of known stratigraphic thicknesses we have recognized that the vertical separation into the trough could be on the order of 25,000 ft. However, Joesting, Case, and Cordell (1961) interpreted gravity and magnetic data to indicate a displacement of 22,000 ft.

TIJERAS RIFT ZONE

One of the more unusual structural trends in New Mexico is the Tijeras rift zone. It extends northeastward across the Sandia map area (fig 52, map 1). The zone consists of four principal parts: 1) Tijeras fault, 2) Gutierrez fault, 3) Tijeras graben, and 4) Monte Largo horst. The Tijeras rift zone is continuously exposed for 31 miles from the edge of the Rio Grande trough to near Golden in the southern side of the Ortiz Mountains. Relative to the surrounding structure the faults are mostly obliquely transverse; but both parallel and obtusely transverse relationships occur. The trend is part of a longer lineament of on-line structures to as far north as the southern Sangre de Cristo Range and to the southwest into the Rio Grande trough, possibly to the Ladron uplift.

TIJERAS FAULT

The Tijeras fault, the dominating structure of the rift zone, is exposed in the southwestern part in Precambrian rocks, where pronounced contrasts in rock types on opposite sides of the fault suggest displacement. Stratigraphic units ranging from Pennsylvanian to late Cretaceous are cut and greatly displaced along and through the western side of the Tijeras basin. Along the northwest side of the Monte Largo horst, Pennsylvanian and Permian beds are dragged steeply down against Precambrian rocks. In places the fault parallels the strikes of adjacent beds, but elsewhere it is diagonal (normal) across adjacent attitudes.

Vertical separation across the fault differs greatly (zero to several thousand feet). Direction and magnitude of vertical separation differs laterally along either side as shown in the table.

1) Locally east of Four Hills	down 700+ft
2) Near Seven Springs	up 200+ ft
3) Cedar Springs and San Antonito	down 3,000 +ft
4) Northwest corner sec. 2, T. 11 N., R. 6 E.	0 ft
5) Monte Largo	up 3,000+ ft

Figure 67 shows the vertical comparisons of the walls of the rift zone by a longitudinal profile at Precambrian levels midway to the Tijeras graben and the Monte Largo horst.

Strike-slip movement is suggested by drag folds and horizontal separations. Several horizontal separations of stratigraphic units and fold axes indicate left slip. In sec. 15, T. 10 N., R. 5 E. north of Tijeras a steeply dragged Todilto-Morrison contact shows left-lateral separation of 1.5 miles. In sec. 36, T. 11 N., R. 5 E. east of Cañoncito, adjoining anticline and syncline axes have been separated left 1,300 to 1,800 ft. One mile to the northeast the left separation of the Mancos-Dakota contact is 3,550 ft and the Morrison-Todilto contact, 2,500 ft. Nearby in the area of Sandia Knolls a narrow section of San Andres beds is dragged to the left in a horst. In the same area Abo and Yeso beds are similarly separated.

Two examples of possible drag folds also suggest left offset, the best of which is the steeply plunging small anticline in the northwest corner of sec. 22, T. 10 N., R. 5 E., half a mile west of Tijeras and north of US-66. Marker beds of sandstone high in the Madera Forma-

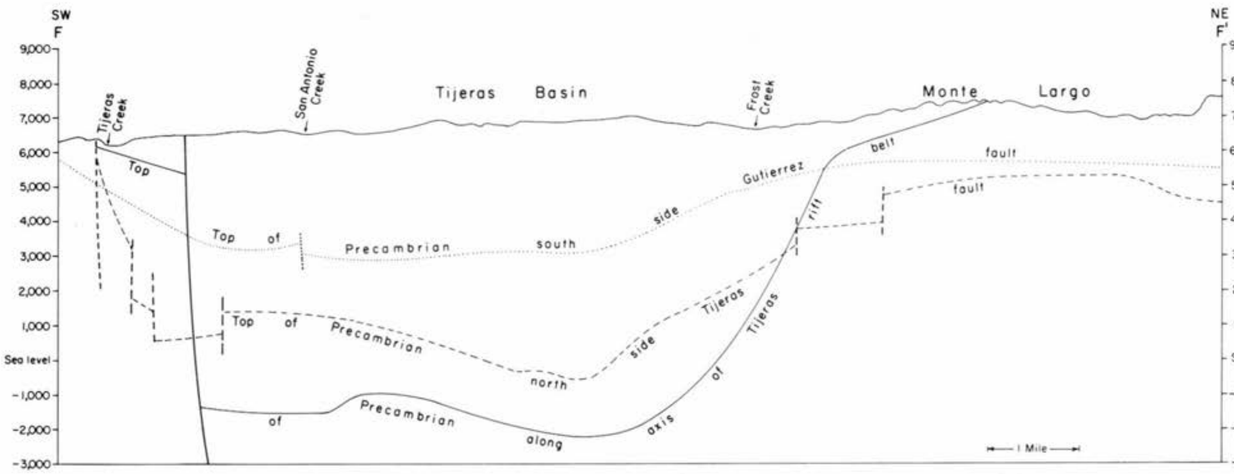


FIGURE 67—LONGITUDINAL STRUCTURE PROFILES ON TOP OF PRECAMBRIAN, IN AND ADJOINING TIJERAS GRABEN AND MONTE LARGO HORST.

tion can be traced regionally rather sharply around a drag fold plunging about 45 degrees to the northeast. Individual beds are doubled back by left drag from 20C to 300 ft, where they abut the fault and Triassic beds on the opposite side. Another possible example of left drag folding is in the southeast limb of the anticline through sec. 20, T. 11 N., R. 5 E., southeast of San Antonito. Although there is the suggestion that this anticline is a continuation of the Tijeras anticline, the pronounced steepening and sharp turning may be to a considerable degree the effect of the drag. If this is so, then the left separations given for the Dakota and Todilto outcrops might be increased to nearly 1 mile. Additionally the Sandia uplift appears to be offset 1 to 1.5 miles west of the Manzanita-Manzano uplift. Bases of the ranges and the projected crestal axes are both offset, and horizontal separation of the crestal axes is 3 to 3.5 miles across the Tijeras fault.

In summary, there is much evidence that the Tijeras is a left wrench fault and that strike-slip movement in post-Cretaceous time could have been as much as 1.5 miles. Differences in separation along the fault are expected, especially in view of the folding normal to the fault; also, plunging into the Tijeras basin, as well as arching over the Monte Largo horst, may have accompanied wrenching movement along the Tijeras fault.

GUTIERREZ FAULT

The Gutierrez fault is 15 miles long and bounds the Tijeras graben and Monte Largo horst on the southeast. Southwest it splits into 2 short branches, 1 of which connects with the Tijeras fault and closes the southwest end of the Tijeras graben. The northeast end is beneath alluvial outwash south of the San Pedro Mountains. Vertical separation differs greatly from strongly upward to strongly downward; there is probably none in the southeast quarter of sec. 22, T. 11 N., R. 6 E.

Figure 67 compares elevations on the top of the Precambrian along the southeast wall of the Gutierrez fault with those along a profile across the middle of the Tijeras rift belt. Opposite the Tijeras syncline the vertical difference is about 3,600 ft. Some vertical separations of the northwest side are:

1)	Section 6, northwest of Zuzax fault	down 3,900 ft
2)	Section 12, near Gutierrez Canyon road	down 4,200 ft
3)	NM-14	down 6,000 ft
4)	SW sec. 22, T. 11 N., R. 6 E.	0 ft
5)	Monte Largo	up 1,500 ft

There is little horizontal offset or drag to indicate strike-slip movement on the Gutierrez fault. Some evidence that left slip may have occurred is described.

TIJERAS GRABEN AND BASIN

The Tijeras graben is the southwestern half of the elongate Frost fault block lying between the Tijeras and Gutierrez faults (map 3). The northeastern half of the block is referred to as the Monte Largo horst. The block is about 16 miles long and ranges in width from 0.5 mile at the southwest end to 3 miles at the northeast end. The Precambrian base of the elongate block is tilted southwestward, and the basement is as much as 2,200 ft below sea level in the Tijeras graben and about 8,200 ft above sea level in the Monte Largo end of the block. The boundary between the graben and the horst is drawn at the change from downthrow to upthrow across the block, and this is about midway through the Pennsylvanian outcrop in the southwest end of Monte Largo and about midway of the total length of the fault block.

The Tijeras graben whose side limits are the Tijeras and Gutierrez faults is a central part of a larger depression known as the Tijeras basin. On the west the basin margin merges with the eastern side of the Sandia uplift. This margin is arbitrarily drawn through Cañoncito along the Santa Rosa-Chinle contact, northward around the southward-plunging part of the San Pedro syncline, to a junction with the northwestern end of the Tijeras graben. Along the western limb of the San Pedro syncline downthrow on the San Antonito fault of several hundred feet enlarges considerably the area of the basin in the San Pedro embayment. The strip of basin that is beyond the graben on the west is 2 miles wide. A similar strip flanks the graben on the southeast. This limb of the Tijeras basin is taken to extend through steep dips (Bartola monocline) southeast of the Gutierrez fault to the Chamisoso fault and the eastern part of the Los Pinos fault. In the 2-mile strip southeast of the graben are 3 faults that accentuate the basin. These are the Chamisoso, Los Pinos, and Zuzax faults, which step the basin strip downward parallel with the graben boundary at the Gutierrez fault (map 3). The Chamisoso fault is also part of the northern boundary of the Manzanita uplift. North of the Chamisoso fault the beds steepen markedly and they constitute a monocline that bounds the Manzanita uplift and the Tijeras basin. The southwestern boundary of the Tijeras basin is taken arbitrarily a little east of Cedro Canyon, from the Chamisoso fault to the Tijeras fault. The Tijeras and Gutierrez faults cut through the Tijeras basin and divide it into 3 parts, the central part being the Tijeras graben.

A strong contrast in internal deformation exists between the Tijeras basin and the Monte Largo horst. In the Tijeras graben there are pronounced internal right-oblique folds consisting of the Cedar Crest syncline on the west, the Tijeras anticline in the middle, and the Tijeras syncline on the east (fig. 68). The Cedar Crest syncline and the Tijeras anticline are nearly level folds. The Tijeras syncline is doubly plunging, partly parallel to the trend of the block, with the trough bottom coincident with the deepest part of the Tijeras basin. All these folds terminate abruptly on the south at the Gutierrez fault, and no such folds exist immediately to the south. Both ends of the Tijeras syncline also terminate against the Gutierrez fault. To the northwest the Cedar Crest and Tijeras folds appear to have offset extensions beyond the Tijeras fault.

FIGURE 68—AIRVIEW NORTHEAST OF TIJERAS ANTICLINE AND SYNCLINE. HAGAN BASIN; ORTIZ MOUNTAINS, OF PORPHYRY, IN BACKGROUND; AND DIMLY, THE SANGRE DE CRISTO RANGE OF THE ROCKIES BEYOND. VILLAGE OF TIJERAS, LOWER LEFT.

The Tijeras syncline is the dominant fold of the graben and the basin (fig. 68). The basin is asymmetrical to the southeast. The southeast limb dips 25 to 50 degrees and has structural relief from the trough to the Gutierrez fault of as much as about 2,000 ft at the Mesaverde level. The northwest limb dips 15 to 30 degrees and has structural relief of only about 700 ft from the trough to the northern end of the Tijeras anticline. In general, dips are highest from the north rim around the eastern end of the axes and along the southeast side; they are lowest along the west side of the basin.

The Tijeras anticline plunges very gently northward at about 300 ft per mile. Its limbs have structural relief at the Mesaverde level of 600 to 700 ft, and the fold is nearly upright, with the eastern limb being steeper in the southern part and the western limb steeper in the northern part.

The Cedar Crest syncline lies between the Tijeras anticline and the Tijeras fault. The east limb (west limb of the anticline) dips as much as 20 degrees, but the fold is asymmetrical to the east with the west limb inclined from 30 to 85 degrees with the steeper dips toward the Tijeras fault.

The presence of folds in the Tijeras graben and their absence in the Monte Largo horst is puzzling. It may be due to the higher stratigraphic level at the surface and weaker beds in the basin; the folds in the basin may be concentric and flatten or die out at depth; or there may be a stratigraphic level of change in deformation. Examination of Chinle configuration across the fault block at Frost Canyon supports this possibility. Outcrops in this area appear to afford the down-viewing cross section described by Mackin (1950). The Chinle has the thickness and weak physical characteristics that could facilitate a rapid change in relative deformation between two depth zones. There are other possibilities that could be related to the attitudes of the faults, differences in width of the block, and timing and nature of relative movement in the block and adjacent masses. Grabens and horsts are quite commonly associated with large wrench faults, where splits or acute branches occur along the belt (Lensen, 1958).

Dips of the Tijeras and Gutierrez faults have been presumed to be steep to vertical in the absence of exposures of the fault surfaces, and the evidence of strike-slip motion favors their steepness also. If, however, the generally accepted fault-boundary attitudes of grabens and horst are considered, then the attitude of each fault would change from inward to outward in passing from the graben to the horst. Furthermore, mechanics of deformation would have been extensional as vertical separation increased. The width of the horst would increase and that of the graben decrease with depth or erosion. That this geometry does exist is supported by the graben being narrower than the horst, assuming that the two faults were parallel to begin with. In the parts of normal faults where dips would have to change from northeastward to southeastward the faults would be vertical or quite steep. In this area the outcrop width is less than along the horst as it should be, but it is also less than that of the graben and this is not what would be expected. The widening of the graben by northwest bowing of the Tijeras fault next to the deepest part of the basin could be due to warped flattening of the fault which might result from a downward wedging action by the subsiding graben. Westward flattening could take place where it appears owing to the presence of relatively weak Mancos, Morrison, and Chinle beds west of the Tijeras fault where the bowing exists.

The matter of timing between the folding and the faulting in the Tijeras basin is important. For the Tijeras fault, it appears that the folds are offset and therefore older. In contrast, all the basin fold axes terminate at the Gutierrez fault and therefore could not be older. Thus the Gutierrez fault may be older than the Tijeras fault, or possibly the more recent episodes of movement on the Tijeras fault. That the Gutierrez is older is also suggested in sec. 12, T. 9 N., R. 5 E., where the short northwest-trending fault that bounds the Tijeras graben at the southwest end is terminated at the Tijeras fault. The right obliqueness of the folds across the basin suggests clockwise rotation or left shift between the Sandia and Manzanita blocks which could explain the internal deformation of the graben. This would also suggest some right slip on the Gutierrez fault.

MONTE LARGO HORST

The northeastern end of the Frost fault block is the Monte Largo horst. Bounded by the Tijeras and Gutierrez faults, the horst merges into the Tijeras graben on the southwest (fig. 67) and is terminated on the northeast at the San Pedro porphyry complex and where the Gutierrez fault dies out.

Along the central part of the horst Madera limestone is faulted down on both sides against Precambrian rocks of the core. Longitudinally the horst is a broad anticline with a narrow southeast limb that dips 25 to 35 degrees into the Tijeras syncline and a more gentle northeast limb dipping into the San Pedro porphyry complex.

OTHER STRUCTURES

An examination of the geologic map (map 1) reveals a salient of Madera Formation extending eastward from the main part of the Sandia uplift toward the Monte Largo horst. The limestone hills stand physiographically as well as structurally above the terrane on all sides except on the west in the direction of the uplift. This feature is the Madera salient. Structurally the salient is a part of the tilted fault block elevated on the Barro fault and forms a rough nose even though bed attitudes do not trend smoothly around it. However, northward dips do occur north of Madera Canyon and adjacent to the Seco fault and southward dips occur along the southern side of the salient. The eastern end of the salient is crossed by a prominent fault with 2 parallel, narrow, closed folds. Relationships do not reveal clearly the direction of movement on the fault, but distribution and attitude of the Abo Formation east of the fault suggest that the east side is upthrown. Abo probably wraps completely around the eastern end of the salient.

San Pedro syncline plunges into the Tijeras basin. This syncline is a long northeast-trending downwarp that separates the Monte Largo horst from the Sandia uplift and from the Madera salient, in particular. Between the eastern end of the salient and Monte Largo the San Pedro syncline crosses a long structural saddle and plunges into the southern end of the Hagan basin. San Pedro saddle forms the structural divide between the Tijeras and Hagan basins. The southeast limb is much steeper making the syncline asymmetrical to the northwest and away from the Monte Largo horst.

In 2 places contacts between Paleozoic beds and the Precambrian show some missing section, notably the Sandia Formation; low-angle, near-bedding faulting could have caused omission of some strata. One of these situations lies about 3 miles west-southwest of Placitas in sec. 12, T. 12 N., R. 4 E. In this area there is a local patch of Mississippian Arroyo Peñasco Formation overlain by Madera limestone with little or no Sandia Formation, and even where the pre-Pennsylvanian beds are absent the Sandia is thin or absent. The relationship could have been brought about by low-angle gravity faulting down the dip of the rising late Tertiary uplift in such a way as to have scooped out the weak Sandia beds, or the relationship could indicate Laramide low-angle faulting. Because direct exposure or other deformational evidence is lacking, possibly the Sandia beds wedge out to the west by overlap of Madera beds onto a high.

The other instance of missing Sandia beds is at the inselberg along the base of the uplift, in sec. 14, T. 10 N., R. 4 E., a short distance north of "U" rock. In this small hill massive gray Madera limestone rests directly on Sandia Granite. The missing Sandia beds could again be explained as above. Their absence is equally likely to be due to either gravity sliding or to depositional overlap. Kelley has seen evidence of missing basal beds along steep east-flank beds in the San Andres uplift of southern New Mexico that are very unlikely to be due to sedimentary overlap. However, we have several suggestions for a former positive area in the site of the Rio Grande trough (Wilpolt and others, 1946; Read and Wood, 1947, fig. 3). In the recent Shell Oil Santa Fe #1 well drilled about 14 miles west of Placitas the Pennsylvanian is reported to be only 545 ft thick.

A quite unusual occurrence of horizontal shearing occurs along the road to the lower terminal of the Sandia Peak tramway in sec. 10, T. 11 N., R. 4 E. At this locality the Sandia Granite is mylonized to thick, flat-lying gneiss. The highly sheared rock consists of broadly undulatory foliation with lineation normal to the mountain front. The occurrence is incompletely exposed, and neither top nor bottom of the sheared rock is revealed in the acre or so of outcrop. The zone cannot be traced along the front because of alluvial cover. Movement indicated by the shear zone could have been in either Precambrian or Laramide time. In either case it is interesting that the lineation indicating the direction of movement is normal to the uplift and to the most likely Laramide trends.

ORIGIN

Prior to the Cenozoic the only structure in the Sandia area had been produced in the basement orogenies long before Paleozoic time. At the end of Cretaceous time the Sandia area was a low plain underlain by some 10,000 ft of flat-lying Paleozoic and Mesozoic strata with little or no deformation beyond minor subsidence-related tilts during accumulation of the sediments. Except for the Precambrian terrane all the present structure of the area must have been produced during Cenozoic time. On the basis of direct evidence alone, all the structure above the basement could have been late Tertiary, accompanying the formation of the Rio Grande trough. However, based upon indirect evidence and by analogies with nearby structures it appears that some of the present structure may have formed prior to the subsidence of the Rio Grande trough and possibly during the Laramide.

To directly establish a Laramide age for deformation, Cretaceous or early Tertiary beds must be found in a folded, tilted, or faulted condition overlain unconformably by late Tertiary (Miocene or Pliocene) beds in either an undeformed or less deformed condition. West of Placitas, Galisteo (Eocene) rests on a somewhat thinned section of Mesaverde beds, compared to the sections in the Tijeras and Hagan basins. Although this is indicative of an early uplift and erosion, it is not possible to determine whether Laramide uplift took place in the area of the present Sandia uplift. Some of the structure may be pre-Rio Grande trough and possibly Laramide, for several reasons, chief among which is that a number of structures do not fit the form or the mechanics of deformation observed in the known late Tertiary fault-block uplift. The main structures of the Sandia-Manzano line of uplifts are great high-angle normal faults accompanied by gentle to moderate eastward tilting. The northeast-trending Tijeras rift zone does not fit the mechanics of the late Tertiary deformation. Furthermore, it lacks the fault scarps that characterize the trough boundary.

A number of the east side structures such as the Barro, Lagunita, Ellis, and Las Huertas uptilted fault blocks are most likely late Tertiary, forming in coordination with the main movement of the uplift. However, several high-angle reverse faults such as the Flatirons, Tejon, and Montezuma, which are upthrown to the west, do not fit well with the mechanisms of the uplifting Sandia fault or the Barro fault.

Similar faults, with related folds commonly overturned, occur along the eastern flanks of the Los Pinos and Manzano uplifts and were first recognized as west-dipping thrusts (Wilpolt and others, 1946) formed most likely in Laramide time. They were later described in more detail by Stark (1956, p. 30-34) who also suggested Laramide orogeny. However, all the evidence is indirect and based on analogies with the Rocky Mountain La ramide style rather than Basin and Range block-faulting style. Kelley and Silver (1952, p. 136-137; 162-165) found similar compressive structures in the Caballo tilted fault block and with the presence of early and late Tertiary beds were able to more directly demonstrate Laramide orogeny along the Rio Grande belt. R. L. Koogle working under Kelley found direct age evidence for deformation, long considered Laramide, along the eastern flank of the San Juan basin.

The belt of upthrusting toward the east extends, with interruptions, from the northern end of the Sandias through the Manzano, Los Pinos, Fra Cristobal, and Caballo Mountains lying east of the normal faults bounding the east side of the Rio Grande trough. Notable among the interruptions in thrusting is the Manzanita uplift. Upthrusts formed a staggered line of uplifts asymmetrical to the east, the highlands of which appear to have coincided with the present late Tertiary uplifts or to have lain along the edge of what is now the border of the Rio Grande trough. The uplifts probably resembled the Colorado Plateau monoclinal uplifts and may have been part of that province prior to the formation of the Rio Grande trough. This concept is not unlike the more generalized Laramide uplift proposed by Eardley (1962, p. 399-402), and that of Herrick (1898a, p. 27). Some of the thrusts that produced the uplifts lie rooted in the trough, as in the southern end of the Manzano uplift and possibly west of the Caballo and Fra Cristobal uplifts. In some instances, as near Abo Pass and in the Caballos, it appears that the normal faults of the trough may have the same root as the upthrusts but with opposite displacement.

Inasmuch as we believe that the high-angle thrusts and the Tijeras rift zone predate the Rio Grande trough, the question of their relative ages remains to be considered. Displacement on the Tijeras fault in the Precambrian terrane appears much greater than in the overlying Paleozoic rocks, especially in Tijeras Canyon. It is probable that the fault in the sedimentary rocks is a Laramide extension of a preexisting Precambrian fault. The Flatirons high-angle thrust impinges on the Tijeras fault in a zone of squeezing, shearing, and some overturning. The upthrusting appears to disturb and bend the Tijeras fault to the east. Assuming that the Tijeras rift zone was already in existence at the time of the Flatirons upthrusting, it is possible that the same force might also have aided in the development of the folds in the Tijeras basin. The strain pattern of the right echelon of faults from the Flatirons to the Wolf Springs is clockwise and the stresses involved would *be the* same as those responsible for the left separations along the Tijeras fault.

In summary, most of the structure along the east side of the Sandia uplift is quite different from the structure responsible for the great relief on the west side. A regional correlation with similar structures for 200 miles along the Rockies trend, and direct evidence for Laramide age in the southern part, suggest that the Sandia structures are also Laramide. Assuming further that much erosion would have accompanied the Laramide deformation, then a considerable part of the sedimentary section may have been removed from the Sandia Mountains area prior to their late Tertiary uplifting. Where the products of such erosion are is puzzling, but perhaps they are in the Galisteo Formation. If so the Galisteo, which rests with minor unconformity on the Mesaverde in the Hagan basin, would probably have had to overstep down to the Morrison or the Triassic in order to receive any sediments from the Sandia direction, and the distance of 2 or 3 miles would suggest sharper and greater uplifting than is apparent. From the nature of the proposed uplifting it would appear that the erosional product would lie to the east, but none is known in that area; there is little gravel to the east that is derived from late Tertiary uplift. The only remaining locale is in the Rio Grange trough, notably in its western part where great thicknesses of post-Cretaceous sediments are known. Importantly, because of earlier uplifting and erosion there, not as much of the 10,000 ft of pre-Tertiary sediments had to be removed from the Sandias during late Tertiary uplifting.

The most direct evidence of possible pre-Basin and Range deformation is in the Placitas area. In this area the folded Santa Fe rests with marked angular unconformity on early Tertiary and older formations (fig. 69). The Santa Fe is a fanglomerate consisting of fragments of Abo, which does not now occur in the nearby Sandia Mountains in places that could have been the source. These Abo fragments could have come from the Sandia uplift when it was much lower and before all or most movement on the Placitas fault. The gravel is not a high, Pleistocene gravel as Hoge (1970, fig. 19) thought but instead must be well within the Santa Fe sequence, if not in the lowest part. Considerable pre-fanglomerate uplift and erosion are indicated by steepness of beds as old as Triassic that underlay the surface on which the Santa Fe was deposited. The considerable deformation and erosion of pre-Santa Fe age in the Placitas area suggests pre-Basin and Range uplifting in the Sandia area.

Late Pliocene Santa Fe beds are downfaulted against the east-tilted Sandia uplift in many places. The general evidence suggests that the Santa Fe beds are the principal trough-filling sediments derived from the bordering uplifts. The uplifting appears to have gone on concurrently with the subsidence and filling of the trough; therefore, uplifting dates from the oldest of these sediments, or from the late Miocene. However, as suggested in the discussion of the Rio Grande trough much of the rise of the Sandia block may have come after early Santa Fe time. The uplifts continued rising through the Pliocene and into the Quaternary. The Santa Fe is dropped and tilted along the San Francisco fault at the north end of the range and at Tijeras Arroyo. There is further evidence in the form of Holocene fault scarps that the uplifting may still *be* continuing.

Just as the bordering uplifts may be considered as rims of the trough the trough margin may be considered a side of the uplift. In many respects the Rio Grande uplifts, such as the Sandia, are reactions that are complementary and counterpart to the trough subsi

FIGURE 69—SANTA FE FANGLOMERATE UNCONFORMABLY OVERLYING MESAVERDE CLAYSTONE AND SANDSTONE. FANGLOMERATE CONSISTS MOSTLY OF ABO AND DIPS ABOUT 45°. MESAVERDE DIPS 65° TO 70°.

dence. Although this is generally true, subsidence of the trough margin does not appear to be always matched or equalled by uplifts of the border. The crustal control, however, appears to have been primarily in the trough belt with uplifting primarily a reaction to the crowding action of the subsiding wedge. It is obvious that the reactive uplifting occurred irregularly along the border. The principal concern here is with the mechanics of growth of the Sandia uplift.

Many early explorers were impressed with the abruptness and grandeur of the Sandias. Marcou (see Introduction, this memoir) climbed the Sandias in 1853 studying the formation but ventured nothing concerning the origin of the escarpment. Herrick (1898a, p. 27) speculated that the "abrupt escarpment . . . may have been the axis of a monocline" but even if so the western limb must have "been faulted many hundreds of feet below the river level." Johnson (1903, p. 457) estimated a throw of over 4,000 ft in places; he also (1903, p. 136) cited limestone at the bottom and the top of the range and suggested a fault displacement of 3,000 ft. Fayette A. Jones, engineer and geologist, appears to have been the first to have suggested faulting as the main cause of the scarp and illustrated it as such (Ellis, 1922, p. 29). Jones (1904, p. 1-2) stated that "The great tilted orogenic block composing the Sandia range, lying east of Albuquerque, is regarded as classic in this extraordinary type of mountain modeling." It appears likely, however, that both Jones and Johnson may have gotten their ideas from Herrick who worked more in the area. Herrick (1904, p. 393), about the same time, began to believe in the fault-scarp concept, but related it to the limb of a broad anticline whose arch had collapsed into the Rio Grande valley. In 1908 Keyes (1908b, p. 435) published a cross section showing the frontal fault and also the back-slope (Barro) fault. He also showed the fault (p. 447) on three regional structure sections radiating from the Sandias—one to Santa Fe, one to Glorieta Mesa, and one to the Pedernal Hills.

In 1922 Ellis (p. 29-34) followed the fault origin but emphasized only a fault zone high along the western escarpment near the bases of the great granite facades. He ventured that the Pennsylvanian, seen in a small patch near the mouth of Embudo Canyon (map I), lay all along the base beneath the mesa gravel. He thus appears to have suggested that these beds projected upward to the high fault zone as a downfaulted western limb of an anticline. Darton (1922, p. 219) showed the uplift in cross sections as a faulted anticline with the faults well up in the granite and with none at the base. Later he (1928, p. 95-100) used the same cross sections and referred to the Sandias along with the Manzanos as "an anticline of great prominence" recognizing a northern "pitch" (plunging) of the uplift that has been described above. He (p. 99) also stated that "The strata on the west side of the Sandia Mountains are crushed and faulted along the higher part of the uplift, but the general structure is that of an anticline with a steep western limb." In part he appears to have reached this conclusion on the basis of limestone beds at the base near Embudo Canyon, but it appears possible that he was more influenced by his mapping and observations in such places as the southern end of the Los Pinos Mountains and in the Oscura and San Andres Mountains. The San Andres Mountains, in particular, show many examples of reversal of dip across the faulted uplift and basinward-dipping beds at the base of the clearly block-faulted uplift. It is quite probable that the Sandia uplift would have shown parts of such a limb at an earlier stage of uplift and erosion. Nevertheless, the evidence points to faults as the dominating final structure. The early form of the uplift may have been an anticline, but as the trough sank more deeply the western limb was dragged more steeply and sheared into one or more normal faults. By this hypothesis the early rise would have been anticlinal or monoclinal uplift which was then later faulted resulting from the trough subsidence. It is quite likely that the more strongly tilted Sandia uplift resembled the gentle Manzanita uplift at an early stage of deformation.

Another quite different hypothesis follows the Herrick suggestion of 1904, recently adopted by Eardley (1962, p. 401), which suggests that there is a broad anticline with one limb west of the Rio Grande trough and another forming the present eastern flank of the Sandia-Manzano uplift. By this hypothesis the broken steep-limb dips would result entirely from drag against the normal trough-bounding faults. It is difficult to accept the idea of an uplift as wide and long as the Albuquerque basin. It is also difficult to believe that pre-existing anticlines existed independently of the Rio Grande trough. Instead it appears that trough subsidence initiated the uplift and that westward dip in such an uplift would have been monoclinal drape or drag. The resulting form could have been a large doubly plunging anticline, the Sandia anticline as depicted in maps 3 and 4. The physiography of the escarpment indicates that there was one dominant fault although lesser ones existed. However, the base of the high granite facade is not a fault line. The individual faces are irregular and due largely to contrasts in the type of erosion at high altitude which produces cliffs rather than the rounded forms of lower altitudes.

Deformation by monoclinal bending may have ceased with the development of a few persistent faults, and in the Holocene, creep and occasional discontinuous slips may be the mode of uplifting. Current or recent creep has not been determined, but the existence of a small Holocene scarp along the Rincon fault (fig. 57) indicates that strain is likely accumulating and/or being dissipated in creep. Recent and possible continuing rise of the uplift and/or subsidence of the trough is indicated by relatively undissected fault facets like those of the bold escarpment between Sandia Peak tramway and Juan Tabo Canyon.

EARTHQUAKES

So far as we know, only two earthquakes have been reported in the Sandia Mountains, one in 1947 and another in 1956. In view of the high seismicity of the Rio Grande depression (Rio Grande rift or rift zone of some writers) between Socorro and Belen, and to a lesser extent through Los Lunas and Albuquerque, the low seismicity of the Sandia Mountains is rather remarkable. Earthquakes have been recorded in New Mexico since 1849, and since then hundreds of shocks have been recorded in the Rio Grande depression, chiefly in the Socorro-Belen segment. (See Northrop, 1942, 1945, 1947, 1961b; Northrop and Sanford, 1972; Sanford and others, 1972; and numerous papers by Sanford and by Sanford and others, not included in References, published from 1961 on.)

Earthquakes have been felt in Albuquerque on at least 28 different days in 13 different years from 1893 to 1974. Some of these originated near Socorro; some were near Belen; one severe one (May 18, 1918 of M.M. Intensity VIII-IX) occurred at Cerrillos; and at least 15 shocks originated beneath Albuquerque.

The first recorded earthquake in the Sandia Mountains occurred in the Tijeras coal basin between Tijeras and San Antonito at 9:50 a.m., November 6, 1947. Detailed information gathered from a questionnaire-card survey is given in Appendix 2. Greatest intensity (M.M. VI) was apparently at the C. A. Dooley ranch, Gutierrez Canyon, Zamora; M.M. Int. V was reported at Cedar Crest, San Antonito, and Sandia Park. This shock was not felt at Albuquerque or at Placitas.

The second earthquake in the Sandia Mountains apparently originated at the north end in the vicinity of Placitas at 8:30 p.m., April 25, 1956. Detailed information is given in Appendix 2. Greatest intensity (M.M. V) was reported at Placitas; M.M. Int. IV was reported from Tijeras and Tres Pistolas Canyon. It is curious that the shock was not felt at the Forest Service Ranger Station in Cedro Canyon, but shocks originating in mountainous regions of New Mexico have smaller areas of perceptibility than those originating in the Great Plains to the east (Northrop and Sanford, 1972, p. 151).

Geologic History

A geologic history should summarize in chronological order the processes, events, and condition of the area (and adjacent areas, where necessary), including past environments, sedimentation, crustal warping or orogeny, erosion, metamorphism, and igneous activity; it should not deal in terms of rocks, batholiths, uplifts, mountains, pediments, plains, or faults. It should not be a repetition of stratigraphy or structure but rather an integrated, sequential interpretation of observed geologic events and processes.

The evidence of Precambrian events is fragmentary throughout the region owing to widely scattered outcrops. Even with extensive continuous exposures interpretation of the history is difficult because of the profound metamorphism and deep erosion. However, from the existing exposures in the Sandia area it can be interpreted that sedimentary and volcanic materials were deposited in the area at different times as early as 2 billion years ago. Judging from the evidence of profound deformation and metamorphism, much mountain building or orogeny of northeasterly trend occurred in the area. What remains represents the considerably infolded or downfolded roots of the ancient mountains, indicating that the mountains were high and subsequently deeply and widely eroded to a low level. It is also evident from the existence of the large Sandia batholith that the roots of the old folded mountains were invaded from the lower crust by large masses of magma which thermally metamorphosed and shouldered aside mountain roots. This event took place about 1.5 billion years ago prior to the prolonged deep erosion which eventually brought most of the Precambrian rocks to view. By the end of Precambrian time the region had been stable so long as to allow erosion to reduce the area to a vast low plain.

Paleozoic time began with broad downwarping of the ancient peneplain which allowed the spreading of shallow seas across most of New Mexico. From about 500 m.y. ago, to about 300 m.y. ago, calcareous mud and sand were slowly deposited in the seas. The absence of these deposits in central New Mexico suggests that the Sandia area was exposed above Paleozoic seas, was undergoing erosion, and was contributing sediment to the adjacent seas. However, if the area had been submerged at times, subsequent broad, low upwarping in middle Paleozoic, mostly Mississippian, time allowed the removal of any previously deposited middle and lower Paleozoic sediment. Scattered remnants of thin Mississippian beds in the northern Sandias and in nearby uplifts indicate a marine shelf inundation of short duration.

With the beginning of Pennsylvanian time the sea moved widely into central New Mexico as the entire area gradually subsided except for a few islands and long north-south ridges or archipelagos that lay west and east of the Sandia area. One land area, known as the ancient Pedernal Mountains, lay some 40 miles to the east. Another, the Peñasco, lay perhaps 15 to 40 miles to the west (Read and Wood, 1947, fig. 2). During all of Pennsylvanian time the Sandia area continued to subside and receive lime mud, sand, and argillaceous mud, but during late Pennsylvanian time a rejuvenation in the height or size of the land sources is indicated by increased sand and granitic debris in the Pennsylvanian sediments. Finally in latest Pennsylvanian and/or earliest Permian time the sea became filled and continental nonmarine sand and mud spread on a vast river flood plain. Subsidence, however, continued as Early Permian (Abo) red-bed deposition continued apace with the growing adjacent mountains. By Middle Permian time wearing down of the mountains and the long persistent regional subsidence allowed seas to again spread widely across all of central New Mexico, this time as a shallow shelf and under arid conditions (Kelley, 1972a, p. 41). This was the time of the Yeso and San Andres deposition in which normal marine-water influxes alternated with drainage or desiccation, which left large and small lagoons or pools where evaporation was so high as to precipitate calcium carbonate and calcium sulfate. However, as before, the epeirogenic action was one of continued slow subsidence of most of central New Mexico, allowing several hundreds of feet of shelf sediments to accumulate.

Beginning in Late Permian time crustal subsidence of the central New Mexico area ceased, and widespread lack of sediment of that age indicates slight broad rise and possible erosional stripping of earlier shelf beds. The fine grain size of all the Middle Permian sediments indicates either absence or greatly subdued presence of the old lands as a source area. The positive stable condition of central New Mexico during Late Permian time continued into the Mesozoic Era, and the Sandia area is without sedimentary record during Early Triassic time.

In Late Triassic time the physical environment returned to river flood-plain conditions similar to those of the Early Permian. The climate was probably warm and wet as the red Santa Rosa and Chinle mud, sand, and locally gravel were deposited. Again subsidence by very broad epeirogenic downwarp attracted rivers carrying the sediments. The nearest source of the sediment appears to have been south-central Colorado. Before this period of slow Triassic subsidence ended, the Sandia area had more than a quarter of a mile of new thickness added to its crust.

Some of the latest Triassic and Early Jurassic sedimentary record is missing in the Sandia area, most likely by nondeposition and/or some slight broad stripping arising out of cessation of the subsidence and possible slight rise. In any event, the Late Triassic flood-plain fluvial environment came to a halt either by obliteration of the upland sources or by a change to aridity, and a whole new environment characterized Middle Jurassic time. The first Jurassic sediment of the area is largely eolian Entrada deposit. This clean, reddish and white sand blanket with its dune structures was spread over a vast area by strong and persistent winds as the Sandia climate again markedly changed. Soon, however, the Saharan conditions vanished as the shallow Todilto lake spread into the area from the western seaway. The howling Jurassic winds subsided, and the tranquil lake dominated most of central New Mexico for a short time; then arid conditions returned and evaporation turned the lake to wide white flats of gypsum.

In Late Jurassic time the lacustrine environment of Todilto time was superseded by a higher energy environment. It was a return to slow persistent subsidence in which mud, sand, and gravel were spread in the vast lakes and associated flood plains of Morrison time. It was not an inhospitable time, as the plants and dinosaurs that had made a beginning in Triassic time flourished. Sediment of the Sandia Morrison was borne in by rivers, lake currents, and winds from various sources, much from the south but some from low hills in south-central Colorado. Volcanic sand, dust, and some lapilli were contributed by streams from probable vents to the south. As elsewhere in central New Mexico the rather special Morrison environment probably continued into earliest Cretaceous time.

The southern source area for much of the Morrison sediments appears to have been an east-west-trending upwarp, low and slow-developing at first, but growing in late Morrison time to become important through Early Cretaceous time. Concurrently, the large Cretaceous seaway was spreading into southern and northeastern New Mexico as a forerunner to the return in force of the oceans that had not occupied the Sandia scene since Pennsylvanian time. The general evidence from New Mexico indicates that marine waters moved into the Sandia area from the east and northeast and progressively encroached or lapped onto the southern land area. About midway through Late Cretaceous time flood-plain deposits from the southwest pushed the shoreline northeastward out of the Sandia area and for the remainder of the Cretaceous the geosyncline continued its subsidence under nonmarine conditions. It was in this wet and swampy environment that the coal deposits of the Hagan and Tijeras areas accumulated.

During Late Cretaceous time central New Mexico must have subsided at a much accelerated rate, as is indicated by the relatively great thickness of the *deposits*. The area subsided into the Rocky Mountain geosyncline at a rate nearly 3 times as fast as all previous subsidence that may be inferred from the thickness of the preceding sedimentary deposits in the Sandia area. This rapid rate of subsidence was in a sense a prelude to the disturbances that were to come in the Cenozoic Era.

The next record of events in the Sandia area is from the thick Tertiary Galisteo deposits. Their age is not definitely known as the only fossils are a few vertebrates, suggesting an Eocene age. Based on comparative lithology it appears likely that the Galisteo is equivalent to several Paleocene (Raton, Nacimiento, and McRae Formations) and Eocene deposits (San Jose and Baca Formations). Even with the Galisteo being Eocene in age there is a possibility that some latest Cretaceous and earliest Tertiary, Paleocene, record is missing in the Sandia area. The Galisteo beds rest with erosional unconformity on the Mesaverde deposits; it may be concluded, therefore, that some uplifting and erosion occurred in the Sandia area prior to or during deposition of the Galisteo beds. Exactly what form or where within the area cannot be known directly and one must examine the mountain structures for type and compatibility with the latest deformation in the Sandia uplift. Tijeras rift zone faulting and folding took place earlier than the late Tertiary rise of the dominant uplifts, although there is some apparent offsetting of the Sandia and Manzanita uplifts. The Tijeras belt is a wrench zone which probably developed mostly in early Tertiary time and possibly just prior to or during the deposition of the Galisteo beds.

The echelons of high-angle reverse faults along the east and northeast sides of the Sandia uplift have aspects comparable to similar faults farther south in central New Mexico that have also been considered to be early Tertiary in age. However, there is some possibility that some, if not all, the movement on these faults occurred during middle or late Tertiary uplift of the Sandia Mountains.

Record of middle Tertiary history in the Sandia region is largely missing, as in many other parts of New Mexico. It appears that this was a time of general rise of the backbone of the continent. The broad north-south rise could have been several thousands of feet and may have resulted in elevating the still low-relief Sandia area from close to sea level to nearly its present altitudes, with the exception of the large uplifts which were to come later. In the northern ramp of the Sandia uplift west of Placitas, considerably deformed Santa Fe beds rest with marked angular unconformity on the Eocene Galisteo beds, strongly suggesting not only Laramide but possibly middle Tertiary deformation.

The late Tertiary record is good and filled with sedimentational, deformational, and erosional events. Beginning sometime in the Miocene, downbowing and faulting began in what is now the Rio Grande valley. Accompanying the subsidence, probably from the beginning, the borders buckled or were fault-tilted in response to the outward stresses induced by the subsiding wedge or wedges that were part of the trough. As the trough subsided, drainage into it from the sides, and the transfer of mass by erosion from the rising borders into the trough, probably isostatically aided the movements.

Throughout the development of the trough the terrain was undoubtedly similar to that of the present, although lacking the present magnitude of relief. Broad playa valley floors, alluvial fans, pediments, terraces, fault scarps, and volcanoes all could have been a part of the *scene 5* to 10 million years ago. In the subsiding valley, successive surfaces were buried, locally dissected, and reburied. Older terraces, pediments, alluvial fans, marginal faults, unconformities, and some volcanoes were repeatedly buried. These varied and complex features should be expected at depth, especially in the trough margins. At the rising borders, such as the Sandia uplift, the sedimentary section was dissected and stripped from the uppermost Mesaverde and perhaps the Galisteo downward until—near the crest of the uplift and especially on the steep, trough side—Pennsylvanian beds were stripped to the Precambrian. At that time, perhaps as much as 5 million years ago, the western escarpment began developing the rugged, cliffy topography that is present today. Is trough subsidence and mountain-building over? Quite likely not. A few young fault scarps are present, and the uplift as well as the trough may be imperceptibly moving just as it did in the Pliocene and Quaternary. Some small alluvial cones at the mouths of canyons are sharply dissected in ways that indicate a recent change to a steeper gradient. If they are under strain, the strain could be released by sudden faulting as appears to have occurred recently along the base of Rincon Ridge. The 1935 Soil Conservation air photos of Rincon Ridge show little sign of the fan scarp that Kelley discovered about 1965. If 10- to 15-million year geologic processes are continuing, then sedimentation, flooding, valley-filling, erosion in the mountains, and strain or release of strain by warping and faulting (with earthquakes) at the margin are all in progress.

Mineral Resources

Mineral resources in the Sandia Mountains area are varied and include metalliferous, nonmetalliferous, and coal deposits. Exploration for oil and gas has been conducted, but as yet without success. Among the metals, gold, silver, copper, lead, and zinc have been found, but little or nothing has been produced. The industrial mineral resources constitute the principal potential. Among these, limestone, shale, gypsum, and a variety of rocks for use in construction, landscaping, and roads have been mined. Barite and fluorite deposits have been prospected, but little or nothing has been produced. Coal occurs in the Mesaverde Formation in the Hagan, Tijeras, and Placitas areas. In the period from about 1900 to the early 1930's some mining was done, but, except for the Hagan basin little more than household or smithing usage was made. Ground-water resources are not considered in this memoir; the Bureau has a report in progress.

EARLY MINING OPERATIONS

Prehistoric inhabitants of the Sandia Mountains made use of chert and chalcedony thousands of years ago. Artifacts such as points and scrapers in the Sandia layer of Sandia Cave are composed mostly of chert although fragments of chalcedony occur; much of this material had a local source, chiefly chert nodules in the Madera limestone. Artifacts in the Folsom layer include scrapers made of Pedernal chalcedony and chert, believed to have come from quarries in the Jemez Mountains, and Folsom points of white chalcedony, "brownish agate chalcedony," and mottled purplish chert (Bryan, 1938b; Church and Hack, 1939; Hibben, 1941; Northrop, 1959, p. 5).

The chronicles and narratives of Spanish expeditions of exploration and colonization, starting with Coronado in 1540 through 1700, contain numerous references to mineral deposits of the Cerrillos, Old Placers, and New Placers districts, but no specific mention of the Sandia Mountains area.

The earliest record of mining in the Sandia Mountains area was in 1667. Toomey (1953, p. 5, 7) states:

> Documents now in the archives of Mexico and old Spanish documents in possession of the Gurule family of Placitas, bearing the date 1667 A.D., refer to five lost mines in this region of which the Montezuma Mine is one. This document mentions "la mina de Bentana, la mina de la Escalera," and states: "al sur *de* Placitas la mina Nepumeseno y en el miseno Canon la mina de Coloa," ("the Window Mine, the Ladder Mine, and to the south of Placitas is the Nepumeseno Mine and the Coloa Mine"). The document goes on to say, "lado orenta de Placitas Travegardo la mina Montezuma Antonio Jimenez," meaning, "that to the east of Placitas, Antonio Jimenez was working the Montezuma Mine," and supplements it with the statement that "Jimenez took twetve mules loaded with bullion to Old Mexico and never returned."
>
> Prior to the Indian Uprising of 1680 these so-called "Mines of Montezuma" were extensively worked by Indian slaves from the pueblos of Cochiti, San Felipe, Santo Domingo, and Sandia, all situated within a half day's ride of the mines. During the Indian insurrection the mines of this district were filled in and completely covered up and to this day some defy detection. However, during the latter part of the last century, five old Spanish ovens or ore roasts were located and in their vicinity two gold bars worth approximately $2,000 apiece were ploughed up by a local farmer. The above facts prove conclusively that the mines in the district were extensively worked and that rich ores had been taken from them.

The following excerpts pertaining to early mining and prospecting activities in the Sandia Mountains and nearby areas are from Northrop (1959).

> Wislizenus (1848) stated that several rich silver mines were worked in Spanish times "at Cerrillos, and in the Nambe mountains, but none at present." In the Cerrillos district,
>
> > ". . . the water as well as the ore had to be conveyed to the surface upon the backs of peons who climbed from terrace to terrace upon notched logs" (*Mining World,* Las Vegas, v. 2. no. 9. Jan. 16, 1882, p. 154).
>
> The estimated Spanish production of the Cerrillos district was more than $3,000,000 to the church and, in addition to this, they "filled the coffers of their king" (*Mining World,* Las Vegas, v. 2, no. 19, July 15, 1882, p. 260). A single mine, the Mina del Tero (Tiro), paid in tithes "to the Catholic Church of Spain" more than $300,000 at a depth of 100 feet. Another mine, the Rue Alevia, paid $237,000 to the Church of Spain in three months (*Mining World,* Las Vegas, v. 3, no. 6, Dec. 1, 1882, p. 88).
>
> In the Old Placers district,
>
> > "In 1680 the Ortiz mine . . . was a famous gold producer. Here the Pueblo Indians . . . were made to do almost superhuman tasks, climbing notched poles, which answered as ladders, with their burdens of gold-bearing ores" (Anonymous, 1901, p. 56).
>
> The placers here and in the New Placers district were operated onty with the greatest difficulty. Water had to be packed in on burros for many miles during the dry season and, in winter, snow was often melted with heated rocks. Referring to the New Placers district, Howe (1881) stated that
>
> > "In former years the dirt was carried to the Rio Grande on burros and there washed. The dirt is so rich that *even* this expensive method was profitable."
>
> In his report on the mines and mining of Bernalillo County, Howe (1881) wrote:
>
> > "Numerous ruins of smelters are atso found, giving indisputable evidence that mines were once worked on a large scale. Two hundred years ago the Indians, who had been enslaved and forced to work these mines broke out in rebellion and drove the Spaniards from the country. So intense was their hatred toward those places in which they had been forced to labor, that they filled up every old mine so that no trace could be found of them. A number of years after the Spaniards were allowed to return. . . ."
>
> More specific citations are certain news items such as this:
>
> > "An old mine has been discovered in the Tijeras canyon, with a tunnel 75 feet in. Tools of the old Spanish pattern were found in the tunnel" (*Mining World,* Las Vegas, v. 1, no. 11,July, 1881).
>
> In a description of the mines of Bernalillo County, one author (Anonymous, 1906, p. I I) stated that
>
> > "About two miles from the Ptacita of Tijeras, on the eastern slope of the Sandias, is the Longfellow mine. . . . It was discovered in 1840 and was operated by a Frenchman who reduced the ore to matte in a small adobe furnace. The metal produced by this furnace was used in casting many of the church bells for smalt towns in this portion of New Mexico. The remainder of the product was shipped east by pack train. The owner, by getting into trouble with the native populace, was forced to leave the country. Some time later the mine was again worked by a party from Chihuahua. Mexico, who shipped part of the ore east, but most of it went to Chihuahua. In 1863 the mine passed into the hands of a Las Vegas merchant, who, after a small amount of development work, encountered a large body of copper glance. He made no attempt to treat the ore, but sent it by ox-team to Kansas City, whence it

was shipped to the Atlantic Coast, the first shipment being to Baltimore, Maryland, and later shipments to Newark, New Jersey. His last shipment of three six-mule team-loads netted a profit of $8,000. The ore was a high-grade copper glance with yellow and red oxide and argentite. The gold values in the ore alone paid all cost of production, transportation and treatment. In 1882 a contract was let to clean out the old shaft and retimber the mine. A body of ore blocked out in 1863 was taken out, part being treated at San Pedro. Santa Fe County, and the rest was sacked and shipped east. An epidemic of smallpox among the miners resulted in the closing of the mine. Once more, in 1891-2, work was commenced under contract."

Ruins of ancient smelters were reported at many places in the Sandia Mountains and "much of the slag now found near these old smelters contains gold in considerable quantities" *(Mining World,* Las Vegas, v. 2, no. 9 [10], Jan 16 [Feb. 20], 1882. p. 169).

According to Burke (1896, p. 24),

"The Longfellow mine, between Tijeras and Coyote canons, is an old Spanish working from which great quantities of copper were produced in the early days of Spanish occupancy. Old copper vessels and implements made from this ore are found occasionally, and the old workings show that much ore has been mined here."

No mine is known two miles from Tijeras except possibly the Shakespeare about 1.5 miles to the south, but it is very doubtful that it was intended, as production of copper or other base metals in quantity is not known. Other possibilities are not present short of 5 miles to the southwest or 10 miles to the north. Reports of the type quoted above are often inaccurate or exaggerated. However, if the Longfellow mine is in the area it is most likely either the Mary M or Great Combination which are described below.

Gen. and Mrs. U. S. Grant visited the New Placers district in July 1880. Grant was elected president of the San Pedro and Cañon de L'Agua Company. It was reported that $800,000 was paid for the San Pedro property.

"Some large nuggets have been taken out, and Grant, who recently went to New Mexico to take a look at the place, is credited with expressing his belief that there is a good deal of money there if worked the right way. The great drawback is a scarcity of water. If this can be obtained it is said the placers can be worked profitably, and Gen. Grant has an idea that pipes can be laid from the Sandia mountains and sufficient water obtained" *(Mining World,* Las Vegas, v. I. no. I. Sept., 1880, p. 4).

In the New Placers district, Golden had 1,000 inhabitants and a newspaper, the *Golden Retort.* According to Howe (1881), pipes were being laid to bring water from reservoirs in the Sandia Mountains to the New Placers, a distance of 15 miles, *at a* cost of $500,000. Later, excessive pressure caused these pipes to burst on several occasions.

Remnants of hillside cuts for this old line are still present south of Palomas Peak.

According to Howard Bryan, in his column "Off the beaten path" *(Albuquerque Tribune.* Nov. 7, 1955), an article in the *Albuquerque Democrat* of May 18. 1889 stated:

"Considerable excitement prevails among prospectors regarding the whereabouts of a certain vein of horn silver that is supposed to be hidden by the Indians in the northern portion of the Sandias.

"For years the Pueblos have been known to be the possessors of a secret mine of silver that surpasses in richness anything known to exist in northern New Mexico. They make rings, bracelets and other barbaric ornaments out of pure silver, and when asked where the metal is obtained only answer by a shrug of the shoulders or a grunt."

The article stated further that pieces of the silver ore had been found in arroyos along the western foot of the Sandias, and that an old sheepherder had visited the mine one year before, or in 1888.

South-Western Mines, a monthly mining newspaper edited by F. A. Jones, started publication Oct. 5, 1908. The first number carried an article entitled "Mining activity in the Sandias" (Anonymous. 1908). A review of the Placitas district contains the statement that "the Valley View properties belonging to the well known aeronaut, J. A. Blondin,* are showing up quite favorable. . . ." Col. B. Ruppe and associates were engaged in developing the La Luz mine, near the crest of the Sandias. Also, there was activity in the Carnuel —Tijeras Canyon area, the Hell Canyon "district," and the Coyote Springs "district." In all, a dozen different and independent operations in the Sandia Mountains were described in the article.

**I had not a little difficulty determining why Mr. Blondin was reputed to be well known. Eventually I found a news item in the* Albuquerque Journal *(July 7, 1907), reporting that 'Joseph A. Blondin, of Albuquerque . . . better known throughout the east as an expert in ballooning and airship trials, proposes to make Albuquerque famous in the world of aeronauts by attempting this fall to beat the record for long distance ballooning held by Lt. Lahm, who won it last year by sailing in a balloon from Paris across the channel to the English coast, a distance of 402 miles."*

In 1909, Blondin and Roy A. Stamm became the first in America to make a balloon ascension above 5,000 feet. According to an obituary of Mr. Stamm (Albuquerque Journal, *Aug. 8, 1957), "The two . . . took of from Sixth and Central, sailed over the Manzano Mountains and reached a height of 13,000 feet before landing two and a half hours later and 90 miles away considerably short of their destination—Kansas. Loss of lift—not bullets which were fired at them by a woodsman near Escabosa —was blamed for the balloon's abrupt descent."*

MINING DISTRICTS, SUBDISTRICTS, AND CAMPS

For a long time the standard practice has been to locate claims, prospects, and mines by mining district and subdistrict. Distribution of mines and prospects is shown in fig. 70. A confusing array of names is found in the early literature on New Mexico mining operations. Before 1882, the terms "area" or "locality" were generally used. Beginning about 1883, the term "district" was used increasingly. The first map of New Mexico metals districts was by Lindgren, Graton, and Gordon (1910). This recognized only two districts in our area, Tijeras Canyon and Placitas.

A *Mining Map of New Mexico* was published in 1911 by the Clason Map Company of Denver. This map was also in Bulletin 1 of the Mineral Resources Survey of New Mexico (Jones, 1915). The text recognizes only 100 districts whereas the Clason map shows 141. Four districts are shown in Bernalillo County: Bernalillo, Coyote Springs, Tijeras Canyon, and Hell Canyon or Star (the last district is in the Manzano Mountains east of Isleta and will not be considered). In Sandoval County 3 districts are shown: Nero Placers, Placitas, and Sandia. The Nero Placers constitute a westward extension of the New Placers district of Santa Fe County.

An interesting feature of the Clason map is that the A. & E. Railway is shown heading southeastward from Elota, on the Santa Fe line a few miles northeast of Algodones, to Hagan, A dashed line indicates a projected railroad from Hagan southward to Frost, a few miles north of Barton, and through Venus to join the New Mexico Central Railway at Moriarty. Another projected railroad is shown extending southwestward from Frost through Tijeras Canyon to Albuquerque.

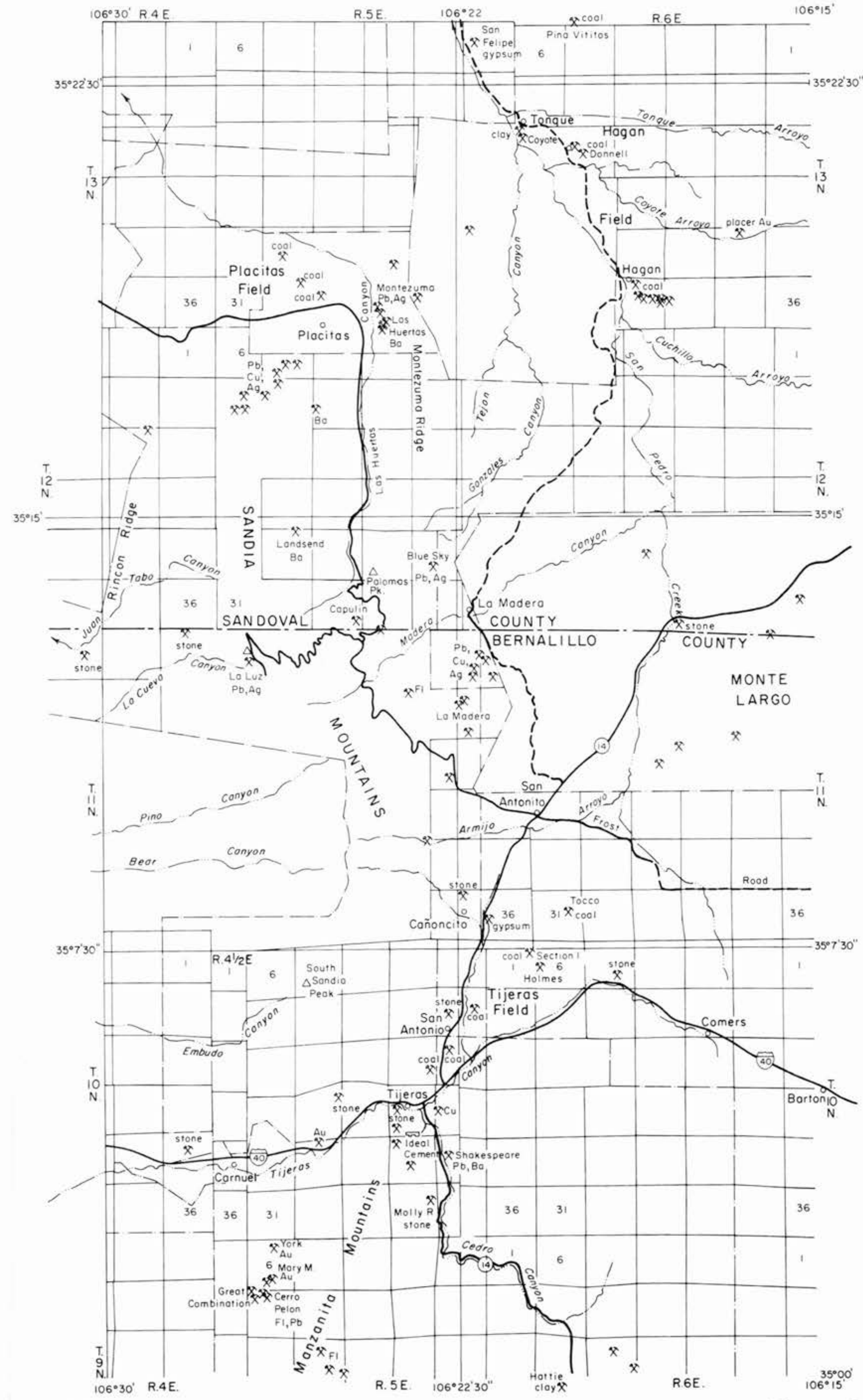


FIGURE 70—MINES AND PROSPECTS (INCLUDES ADITS, SHAFTS, INCLINES, TRENCHES, PITS, AND QUARRIES). Pb, LEAD; Cu, COPPER; Ag, SILVER; Au, GOLD; Ba, BARITE; Fl, FLUORSPAR.

Although extensive cuts were made south of Hagan rail was never laid.

A few years earlier Frost and Walter (1906, p. 2) had noted:

> The Santa Fe Railway traverses the southeastern part [of Sandoval County] for about forty miles, and part of the branch road of the Santa Fe Central from Moriarty to the coal camp of Hagan via Frost. now under construction, is within the county limits.

So many district names had been used for various prospects in the area that Northrop (1959) decided tc recognize only two large districts, the Tijeras Canyon it Bernalillo County and the Placitas in Sandoval Count) (see also File and Northrop, 1966).

The Tijeras Canyon district embraces the following "districts," subdistricts, and camps:

Carnuel	Manzanito Mountains
Coyote	North Manzano
Coyote Basin	Sandia (in part)
Coyote Canyon	Sandia Mountains (in part;
Coyote Springs	Soda Springs
Hell Canyon	Star
Hells Canyon	Star Canyon
	Tijeras

Of these, Hell Canyon, Hells Canyon, Star, and Star Canyon are beyond our area.

According to Frost and Walter (1906, p. 191),

> The Tijeras Canyon district has been prospected more or less, during the past fifty years, and . . . The principal propertie are the Silver Dollar, the Carnuel, the Long View and the Magnolia . . . Nearby is the Coyote district, better known fo its mineral springs than its mines, although at a very earl: period the Spaniards prospected near Chaves Spring and olc prospect holes are scattered over the district.

The Placitas district embraces the following:

Algodones	Las Placitas
Bernalillo	Montezuma
Capulin Peak	Nero Placers
Juan Tabo	Placitas-Montezuma
La Luz	Sandia (in part)
La Madera	Sandia Mountains (in part;
	Sandia No. 1

The town of Bernalillo is in Sandoval County but the Clason map shows the Bernalillo district in Bernalillc County east of Alameda.

According to Frost and Walter (1906, p. 303),

> The Placitas district is on the northern slope of the Sandia Mountains . . . The following claims have been located Balcomb, W. J. Bryan, Nineteen Hundred, Shamrock, Bibo Iron Cap. Montezuma. Yellow Jack and Valley View. East of the Placitas district is the Sandia district, in which are cement beds carrying gold. while copper, silver and lead ores arc found. The leading groups are the Gold Ring and Maceo.

METALS

Gold, silver, copper, lead, and zinc are extracted from small mineral deposits consisting of fissure-vein fillings with replacements and impregnations of fractured, permeable, or readily replaceable bedded rocks, especially limestone. These deposits are usually formed from hot juvenile or hypogene solutions ascending from depth. Possibly some of these deposits may be attributed to percolating ground water. Deposits found in the Sandia area typically contain one or more of the metals together with barite or fluorite which might be present in sufficient quantities to constitute an ore.

Small deposits of this type are present in the northern end of the mountains (Placitas district); in the southern part (Tijeras district); along the eastern flank of the mountains (assignable to either of the above districts); and in the Monte Largo area (assignable to the New Placers district around Golden). The deposits are mostly in the Pennsylvanian and Precambrian rocks. With the exception of some minor red-bed copper deposits in the Abo formation and possible small uranium deposits that could occur in the Santa Rosa, Morrison, or Galisteo Formations, the metalliferous deposits are restricted mostly to the Pennsylvanian limestones and those Precambrian rocks in proximity to the limestones. Thus, no precious or base-metal deposits are likely in the Sandia Granite distant from the Paleozoic unconformity, or in the younger (post-Permian) rocks in and around the Tijeras basin, Hagan basin, or those west of Placitas.

Numerous small prospects, a few of which have produced some ore, occur in the vicinity of Placitas. The Montezuma mine, best known of these, lies at the western base of Montezuma Mountain in projected N1/2NW1/4 sec. 34, T. 13 N., R. 5 E. 1 mile east of Placitas (map 2). The deposits generally lie on or near the large Las Huertas fault which has elevated Precambrian, Mississippian, and Pennsylvanian rocks of the Montezuma fault block against red sandstone and mudstone of the Permian Abo Formation. Vertical separation on this fault may be 2,000 ft. The wall rocks are considerably broken and dragged as seen on the surface and in the shafts and small cuts. Three shafts were dug within 200 ft. The northern shaft collars in limestone of the Mississippian Arroyo Peñasco Formation. It descends vertically and then inclines steeply to the west, evidently following a vein on the fault zone. The shaft is covered with heavy wire mesh and not readily accessible. The dump contains much vein matter of fine-grained drusy quartz and gossan along with green trap rock from either a dike along the fault or from Precambrian greenstone of the wall rocks. The middle shaft is about 90 ft deep and lagged the full depth. It would be inaccessible except in a rope sling. Similar vein matter and rock fragments constitute the dump. The southern shaft is untimbered and is about 8 x 8 ft. The much-broken walls are of the same limestone as in the northern shaft. The opening is wired over and an old headframe of steel pipe surmounts the shaft. From outcrops to the south it can be seen that Abo red beds lie just west of the shaft. Several hundred feet of drifting and stoping extends from the shafts. Small blebs of galena are readily found in vein quartz on the dump, but no sphalerite or any copper minerals are evident. Soft seams of micaceous hematite occur locally along the vein zone (Kelley, 1949, p. 230). A shipment of 21 tons of ore reported in 1920 averaged 12.5 percent lead and 11 ounces of silver (Elston, 1967, p. 29). Other shipments were made as late as 1926 but the record is masked by combined reporting from more than 1 mine. Ellis (1922, p. 41) reported copper and abundant fluorite from the mine.

Numerous small prospects are scattered through the hills south of the Placitas fault. These prospects are situated principally south and southwest of Tunnel Springs and the old abandoned fish hatchery. The area is extensively faulted and fractured. Numerous small faults either parallel or branch from the principal faults (map 1). Most of the prospects are in Pomecerro and Agua Sarca Canyons. Veins and irregular pods cement brecciated or shattered rocks. Commonly deposits occur along faulted contacts between Precambrian crystalline rocks and limestone. Until a few years ago many of the prospects were still open to inspection, even though much of the prospecting had been done as much as 100 years or so ago. Much information could be found as to the nature of the deposits and the faults or other structures that influence the formation of the deposits. Unfortunately, within the past few years many of the prospects have been bulldozed in some misguided effort to restore the surface. Small piles of ore and mineral specimens of the vein have been obliterated and mixed with dump material. In some instances soil and rock from adjacent gravel along with shrubs have been dozed and shoved over the old prospects thus creating more scarred land than existed before.

Veins that have been seen or still may be partly observed are generally 2 to 3 ft or less in width and not very persistent along strike. In most deposits barite, fluorite, quartz, and calcite dominate, with usually only minor or local metallic minerals such as galena, pyrite, marcasite, chalcopyrite, or sphalerite. The presence of former sulfides containing iron is markedly evident from the abundance of gossan.

Ellis (1922, p. 41) described 2 groups of claims: the San Jose, 2 miles southwest of Placitas at 6,000 ft and the Buckeye, 3.5 miles southwest at 7,500 ft. We have not identified these. According to Ellis the deposit, which had been developed by two shafts and a tunnel, is a fissure vein striking southwest "paralleling the main line of displacement" (probably the Placitas fault). The ores are copper, lead, and silver. Silver and gold usually occur in such deposits but rarely in observable quantities. Their presence is substantiated by the existence of some gold-bearing gravel in the Placitas area.

Wells and Wootton (1932, p. 16) reported that "a deposit of gold-bearing gravel conglomerate" had been worked as a placer in the Placitas area. This might have been along Las Huertas Canyon, the gold having come mostly from scattered small Precambrian deposits along the base of Montezuma Mountain and in the head of the canyon.

A small fluorite prospect known as the Capulin deposit is located in SE1/4 sec. 33, T. 12 N., R. 5 E. on Capulin Peak. It is on the Lagunita fault in Madera limestone striking about N. 20° W. and dipping 60° SW (map 1). The vein cements a fault breccia 3 ft wide and consists of fine-grained purple fluorite. Small pockets of galena are present along with some barite, calcite, and quartz. The deposit is reported to have been opened in 1925 (Talmage and Wootton, 1937, p. 74) and Rothrock and others (1946, p. 40) found that in 1927 the workings consisted of inclined shafts 20 ft deep and several small pits.

A deposit known as the Blue Sky (Phillips, 1964, p. 58-60) is located in the SW1/4 sec. 26, T. 11 N., R. 5 E. 1 mile northwest of La Madera. The vein is along a nearly vertical fault striking N. 40° W. with Madera limestone on the east side dropped against Sandia Granite and Sandia Formation on the west. The vein is 4 ft wide, 90 ft long, and is exposed in mine workings through a vertical extent of 40 ft or more (fig. 71). The vein zone is much brecciated and cemented by numerous white quartz stringers, often with coxcomb crystal development. Fluorite is widely distributed replacing both the granite footwall and the limestone hanging wall. Stringers and bunches of galena with minor chalcopyrite constitute the principal ore. Calcite and barite are also hypogene minerals in the vein. Drusy and vuggy textures are common, and Phillips found malachite, chrysocolla, cerussite, and limonite as common secondary minerals.

The main adit enters from the south on an 18-degree incline intersecting the vein 75 ft from the portal. An incline upward from the main adit reaches the vein 12 ft above the back part of the lower level.

The La Madera mine is in sec. 11, T. 11 N., R. 5 E. high on the west side of a ridge 2 miles south of the old site of La Madera village. At the base of the ridge in Tecolote Canyon are ruins of an old smelter which may have treated ores from a number of sources. The La Madera mine consisted of several tunnels one above another. The veins are narrow and contain barite, fluorite, quartz, and some galena. The La Madera mine is probably the same as the Darrel prospect mentioned by Rothrock and others (1946, p. 37, 39-40).

North along the ridge in sec. 2 a large cut 250 ft long, 30 ft wide, and 20 ft deep (Phillips, 1964, p. 60) opened a north-trending vein along a fault in Precambrian rocks. Granite forms the west wall with quartzite and gneiss in the east wall. Fluorite, barite, galena, and chalcopyrite are the original minerals. Secondary fibrous malachite, chrysocolla, and cerussite are common. This mine may be the Schmidt prospect referred to by Rothrock. Near the northern end of the ridge and the east quarter corner of sec. 2 are several short tunnels and shallow shafts with similar but smaller veins.

The best known old mine in the Sandia Mountains is probably the La Luz, perhaps the highest mine in New Mexico. The altitude of the tunnel is 10,040 ft (fig. 72). According to Ellis (1922, p. 40-41) the La Luz vein was

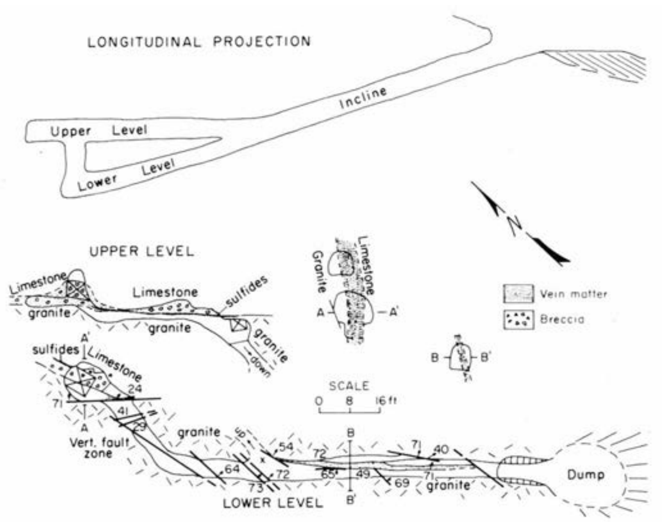


FIGURE 71—Plan and sections of Blue Sky mine. Sec. 26, T. 11 N., R. 5 E. (modified from C. H. Phillips, 1964).

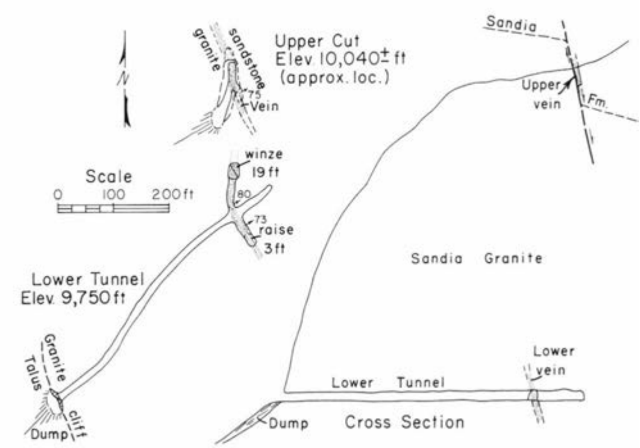


FIGURE 72—LA LUZ MINE WORKINGS.

discovered in 1887 by Juan Nieto. The approximate position of the upper, discovery tunnel is shown at the head of La Cueva Canyon on the U.S. Geological Survey Sandia Crest quadrangle. It is actually about 50 ft lower than the present trail on an old original trail to the mine. The tunnel was driven northward into Sandia Granite about 15 ft to intersect the vein, which strikes N. 23° W. The cut is considerably caved, but much-timbered small workings can be seen and partly entered. The vein at the upper tunnel is on a fault dipping eastward 75 to 80 degrees with Sandia calcareous sandstone in the hanging wall and reddish granite in the footwall. The Sandia is downthrown 50 ft. The vein is 2 to 4 ft wide in a sheeted and brecciated zone. Mineralization consists of fluorite with minor scattering of grains and small irregular patches of galena. The ore consisted mostly of lead and silver, but quite minor gold and copper were reportedly present. Currently the La Luz patented mining claims are owned by Maxie Anderson of Albuquerque.

According to Ellis the deposit was lost after first being located but was rediscovered in 1907. The property was purchased by Col. Bernard Ruppe and others. In 1909 the La Luz Mining, Smelting, and Development Company was formed. Between 1909 and 1921 a crosscut was dug from the base of the granite cliffs southwest of the upper tunnel and at 9,750 ft. It was driven northeastward about 272 ft to intersect the La Luz vein and hopefully develop considerable backs of ore to the surface. A vein in reddish granite walls was cut at 230 ft from the portal (fig. 73), and a small amount of raising and sinking was done without finding appreciable ore. The vein zone is 3 to 5 ft wide in sheeted and shattered granite. Vein matter consists of thin seams and irregular small replacements and void fillings. Purple fluorite and white to brown calcite are the principal minerals along with considerable supergene limonite. Galena or copper minerals are not readily evident, but minor quantities may be present.

There remains some possibility that the vein in the lower tunnel is not the one of the upper tunnel and that the latter would lie a short distance east of the end of the lower tunnel. We have not surveyed the position of the lower portal with respect to the vein outcrop, and as a result the projected connection of the two veins as shown by Fayette A. Jones (Ellis, 1922) may or may not be correct.

According to Eldred Harrington (personal communication, 1973) the mine was first known as the Ruppe mine, and the term La Luz was not used until after the La Luz trail was built. Original access to the mine was by trail similar to the La Luz trail, and all mining materials and any ore went over the trail, as a road to Sandia Crest did not exist then. A small cabin used to stand near the lower tunnel. The present La Luz trail differs considerably from both the original trail to the workings and the trail shown on the U.S. Geological Survey Sandia Crest quadrangle sheet (1961). The lower portal is only about 100 yards north of the trail where the trail is still on the north side of the canyon, near its head.

There are several prospects along the belt of the Tijeras Greenstone south of Tijeras Canyon. The Tijeras quadrangle shows 4, and 3 of these lie just southwest of Cerro Pelon in the Coyote Creek drainage. The other, the York mine, is 0.5 mile north of the peak in Tijeras Creek drainage.

The York mine is at an elevation of 6,680 ft in NW1/4 NE1/4 sec. 6, T. 9 N., R. 5 E. It is reached by traveling 2.5 miles south up Garcia Canyon and thence 0.8 mile up a steep side road to the mine, the last 100 yards requiring a 4-wheel drive vehicle. The deposit is in a 30-inch-thick band of marble in a fine-grained, greenish-gray green-stone schist. Dip of the beds is S. 77° E. (47 degrees at the surface, but appears to increase to nearly 80 degrees

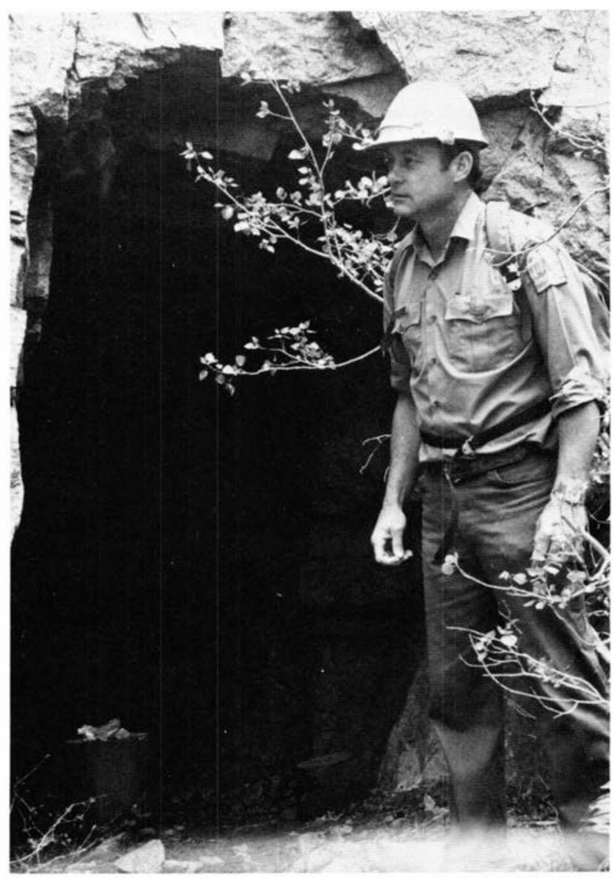


FIGURE 73—LOWER PORTAL OF LA LUZ MINE. AT BASE OF SHEER, 100-FT CLIFF OF GRANITE.

in the lower part). An inclined shaft follows the ore to a depth of 120 ft (Bruns, 1959, p. 30). The marble is sugary grained and gray to white. It is irregularly impregnated with grains of pyrite, chalocopyrite, sphalerite, and quartz, usually in separate bands. Some gold probably occurred with the sulfides though concentration is too low to constitute an ore. Bruns studied the ores in polished sections and found an early pyrite replaced and cemented by chalcopyrite and sphalerite and a later pyrite that either replaces chalcopyrite and sphalerite or is contemporaneous with them. Late quartz is also associated with the late pyrite. The ore minerals do not appear to be syngenetic and in fact appear to have been deposited after metamorphism of the country rock. Bruns suggests the possibility that the ores were of Precambrian age and introduced either from ore fluids from the Sandia Granite magma or from a Precambrian metarhyolite 1 mile south of the mine. If the latter source is considered, an early stage of pre-metamorphic ore deposition would have been followed by redeposition after metamorphism.

The deposit was most likely exploited for its gold content. No record of production is known. It was last worked to some extent in the late 1930's.

The prospects southwest of Cerro Pelon Peak are located around the head of a small valley that drains southward to Coyote Canyon. Four are in the Tijeras Greenstone and one in the quartzite which lies to the east. The 2 prospects shown at the head of the jeep trail on the topographic map are the Mary M prospects. The lower of these (probably on the Mary M no. 2 patented claim) consists of a tunnel driven S. 48° E. for 220 ft, several short branches, and a finger raise about 75 ft to the surface (fig. 74). The base of the raise is much caved and very little vein material or mineralized rock is evident in any of the faces. However, 2 small shipments of gold ore are reported to have been made to the A. S. & R. smelter in El Paso (Vincent Moore, written communication). The upper prospect, probably Mary M no. 3 patented claim, is a nearly vertical, considerably caved shaft sunk on a zone 6 to 8 ft wide, of quartz, calcite, and tourmaline stringers reticulated roughly parallel to the greenstone foliation. At the surface the foliation dips 63° S. 45° E. Gold assays probably motivated the prospect.

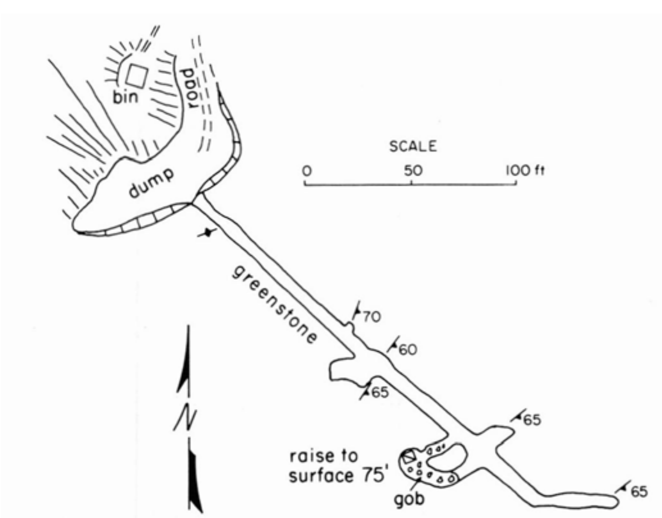


FIGURE 74—PLAN OF MARY M MINE.

The Great Combination mine lies in the northwest corner of sec. 7. The workings consist of a 255-ft adit driven S. 17° E. in greenstone to the quartzite contact exposed up the ridge from the portal. A narrow, apparently mineralized, shear zone was crossed at 200 ft from the portal (fig. 75). This zone was followed and apparently encountered good gold values not far to the west of the adit. All the gold ore was mined from the raise and stopes in this area, which is now caved. The raise and stopes were open in the early 1940's during a cursory examination of the mine. At that time an open stope 20 to 30 ft above the adit level was entered through a manway ladder. The mined area was not large and mineralization appeared lenticular and spotty. Nevertheless, considerable free gold in pockets was found, and shipments are reported to have been made to a smelter in Socorro (Vincent Moore, written communication). In the early days the mine was owned by a negro miner named Oxindine who was killed by a benzine explosion in his kerosene cook stove! Along with the spottiness of the gold came good specimens, and this is reported further to have led to considerable trouble with high-grading of samples.

The remaining exploited prospect in this area is in fluorspar veins in the quartzite. In the absence of a known name for the property it is herein referred to as the Cerro Pelon mine. The workings consist of two tunnels, a lower crosscut adit at an altitude of 6,730 ft and an upper drift adit 130 ft higher on the ridge (fig. 76). The lower tunnel was driven S. 34° E. for most of its straight-away length of 475 ft. The upper, probably first, tunnel drifts on a slightly arcuate vein whose

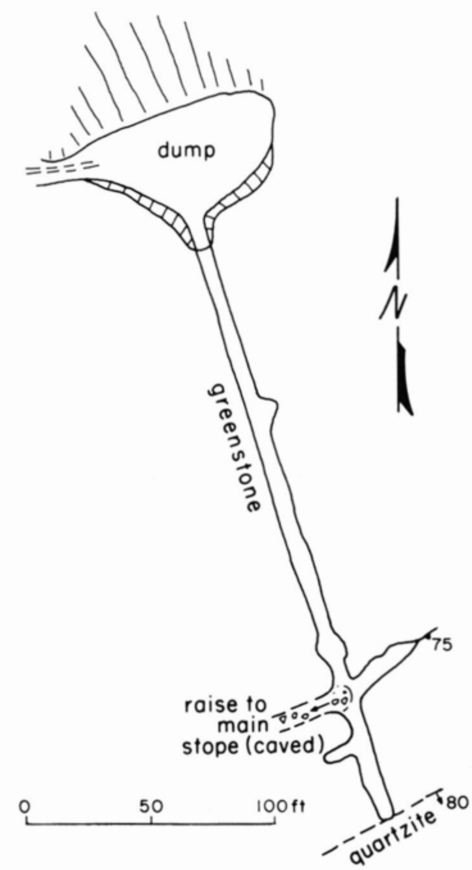


FIGURE 75—PLAN OF GREAT COMBINATION MINE.

overall direction is S. 16° E. The lower tunnel appears to have been driven to intersect the upper vein at depth where ore might have been stoped in raises to the original development level. A similar vein was cut in the lower tunnel about 350 ft from the portal. Its strike, however, is N. 4° E. with a dip to the east of 43 degrees whereas the upper vein strikes 10° to 28° W. and dips eastward 50 to 80 degrees. The southern end of the upper vein in the tunnel is about 140 ft northwest of the northern weak exposure of the vein in the lower tunnel. Furthermore, the upper vein cannot be traced in outcrop above the upper tunnel more than a few feet south of its exposure at the face of the tunnel. Likewise the upper vein cannot be traced in outcrop down the ridge north of the portal more than 50 to 60 ft. Whether the two veins have a single common fissure connection is not certain, unless the fissure rakes flatly to the southeast. Figure 76 shows a possible projection of the vein in the lower drift in the plane of the lower level to conform with the vein curvature in the upper drift. Had the lower adit been driven about S. 55° E. the vein might have been intersected in half the distance.

The upper vein cuts across quartzite beds dipping to the south at 55 to 60 degrees. The vein occupies a sheeted and brecciated fracture zone and consists of pale greenish fluorspar, quartz, and jasper with local patches of barite blades. Galena crystals occur locally. The vein ranges from 12 to 30 inches wide and varies from stringers and cavity linings in breccia voids to rather coarse massive shoots. The lower vein is similar. It ranges from thin stringers on joints to a 2- to 4-ft shoot where stoped in the short raise and winze from the diagonal drift driven south from the main tunnel. In the raise patches of galena remain along with fluorite. Some fluorspar and possibly lead ore might have been

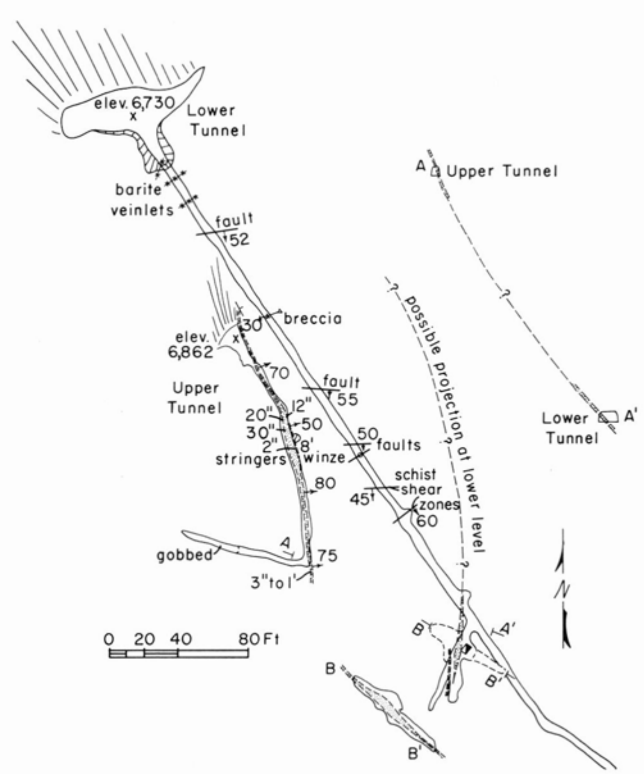


FIGURE 76—PLAN OF CERRO PELON MINE WORKINGS.

mined. Minor malachite and azurite may be found on the dumps and rare yellowish-green descloizite has been found in thin coatings along fractures in other vein material. Significant production from either level is doubtful.

The quartzite bed in the gneiss along Tijeras Canyon has been prospected in a few places, presumably for gold. It is doubtful that more than traces would have been found. Also small pegmatite dikes in the Sandia Granite and the Tijeras Gneiss have been prospected, probably for feldspar or mica but without success.

The deposits described above include the principal ones known to us. Doubtless, other numerous smaller deposits—perhaps important—remain to be discovered. In addition, a few other minerals like uranium, have some potential because of formational characteristics that have yielded discoveries elsewhere. In 1954 E. C. Anderson (1955, p. 18) noted that uranium claims had been filed for two localities in the Tijeras Canyon and Coyote Springs districts: 1) in sec. 23, T. 10 N., R. 5 E., in Madera limestone and associated carbonaceous beds, and 2) in sec. 2, T. 9 N., R. 5 E., with copper minerals in Abo Sandstone. The latter location is erroneous as it contains no Abo outcrops.

The Abo Formation has a small red-bed copper deposit near the center of sec. 23, T. 10 N., **R.** 5 E. The deposit follows a thin shaly seam in a light-brown feldspathic and locally granulitic sandstone. An inclined tunnel about 60 ft long follows bedding in the sandstone (dips 5° N.). The seam is discontinuous and only 1 to 6 inches thick. Malachite and minor azurite are the ore minerals impregnating the seam. A local flattened log about 3 ft long is especially mineralized in its bark area.

Small barite-fluorite veins occur at scattered localities in the Precambrian rocks of Monte Largo. Lambert (1961, p. 68-70) has described a small body of carbonatite associated with intrusive breccia in the southwestern corner of Monte Largo (sec. 16, T. 11 N., R. 6 E.). A gravimetric analysis made of a favorable sample yielded 0.295 percent Nb_2O_5. The exposure is small and scattered and no commercial ore body is indicated.

Several valley and terrace gravel deposits in the area have been prospected in small placer operations. Most of these have been more exploratory than productive. These include:

1) Las Huertas Creek near Tecolote
2) San Pedro Creek, mostly in the northern part of T. 12 N., R. 6 E.
3) Coyote Arroyo, especially secs. 25-27, T. 13 N., R. 6 E.
4 Cuchillo Arroyo, especially secs. 2, 3, 11, T. 12 N., R. 6 E.

In the Hagan basin uranium has been prospected using ground as well as airborne methods along the Morrison and probably Mesaverde and Galisteo outcrops. Numerous claims are reported to have been staked. According to Elston (1967, p. 59), "Selenium is reported to be associated with uranium in sandstones of the Mesaverde and Galisteo Formations in the Hagan basin." Doubtless other formations such as the Abo, Santa Rosa, Chinle, and even Santa Fe have been considered as targets. So far significant anomalies or shows have not been reported.

NONMETALS

Under this category are mineral and rock resources which have potential use and worth for their physical of chemical character without extraction of the contained metals. For the Sandia area they could include barite. fluorspar, limestone, shale, gypsum, and stone. Some of the barite occurrences described here are similar tc several described above under Metalliferous Deposits where they were considered as gangue. The deposits included here have greater quantities of barite and very few metalliferous minerals.

BARITE

A small barite mine referred to as the Las Huertas deposit (Williams and others, 1964, p. 21-23) occurs near the projected southern quarter-corner of sec. 34, T. 13 N., R. 5 E. (fig. 77). The deposit is in overturned basal Sandia Formation sandstone and limestone at 6,450 ft on the steep western slope of Montezuma Mountain. A small diapir of fine-grained Precambrian gneiss is thrust up from the west overturning the beds to a dip of 65 to 80 degrees southwestward. The deposit cannot be traced more than about 50 ft up slope above the cut face; it has the form of a steep lens. An adit enters on the horizontal, then inclines into steep slopes and to a vertical winze which is inaccessible but appears to be nearly 100 ft deep. Two caved tunnels 150 and 250 ft lower on the hill appear to have been driven to intersect the deposit, and if they did, some barite may have been mined in raises.

The deposit is predominantly coarse, tabular white barite, but considerable pale-green fluorite is present along with occasional 0.25 to 0.5-inch galena cubes. The deposit is as much as 8 to 10 ft wide. A sample taken by Williams and others (1964, p. 23) contained $BaSO_4$, 71.1 percent; CaF_2, 9.8 percent; and Pb, 0.17 percent.

The Landsend barite is on a high ridge spur at 8,980 ft in NE^1/4 NW1/4 NE1/4 sec. 29, T. 12 N., R. 5 E. not far from Osha Springs (Williams and others, 1964, p. 23). The prospects can be reached best by 4-wheel drive vehicle, traveling a distance of 4.5 to 5 miles over a rough side road that leads from NM-44 at the end of the paved section. The deposits are in highly fractured and brecciated limestone along a small fault striking N. 52° W. that is downthrown a few feet on the southwest side. The Madera limestone dips a few degrees eastward on a low dip-slope bench. Eight bulldozer trenches have been dug across otherwise rather poorly exposed outcrops. Some drilling in the trenches is reported to have been done, and it appears that the better holes were subsequently opened into pits to check the ore. The prospected area is about 400 to 500 ft in length along the zone.

The distribution of ore is irregular along, and a short distance away from, the fault zone. A honey-yellow fluorite and a white, very coarse, tabular barite are the dominant minerals. Minor galena crystals are present and in places considerable gossan suggests former pyrite. No copper minerals were observed. Large rosettelike masses of barite in plates nearly 12 inches in diameter dominate the deposits. The vein minerals both cement and replace coarse limestone and chert or jasperoid blocks. In one place there is a mass 5 to 6 ft across of alternating chert and coarse barite bands with the latter constituting about 60 percent of the exposure.

A similar deposit is located along a fault zone in NW1/4 NW^1/4 SW^1/4 sec. 9, T. 12 N., R. 5 E. at 7,000 ft. The fault strikes N. 10° W. and is downthrown on the east. As with the Landsend deposit the mineralization has spread irregularly away from the fault in several limestone beds. Because the slope of the hill is normal to the strike of the fault, and because the vein occurs mostly along the fault, early prospectors probably thought the vein trended up the ridge to the west. In an effort to find the ore in that direction a number of shallow dozer trenches were dug up the hillside for a thousand feet or so, but with nothing uncovered.

A prospect known as the Shakespeare mine existed atop a small hill in the NW'/4 sec. 26, T. 10 N., R. 5 E. 1,000 ft northeast of the junction of the Chamisoso Canyon road with NM-14 South. The deposit was developed by a vertical shaft and a few cuts. The shaft was more than 100 ft deep and had water in the bottom. Another shaft had been dug on the vein near the southern base of the hill (Brown, 1962, p. 60). A short tunnel on the vein exposed the Otero fault on which the vein is developed. The dip is 80° to 90° W. and the fault is downthrown to the west (map 1). The principal mineral in the vein is barite; some fluorite, quartz, and calcite are present.

Unfortunately all these prospects have been completely bulldozed away within the past two or three years. It is unfortunate as the exposures contained very worthwhile geologic relationships for the area.

MINERAL SPECIMEN OCCURRENCES

Exact localities are not known for many of the following interesting occurrences. In other cases, the old dumps of prospects and mines have been destroyed by owners or others wishing to discourage trespassers.

Beryl In 1972 Jerry Cape found a specimen of beryl imbedded in quartz of a pegmatite dike. The hexagonal crystal is 1.5 inches in diameter and light-greenish white. The locality is on the top of a small ridge spur in the SW'/4 NE1/4 sec. 2, T. 10N., R. 5 E.

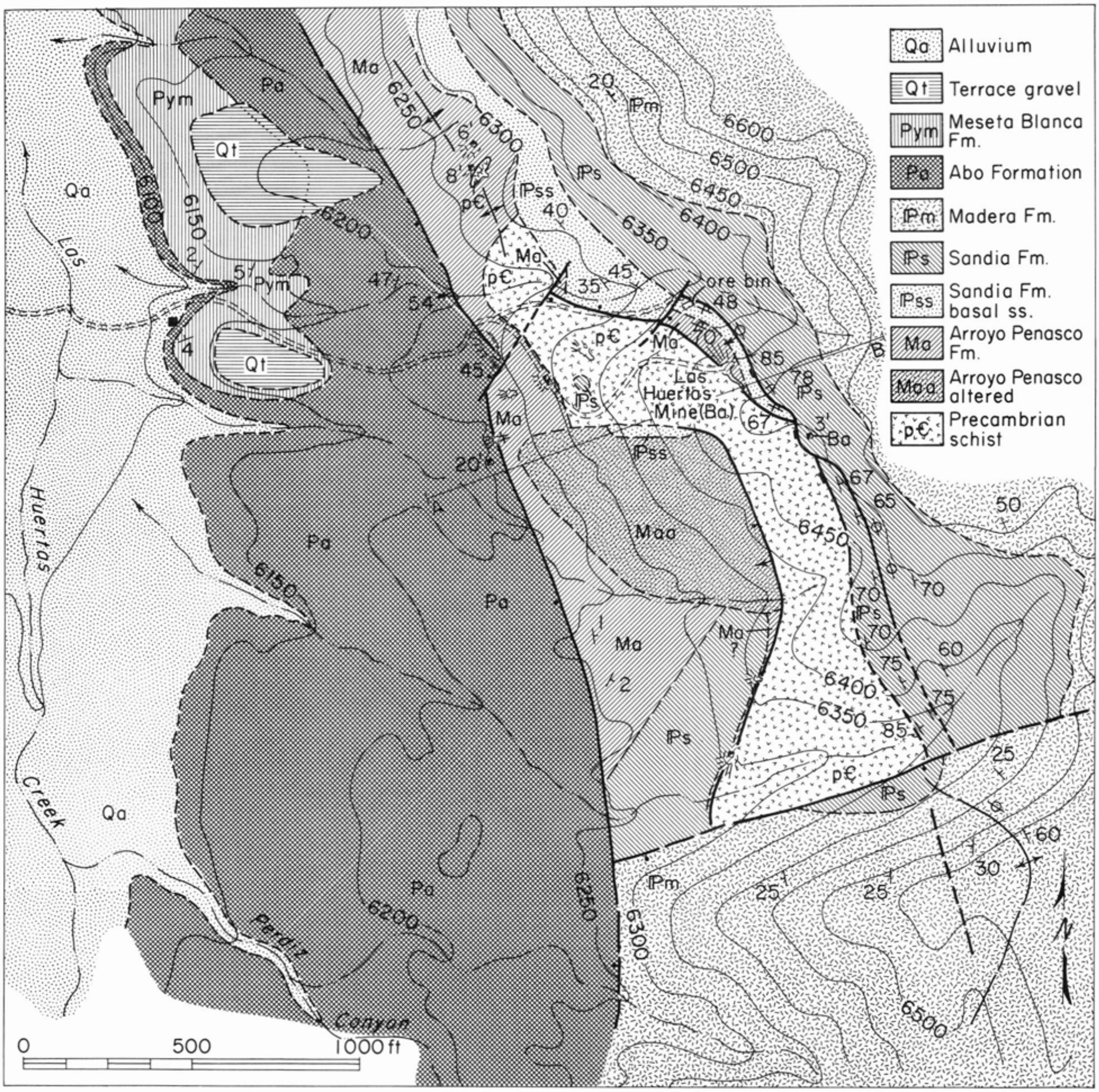
Calcite Several varieties have been reported. Good crystals occur in concretions near Hagan. Anthraconite has been mentioned in early accounts as occurring between Placitas and Golden, possibly in the Todilto Formation. Dripstone, calcareous tufa, travertine, and Mexican onyx occur in Las Huertas Canyon and especially in several caves.

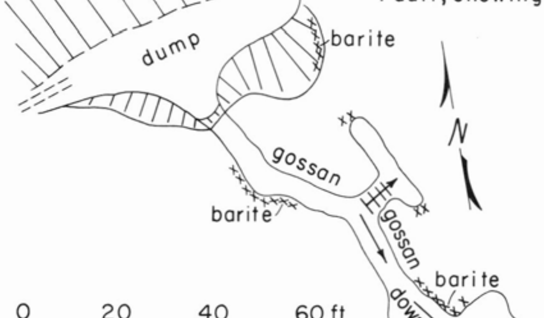
Cerargyrite (?) A news story in the *Albuquerque Democrat,* May 18, 1889, reported a vein of horn silver somewhere in the northern Sandia Mountains; prospectors had found pieces in washes along the foot of the mountains, and these specimens would readily melt in the flame of a match.

Cuprodescloizite or Descloizite A thin yellowish-green stain and crust on fluorite and quartzite was found on the dump of the Cerro Pelon mine.

Garnet Crystals as large as 2.5 inches across were found just north of Embudo Canyon by Gordon H. Wood, Jr. in 1941.

"Graphite" Herrick (1900b, p. 12) described near Whitcomb's Springs "a considerable band of graphite which has been opened under the supposition that it





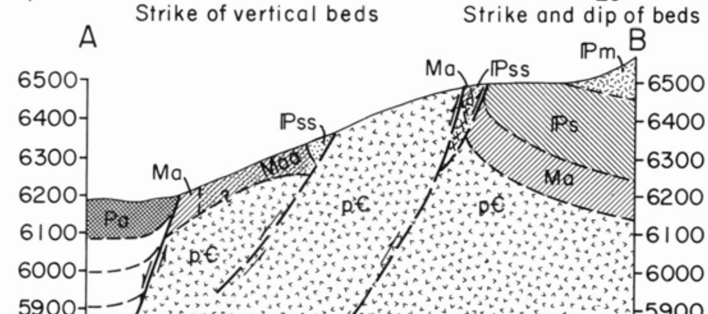


FIGURE 77—Geologic map and section of Las Huertas mine area.

was coal." Ellis (1922, p. 40) described it as "a rather impure grade of the amorphous variety," in a bed 1 to 3 ft thick.

Hematite var. Specula rite Narrow seams of soft micaceous material were once mistaken for cinnabar in the Placitas district.

Ilmenite Tyson Ashlock (personal communication, July 10 and Sept. 13, 1954) found radioactive ilmenite in a small pegmatite in Tijeras Canyon; plates 3 inches across and 0.4 inch thick contained 0.005 percent uranium, a trace of vanadium, and possibly a trace of thorium.

Ocher Older reports mentioned both red and yellow ocher, one bed several feet thick, in the Tijeras Canyon district. Elston (1967, p. 58) notes that Kelley thought one occurrence was probably a local spring deposit. Hibben (1941, p. 3) found that yellow ocher "pervades the [Sandia] cave in all but the very lowest strata."

Pyromorphite Small crystals, less than 0.04 to about 0.08 inch long, of greenish amber-yellow color, and highly resinous luster, were found by Parry Reiche Nov. 20, 1943 in a small prospect pit on the north side of Coyote Canyon north of Coyote Springs. The pyromorphite is associated with fluorite and calcite.

Silver In 1909, somewhere in the Placitas district, Emil Kleinwort struck "some very high grade silver ore. One nugget, as large as an egg of almost pure silver was taken out" *(South-Western Mines, v.* 1, no. 12, Sept. 5, 1909, p. 5).

Strontianite Apparently the first reported occurrence in New Mexico was by Guy V. Martin (oral communication, June 27, 1936) at a locality about 2 miles west-southwest of Tijeras. It occurs as radiating fibrous masses, with fibers 2 inches long, of pale yellowish brown color.

Tourmaline Masses weighing as much as 50 lbs were found by Gordon H. Wood, Jr. (oral communication, 1941) just north of Embudo Canyon.

Check lists of minerals, both megascopic and microscopic, reported through 1960 from the Tijeras Canyon and Placitas mining districts are given by Northrop (1961c, p. 172, 173).

CEMENT MATERIALS

By far the largest and most important mineral resource of the Sandia area is limestone for the manufacture of cement. Although limestone is the most widespread sedimentary rock in the area, much of it is in high and inaccessible parts of the Sandia and Manzanita Mountains. The most accessible areas lie near Tijeras, along NM-14 South, along 1-40 east of Zuzax, and around Placitas. Before Ideal Cement Company built its plant both the Tijeras and Placitas areas were prospected.

Ideal's quarries and plant south of Tijeras (fig. 78) are situated along the bottom of the northern end of the Apachitos syncline in the Wild Cow Formation (Myers, 1973, p. 1). The limestone bed currently being quarried occurs at the surface of the following places: dip slopes of the west limb of the syncline west of the cement plant, dip slopes to the south near the syncline axis, and the ridge top south of the plant about on the axis. The mine geologists early assigned names to the units that were drilled during exploration and development in the 1950's. The bed that is being mined is 30 ft thick, but erosional stripping has limited it to about 20 ft in some faces (fig. 79). The bed is referred to as the Lime Kiln, a name given for its occurrence and use at the old lime kilns northwest of the plant. It is immediately underlain by a reddish-brown shale which is mined for the clay needed in portland cement; this unit is 16 to 20 ft thick and is termed the Red Bed. Beneath the Red Bed there is another limestone unit 65 ft thick referred to as the Knobby, a name apparently given for nodular limestone and perhaps some nodular chert. The Knobby unit also has much intercalated shale, and only about 15 ft of the unit would be mineable limestone. All these units are in the Sol se Mete Member of the Wild Cow Formation.

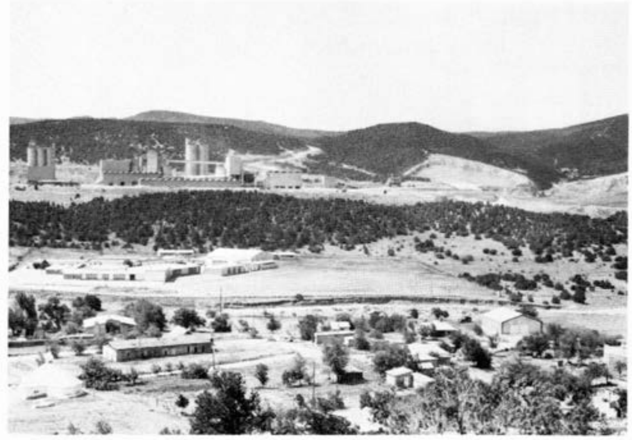


FIGURE 78—IDEAL CEMENT CO. PLANT AT TIJERAS (LOOKING SOUTH). TIJERAS CREEK AND VILLAGE DWELLINGS IN FOREGROUND. ROOSEVELT A. MONTOYA PUBLIC SCHOOL ON FLAT SOUTH OF CREEK. CEMENT PLANT AND 2 QUARRY PITS IN BACKGROUND.

The Lime Kiln bed is variable in overall mine-run composition. Its better parts run about 94 percent $CaCO_3$ and mining cut-off is at about 75 percent. Silica is less than 5 percent and most of the lower grade between 75 to 95 percent of the lower grade is attributable to shale laminations and the argillaceous nature of some parts of the limestone beds.

Analyses (Ideal Cement Company) of average quarry face samples are as follows:

FIGURE 79—QUARRY OF IDEAL CEMENT CO. WEST OF PLANT. LIME KILN BED WHICH HAS PRINCIPAL LIMESTONE SOURCE IS IN FACE OF SHALLOW QUARRY. "RED BED" SHALE ALSO QUARRIED IN LOWER SHALLOW CUT, IS JUST BELOW THE LIMESTONE.

Chemical analyses of average quarry face samples at Ideal Cement Company, % weight

Composition	Limestone: (Loss-free oxides)		Red Bed
	No. 1	No. 2	
SiO_2	21.39	13.48	52.04
Al_2O_3	3.95	2.49	18.64
Fe_2O_3	1.06	0.67	1.49
CaO	71.47	45.03	8.13
MgO	1.20	0.76	2.38
SO_3	0.03	0.02	0.06
Na_2O	0.21	0.13	0.66
K_2O	0.22	0.14	1.81
Loss		36.99	13.86
Total	99.43	99.71	99.07

Production from the Ideal plant began in 1959 with a capacity of 1,000,000 barrels a year. However, expansion was almost immediately necessary to its present annual capacity of 2,500,000 barrels. It has two raw grinding mills, two kilns, and two finish grind mills. Fuel is gas. At present limestone is being mined from the third strip quarry to be opened, located on top of the ridge south of the plant.

In the beginning gypsum needed in the cement was mined from a local lens of steep-dipping Todilto gypsum 4.5 miles north of the plant along NM-14 North in SW1/4 sec. 36, T. 11 N., R. 5 E. This deposit soon proved inadequate as a source and Duke City Gravel Products Company was contracted to develop a much larger source on the San Felipe Indian Reservation along Tongue Arroyo in SW1/4 sec. 1, T. 13 N., R. 5 E. On the average about 60 tons of gypsum per day is trucked some 50 miles from Tongue to Tijeras. In addition to limestone, shale, and gypsum, a small quantity of iron oxide is necessary in the manufacture of portland cement. For this requirement about 20 tons per day of iron ore is contracted from a mine at Jones Camp (Kelley, 1949, p. 213-223) in Socorro County.

BUILDING STONE

Included here is any hard rock trimmed, broken, or untrimmed that is used in construction. Such rock must be well cemented, crystalline, and durable against wear, solution, or staining by weathering. In the Sandia area a variety of rocks has been used or could be used such as granite, gneiss, quartzite, schist, limestone, sandstone, and certain dike rocks. In the past many small buildings, walls, streets, or walks in the Albuquerque region have been built of rocks from the Sandias. More use probably would have been made of these rocks had not adobe been so available and suitable. Further curtailment of the use of natural stone as well as adobe has come during the past three decades with the development of fabricated blocks, slabs, and walls from crushed stone, gravel, and volcanic cinders.

In the past many dwellings in the Sandia area have been constructed of the local stone, most commonly Precambrian granite, gneiss, or quartzite, Madera limestone or sandstone, and sandstone from the Mesaverde, Dakota, Entrada, Santa Rosa, Yeso, Abo, or Sandia Formations. In the construction of such buildings and associated walls or walks pieces of suitable shapes and colors are found in the nearby area or dug by hand from local outcrops or soil, and usually used with a minimum of breaking or trimming.

The many abandoned buildings at Hagan usually have foundations or lower walls of Mesaverde (Una de Gato) sandstone surmounted by adobe bricks although some of the larger ones like the old recreation hall have parts constructed of concrete or fired clay bricks and tile. Possibly some of the brick and tile came from the Tongue brick plant. The few remaining walls at Coyote are largely adobe although most foundations are from nearby Mesaverde sandstone.

In the old part of Placitas dwellings consist mostly of adobe walls with foundations of sandstone blocks from either Dakota or Mesaverde sandstone. At old Cañoncito, just off NM-14 North on the east side of the mountains, the houses are a mixture of Santa Rosa sandstone and adobe, but considerable exterior stuccoing prevents easy recognition. At Tijeras the old buildings include stone, adobe, and log types. The stone-walled buildings are scarce but the few remaining ones are built largely of red-brown sandstone of the Abo Formation (fig. 80). Some are a combination of red sandstone in the lower parts surmounted by adobe or logs. Along NM-14 North there are a few dwellings made of Mesaverde sandstone whereas on NM-14 South are some of Madera limestone. In Tijeras Canyon there is one stone house built in the 1940's entirely of the surrounding Sandia granite (fig. 81) and another built on Cibola Gneiss constructed of assorted gneiss types and associated aplite (fig. 82).

FIGURE 80—DWELLING EAST OF TIJERAS STURDILY CONSTRUCTED OF ABO SANDSTONE.

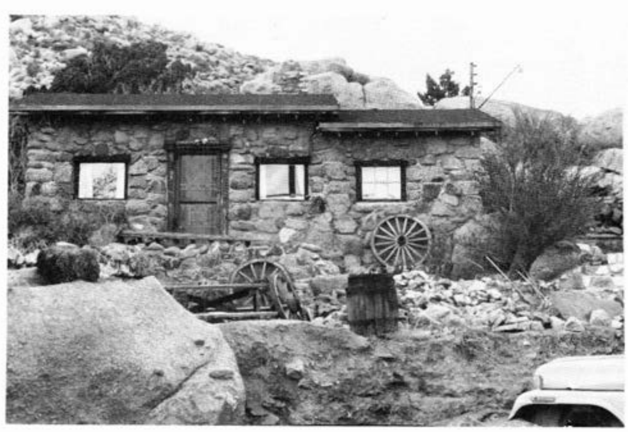


FIGURE 81—DWELLING IN TIJERAS CANYON SOLIDLY BUILT OF SANDIA GRANITE.

Flagstone for walks has come most commonly from thin-bedded but well-cemented sandstone of the Santa Rosa or Chinle Formations. Bedding needs to be parallel with easily split partings at intervals of 2 to 4 inches. Weak clay laminations within the flagstone slabs cause them to peel and flake with weathering and use.

During the past decade with the surge in highway construction, park development, and architectural landscaping many boulders and huge blocks have been brought from the mountains to the city. Some of these have been quarried from favorable outcrops, but the best are the very large, weathered, and natural-appearing boulders often with lichen coverings that have been selected individually from readily accessible spots along the edges of the mountains. Small local firms are sporadically in the business of finding and supplying such rocks to lawn and landscaping companies. In other instances contractors and institutions simply find their own as needed. Thus, the University, the city or the county may on occasions use their own equipment such as small lifts or cranes to get the stone. Along the numerous road dividers in Albuquerque there are examples of large boulders brought from the Sandias. Perhaps the best of these are the large spheroidally weathered residual boulders of Sandia Granite. These fine specimens were weathered in place and commonly have a nubby appearance caused by the resistant large feldspar phenocrysts standing out on the surface. Elsewhere on road dividers are reddish-brown sandstone blocks from the Abo Formation, Precambrian quartzite and even some white gypsum from the Todilto Formation.

Another use of stone is as riprap, which is commonly laid to prevent rapid erosion. It is used as a lining in the south diversion channel, locally on steep fill slopes along highway fills, especially near overpasses, and along certain dams, spillways, culverts, and river embankments. Angular rather than rounded rocks are less likely to roll in heavy run-off. Most riprap used in the Albuquerque area has been angular volcanic blocks, obtained along the Rio Grande, as seen in the south diversion channel and around the Dukes Baseball Stadium. However, in a few small areas quartzite from the Manzanita Mountains has been used.

LOOSE AGGREGATES

Sand and gravel are the principal loose aggregates used in construction, especially in concrete. Because of abundant supplies in the Rio Grande valley little is produced in the Sandia area. Sources are, however, plentiful in the lower courses of most canyons and in the widespread alluvial aprons bordering the front of the Sandias and spreading widely east of the mountains into Estancia Valley. Much sand and gravel is also present on the Ortiz pediment surfaces around the San Pedro drainage system north and east of the Sandias. Elsewhere, particularly along the Tijeras drainage system, local old river terrace gravels constitute lesser sources. The New Mexico Highway Department has used these supplies at times mostly as fill barrow material or on occasions as a subgrade. As the area to the east of the mountains is developed these local supplies continue to be used by individuals as well as contractors for road surfacing and other construction.

Rock for preparation of crushed aggregate used in building subgrades has been mined from two quarry pits, both in Madera limestone beds. One of these is in SP% sec. 5, T. 10 N., R. 6 E. (fig. 83) along the old US-66 route. This pit has not been used for nearly 40 years. Another pit along NM-14 near the edge of sec. 34, T. 10 N., R. 5 E. on the Molly R mining claim (owned by W. G. Nickol), has been a source of crushed aggregate for 1-40.

LIME

In the past lime has been made in small kilns using the local limestone. Lime is calcium oxide, CaO, and is made by dead burning limestone or dolomite to drive off the carbon dioxide. Lime has a variety of uses as in plasters, agricultural soil improvement, smelting of ores, refractory furnaces, and numerous chemical processes. Talmage and Wootton (1937, p. 107) reported that at least nine counties in the state had quarried limestone for the production of lime.

A number of old small kilns are scattered in Madera outcrops of the mountains. Two of the largest of these kilns are at the base of the limestone ridge on the south side of Tijeras Creek about one-third mile west of the

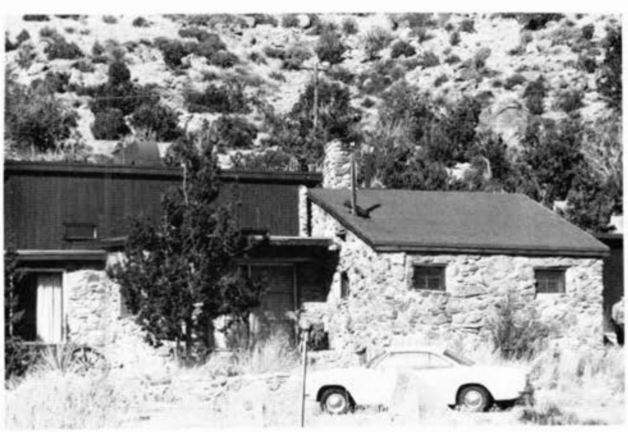


FIGURE 82—LARGE DWELLING IN TIJERAS CANYON AT ATANACIO RD., BUILT OF VARIOUS TYPES OF GNEISS, SOME APLITE, AND MINOR AMOUNTS OF GREENSTONE.

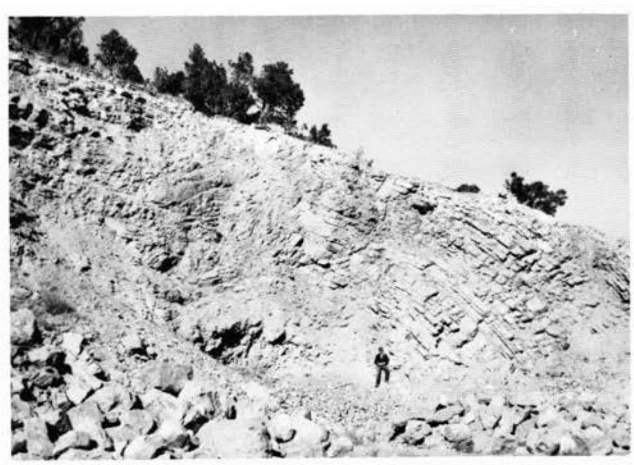


Photo by Gene Polk, Marvin Matheny, and John Lookingbill

FIGURE 83—HIGHWAY LIMESTONE AGGREGATE QUARRY ALONG OLD US-66. SMALL ANTICLINE EXPOSED IN WALL IS FORMED BY DRAG ON FAULT TO RIGHT OF VIEW.

village of Tijeras. The old kilns have been filled recently to prevent people from falling into them. They are about 25 ft apart and about 30 ft high. One kiln is lined with a buff-colored sandstone and the other with brick; they are surrounded by a buffer fill of sand held in place by a rock wall. The limestone used to make the lime came from a quarry immediately south of the kilns. The quarry, which was 150 ft long, 100 ft wide, and 15 ft deep is in the same limestone bed now quarried by the Ideal Cement Company a short distance to the south.

SHALE AND CLAY

Shale and claystone occur principally in the sedimentary rocks of the Madera Formation and in the Mancos and Mesaverde Formations. Additionally clay of worth might be found in the Sandia Formation, in red claystone of the Abo and Chinle Formations, and in the gray claystone of the Morrison Formation (Hawks, 1970, p. 7-13, 15-22). Some valley-bottom alluvial clays are of potential use in the mountain areas, just as brick clay has been produced from flood-plain clays of the Rio Grande valley (Talmage and Wootton, 1937, p. 64).

The only clay mining in the Sandia area is from a 40-ft dark-gray claystone bed in the upper part of the Madera. These beds have recently been included in the middle Pine Shadow Member of the Wild Cow Formation by Myers (1973, p. 1). The Kinney Brick Company, successor to the New Mexico Clay Products Company that made bricks from Rio Grande clays, discovered the good claystones of the Pine Shadow in secs. 18 and 19, T. 9 N., R. 6 E. in the early 1950's and located the deposits under several Hattie claims. The Hattie clay pits have continuously produced brick claystone since 1954 and have averaged 18,000 tons per year. The claystone is trucked to the brick plant in Albuquerque. Test data on the Hattie claystone has been given by Hawks (1970, p. 12) as follows:

SAMPLE B64-1 (Madera Fm.)

Raw color	medium-gray		
Munsell designation	N 5.5		
Water of plasticity (%)	18.9		
Drying behavior	good		
Linear drying shrinkage (%)	6.0		
Dry modulus of rupture (psi)	1006		
Firing temperature (°F)	1800	1900	2000
Firing behavior	good	good	small cracks
Color	red-brown	red-brown	red-brown
Munsell designation	10R5/10	10R5/8	10R5/10
Firing shrinkage (%)	0.0	–0.4	–0.4
Total shrinkage (%)	6.0	5.6	5.6
Modulus of rupture (psi)	2750	2594	2165
Water absorption (%) (5 hrs)	12.4	12.1	10.8
Apparent spec. grav.	2.36	2.36	2.44
Bulk density (g/cm³)	1.86	1.86	1.87
Ignition loss (%)	13.2	13.2	13.2
Pyrometric cone equiv.	cone 4—dark olive		

In the early 1930's a claystone pit in Mancos Shale was opened up along Tongue Arroyo near the abandoned settlement of Tongue in the Hagan basin. The claystone was used for making brick, and kilns near the pit are reported to have been fired by coal from the Hagan basin. The principal pit next to the abandoned brick plant foundations is 150 x 150 ft and as much as 20 ft deep. The deposit consists of moderately dipping dark-gray claystone in the east and west walls, but consists of fine-grained shaly sandstone in the south wall. Another smaller pit lies 200 yards to the south. The last production from the operation is reported to have been about 1938. The following is an analysis of the Tongue pit clay by Hawks (1970, p. 17).

SAMPLE SD64-3 (Mancos Sh.)

Raw color	yellowish-brown		
Munsell designation	10YR5/2		
Water of plasticity (%)	17.2		
Drying behavior	good, slight scumming		
Linear drying shrinkage (%)	6.2		
Dry modulus of rupture (psi)	921		
Firing temperature (°F)	1800	1900	2000
Firing behavior	good	good	good
Color	light-brown	light-brown	grayish-orange
Munsell designation	5YR5/8	5YR6/6	10YR7/4
Firing shrinkage (%)	–0.5	–0.2	0.2
Total shrinkage (%)	5.7	6.0	6.4
Modulus of rupture (psi)	1918	2206	2302
Water of absorption (%) (5 hr)	18.4	18.8	16.3
Apparent specific gravity	2.70	2.70	2.62
Bulk density (g/cm³)	1.80	1.79	1.80
Ignition loss (%)	11.3	11.4	11.5

Many of the bricks made at Tongue are reported to have been of poor quality.

COAL

In areas surrounding the Sandia Mountains coal is almost entirely in the Mesaverde Formation. Very locally it may be found in seams a few inches thick in the Sandia Formation. One of these may be seen in the roadcut opposite the Doc Long picnic grounds. Surrounding the Sandia uplift Mesaverde occurs in the Hagan basin, Tijeras basin, and 2 patches west and northwest of Placitas. In general, Mesaverde seams are thin, discontinuous, and scattered through the section. Available analyses indicate the coals to be high-volatile bituminous with fixed carbon ranging from 31 to 55 percent. Sulfur content, for the most part, is less than 1 percent, although 1 analysis from the Holmes mine in Tijeras basin averaged about 3.5 percent. Keyes (1904, p. 671) records 4 analyses as follows of Hagan coals but from his context it is not clear whether they are from the Hagan mine or from any of several other mines in the basin.

	I	II	III	IV
Moisture	5.10	2.50	7.09	0.89
Volatile matter	39.60	39.35	41.29	32.36
Fixed carbon	48.92	50.60	48.17	54.88
Ash	6.18	7.18	3.45	11.87
Sulfur	0.53	0.45	0.67	1.07

HAGAN BASIN FIELD

Coals of the Hagan basin were designated the Hagan coal field by Keyes (1904, p. 670) and Una del Gato coal field by Campbell (1907, p. 427) from the abandoned Mexican settlement of Una de Gato (cat's claw) 1 mile south of Hagan. However, Campbell further referred to the Hagan field for the coals mined near the now-abandoned mining town of Hagan, the Sloan field for the Sloan mines, and Pina Vititos field for the seam at the Pina Vititos mine. These small areas would have been better referred to as camps or settlements. Inasmuch as the coals occur in a downwarp best referred to as the Hagan basin the term Hagan coal field is preferred.

The most work to date on the Mesaverde Formation of the Hagan basin was done by Harrison (1949). He measured a section along Pinovetito Arroyo (on modern topographic quadrangles referred to as Tuerto Arroyo) in sec. 6, T. 13 N., R. 6 E. and subdivided it into informal units as follows:

Coal-bearing shale member no. 3	590 ft
Sandstone member no. 4	656
Coal-bearing shale member no. 2	521
Sandstone member no. 3	248
Shale member	67
Sandstone member no. 2	589
Coal-bearing shale no. 1	661
Cano sandstone member	246
Total:	3.578

Of the 3 coal-bearing units, only member 3 contained coal seams in the Pinovetito section, although coal does occur elsewhere in the lower coal-bearing units. In the 590-ft upper shale unit Harrison described 9 seams distributed in the middle 245 ft as given in Appendix 1; dimensions are tabulated below:

Interval No. (see Appendix 1)	**31**	**32**	**43**	**45**	**50**
Interval thickness, ft	24	7	15	43	11
Seam thickness, inches	30	12	12.22	12.16.18	4.36
Ft above base, No. 3 shale	124	148	241	263	358

For the Pina Vititos area in general, however, Harrison (1949, p. 167) gave 11 seams ranging from 4 to 44 inches, but only 3 were greater than 24 inches thick. The 36-inch seam of interval no. 50 above is the principal coal at the Pina Vititos mine.

Pina Vititos Mine—The Pina Vititos mine lies in the SW'/4 sec. 32, T. 14 N., R. 6 E. Pina Vititos (small silver fir tree) is a corruption of Pinabetitos, the diminutive of "pino abeto," according to Ruben Cobos (personal communication). Various spellings have been used, such as Pinovetito. The principal workings at the Pina Vititos mine is an incline driven N. 85° E. down the seam at 28 degrees. The incline appears to have been dug with 7-ft auger as shown by a circular cross section partly preserved in the roof sandstone 50 ft below the portal. At the right side of the portal the seam is 27 inches thick including a 2-inch carbonaceous shale parting 8 inches from the top. However, on the left side of the portal the seam is 40 inches thick with no parting (fig. 85). The roof of the coal at the portal is 36 inches of gray claystone beneath massive buff sandstone. Followed down the incline the claystone thins to 6 inches as the sandstone channels into the coal. The floor consists of grayish-brown shale.

The Pina Vititos coal has been prospected for 1,500 ft to the south in several similar inclines (fig. 86). At one of these there is a remnant drum of an old horse whim used in mine haulage. In one of the better preserved openings a double seam consists of a 24-inch lower part and a 22-inch upper part separated by an 11-inch claystone parting. At the left of the portal a small fault confined to the coal zone brings claystone opposite the coal seams. The massive sandstone of the main portal also forms the roof at this opening, but south it pinches out locally. The same brownish shale forms the floor. Irregularities of seam thickness, splits, and abrupt

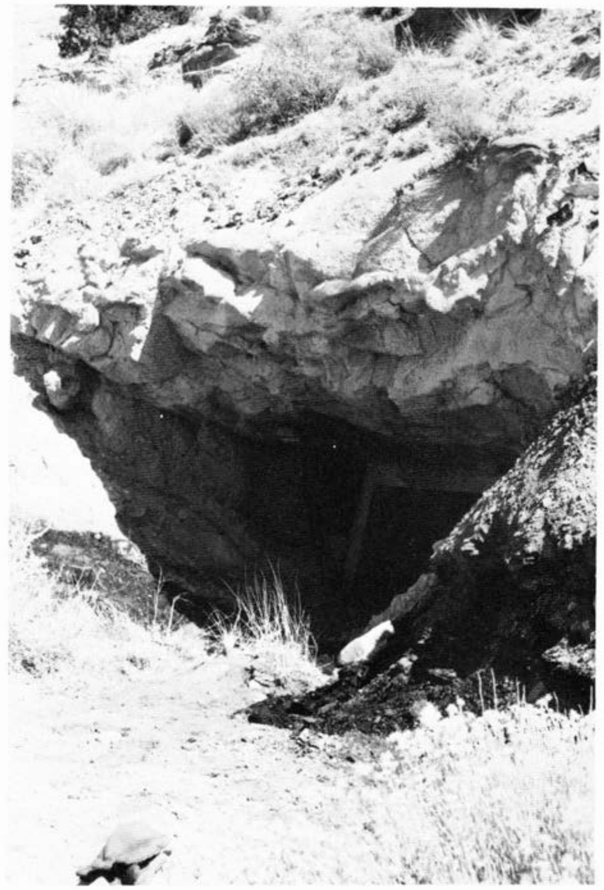


FIGURE 84—PINA VITITOS MINE PORTAL.

lateral variation would likely be problems for development and mining. Campbell (1907, p. 429) measured 66 inches of coal in one exposure with two partings, 11.5 and 15.5 inches, with the middle coal 7.5 inches thick.

Campbell (p. 430) gave an analysis of the Pina Vititos coal as follows: moisture, 9.03; volatile matter, 42.35; fixed carbon, 44.17; ash, 4.45; and sulfur, 0.66 percent.

Sloan Mine—The Sloan mine is 2.3 miles south of the Pina Vititos mine; in spite of soil and alluvium concealing 1.5 miles of this distance, the two mines are doubtless in the same coal zone. The Sloan mine lies just east of the adobe ruins of the old settlement of Coyote which is along the Tongue road 0.5 mile east of the Diamond Tail ranch headquarters. Seams appear to

FIGURE 85—COAL OUTCROP AT LEFT SIDE OF PINA VITITOS MINE PORTAL. BOTTOM OF SEAM AT HAMMER HEAD; TOP, AT PENCIL.

FIGURE 86—PINA VITITOS COAL-BEARING ZONE SOUTH OF MAIN PORTAL. NOTE 3 SMALL ENTRIES. ORTIZ MOUNTAINS IN DISTANT BACKGROUND.

be in two zones separated stratigraphically by 90 ft (fig. 87). Several inclines are along each zone, but all are either caved or only narrowly open. Keyes (1904, p. 671) observed 4 coals in 92 ft of shale, claystone, and sandstone, the thickest being 30 inches.

The principal exposures are along a dissected 600-ft exposure north of a left-offset oblique fault (map 1). A massive white sandstone unit lies about 100 ft west and stratigraphically below the lower coals. This is the Una de Gato sandstone (Keyes, 1904) that forms the hog-backs above the coal at Hagan. About 800 ft south of the main portals and dumps, the Una de Gato is offset about 500 ft northwestward to a ridge position near the fault termination of the uppermost coals. The offset seams should be north of this sandstone ridge but little prospecting appears to have been done in this area. The seams dip east at 25 to 35 degrees, the steeper near the fault.

At the southern end of the lower zone and near the fault a portal exposure contains a 20-inch seam with a 4-inch shale parting. In the upper zone also near the fault there are several portal exposures. One of these shows 2 seams each, 20 to 24 inches thick, separated by 10 ft of shale; however, most of the opening is caved and it appears that the main, perhaps thicker seam, lies beneath the caved material. The roof of the principal seams is mostly shale and claystone, but a massive sandstone bed lies 5 to 10 ft above. In a small canyon 100 to 200 ft to the north 5 small coal seams crop out in a weathered slope, but only 2 appear to approach 30 inches in thickness. All the main workings at the north end of the exposed belt are nearly completely caved and exposures are lacking, although there is much evidence of mining in the form of widely spread waste dumps. In 1904 the U.S. Mine Inspector described the Sloan seam (p. 38) as 7 ft thick just above a fault at 200 ft down the slope, but stated that "two shale splits . . . reduced the net coal materially."

Harrison (1949, p. 167) measured 6 seams near the Sloan mine ranging from 8 to 34 inches in thickness, but with only 2 above 24 inches. Campbell (1907, p. 429-430) measured 1 coal section at the mine 44.5 inches thick including an 8.5-inch middle shale split. He further reported two analyses as follows:

	(a)	(b)
Moisture	9.68	7.28
Volatile matter	42.32	42.49
Fixed carbon	41.36	43.60
Ash	6.64	6.63
Sulfur	0.66	0.67

(a) Analyst A. A. Somermier
(b) Pittsburgh Testing Laboratory

Two other analyses of the coal of this zone were made in 1936 (Fieldner, Cooper, and Osgood, p. 56-57; 93-94) by the U.S. Bureau of Mines which are as follows:

	Sloan[1]	Donnell[2]
Moisture	9.7	11.0
Volatile matter	42.3	38.5
Fixed carbon	41.4	44.3
Ash	6.6	6.2
Sulfur	0.7	0.6

[1]Seam 36 inches and 20 ft from portal.
[2]Prospect southeast of Sloan mine in SE1/4 NW1/4, sec. 17, T. 13 N., R. 6 E. sampled 60 ft downslope from 18-inch seam.

Hagan Mines—The Hagan mines lie in the N1/2 sec. 33, T. 13 N., R. 6 E., south and east of the abandoned town of Hagan (fig. 88). The seams are in a lower zone than those around the Sloan mine.

Keyes (1904, p. 671) found 8 seams in a 151-ft section

FIGURE 87—UPPER COAL-BEARING ZONE AT SLOAN MINE. FIVE COAL SEAMS RANGING IN THICKNESS FROM 6 INCHES TO 2.5 FT ARE IN SHALE AND CARBONACEOUS SHALE SLOPES BEYOND SMALL TREE. DUMP OF SLOAN MINE IN UPPER LEFT CORNER.

FIGURE 88—HAGAN RUINS AT CENTER OF CAMP. INCLINE PORTAL FOR SEAM NORTH OF DIVIDING FAULT IS AT BASE OF RIDGE AT RIGHT EDGE OF PHOTO. DUMP FROM RIDGE TOP IS FROM CUT MADE FOR CONCRETE WATER TANK. PORTALS FOR SEAMS TO SOUTH OF FAULT LIE BEYOND RIDGE IN UPPER RIGHT CORNER.

of shale and thin sandstone beds beneath the ridge-forming massive sandstone unit above the Hagan site. This unit he designated the "Una de Gato sandstone," a name which has been missed by compilers of the U.S.G.S. Lexicon of Geologic Names. Keyes' section of the coal-bearing sequence beneath the Una de Gato sandstone is as follows:

Coal No. 8	1 ft
Shale	36
Coal No. 7	2
Shale	3
Coal No. 6	1
Shale	33
Coal No. 5	2
Shale	8
Coal No. 4 Hopewell seam	4
Shale	9
Coal No. 3	3
Shale	19
Coal No. 2	1
Shale	26
Coal No. 1	3
Total:	151

Harrison (1949, p. 166) traced and measured 4 seams with average thickness of 18, 45, 8, and 17 inches in order upward in the zone. According to him the 45-inch seam is relatively uniform in thickness, whereas the others thicken and thin through short distances and grade into carbonaceous shale. In 1904 the U.S. Mine Inspector (p. 37) gave 4 seams for the zone ranging from 3.5 to 5 ft thick named in ascending order: McCance, Kennedy, Hopewell, and Andrews. The Hopewell was the principal bed; 54 inches thick, dipping 15 degrees.

An east-trending fault followed by a canyon separates the seam and mining into two parts. It is reported that the two parts were separately owned mines. A single portal enters the principal seam north of the fault and near the center of the old town. The beds in this upthrown segment dip N. 55° E. at about 25 degrees. Mining from this incline extended in places to the basalt dike 3,000 ft to the north where the coal was cut off.

South of the fault there are 6 inclines, mostly caved, along the base of an east-trending hogback through an outcrop distance of 3,000 ft. The seams in this downthrown block dip 35°N. Three principal coal seams are along this stretch. The middle seam is located 50 ft stratigraphically above the lower end and about 100 ft below the upper one. Only the incline at the west end is on the upper coal. Likewise only 1 incline is on the lower seam and this is at the next to the easternmost mine location where there is also an incline on the middle seam. Only the easternmost incline is open, but even this is caved about 40 ft down. A seam 35 inches thick was measured.

The coal seams terminate against the upthrown northern block approximately 1,000 ft downdip, with the upthrown seam lying 600 to 1,200 ft higher on the north side. Some mining is reported to have reached the fault. The situation is such as to have required 2 separate operations.

Fieldner, Cooper, and Osgood (1936, p. 56, 57, 93) analyzed two samples from the Hopewell seam taken by C. C. Mather, Nov. 14, 1923, 1,200 ft down the slope of what was referred to as the number 1 left entry:

	(1)	(2)
Moisture	7.8	6.1
Volatile matter	29.1	38.5
Fixed carbon	51.0	43.3
Ash	13.8	6.2
Sulfur	0.9	0.6

Sample no. 1, 48 inches thick; sample no. 2, 49 inches; both with an 18-inch claystone split, a roof of sandstone, and a floor of shale.

Coal reserves of the Hagan basin have been measured by Harrison (1949, p. 166-169) and by Read and others (1950, p. 16-17, 20-21) with general agreement. Read and his associates discussed with Harrison the methods they had employed. Read and others (1950) computed the following indicated original reserves for the Hagan field (in tons).

Overburden (ft)	Thickness Intervals (inches) 14–28	28–42	>42	Total Tons
0–1000	3,900,000	3,100,000	–	7,000,000
1000–2000	2,900,000	2,800,000	–	5,700,000
2000–3000	2,600,000	600,000	–	3,200,000
Totals:	9,400,000	6,500,000		15,900,000

Harrison, although using the same general guidelines with regard to extrapolation of reserves to depth on the basis of outcrop lengths of measured thicknesses, chose to present his data by individual seams for which he assigned average thicknesses. He did not lump the reserves into the 18-, 28-, and 42-inch categories, except to exclude all seams of average thicknesses less than 14 inches. His totals, which are within the same certainty degrees, are as follows:

Hagan area	11,504,800 tons
Sloan area	2,537,050
Pina Vititos area	8,524,800
Total:	22,566,650

Almost one-half of Harrison's reserves are for one 45-inch seam at Hagan. In both estimates it is obvious that most of the reserves include seams impractical to mine, especially on the 25- to 35-degree slopes prevalent in most of the Hagan basin. On the geologic side of potential (or inferred) reserves it is interesting to note that Read's group (1950, p. 20-21) gave no reserve for the field at any depth for seams that might be greater than 30 inches thick and only a potential (above their total of 16.2 million tons of indicated and measured categories) of 800,000 tons above 14 inches thick. The basin certainly has more potential, especially if underground gasification were to become feasible. Also, these calculations of reserves do not include the potential of the covered areas in either direction from the Sloan camp, in the covered area north of the Pina Vititos exposures, or beneath the Ortiz gravel cap east of the Hagan camp.

Prospecting for coal and some production for household and local use probably went on in the Sandia area for some years prior to 1900. However, better sources in the Gallup, Raton, and Cerrillos areas tended to concentrate development and mining in those fields where coal mining began in earnest with the building of railroads in the period of 1878 to 1882. In 1903 the U.S. Mine Inspector (Annual Rept., p. 66) reported, under "new mines opened," the Una del Gato (Hagan) and Pina Vititos mines in Santa Fe County operated by the New Mexico Fuel & Iron Company owned by E. B.

Field. In 1904 the inspector first reported a railroad branch from the A.T. & S.F. near Algodones. Although plans for such a spur line continue to be mentioned in many succeeding reports and a bed was built, no line was ever completed. The Pina Vititos mine may have been the first to produce coal, but there is little tonnage recorded despite the considerable evidence of mining. The Sloan mine, early referred to as Coyote, appears to have accomplished most of its development and mining by 1905. According to U.S. Mine Inspector reports it was not in operation from 1906 to 1908. It produced only small tonnages to the nearby Tongue brick plant in 1909 and was thereafter idle. The Hagan mine, early referred to as the Una del Gato, operated in two periods one from about 1903 to 1909 with two slopes to depths of at least 1,020 and 712 ft. Production was as follows:

Year	Days worked	Tons produced	Value/ton
1904	104	970	$1.50
1905	300	1,500	$1.25
1906	?	1,000 (est.)	$2.00
1907	300	2,618	$2.00
1908	320	5,000	$2.00
1909	200	1,000	$2.00
Totals:	1,224	12,088	

From 1910 to 1917 the Hagan mines either did not operate or production was so small that it was not reported. The figures given here are gross production. The amount sold was often somewhat less owing to operating use of the coal at the mine. For example, in 1904 of the 970 tons mined, 200 tons were used in operations by the mine. On the other hand, in 1908 with 5,000 tons produced only 250 tons were used by the mine. In the later period of mining at the Hagan mine from about 1919 to 1931, coal-generated power used to operate the mine was at times extended by line and sold to metal-mining operations at Golden and San Pedro. For example, in 1927 of the 22,215 tons mined 3,353 tons were consumed at Hagan, most of it probably to run the 750-kilowatt power plant that they had. In 1928 the local use was even greater amounting to nearly 21 percent of the gross production.

During the second period of mining at Hagan the property appears to have been owned by J. J. De Praslin and W. H. Stark. From 1919 to 1925 most of the work was development and construction. The work appears to have been desultory and interrupted possibly only as financing became available. In 1925 mining again got underway for Hagan's most productive period which extended through 1931. By 1932 the mines appear to have been completely idled, and the settlement was soon abandoned. Yet today 35 to 40 building foundations and collapsed walls can be found. The railroad was never completed to Hagan. Work on the road bed is reported to have commenced in 1909 but was suspended that year. Additional efforts were probably made during the 1920's, but although the bed was completed to Hagan it is doubtful that track was ever laid to the settlement. A bed was worked on from the railroad in Estancia Valley down San Pedro Creek, but the bed and necessary cuts were abandoned about 5 miles from Hagan.

Production of coal from the Hagan mines for the second period of mining is (State Mine Inspector reports):

Year	Days worked	No. men	Tons mined	Tons sold
1926		10?	7,557	
1927	276	12	22,215	16,477
1928	234	16	18,440	13,712
1929	190	19	16,348	12,080
1930		no reports		
1931	?	15	3,110	1,291
		Total:	67,670	

The Hagan coal was hauled by wagon or truck to the railroad near Algodones, a distance of about 15 miles. It is reported to have been marketed in New Mexico, Arizona, and Texas during its principal period of production at prices of about $3.00 per ton. Total production from the Hagan mines is not precisely known owning to lack of reports in some years and the fact that the mine and local consumption is not often reported. An estimate is:

	Tons
1904–1909	12,100
1910–1925	3,200[1]
1926–1931	67,700
Total:	83,000

[1]Estimated on basis of men reported working and small tonnages partly reported by day or year.

The Hagan mines were open through several down slopes with cross entries and back slopes. Mining rooms are reported to have been 250 ft long and 30 ft wide. Pillars between the rooms were 50 ft wide. Two mining machines were introduced in 1926, but more than half of the coal was still conventionally mined by drilling and shooting.

Production figures are not known for either the Pina Vititos or Sloan mines but on the basis of the number of openings and size of dumps, production is estimated respectively at 2,000 and 8,000 tons most of which was probably consumed either at the mine or at very local markets. Further production for the Hagan coal basin came from the Tejon mine as reported by the State Mine Inspector without identifying its location. The first record is for 557 tons in 1926 by 1 miner. Later, from 1933 to 1939, 8 to 15 men were reported working at the mine with production of 3,711 tons in 1937 and 5,137 tons in 1939. John Jackson of Albuquerque was manager in 1939.

TIJERAS BASIN FIELD

An area of about 5 square miles of Mesaverde beds occurs in the Tijeras down-faulted graben. Most of the coal occurs in the Tijeras syncline in an area approximately 1 square mile (fig. 89). Coal was being mined as early as 1898, for Herrick (1898b, p. 108) observed that "coal is occasionally mined, as is the case north of the cabins of Gutierez [sic]." A minor occurrence exists in a narrow nearly vertical strip of Mesaverde in the west limb of the Cedar Mesa syncline (map 3) in the southwestern corner of the graben. Most of the Mesaverde Formation has been removed by erosion and possibly less than half of its original thickness remains. Three major sandstone units with two intervening coal-bearing shale units constitute the preserved section. Coal seams in the shale units have been prospected and mined to some extent probably all for smithing or household consumption. The seams are generally thin and moderately to severely deformed.

Lee (1912, p. 578) had 2 analyses (dry basis) made of the coal:

	Holmes Mine	Tocco Mine
Moisture	1.6	0.8
Volatile matter	31.3	36.4
Fixed carbon	36.3	53.9
Ash	31.3	8.9
Sulfur	3.26	0.88
Btu	10,000	13,900

Lee (p. 574-575) measured the Cretaceous section and got a thickness of 1,309 ft for the preserved Mesaverde beds. The seams in his section fall into 3 stratigraphic positions: 1) in a 32-ft shale section near the top of the lower sandstone sequence that surfaces most of the Tijeras anticline (Section 1 and Holmes zone), 2) near the base of the lowest of the 2 principal shale units, and 3) in the upper of the 2 principal shale units (Tocco zone). Lee did not indicate in his stratigraphic section giving 3 coal zones which one was the Holmes seam. Our mapping indicates that the Section 1 and Holmes mines are on the same seam (fig. 89). Since no coal is known below the seams mined in the 2 mines it is assumed that his middle zone of 2 coals separated by 15 ft of shale is above his 30 ft of sandstone. This appears to fit the field mapping and a 40-ft shaft 1,200 ft up canyon from the Holmes mine may have been dug to the middle coal zone. However, this zone has not produced coal. Furthermore, although all 3 zones can be mapped throughout the basin, some exposures indicate that none of the coal seams can be expected to be continuous throughout their zones.

Section 1 Mine—The Section 1 mine lies in the NE1/4 SE'/4 NE1/4 sec. 1, T. 10 N., R. 5 E. The incline enters the side of a small sandstone-capped cuesta that is stripped down the east flank of the Tijeras anticline. The beds dip S. 85° E. at 15 degrees and the incline slopes N. 85° E. at 10 degrees. The length is 225 ft (fig. 90). Little or no work appears to have been done on the property since about World War I. The portal is nearly closed from caving of the weak claystone which forms the roof. There are no drifts or stopes; no coal, beyond that of the incline, has been mined. The dumps are considerably eroded. Some sand and mud have been washed into the incline so that the base of the seam is largely covered. Inasmuch as the incline is still 5 to 7 ft high, the seam apparently is not more than about 2 ft thick.

Unusual exposures of folding and faulting of the coal and shale make the prospect a valuable geological feature for teaching and for interpreting the mechanics of deformation of the Tijeras basin. In numerous places, well exposed in the tunnel walls, the coal has been thrust or buckled into the overlying claystone beds (figs. 91, 92). The protrusions rise from as little as 1 ft to well above the tunnel roof and usually taper upward from 1 to 2 ft thick at the base of merging with the undisturbed seam. They typically dip about N. 55° to 65° E. at 45 degrees. This direction is toward the bottom of the Tijeras syncline and oblique to the S. 85° E. dip of the beds at the mine. Although basinward dips are dominant there also conjugate coal flyers dipping in the opposite directions. The coal does not completely crosscut the claystone, rather the claystone beds above the flyer are parallel to the coal. With the shorter, stumpier coal penetrations there is commonly considerable contortion of the surrounding beds.

The coal in the offshoots is laminated parallel to the walls, and 'it therefore appears that they are some part of the underlying seam that has been thrust in sledrunner style over the younger beds. If this is so the thrusts would be rooted within or at the base of the seam. The action would arise from the usual slipping of upper over lower beds in the limbs of synclines.

Holmes Mine—The Holmes mine lies in the N1/2 NW'/4 SW1/4 sec. 6, T. 10 N., R. 5 E. The Holmes seams are in the same zone as the Section 1 seam but on the opposite or southeast limb of the Tijeras syncline. The portal is only about 200 ft from the canyon bottom and the syncline axis, and the tunnel is driven N. 40° E. into the hillside horizontally. The hillside slopes above the tunnel are not much less than the dip of the coal; coal can be found in the hill, mixed with soil in mantle creep. Below the tunnel level the seam must flatten rapidly toward the creek and the syncline axis. The portal is completely caved. If the tunnel continues horizontally, a considerable zone would be available on strike. After a few hundred feet in from the portal, backs of coal would not increase to more than about 100 ft for a distance of nearly 3,000 ft from the entry. Below the tunnel, near the portal, the seam flattens rapidly toward the creek and the syncline axis. Into the tunnel and above it, the dips probably steepen from 20 to 30 degrees. Still farther east the dip increases to 45 degrees along the zone. According to Lee (pl. 59) the Holmes seam ranged from 1 to 2.5 ft in thickness. He also suggested that "thicknesses vary greatly within short distances" and that the coal is often "crushed and impure." Some coal has been produced from the Holmes mine.

Tocco Mine—The Tocco mine lies near the center of sec. 31, T. 11 N., R. 6 E. in Tijeras basin. The portal is caved but the incline can be seen to descend S. 12° E. at about 28 degrees. A waste tipple 25 ft high stands on the flat just north of the incline, which is reported to have descended on the seam to 260 ft where water made mining more and more difficult. Of the 2 seams reported for the Tocco zone, Lee (p. 577) reports the upper 1 to have been mined, perhaps because it is more uniform. However, he reported its thickness to range from 14 to 20 inches. The area underlain by the Tocco seam is only about 80 acres.

Even though 1 or 2 other seams may lie just below the one mined, the original inferred reserves would hardly be 1 million tons, quite small and essentially uneconomic.

Very little history of development activity or mining exists for the Tijeras basin coal mines, although the State Mine Inspector report (1908, p. 13) sheds some light on the Tocco mine. It was first opened in 1908 and that year shipped 350 tons valued at about $4.00 per ton. It was reported to have the rather dubious "distinctions of operating the smallest coal seam developed in New Mexico" and one of the smallest in the United States and Europe. The seam exposed at that time was 12 to 15 inches thick with 1 to 3 inches of bony coal at the top leaving only 10 to 13 inches of clean coal. The slope had been driven down 255 ft an average of 25 degrees. Cross entries were driven about 30 ft apart and a right entry at the bottom was 70 ft long and a left

FIGURE 89—AIRVIEW OF TIJERAS BASIN SHOWING COAL-BEARING ZONES, MINES, AND PROSPECTS.

entry 30 ft. It was very good coal and was hauled to Albuquerque where the principal marketing was for smithing at $9 to $12 per ton. In 1908 the mine operated 270 days with an average of 4 miners per day. The mine operated only into 1911 and produced 300 tons in 1909, 160 tons in 1910, and 160 tons in 1911.

Three small coal prospects occur along the steep hogbacks of Mesaverde that form the west limb of the Cedar Mesa syncline (map 1) east of San Antonio. The prospects appear to be in the same zone as the Holmes and Section 1 mines. Attitudes are steep to near vertical and the seams are not thick. Lee measured seams in 3 portals that range from 1 inch up to nearly 2 ft in thickness. Some household coal appears to have been mined sporadically from one of these prospects.

Reserves for the Tijeras basin cannot be given a realistic estimate within measured and indicated categories because of poor surface and subsurface control. Much trenching or drilling would have to be done. Such an effort is hardly warranted because the inferred or geologic potential is relatively small. Nevertheless, Read and others (1950, p. 21) calculated 400,000 tons of what they termed measured reserve and 1,200,000 tons of indicated reserve—all under 28 inches thick and only to a depth of overburden of 1,000 ft. This depth would take in essentially all the potential coal-bearing zones.

FIGURE 90—Section 1 mine in Tijeras basin. Eroded dump and partly caved portal to incline.

PLACITAS FIELD

Three coal prospects occur in steeply dipping Mesaverde beds on the San Antonito Las Huertas Grant 1 to 2 miles west of Placitas; all are caved. Judging from the size of dumps, the easternmost prospect just north of the road appears to have been the largest. The enclosing beds dip N. 50° E. at 47 degrees. The middle prospect is near the creek about 200 ft east of a prominent basalt dike. The seam near the caved portal is 1 to 2 ft thick and dips N. 20° E. at 68 degrees. This prospect and the one to the east appear to be on the same seam. The easternmost prospect is down the same arroyo 3,000 ft west of the dike. A drift adit appears to have been driven easterly on the N. 80° E. strike of the beds and coal. The dip is 65 degrees to the north. The seam is poorly exposed in the arroyo banks and appears to have been 1 to 2 ft thick. The State Mine Inspector report for 1933 (p. 12) reports the Traddei mine with 4 men working the Placitas area, but its precise location is not given.

PETROLEUM POSSIBILITIES

The Madera Formation and the Cretaceous rocks are the principal rocks of hydrocarbon potential in the area. All the large areas surfaced by Madera are not likely to contain petroleum, owing to the relatively shallow depth to Precambrian crystalline basement. Cretaceous formations of potential are the Dakota, Mancos, and Mesaverde principally found in the Hagan and Tijeras basins. These are also the better places for finding the Madera at favorable depths.

The most extensive Cretaceous terrane is the Hagan basin which forms an open broad arcuate syncline plunging to the northeast. Dips throughout the basin are from 20 to 30 degrees. No anticlines are present, but traps of sorts could be fashioned against faults or dikes in a few places. Perhaps the best possibilities are stratigraphic traps that might exist in some of the lenticular or intertonguing sandstone beds of the Mesaverde and Mancos Formations. There is also some possibility of fracture reservoirs in the Mancos Shale.

The Tijeras anticline of the Tijeras graben has long been a target for petroleum exploration. The north-trending anticline is 2.5 to 3 miles long and 1 mile wide from the Cedar Crest syncline axis on the west to the Tijeras syncline axis on the east. It is a nearly upright anticline with flank dips of 8 to 15 degrees on the west and 40 degrees on the east. The anticline is nearly level with possibly a plunge of 1 or 2 degrees northward. The anticline is terminated against the Tijeras fault on the north and the Gutierrez fault on the south. Height of the fold is 500 to 700 ft. The anticline has been drilled a number of times without finding oil or gas. The first test was Wright #1 located in the SE'/4 NW'/4 sec. 12, T. 10 N., R. 5 E. It was drilled with a rotary rig, possibly to the Dakota. A second well, the Hickerson-Wright #2, was drilled in 1947 a few tens of feet south of the first well using cable tools. The location of the second well is immediately east of a north-trending basalt dike. Both

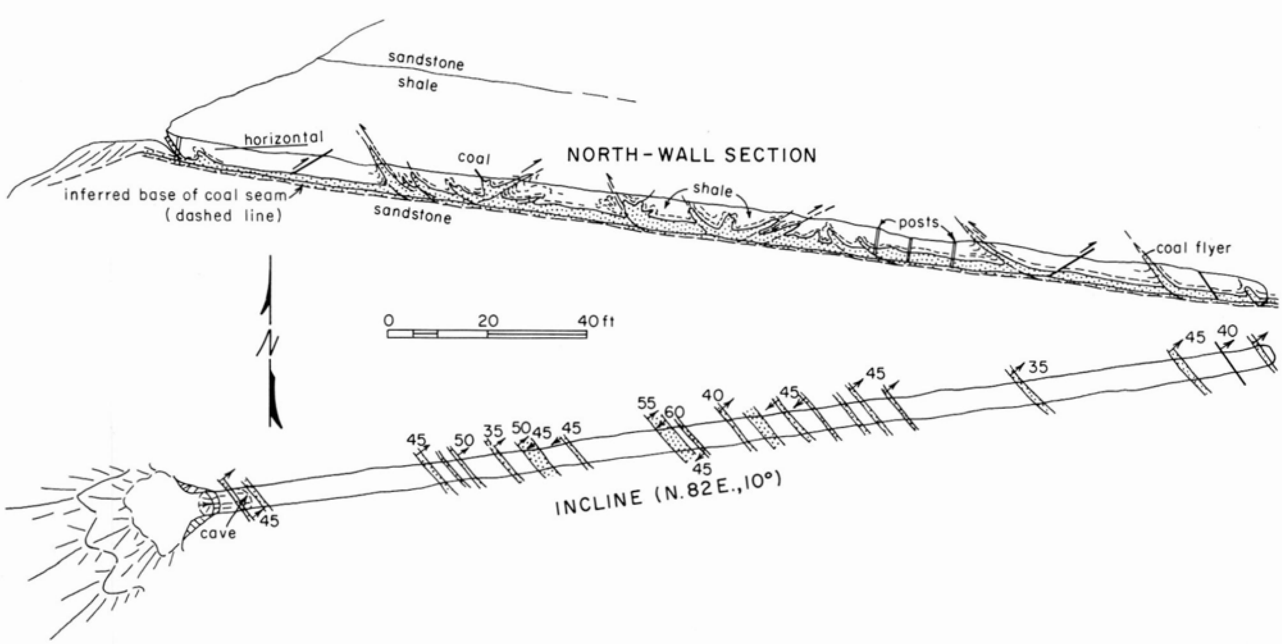
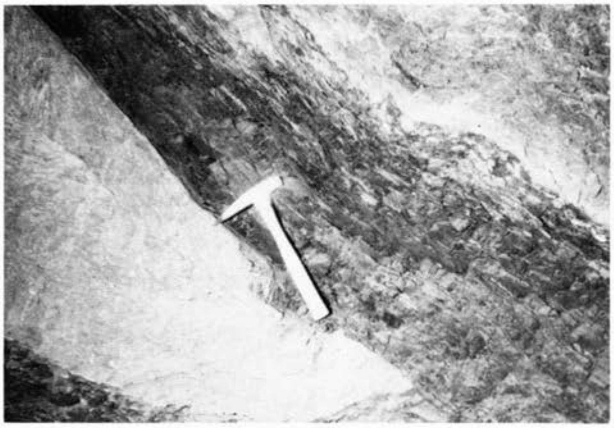
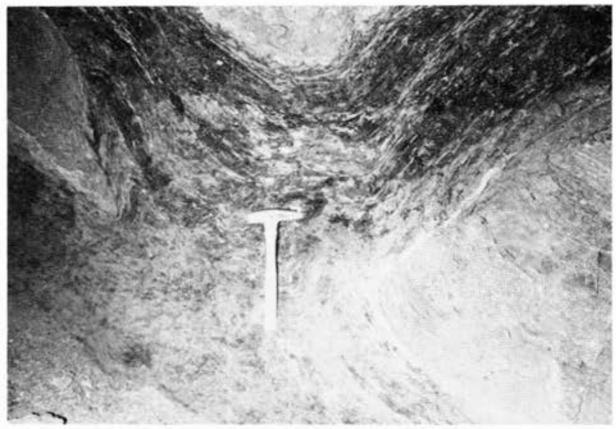


FIGURE 91—Plan and longitudinal panel of Section 1 mine.

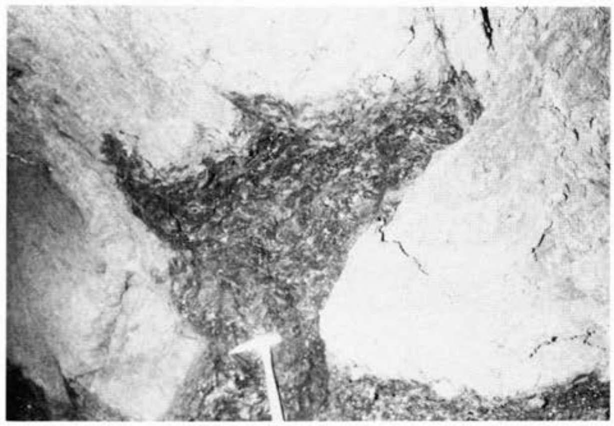


A—FLYER UPDIP; SEAM IN PLACE ALONG INCLINE FLOOR, LOWER LEFT CORNER.



B—CONJUGATE FLYERS, UPDIP AND DOWNDIP FROM SEAM ALONG FLOOR.

C—SMALL THRUST DOWNDIP.



D—PROTRUSION WITH CONJUGATE FLARE.

FIGURE 92—COAL PROTRUSIONS AND FLYER THRUSTS IN NORTH WALL OF SECTION 1 MINE.

locations collar in Mancos Shale and are about 700 ft east of the crest of the anticline. The penetrated Mancos probably dips east 5 to 10 degrees. The top of the Dakota was reached at a depth of 1,295 ft and the Morrison Formation at 1,360 ft.

Despite low porosities reported for the sandstones in previous tests, in 1964 Southern Union Gas Company drilled 3 wells on the southern end of the structure, testing it as a possible gas storage reservoir for meeting peak winter demands of Albuquerque. Southern Union tested Dakota, Morrison, and Entrada sandstone without finding a suitable reservoir. These wells were drilled on a north line in the Mancos shale 900 ft east of the west boundary of section 12. The southern well is only about 600 ft from the Gutierrez fault; the northern well (No. 3) is 3,200 ft north of the southern well (No. 1). The northern well is about 700 ft west of the anticline crest, and the southern well is 200 ft west.

A small oil seep is reported along the creek just west of San Antonio (Katherine M. Wright, personal communication). The location, now much obscured by brambles, was near the base of the steeply overturned Dakota Sandstone.

Winchester (1933, p. 120) found that some shale of the Madera yields oil on distillation, and Foster and others (1966, p. 8, 15) found that shale from the Sandia Formation in the Manzano, Manzanita, and Ladron Mountains and from Cretaceous shales such as the Mancos and Mesaverde Formations contained traces to a few gallons per ton. For the Sandia Mountains area the potential would appear to be only slight for the Mancos or Mesaverde in the Hagan basin. Judging from Foster's results the Sandia shale appears to be more likely as a source.

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Appendix 1—Stratigraphic Sections

MADERA FORMATION

Montezuma Ridge, Las Huertas and Tejon grants

(*Modified from Harrison, 1949*)

Unit	Description	Thickness (ft)
	Abo Formation above	
	Madera Limestone (total thickness)	1,267
31	Limestone: gray, fossiliferous	1
30	Limestone: gray-green, extremely fossiliferous, thin-bedded, with shaly partings, nodular	15
29	Limestone: gray crystalline, fine-grained, thin-bedded, fossiliferous	15
28	Shale: gray	8
27	Sandstone: buff, medium-grained, thin- to medium-bedded, hard, quartz and feldspar grains	15
26	Limestone conglomerate: gray	1
25	Shale: red, slope covered	14
24	Shale: blue-gray, with limestone nodules	4
23	Limestone: gray, dense to fine-grained, crystalline, thin- to massive-bedded, with silty shale partings, fossiliferous, weathers to olive-drab, buff-brown surface; forms front slope and ridge	122
22	Sandstone: grayish-pink, medium to coarse, angular to subrounded grains, thin- to thick-bedded, with shale partings locally, cross-bedded locally; grades upward to maroon-lavender near the top; color and texture vary laterally and vertically; slope-forming	28
21	Sandstone: grayish-pink, fine-grained, thin, shaly-bedded, micaceous, slope-forming	14
20	Sandstone: greenish-maroon, arkosic, medium- to coarse-grained, thin- to medium-bedded, with soft, silty, conglomeratic partings; angular to subangular grains	5
19	Limestone conglomerate: red-lavender; with quartz, limestone, feldspar, and chert fragments; with thin, red shaly streaks	2
18	Siltstone: gray-green micaceous and shaly; grades upward into top 6 ft of gray-maroon, mottled, micaceous siltstone	15
17	Sandstone: red-gray, silty and shaly; 4 inches of red shale at bottom	2
16	Claystone: red, with earthy limestone nodules	29
15	Shale: gray	6
14	Limestone: green, crystalline, fine-grained, brittle, with silty, shaly partings and some earthy limestone nodules	8
13	Shale: gray-green, friable	9
12	Limestone: gray, crystalline, fossiliferous	6
11	Limestone: gray, crystalline, with earthy limestone nodules, fossiliferous, thin-bedded	39
10	Limestone: blue-gray, dense, thin- to medium-bedded, cherty along seams, in pods and lenses, slightly fossiliferous; weathers to a brownish-colored surface; probable base of Arkosic member	126
9	Limestone: gray, crystalline, fine-grained, medium- to thick-bedded, cherty along seams and in nodules, fossiliferous; weathers to rough, irregular surface; forms crest of ridge	131
8	Sandstone: greenish, buff-gray, medium to coarse, subangular, to subrounded grains, scattered mica flakes, thin- to medium-bedded, rather friable, orange limonitic specks	5
7	Limestone: light buff-gray to gray, crystalline, thin- to thick-bedded, with highly fossiliferous zones, scattered chert nodules and pods; weathers to a rough, spiny surface	194
6	Limestone: gray, conglomeratic, quartz, feldspar, and limestone fragments; arkosic appearance on weathered surface	5
5	Limestone: gray, medium-grained, crystalline, medium-bedded, nodular; highly fossiliferous zones	31
4	Sandstone: greenish-gray; medium- to coarse-grained, slightly conglomeratic, thin- to medium-bedded, rather friable, angular to subangular grains	9
3	Limestone: gray, crystalline, fine- to coarse-grained, medium- to thick-bedded, fossiliferous	130
2	Limestone: dark-gray, fine-grained, crystalline, with irregular brown cherty deposits on weathered surfaces, medium- to thick-bedded, fossiliferous, cliff-forming	215
1	Limestone: gray-buff, crystalline, medium- to thick-bedded, very fossiliferous; weathers to very rough, irregular surface; slope partly covered	63
	Sandia Formation	

ABO FORMATION

Projected S½ sec. 23, T. 13 N., R. 5 E.

(*Modified from Harrison, 1949*)

Unit	Description	Thickness (ft)
	Abo Formation (total thickness)	891
45	Sandstone: red-lavender, fine- to coarse-grained, subangular to subrounded, thin- to thick-bedded, with shaly partings; also thin, gray limestone bands; extreme cross-bedding present	103
44	Shale: red, sandy	4
43	Sandstone: white to pink, medium-grained, angular to subrounded; thin-bedded, cross-bedding present	7
42	Shale: red-lavender, sandy	12
41	Sandstone: pinkish-red, medium- to coarse-grained, angular to subrounded mineral grains; medium- to thick-bedded, cross-bedding and shale partings are present; grades into gray sandstone at the top	14
40	Sandstone: red, shaly, fine-grained, thin-bedded; 4-inch gray to white sandstone at base, angular to subangular, medium-grained, thin-bedded, slightly calcareous	1
39	Shale: red, silty to sandy	23
38	Sandstone: gray-buff, medium-grained, thin-bedded, with shaly bands, and slightly conglomeratic shale partings with a red and gray mottled color	12
37	Shale: red, silty	68
36	Sandstone: dark-red, very fine grained, micaceous, thin, shaly bedded, thin white calcareous at top	13
35	Shale: dark red-brown, silty (covered)	68
34	Siltstone: light-red, calcareous, nodular; lateral variation in thickness	2
33	Sandstone: red-brown, very fine grained, shaly, micaceous	1
32	Sandstone: gray-lavender, very fine grained to silty, thin, shaly bedded, extremely cross-bedded with lenses of green-gray, oolitic limestone conglomerate; limestone, feldspar, and hematite grains, very hard, very irregularly bedded; grades laterally into calcareous nodular siltstone	6
31	Sandstone: brick-red, very fine grained to silty, thin to shaly bedded, with bands of red shale; interbedded thin, gray, micaceous sandstone lenses	46
30	Shale: dark-gray, with 2 ft of black shale in the middle; locally, highly stained by malachite and some azurite	16
29	Sandstone: brown, fine-grained, thin- to medium-bedded, cross-bedding present; conglomeratic band near top with limestone, quartz, and feldspar granules	8
28	Shale: red, with sandy streaks	11

Unit	Description	Thickness (ft)
27	Sandstone: brown-buff, fine-grained, medium-bedded, with shale partings; cross-bedding present, grades into brown siltstone near top, with 1 ft bed of green nodular limestone	12
26	Shale: red	36
25	Sandstone: dark red-brown, very fine grained, silty, micaceous; thin-bedded with dark-red shale partings	19
24	Sandstone: buff to maroon, fine- to medium-grained, subangular to subrounded, medium-bedded, becomes silty at the top	35
23	Shale: red	61
22	Sandstone: buff, medium-grained, subangular to subrounded with quartz, feldspar, and a few dark mineral grains; weathers brown	3
21	Sandstone: gray, medium- to coarse-grained, medium-bedded, cross-bedding present; conglomeratic, with quartz, feldspar, and abundant angular to rounded limestone granules; weathers to dark brown with a sandpaper texture	4
20	Shale: red	34
19	Sandstone: light-buff, medium-grained to coarse-grained, subangular to subrounded, medium-bedded; quartz, feldspathic grains; arkosic locally; hard	13
18	Shale: light-red	27
17	Sandstone: light-buff to light-brown, medium-grained, subangular to subrounded, medium- to thick-bedded; quartz, feldspathic grains	11
16	Shale: red	35
15	Sandstone: maroon-brown, thin-bedded, fine-grained, micaceous, shaly	6
14	Shale: red, with few sandy streaks	61
13	Sandstone: buff to pink, medium-grained, subangular to subrounded, thin- to medium-bedded, with some feldspar grains	31
12	Shale: red and green, partly covered	32
11	Limestone: light-gray, slightly nodular	2
10	Shale: brown	6
9	Limestone: red-lavender, earthy, nodular	2
8	Shale: red	5
7	Limestone: maroon-brown, nodular	2
6	Shale: light-red	7
5	Shale: gray-maroon	8
4	Shale: red	10
3	Limestone: gray, conglomeratic, with limestone, quartz, and feldspar fragments; some fragments may be reworked fossils	5
2	Shale: red	4
1	Shale: green-gray	5
	Madera Formation	

SANTA ROSA SANDSTONE

Center projected sec. 36, T. 13 N., R. 5 E.

Unit	Description	Thickness (ft)
	Chinle Formation above	
	Santa Rosa Sandstone (total thickness)	333
6	Sandstone: white to gray buff, medium-grained, thin- to medium-bedded, micaceous and fine-grained at top; siliceous (partly covered)	284
5	Sandstone: buff, pebble conglomeratic, with subangular to well-rounded quartz and chalcedony pebbles; 6-inch beds of medium-grained, well-sorted gray sandstone	3
4	Sandstone: gray to yellow-buff, medium-grained, thin- to medium-bedded, some cross-bedding	6
3	Sandstone: red-brown, fine-grained, shaly- to medium-bedded, hard, slightly argillaceous	11
2	Sandstone: reddish-brown, granulitic to pebbly conglomerate with rounded red shale and siltstone pebbles and granules, thin-bedded	4
1	Sandstone: light reddish-purple to brown, medium-grained, thin- to medium-bedded	25
	San Andres Formation	

CHINLE FORMATION

Sec. 13, 14, T. 13 N., R. 5 E.

Unit	Description	Thickness (ft)
	Entrada Sandstone above	
	Chinle Formation (total thickness)	1,861
29	Shale: red-brown, with 6-inch gray sandy streak in middle	15
28	Sandstone: brown, medium-grained, subangular to subrounded, thin- to thick-bedded, cross-bedding present, with thin bed of light purple shale; thin conglomeratic lenses of limestone, fine-grained sandstone with red shale pebbles, angular to well-rounded	54
27	Shale: red, with thin, red sandy streaks	346
26	Sandstone: red, fine-grained, shaly, cross-bedded	9
25	Shale: red	18
24	Sandstone: red, fine-grained, shaly, thin- to thick-bedded, cross-bedding present	17
23	Shale: red, with 6- to 12-inch beds of fine-grained gray sandstone	65
22	Limestone: greenish-gray, earthy, nodular, gypsiferous, conglomeratic with well-rounded claystone pebbles	2
21	Shale: red, partly covered	55
20	Sandstone: red, fine-grained, thin- to medium-bedded, with shale partings and thin, gray sandy streaks; cross-bedding present	24
19	Shale: red, sandy, with 1- to 2-inch streaks of conglomeratic, nodular limestone	23
18	Sandstone: red, fine-grained, thin-bedded, shaly; 10-inch greenish-gray, earthy, nodular, conglomeratic limestone near bottom; thin, gray sandy streaks	3
17	Clay: red	40
16	Sandstone: red, fine-grained, thin- to medium-bedded, shaly, with thin calcareous seams; small amounts of barite deposited along seams and fractures	153
15	Clay: light red with streaks of gray, gypsiferous along seams	59
14	Sandstone: red, fine-grained, shaly, thin-bedded	86
13	Clay: light-red with 2- to 4-inch gray nodular limestone bands	65
12	Sandstone: red, fine-grained, shaly with 4-inch to 6-inch beds of gray, medium-grained, calcareous-cemented sandstone	21
11	Clay: light-red, with thin, light-gray nodular limestone streaks	202
10	Limestone: gray-brown, conglomeratic	1
9	Clay: variegated	41
8	Conglomerate: gray-brown, with well-rounded limestone and red claystone pebbles	2
7	Clay: variegated	106
6	Sandstone: gray, fine-grained, thin-bedded	1
5	Clay: light-gray	6
4	Sandstone: gray, medium-grained, thin-bedded, limestone and quartz grains	2
3	Clay: light-gray	8
2	Sandstone: gray-brown, medium-grained, subangular to subrounded, thin-bedded, cross-bedding present; lower part is brown, pebble conglomeratic with gray limestone, gray siltstone bands	5
1	Clay: variegated, highly gypsiferous in seams, with thin, earthy, brown, nodular limestone bands	432
	Santa Rosa Sandstone	

MORRISON FORMATION
Sec. 36, T. 11 N., R. 5 E.

Unit	Description	Thickness (ft)
	Dakota Sandstone above	
	Morrison Formation (total thickness)	392
11	Sandstone: thick-bedded, light-gray to white, medium-grained, friable, considerable kaolinization of grains	68
10	Sandstone: massive, light-gray to light-green, medium-grained, some kaolinization	60
9	Shale: mottled, reddish-brown and green	9
8	Sandstone: medium- to thick-bedded, light-gray, fine- to medium-grained, well-indurated	18
7	Sandstone: medium-bedded, light-gray, fine-grained, argillaceous	6
6	Mudstone: mottled gray, green, and purple, slightly arenaceous, calcareous	28
5	Claystone: gray, calcareous	8
4	Mudstone: reddish-brown and green, calcareous in upper part	42
3	Mudstone: green and purple	82
2	Mudstone: gray-green, calcareous	12
1	Mudstone: variegated reddish-brown, light-gray, and green	59
	Todilto gypsum	

MORRISON FORMATION
SW cor. sec. 31, T. 13 N., R. 6 E. on Gonzales Creek

Unit	Description	Thickness (ft)
	Dakota Sandstone above	
	Morrison Formation (total thickness)	622
27	Sandstone: white, medium- to thick-bedded, friable, medium- and coarse-grained, locally pebbly, locally cross-bedded, white, angular pumiceous and chert fragments in upper 5 ft. Overlain disconformably by 17 ft of yellowish-brown, thin- to medium-bedded Dakota Sandstone	47
26	Claystone: gray	7
25	Sandstone: white, medium-bedded, medium-grained	11
24	Claystone: greenish-gray, floating sand grains in some beds	27
23	Sandstone: white, thin-bedded, medium-grained	10
22	Claystone: like unit 24	63
21	Sandstone: white, medium-bedded, weathers rusty yellowish-brown	3
20	Claystone: greenish-gray, with local thin sandstone beds	15
19	Sandstone: white, thin-bedded, medium-grained	11
18	Claystone: greenish-gray, with several 6-inch lenses of rusty sandstone	19
17	Sandstone: grayish-green, medium-grained, weathered brown	5
16	Claystone: greenish-gray with variable floating sand grains	59
15	Sandstone: white, thin-bedded, medium-grained	18
14	Mudstone and claystone: greenish-gray	27
13	Sandstone: greenish-white, medium-bedded, medium-grained	6
12	Mudstone: purple and greenish-gray, mostly covered	22
11	Sandstone: greenish-white, medium to thick-ledged, medium-grained	11
10	Mudstone: light-gray	12
9	Sandstone: greenish-gray, medium-ledged, medium-grained	11
8	Mudstone: gray and purplish-brown, green in upper 3 ft	24
7	Sandstone: white, medium-ledged, medium-grained	12
6	Mudstone: purplish-brown	9
5	Sandstone: white, medium-bedded, medium-grained	10
4	Sandstone: largely covered, white, friable, medium-grained	16
3	Mudstone: purplish-brown and gray with occasional thin white sandstone beds	59
2	Sandstone: white, thin to thick, friable, medium-grained	27
1	Mostly covered by caliche: float and small exposures indicate purplish-brown mudstone and gray claystone with a few thin friable white sandstone layers	81
	Todilto Formation	

MANCOS SHALE
Sec. 31, T. 12 N., R. 6 E.
(*Modified from Harrison, 1949*)

Unit	Description	Thickness (ft)
	Mesaverde Formation above	
	Mancos Shale (total thickness)	1,544
18	Shale: gray to olive drab with thin silty and sandy layers	309
17	Sandstone: buff to olive drab, fine-grained, thin- to medium-bedded with calcareous zones and cone-in-cone concretions; thin shaly partings; fossiliferous zones, local crossbedding	203
16	Shale: olive-drab to buff-gray, silty to sandy gradations, sand content increases toward top; sandy beds, calcareous concretionary beds or zones, fossiliferous zones; weathers to buff-cream color and is generally slope-forming	487
15	Sandstone: light buff-gray, fine-grained, thin- to medium-bedded, hard, siliceous cement, ledge-forming	18
14	Shale: buff-gray, silty, weathers to cream-buff color, valley-forming	172
13	Limestone: brown, crystalline, silty to sandy, thin-bedded, with thin shale partings, highly fossiliferous	8
12	Shale: gray-buff, silty, with 1.3 ft gray concretionary calcareous bed near middle, and 1.5 ft yellow-brown calcareous bed with few fossils near bottom	70
11	Shale: gray	58
10	Limestone: brown, concretionary, sandy, highly fossiliferous, many fossils in concretions, ridge-forming	6
9	Shale: gray	32
8	Sandstone: gray-buff, fine-grained, thin-bedded, subangular to subrounded, hard, siliceous cement; ridge-forming	3
7	Sandstone: buff, fine-grained, silty; friable	2
6	Shale: buff to gray, sandy	2
5	Shale: gray	12
4	Sandstone: light gray-buff, fine-grained, thin- to medium-bedded, subangular to subrounded; hard, siliceous cement, ridge-forming	25
3	Shale: gray, with thin sandy streaks	34
2	Limestone: gray, concretionary, silty, cone-in-cone structure, forms pods	2
1	Shale: dark-gray, with thin scattered sandy and calcareous streaks	101
	Dakota(?) Sandstone	

MESAVERDE FORMATION
N ½ sec. 6, T. 13 N., R. 6 E.
(*Modified from Harrison, 1949*)

Unit	Description	Thickness (ft)
	Galisteo Formation above	
	Mesaverde Formation (total thickness)	3,057

Unit	Description	Thickness (ft)
	COAL-BEARING SHALE MEMBER NO. 3 (subtotal):	(590)
64	Sandstone: gray, fine-grained, medium-bedded, limonite-stained	8
63	Shale: gray	11
62	Sandstone: gray, fine-grained, with thin brown shale seams	3
61	Shale: brown	3
60	Sandstone: gray, fine-grained, subangular to subrounded, thin- to medium-bedded, black and white mineral grains abundant	14
59	Shale: gray, silty to sandy	12
58	Sandstone: gray, fine-grained, massive-bedded	30
57	Shale: brown-gray	29
56	Shale: brown-olive drab, limonitic concretionary zone, 8 inches of carbonaceous shale at top	23
55	Sandstone: gray, fine-grained, massive-bedded, argillaceous, with limonitic concretions; about 3 ft of thin, cross-bedded sandstone in the middle	27
54	Shale: gray, sandy zones and a thin carbonaceous shale near bottom	25
53	Sandstone: gray-buff, fine-grained, thin-bedded, argillaceous	5
52	Sandstone: gray, fine-grained, massive-bedded, some cross-bedding present	27
51	Sandstone: gray, fine-grained, shaly, with limonitic concretions	4
50	Shale: gray to brown with 4-inch coal seam near top and a 3-ft coal seam near middle	11
49	Sandstone: yellow-buff to gray, fine-grained, subangular to subrounded, thick- to massive-bedded, some cross-bedding is present; brown limonitic concretionary beds with evidence of organic material	41
48	Shale: brown, 2 ft coal seam	3
47	Shale: gray	6
46	Sandstone: gray, fine-grained, massive-bedded	5
45	Shale: gray to brown, one-ft coal seam near bottom, a 1.3-ft coal seam just above the middle, and a 1.5-ft coal seam at top; carbonaceous shale and sandy shale separate the seams	43
44	Sandstone: gray, fine-grained, thin-bedded, limonite-stained	7
43	Shale: gray to brown, carbonaceous, 1-ft coal seam near middle and 1.8-ft seam near the bottom; slope-forming	15
42	Sandstone: gray, fine-grained, shaly at top, slope-forming	2
41	Shale: gray and brown, thin sandy zone, slope-forming	6
40	Sandstone: gray, fine-grained, thin-bedded, with thin brown shale and calcareous concretion beds	6
39	Shale: brown, thin gray sandy streaks	6
38	Sandstone: gray, fine-grained, thin-bedded, argillaceous	4
37	Shale: brown, 8-inch coal seam near bottom	8
36	Sandstone: gray, fine-grained, thin-bedded	3
35	Shale: brown to gray, carbonaceous	13
34	Sandstone: gray-buff, fine-grained, thin-bedded, with shaly and calcareous zones; black, orange, green, and white mineral grains are common	21
33	Shale and Siltstone: gray-buff	14
32	Shale: brown, 1-ft coal seam near middle	7
31	Shale: gray to brown, 2.5 ft coal seam near middle, sandy near top	24
30	Shale: gray to brown, bottom half is more sandy	30
29	Sandstone: gray-white, buff-yellow, gray-buff, and gray, fine-grained, thin- to massive-bedded; shale partings, limonite stains, black and white mineral grains are rather abundant, with minor amounts of orange and green mineral grains in some horizons; friable to well-indurated	72
28	Shale: gray with rust-colored sand seams	22
	SANDSTONE MEMBER NO. 4 (subtotal):	(135)
27	Sandstone: buff, fine-grained, forms small ridge	6
26	Shale: gray to brown, carbonaceous shale, sandy stringers, and calcareous zones; top 8 inches is highly fossiliferous	106
25	Sandstone: gray, fine-grained, thin-bedded with local calcareous concretions, top of ridge	4
24	Sandstone: yellow-buff, fine-grained, thin- to medium-bedded, gypsiferous along seams at bottom	19
	COAL-BEARING SHALE MEMBER NO. 2 (subtotal):	(521)
23	Shale: gray, sandy seams, calcareous concretionary zones; cone-in-cone concretions present, gypsum in seams at top	103
22	Shale: gray, with sandy seams	418
	SANDSTONE MEMBER NO. 3 (subtotal):	(248)
21	Sandstone: gray, fine-grained, thin-bedded, with sandy shale bed in middle	7
20	Shale: yellow-buff, sandy	2
19	Sandstone: gray, fine-grained, thick-bedded, subangular to subrounded, cross-bedding present; fossils locally, ripple-marks, worm-burrows, and fossil casts on exposed top of sandstone bed	9
18	Sandstone: yellow-buff, fine-grained, thin-bedded, shaly; fossil zones, slope-forming	79
17	Sandstone: gray, fine-grained, thin-bedded, very fossiliferous	3
16	Sandstone: gray, fine-grained, thin-bedded, and shaly	80
15	Sandstone: gray, fine-grained, thin-bedded, 8-inch calcareous cone-in-cone concretionary zone in middle	9
14	Sandstone: yellow-buff, fine-grained, thin-bedded, shaly and slope-forming; selenite seams along bedding planes	29
13	Sandstone: gray, gray-buff and brown, fine-grained, thin-bedded, with shale partings and shaly zones, also thin, calcareous concretionary zones, fossiliferous beds present	30
	SHALE MEMBER (subtotal):	(67)
12	Shale: yellow-buff, sandy	67
	SANDSTONE MEMBER NO. 2 (subtotal):	(589)
11	Sandstone: gray-buff, fine-grained, shaly, fossiliferous	32
10	Sandstone: yellow-buff, fine-grained, thin-bedded, shaly, few fossils and worm burrows (?)	270
9	Sandstone: gray-buff, fine-grained, thin-bedded, shaly; bottom 1-ft coarse-grained to conglomeratic locally, fossiliferous (shark teeth)	262
8	Sandstone: gray-buff, fine-grained, thin-bedded, shaly with sandy shale partings	25
	COAL-BEARING SHALE MEMBER NO. 1 (subtotal):	(661)
7	Shale: buff-gray, with sandy seams	108
6	Shale: buff, sandy	83
5	Shale: gray, silty	168
4	Shale: gray, brown to black, with carbonaceous shale and coaly shale beds; also sandy seams and calcareous zones	56
	CANO SANDSTONE MEMBER (subtotal):	(246)
3	Sandstone: gray-buff, fine- to medium-grained, thin- to massive-bedded, subangular to subrounded; with thin shale partings and calcareous lenses; cross-bedding is present in some beds	246
	Mancos Shale	
	(Units 1 and 2 of Harrison are nos. 17 and 18 in the Mancos section above.)	

MESAVERDE FORMATION

A general section in the Tijeras basin measured with students in the E½ sec. 31, T. 11 N., R. 6 E.

Unit	Description	Thickness (ft)
	Mesaverde Formation	
	UPPER SANDSTONE (subtotal):	(387)
24	Sandstone: buff to gray, medium- to thick-bedded, medium- to coarse-grained, local cross-bedding	84
23	Shale and Siltstone: mostly covered	69

Unit	Description	Thickness (ft)
22	Sandstone: buff, medium- to thick-bedded, medium-grained, well-cemented	29
21	Shale: mostly covered, some intercalated sandstone and siltstone	82
20	Sandstone: gray to buff, thin- to medium-bedded, local cross-bedding, friable, local carbonaceous layers	12
19	Covered:	21
18	Sandstone: gray, thin- to medium-bedded, with intercalated shale and siltstone	66
17	Covered: mostly shale	24
	(Top Eroded)	
	MIDDLE SANDSTONE (subtotal):	(224)
16	Sandstone: dark-gray, medium- to thick-bedded, siliceous	30
15	Sandstone: dark-gray, massive-bedded, cross and lenticular bedding, firm siliceous cement, cliff-forming	30
14	Sandstone: light-gray, medium- to thick-bedded, medium- to coarse-grained, feldspathic and micaceous, local cross-bedding, friable, calcareous	57
13	Sandstone: buff to light-brown, thin- to medium-bedded, fine- to medium-grained, argillaceous with some interbedded siltstone and shale	107
	LOWER SANDSTONE (subtotal):	(528)
12	Covered: mostly shale and siltstone	165
11	Sandstone: buff to tan, thick-bedded with some cross-bedding, medium-grained	14
10	Sandstone: gray to buff, thin-bedded, fine- to medium-grained	19
9	Sandstone: gray to buff, medium-bedded, fine- to medium-grained	24
8	Covered	16
7	Sandstone: light-gray, thin- to medium-grained	22
6	Covered	6
5	Sandstone: light-gray, thin- to medium-bedded, medium-grained, friable	10
4	Sandstone: buff, massive and laminated	18
3	Sandstone: gray, thin-bedded, friable	12
2	Sandstone: buff to tan, thick- to massive-bedded	12
1	Sandstone and Shale: mostly covered, largely medium- to thick-bedded sandstone in upper two-thirds and thin-bedded sandstone and intercalated shale in the lower one-third; top eroded	210

GALISTEO FORMATION

Along Pinovetito Arroyo, sec. 4, 5, T. 13 N., R. 6 E.

Unit	Description	Thickness (ft)
	Espinaso Volcanics above	
	Galisteo Formation (total thickness)	2,474
	UPPER SANDSTONE UNIT (subtotal):	(1,116)
71	Sandstone: light-buff, medium-grained, thin- to medium-bedded, argillaceous and thin granule lens near top	107
70	Limestone: white, dense, with clay streaks	1
69	Shale: gray	4
68	Sandstone: gray, fine-grained, shaly	9
67	Sandstone: buff, fine- to medium-grained	7
66	Shale: gray	16
65	Sandstone: gray-buff, fine-grained, thin- to medium-bedded	9
64	Sandstone gray-buff, fine- to coarse-grained, medium-bedded, conglomerate lens in upper one-third	67
63	Shale: red with yellowish calcareous concretionary band near the top	8
62	Sandstone: gray, fine-grained, medium-bedded	23
61	Shale: variegated, with thin gray, fine-grained sandstone near bottom	41
60	Sandstone: gray, pinkish, buff, massive, fine- to coarse-grained, angular to subrounded	92
59	Sandstone: yellowish-buff, fine- to coarse-grained, medium- to massive-bedded, local conglomeratic beds, and shale partings	175
58	Sandstone: buff, fine- to coarse-grained, 4-ft conglomeratic bed near bottom, fragments of petrified wood	141
57	Sandstone: gray, fine-grained, thick- to massive-bedded, friable, limonitic stains	59
56	Sandstone: yellowish-buff, medium-grained, local pebbles	6
55	Conglomerate: buff, fine to coarse, angular to subrounded matrix; fragments are chert, quartz, limestone, and feldspar	2
54	Sandstone: gray, buff, yellowish, and tan, fine- to coarse-grained, thin- to medium-bedded, subangular to subrounded, grains of quartz, chert, feldspar; some intercalated thin, variegated shale and local granule lenses, friable	316
53	Claystone: brick-red with silty streaks	20
52	Sandstone: tan to light-red, fine-grained, massive	13
	SHALE UNIT (subtotal):	(212)
51	Claystone: variegated, with sandy streaks	212
	UPPER CLAYSTONE UNIT (subtotal):	(336)
50	Sandstone: fine- to medium-grained, massive	34
49	Conglomerate: buff, fine to coarse matrix, subrounded to rounded granules and pebbles, limonite-stained, indurated	2
48	Sandstone: gray, massive, fine-grained, silty	8
47	Claystone: grayish maroon	2
46	Claystone: bright-brick-red	10
45	Sandstone: gray, fine-grained, shaly	7
44	Shale: bright-reddish-brown	18
43	Sandstone: cross-bedded, yellowish-gray, fine- to coarse-grained, angular to subrounded pebble conglomerate at bottom	41
42	Shale: brick-red	9
41	Sandstone: light-tannish-red, thin-bedded, fine-grained, shaly	9
40	Sandstone: gray-buff, cross-bedded, fine- to medium-grained, shaly, friable, locally conglomeratic	15
39	Shale: light-red	6
38	Conglomeratic sandstone: coarse-grained, angular to subrounded, pebbles and cobbles of chert, quartz, limestone, and sandstone, limonite-stained	3
37	Sandstone: yellowish-buff, fine- to medium-grained, medium-bedded, conglomeratic toward top	21
36	Conglomeratic sandstone: cross-bedded, brownish orange, fine- to coarse-grained, subangular to subrounded, granules to cobbles of chert, quartz, limestone, and pinkish granite	14
35	Shale: purplish-red	2
34	Sandstone: gray, massive, fine-grained, pebble conglomeratic lenses in bottom 6 ft	23
33	Shale: tan- and purplish-red, with silty and sandy gray streaks	112
	MIDDLE SANDSTONE UNIT (subtotal):	(290)
32	Sandstone: gray, thin-bedded, fine-grained, silty	7
31	Shale: brick-red	8
30	Sandstone: gray, thin-bedded, fine-grained, silty	11
29	Sandstone: buff, medium-bedded, grains angular to subangular, feldspathic, locally conglomeratic	6
28	Sandstone: yellowish-gray, medium-bedded, fine-grained, silty	16
27	Claystone: brick-red	9
26	Sandstone: gray, fine-grained, silty, friable	4
25	Sandstone: yellowish-buff, medium- to coarse-grained, pebbles of quartz, limestone, and minor feldspar	6
24	Claystone: light-brick-red	4
23	Sandstone: gray, fine-grained, friable with indurated streaks	9
22	Clay: reddish	11
21	Sandstone: gray, medium-bedded, fine-grained, bottom 1 ft coarse-grained and granulitic	10
20	Shale: light-brick-red, sandy	19

Unit	Description	Thickness (ft)
19	Sandstone: gray, thick-bedded, fine-grained, granulitic at base	13
18	Shale: variegated	14
17	Sandstone: yellowish-gray, thin- to thick-bedded, fine-grained, 2-ft claystone in lower one-third, scattered granule and pebble lenses, friable	143
	LOWER CLAYSTONE UNIT (subtotal):	(359)
16	Shale: gray, sandy, friable	6
15	Sandstone: gray, medium-bedded, fine-grained, granulitic to pebbly, petrified wood, limestone seams	17
14	Shale: yellowish-gray, sandy	5
13	Sandstone: gray-buff, thin- to thick-bedded, fine-grained, subangular to subrounded; pebble conglomerate 8 inches thick overlain by 5-ft sandy gray shale in lower middle part	110
12	Shale: gray, sandy	22
11	Sandstone: gray, thin- to medium-bedded, fine-grained, argillaceous with thin calcareous nodular concretionary zone	33
10	Sandstone: gray, medium-bedded, fine-grained, shaly	13
9	Sandstone: gray, orange, thin- to medium-bedded, fine-grained, shaly, limonite stains, ridge-former	64
8	Claystone: gray, silty and sandy streaks, thin calcareous bed near bottom	37
7	Sandstone: gray, buff, thin- to medium-bedded, fine-grained, friable with shaly seams	36
6	Shale: yellowish-gray, sandy streaks, gypsiferous	16
	LOWER SANDSTONE UNIT (subtotal):	(161)
5	Sandstone: variegated, thin- to thick-bedded, fine-grained, limonite stains	20
4	Sandstone: gray, thin- to medium-bedded, fine-grained, silty and shaly layers, limonite stains	8
3	Siltstone: gray	30
2	Claystone: gray, brown, red, valley-forming	25
1	Sandstone: thin- to massive-bedded, cross-bedded, fine-grained, argillaceous, scattered granule seams, gravel and pebble conglomerate at bottom, shaly toward top with occasional thin calcareous lenses, limonite prevalent	78
	Mesaverde Formation	

Appendix 2—Earthquakes

EARTHQUAKE OF NOVEMBER 6, 1947, 09:50 MST

The following summary of responses to a questionnaire-card survey of the earthquake of November 6, 1947, 09:50 MST was published by the U.S. Coast and Geodetic Survey (1948) in *Abstracts of earthquake reports for the Pacific Coast and the Western Mountain Region*, p. 12-13.

(Albuquerque Press) Slight tremors believed an earthquake were reported felt Thursday morning at San Antonito, about 24 miles east of here in the Sandias. Bill Marcum, school teacher there, said the shock shook his classroom, jarred the floors and rattled the desks. He gave the time as 9:50 a.m. and estimated it lasted 15 seconds. A housewife in the community said dishes were jarred from shelves in her house, Marcum related. Marcum, who said he had experienced a "quake" before, said he drove around the neighborhood later and in talks with 15 persons representing residents in a 10-mile radius learned they had felt the shock. Dr. S. A. Northrop, seismologist here, said he had no report of a quake but promised to check his instruments today. These, he said, were at the time running vibration tests on truck rumblings on East Central.

The following is quoted from a letter from Professor Stuart A. Northrop, Collaborator in Seismology, U.S. Coast and Geodetic Survey, University of New Mexico, Albuquerque: "This is the first record of a shock in the Sandia Mountain Region. However, it may be noted that San Antonito is only 23 miles SW of Cerrillos, where there was a severe shock (Rossi-Forel VIII-IX) in 1918. San Antonito is 1 mile east of Sandia Park, and 18 miles N-NE of Albuquerque. Cedar Crest and Zamora are located about 4 miles south of San Antonito and Sandia Park. We have no record of this shock being felt outside of this small area. It was not felt here at Albuquerque, nor at Placitas, which is 12 miles N-NW of Sandia Park. The shock was probably not felt at Edgewood or Madrid. This earthquake occurred in the vicinity of the Tijeras Coal Basin, a graben-like block on the eastern dip slope of the Sandia Mountains fault block. San Antonito and Sandia Park are on the north side of the major fault bounding the Coal Basin on the north. Cedar Crest is just south of this same fault. The C. A. Dooley ranch is located either directly on, or within 100 feet of, the major fault bounding the Coal Basin along the southeast side."

Intensity VI:

Zamora (C. A. Dooley Ranch). Motion rapid, lasted 10 or 15 seconds. Felt by all in home and community; frightened all in home. Rattled windows, doors, dishes. Cracked plaster and fireplace. Damage slight to fireplace and south wall of house.

Intensity V:

Cedar Crest. Motion rapid, lasted I second. Felt by all and frightened few in home. Rattled windows. Ground: Soil, compact; level.

Cedar Crest, 41/2 miles N of (Crane's Store). (IV) Motion rapid. Felt by all in home. Rattled dishes. Ground: Soil, compact; sloping.

San Antonito. Motion rapid, lasted 5 seconds. Felt by many in community; frightened few. Rattled windows, doors. Ground: Rock; sloping.

Sandia Park. Motion rapid, lasted a fraction of second. Felt by all in community. Rattled windows, doors, dishes. Shifted small objects. Ground: Rock; level.

Sandia Park and vicinity. Motion rapid, up and down, lasted 1/2 second. Felt by several in home. Rattled windows, doors, dishes. Everything moved up and down. Ground: Rock, compact; sloping.

Reported not felt:

Albuquerque, Placitas (12 miles N-NW of Sandia Park).

EARTHQUAKE OF APRIL 25, 1956, 20:30 MST

The following summary for the earthquake of April 25, 1956, 20:30 MST was published by the U.S. Coast and Geodetic Survey (1956, p. 15-16).

Sandia Mountains, east of Albuquerque.

Placitas (village at north end of Sandia Mountains, about 17 miles north of the Tres Pistolas-Tijeras area). V. Felt by 3 families at least. First a muffled, explosivelike noise followed immediately by a distinct jolt. House creaked. Aluminum tumbler, on the sink in the house next door, rattled enough to be heard in adjoining room. Another neighbor across street felt jar. Dogs barked. Floor and couch on which observer was sitting seemed to fall about an inch and then bounce back. Pictures on SE and NW walls of 2 rooms knocked askew. "Some new cracks in outside plaster may have occurred."

Tijeras Canyon (E of Albuquerque). IV. Awakened many; frightened few. Windows, doors, and dishes rattled. Ground: Rocky, sloping, steep. Ranger reported the shock was not felt at the near-by Sandia Ranger Station.

Tres Pistolas Canyon (branches off north from Tijeras Canyon). IV. Motion rapid, lasted 2-3 seconds. Low rumble heard. Felt by several in home (sitting and active). Doors rattled; roof creaked. Ground: Rocky soil, compact, sloping and steep. Press reported a neighbor of the foregoing reporter heard a noise and noticed that windows and walls shook. "Rather pronounced. I knew it was an earthquake." Lasted about 3 seconds.

Index

Pocket Contents

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GEOLOGIC MAP OF SANDIA MOUNTAINS AREA, NEW MEXICO

by Vincent C. Kelley, 1975

SCALE 1:48,000

1 0 1 MILE

ELEVATION CONTOUR MAP OF SANDIA MOUNTAINS AREA, NEW MEXICO

from U.S. Geological Survey

SCALE 1:48,000

1 0 1 2 MILES

CONTOUR INTERVALS 20 AND 40 FEET
Datum is mean sea level

STRUCTURE CONTOUR MAP OF SANDIA MOUNTAINS AREA, NEW MEXICO

by Vincent C. Kelley, 1975

0 1 2 MILES

STRUCTURAL SECTIONS OF SANDIA MOUNTAINS AREA, NEW MEXICO

by Vincent C. Kelley, 1975

1 0 1 MILE

Locations of structural sections are shown on map 1