Tectonic framework of Albuquerque country

Lee A. Woodward

1982, pp. 141-145. https://doi.org/10.56577/FFC-33.141

in:

Albuquerque Country II, Wells, S. G.; Grambling, J. A.; Callender, J. F.; [eds.], New Mexico Geological Society 33 rd Annual Fall Field Conference Guidebook, 370 p. https://doi.org/10.56577/FFC-33

This page is intentionally left blank to maintain order of facing pages.

TECTONIC FRAMEWORK OF ALBUQUERQUE COUNTRY

LEE A. WOODWARD
Department of Geology
University of New Mexico
Albuquerque, New Mexico 87131

INTRODUCTION

There have been at least five major episodes of deformation in the area of this field conference, including the Precambrian, late Paleozoic, Laramide (Late Cretaceous—early Tertiary), middle Tertiary, and late Cenozoic. Precambrian tectonics are not considered here because of numerous unresolved problems concerning reliability of radiometric dates, lack of data on directions of stratigraphic younging, complications from folding and faulting, and general difficulty in correlations of rock units (Fulp and Woodward, 1981; Armstrong and Holcombe; Cavin and others; and Grambling, this guidebook).

From Cambrian through Devonian time this region was mildly positive, being located on the south flank of the transcontinental arch; as a result, there are no lower Paleozoic strata here. During the Mississippian a thin sequence of shelf carbonates accumulated (Armstrong, 1967; Armstrong and Mamet, 1979). High-angle faulting and epeirogenic uplift resulted in removal of most of the Mississippian strata prior to deposition of Pennsylvanian rocks.

In the late Paleozoic a structurally and topographically high area, the Pefiasco axis (Read and Wood, 1947), developed along the present Nacimiento uplift. This positive area shed granitic elastic debris into adjacent marine basins during Pennsylvanian time and persisted as a mildly positive area into the Permian (Baars, this guidebook).

Mesozoic strata were deposited as relatively uniform blankets across the region. Epeirogenic uplift and tilting resulted in regional, low-angle unconformities between Permian and Triassic, and between Jurassic and Cretaceous strata, with large parts of the Triassic and Jurassic systems being absent.

The major elements of the Colorado Plateau and Rocky Mountains, the Lucero uplift, Acoma sag, Nacimiento uplift, and San Juan Basin, attained their present structural outlines during Laramide time. Numerous dikes, sills, stocks, and laccoliths were emplaced in the Ortiz porphyry belt during middle-Tertiary time. These igneous bodies, mainly porphyritic laccoliths, form the Ortiz porphyry belt.

Late Cenozoic crustal extension was superimposed on the older structures and resulted in development of the Rio Grande rift, a series of en echelon grabens and half grabens filled with elastic sediments. Contemporaneous volcanism occurred in the Mount Taylor and Jemez areas as well as within the rift.

The present physiography of the region is due mainly to late Cenozoic deformation with subordinate topographic expression of Laramide and middle-Tertiary structures.

ROCK UNITS AND MECHANICAL BEHAVIOR

Precambrian igneous, metasedimentary, and metaigneous rocks form the basement in this region and during Phanerozoic time have deformed by fracturing. There are large exposures of Precambrian rocks in the Nacimiento and Sandia-Manzano uplifts and at Monte Largo horst along the Tijeras-Cationcito fault system. A minor Precambrian outcrop is present in the Lucero uplift.

Paleozoic limestone and sandstone are more ductile than the Precambrian rocks but are more competent than the thick shale and mudstone intervals of the Mesozoic strata. In particular, thick Cretaceous shales tend to deform plastically.

Upper Cenozoic sediments of the Santa Fe Group and volcanic rocks within or straddling the western margin of the Rio Grande rift are contemporaneous with rifting. Rocks that are older than rifting (Precambrian to middle Cenozoic) tend to fracture under the tensional stress field associated with rifting.

STRUCTURE

The area of this field conference includes parts of three major tectonic provinces, the Colorado Plateau, the southern Rocky Mountains, and the Rio Grande rift (fig. 1). Both the Colorado Plateau and Rocky Mountain provinces attained their present structural outlines during Laramide time (Late Cretaceous—early Tertiary) although there has been minor deformation of these provinces since then. The Rio Grande rift is a late Cenozoic feature that is superimposed on the older structures of the Colorado Plateau and the Rocky Mountains. The Lucero uplift and Acoma sag are parts of the Colorado Plateau, and the Nacimiento uplift and the eastern margin of the Estancia basin mark the southern extent of structures related to the Rocky Mountains. The Albuquerque basin and the Sandia-Manzano uplifts are parts of the Rio Grande rift system. The Rio Puerco fault zone is a composite element, being related in part to the structural development of the Colorado Plateau and in part to the Rio Grande rift. Likewise, the Estancia basin is composite insofar as the eastern limb is defined by the Pedernal uplift of probable Laramide age (Kelley, 1972) and the western margin is the dip-slope on the east side of the late Cenozoic Sandia-Manzano uplifts.

The Ortiz porphyry belt is of middle Tertiary age and consists of several intrusive centers that are aligned northeasterly along the Tijeras-Canoncito fault system, a major recurrent structure of central New Mexico.

Two major volcanic centers are present: the Mount Taylor volcanic field is of late Cenozoic age and is built upon the Colorado Plateau (Crumpler; Laughlin and others; and Maxwell, this guidebook); the Jemez volcanic field is also of late Cenozoic age and straddles the western boundary of the Rio Grande rift, resting on the Laramide Nacimiento uplift and interfingering with sediments filling the rift.

The Colorado Plateau is an area that is structurally unique in the western United States insofar as it has been only moderately deformed compared to the more intensely deformed regions that surround it. Monoclines appear to be the most distinctive structural features of the plateau, and much of the deformation has occurred along these structures (Kelley, 1955a). The geographically widespread uplifts and structural basins, however, are the main features that define the major tectonic divisions of the Colorado Plateau. Most of the uplifts are bounded on one side by monoclines.

Acoma Sag

The Acoma sag is a structurally low area that was named by Kelley (1951) for an embayment extending southward from the eastern part of the San Juan Basin. As outlined by Kelley and Clinton (1960), the Acoma sag is about 55 km wide (east-west) and about 80 km long with the structurally deepest part along the gently north-plunging McCartys syncline (fig. 1). The sag is markedly asymmetrical with a steep western limb that is the boundary with the Zuni uplift. Toward the east the sag

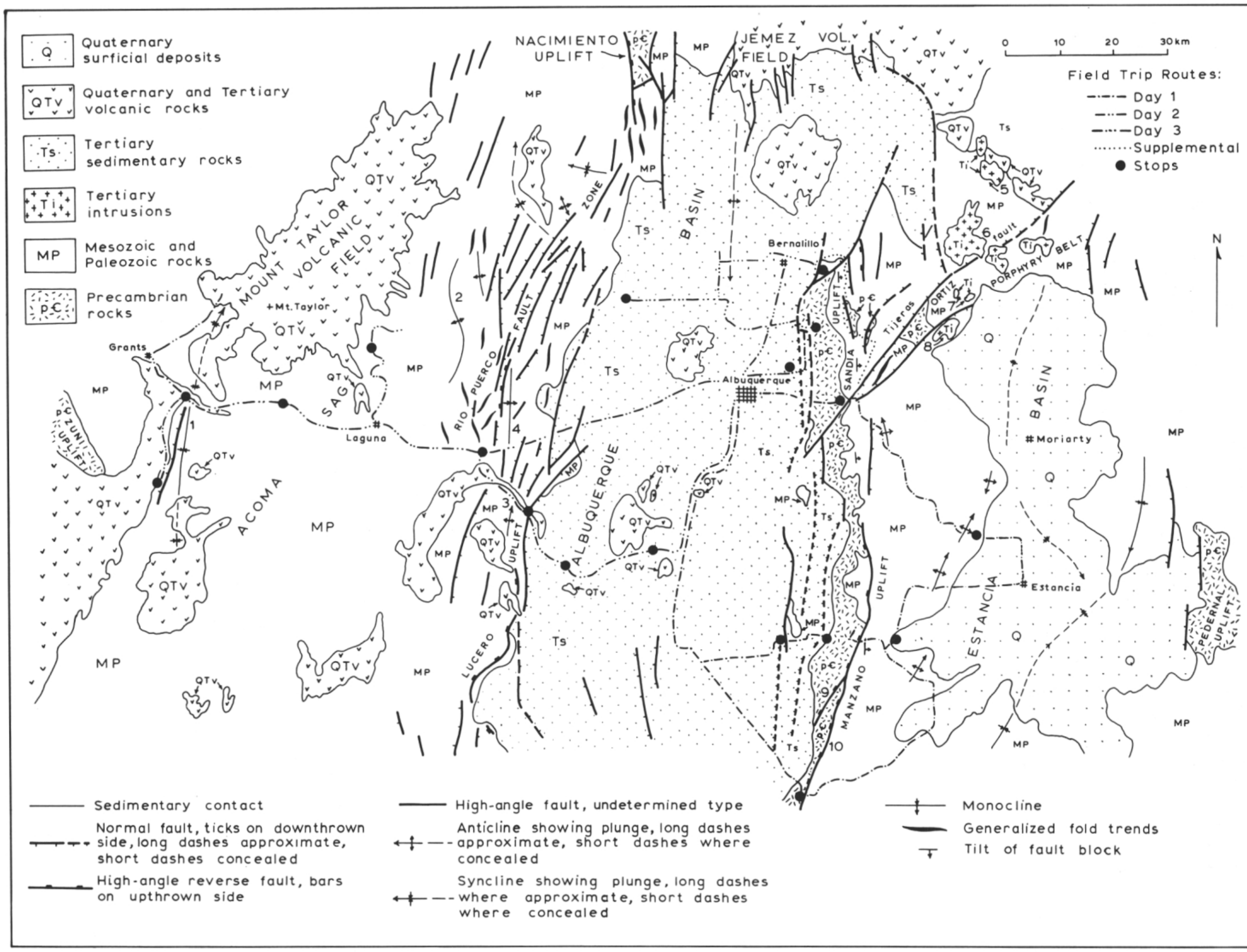


Figure 1. Tectonic map of Albuquerque Country II field conference area showing field trip routes and stops.

merges with the Lucero uplift through a limb dipping 5°-15° to the northwest, and farther north the eastern boundary of the sag with the Rio Puerco fault zone is placed at the east-dipping limb of the broad Santa Rosa—Guadalupe anticline (Kelley and Clinton, 1960; fig. 1). The northern boundary of the sag is transitional with the San Juan Basin or the gently dipping Chaco slope that bounds the southern side of the basin. The southern margin of the sag is also transitional, merging with the Mogollon slope through low dips.

Structure within the Acoma sag is fairly simple, being characterized by low dips observable mainly in Triassic through Cretaceous strata. The largest structure in the sag is the previously mentioned Santa Rosa—Guadalupe anticline. Other smaller folds trend to the northwest or the northeast (fig. 1). A few north-northeasterly trending high-angle faults with minor displacement are present on the western limb of the sag.

Late Cenozoic post-orogenic volcanic rocks are found in several parts of the Acoma sag (fig. 1).

Lucero Uplift

The Lucero uplift is a west-tilted fault block about 55 km long and 11-20 km wide. The western flank of the uplift is transitional with the Acoma sag and is marked mostly by Pennsylvanian and Permian strata dipping northwesterly at 5°-15°. On the north the uplift merges through the Lucero anticline with the Ignacio monocline of the Rio Puerco fault zone (fig. 1). The eastern margin of the uplift is the boundary between the Colorado Plateau and the Rio Grande rift, a structurally complex zone (Kelley and Wood, 1946) with rocks ranging in age from Precambrian to late Cenozoic. Callender and Zilinski (1976) described the Laramide structures along this zone as an east-facing monocline with gravity slides from the struturally high monocline and a subsequent upthrust. Oligocene intrusions occur along some of the gravity-slide faults. Superimposed on this zone is an east-dipping high-angle normal fault with at least 3,500 m of stratigraphic separation that defines the boundary between the Rio Grande rift and the uplift.

Numerous small, complex folds and faults occur in the zone of steeply east-dipping rocks on the east flank of the uplift. Elsewhere, a few north- to northeast-trending minor open folds are present with a few small high-angle, north- to northwest-trending faults having minor displacement (Kelley and Clinton, 1960).

Nacimiento Uplift

The Nacimiento uplift trends north and is about 80 km long and 10to-16 km wide. In general, it consists of an uplifted block that is tilted eastward and is bounded on the west by faults. There are at least 3,000 m of structural relief between the highest part of the uplift and the adjacent San Juan Basin.

East of the range-marginal faults, an anticlinal bend occurs locally along the western margin of the uplift. The Nacimiento fault, an upthrust that is steep at depth but flattens upward and has westward movement of the hanging wall block over the San Juan Basin (Woodward and others, 1972), bounds the northern part of the uplift. Farther south a reverse fault dipping steeply to the east bounds the west side of the uplift.

The northern end of the uplift is a broad, faulted anticline that plunges 10° to 20° northward. The uplift terminates toward the south with folds that plunge to the south beneath an unconformable cover of Tertiary rocks (Slack, 1973).

Structures within the uplift include north-trending normal faults that bound second-order, tilted fault-blocks at the north end of the uplift and a graben in the southern part of the uplift. There are also high-angle faults trending east-west, northwest, and northeast; these faults separate differentially uplifted segments within the Nacimiento uplift. A few northwest-trending folds are seen near the south end of the uplift (Ruetschilling, 1973). Folds with similar trends may have been present elsewhere in the uplift, but stripping of sedimentary strata from most of the uplift has removed any evidence of them.

Rio Puerco Fault Zone

Slack and Campbell (1976) described the structure of the Rio Puerco fault zone, and the following summary is taken mainly from their work. The fault zone is about 75 km long and 13-to-30 km wide. Three major groups of structures occur in this zone and are, from north to south, northwest-trending en echelon folds, northeast-trending en echelon normal faults, and the east-facing Ignacio-Lucero monocline. Major structural relief across the fault zone is down to the east and is a maximum of about 1,000 m. Slack and Campbell (1976) suggested that this complex geometry resulted from early Cenozoic right shift along the fault zone, middle Cenozoic vertical uplift of the Ignacio-Lucero monocline, and late Cenozoic development of the Rio Grande rift.

Ortiz Porphyry Belt

Structures of mid-Tertiary age that are expressed topographically are igneous centers, mostly laccoliths. From north to south these are the Cerrillos, Ortiz, San Pedro, and South Mountain areas (fig. 1). Bachman and Mehnert (1978) report K-Ar dates of 34.0± 2.2 m.y. for a latite sill on the west side of the Ortiz Mountains and 47.1 3.2 m.y. for a latite intrusion in the Cerrillos Hills. These igneous rocks are intruded into strata ranging in age from Pennsylvanian to Tertiary, and the intrusions produced domes, presumably laccolithic. There is a general north or north-northeast trend to these intrusions. Kelley (1978) referred to these collectively as the Cerrillos uplift; however, the doming is localized around the intrusions and the overall geometry is too irregular to be an uplift in the ordinary sense. Therefore, these intrusions are here referred to as the Ortiz porphyry belt.

Rio Grande Rift

The Rio Grande rift is comprised of several north-trending grabens (arranged en echelon north-northeasterly) occurring for a distance of at least 725 km in New Mexico and Colorado (Kelley, 1952). Antithetic and synthetic faults commonly occur within the major grabens, forming step faults as well as second-order grabens and horsts. The major grabens, usually referred to as basins, are described from north to south; the Albuquerque basin, shown on Figure 1, is discussed in more detail than the others.

The Upper Arkansas valley in Colorado, the northernmost graben of the Rio Grande rift (Chapin, 1971), is about 100 km long and narrows to a point at its north end where the graben dies out; it is linked with the San Luis valley to the south by a structural constriction containing upper Cenozoic sediments.

The San Luis basin is about 240 km long and up to 90 km wide. In New Mexico the basin appears to be tilted mostly toward the east. In addition to upper Cenozoic sediments, extensive volcanic rocks of the Taos Plateau occur within the basin and extend into the northern Espanola basin. The San Luis basin merges with the Espanola basin to the south at the Embudo constriction.

The Espanola basin, 65-to-80 km long and 30-to-65 km wide, is tilted mainly to the west, where it is bounded by high-angle faults near Abiquiu. These faults are covered by extrusive rocks of the Jemez volcanic field to the south, but they reappear on the south side of the volcanics along Jemez Creek. To the south the Espanola basin is connected with the Albuquerque basin via the White Rock channel, a constriction along the southwestern edge of the Espanola basin (Kelley, 1978).

The Santo Domingo and Albuquerque-Belen basins (Kelley, 1952) are considered as one tectonic feature in the present report. This feature, about 145 km long and 48 km wide, is here called the Albuquerque basin. The northern end of this basin is asymmetric, with the deepest part on the east side where the depth to Precambrian rocks may be approximately 5,500 m below sea level (Black and Hiss, 1974), giving maximum structural relief of approximately 8,500 m against the eastward-tilted Sandia uplift. The Hagan embayment, an eastward-tilted half-graben marking the northeastern edge of the Albuquerque basin and merging southward through a broad slope with the Sandia uplift, contains upper Cenozoic sediments deposited contemporaneously with rifting. Upper Cenozoic volcanics, mainly basaltic (Kelley and Kudo, 1978; Kudo, this guidebook), occur within the Albuquerque basin. Upper Cenozoic sediments filling the Albuquerque basin interfinger with extrusive rocks of the Jemez volcanic field to the northwest. To the south of the area shown in Figure 1, the Albuquerque basin becomes more symmetrical, and in the vicinity of Socorro it may bifurcate (Woodward and others, 1978) with an arm extending toward the San Augustin Plains to the southwest and the main part continuing to the south, forming the small San Marcial, Engle, and Palomas basins.

Sandia-Manzano Uplifts

Although the Sandia and Manzano mountains are commonly considered to be separate physiographic entities, they are formed by a single, major, east-tilted fault block that includes the Los Pinos Mountains to the south. This fault block is about 120 km long and up to 15 km wide. Precambrian rocks are exposed along the western fault-line scarp (Bauer; Cavin and others; Grambling, this guidebook), and the dip-slope to the east is formed mainly on Pennsylvanian strata dipping about 15° (Kelley and Northrop, 1975). There may be a maximum of 8,500 m of structural relief between the top of the Sandia uplift and the deepest part of the Albuquerque basin. On the east, the maximum structural relief is about 3,000 m between the Sandia uplift and the northern part of the Estancia basin and about 2,100 m between the Manzano uplift and the Estancia basin to the east.

A detailed geologic map of the Sandia Mountains (Kelley and Northrop, 1975) shows a mosaic of high-angle faults mostly having small displacements and trending westerly, northwesterly, northerly, and northeasterly. High-angle reverse faults in the southeastern part of the Sandia Mountains have been suggested to be of Laramide age (Late Cretaceous—early Tertiary) by Kelley and Northrop (1975). However, they note that there is no stratigraphic evidence to pin down such an age asssignment. It seems more likely that these faults formed in response to a local compressional stress field in the hinge or synclinal bend of the eastward-tilted Sandia fault block in the late Cenozoic.

Detailed geologic maps of the Manzano Mountains by Myers (1966, 1967, 1969), Myers and McKay (1970, 1971, 1976), and Myers and others (1981) shows numerous north- and northeast-trending, high-angle faults with small displacements. A few westerly and northwesterly trending faults are also present. In the southern Manzano Mountains two north-northeasterly trending thrust faults, the Palomas and Montosa (fig. 1), have been mapped (Kelley, 1977) and interpreted to be of Laramide age. These faults are high-angle reverse faults at most localities, and when the late Cenozoic eastward tilt of the Manzano fault block is removed they appear to be nearly vertical.

Tijeras Canyon, separating the Sandia from the Manzano Mountains, is underlain by the Tijeras segment of the Tijeras-Cafioncito fault system (Lisenbee and others, 1979). This major, northeast-trending fault is obliquely transverse to the principal uplifts and basins of central New Mexico and has undergone recurrent movement since Precambrian time. The Tijeras and related faults cut rocks ranging in age from Precambrian to late Tertiary and locally offset colluvium of probable late Quaternary age. This major fault probably extends as deep as does brittle deformation, and has localized Paleozoic to Quaternary deformation. Movement has been complex with both left and right strike-slip as well as dip-slip movement.

Estancia Basin

The Estancia basin is about 100 km long and 45 km wide. The basin floor is covered mainly with Quaternary surficial deposits (Bachhuber, this guidebook), but locally, bedrock of Pennsylvanian, Permian, and Triassic age is present. The western margin of the basin is transitional with the eastern dip-slope of the Sandia-Manzano uplift. On the east the low Pedernal uplift bounds the basin (Armstrong and Holcombe, this guidebook). In the vicinity of Gran Quivira a broad, low arch separates the Estancia basin from the Jornada basin to the south. The north end of the basin is arbitrarily placed at the Ortiz porphyry belt.

The Estancia basin consists of two structurally low areas separated by a low, broad arch trending westerly near Moriarty (Woodward and others, 1975). There appears to be about 1,500 m of structural relief between the arch and the low to the north and about 1,200 m of structural relief between the arch and the structural low in the southern part of the basin.

Jemez Volcanic Field

The Jemez volcanic field straddles the western margin of the Rio Grande rift and consists of a thick pile of Pliocene and Quaternary extrusive rocks. Present elevation of the Jemez Mountains is due to accumulation of volcanic rocks rather than to structural uplift. Volcanics of the Jemez field unconformably overlie rocks of the Nacimiento uplift to the west, the Chama basin to the north, and to the south, east and northeast, sediments filling the Rio Grande rift. Some of the older volcanics are interbedded with and grade into sediments filling the rift.

Volcanism began after initial development of the Rio Grande rift and continued contemporaneously with later stages of rifting. Early eruptions of basalt were followed by extrusion of andesite, dacite, quartz latite, rhyolite, and rhyolitic ash flows (Ross and others, 1961).

Major structures within the Jemez field are the Toledo and Valles calderas (Smith and others, 1970), which formed by collapse after extrusion of tremendous volumes of Bandelier Tuff (Ross and others, 1961). High-angle faults in the southern and eastern parts of the Jemez field that are related to rifting were active during and after volcanism, resulting in eastward thickening of the volcanic pile (Ross and others, 1961).

Mount Taylor Volcanic Field

Mount Taylor is a composite volcano built on the Colorado Plateau, with early eruptions of rhyolitic tuff and trachyte, followed by latite, and concluded with porphyritic andesite (Hunt, 1936). Tuff, trachyte, and latite come from a central vent, but the andesite was erupted mainly from radial fissures around the vent. The initial volcanic cone was much larger than the one seen today, as there has been considerable erosion. Younger basalt flows are deposited on erosion surfaces cut around the Mount Taylor cone and were erupted from small volcanoes flanking Mount Taylor. Although most of the basalt flows are younger than the more silicic eruptions, one basalt flow is older than the rhyolitic tuff, and a few are older than the porphyritic andesite (Hunt, 1936).

The Mount Taylor volcanic field is elongate to the northeast, being about 65 km long and 35 km wide. Mount Taylor attains an elevation of about 3,450 m. Radiometric ages of 1.1 to 3.8 m.y. are reported for rocks of the Mount Taylor area by Luedke and Smith (1978). One basalt flow to the south of Mount Taylor is as young as about 700 A.D. (Maxwell, this guidebook).

TECTONIC EVOLUTION

Northeast shift of the Colorado Plateau structural block (Kelley, 1955b) occurred as the North American plate drifted westward over an eastward-dipping subduction zone in Laramide time. Northeastward yielding of the plateau appears to have been related to the bend in the Cordilleran foldbelt in southeastern California. East-west compression in the Nevada-Utah segment of the foldbelt and nearly north-south compression in Arizona and New Mexico give a resultant vector trending northeast. Crowding and compression of the Colorado Plateau structural block by forces in the foldbelt to the south and west resulted in shift of the plateau toward the northeast. En echelon, northwest-trending folds and northeast-trending normal faults along the eastern edge of the San Juan Basin and in the Rio Puerco fault zone appear to have been formed by right shift along the eastern margin of the Colorado Plateau.

The east-facing Lucero monocline probably developed contemporaneously with the northeast yielding of the plateau; whereas, a west-facing monocline formed shortly afterward along the western margin of the Nacimiento uplift. Both monoclines were broken by upthrusts, with eastward yielding along the Lucero uplift and westward yielding along the Nacimiento uplift. Gravitational gliding of small sheets from the structurally and topographically high Lucero uplift was more common than from the Nacimiento uplift.

Subsidence of the San Juan Basin was at least in part contemporaneous with northeast yielding of the plateau as was the rise of the Zuni uplift. The Acoma sag between the Zuni and Lucero uplifts marks a zone of less rise than the bounding uplifts. It is likely that the Pedernal uplift rose during the Laramide, thus defining the eastern margin of the Estancia basin.

During middle Tertiary time numerous dikes, sills, laccoliths, and small stocks were emplaced in the Ortiz porphyry belt. It seems likely that the locations of these intrusions are in part structurally controlled by the Tijeras-Cafioncito fault system, a major transcurrent shear zone that has undergone recurrent deformation since the Precambrian (Lisenbee and others, 1979).

Late Cenozoic crustal extension that resulted in formation of the Rio Grande rift, a Miocene to Holocene event, may have been contemporaneous with epeirogenic rise of the entire region. The bounding shoulder on the east side of the rift, the Sandia-Manzano uplift, is of the same age and forms the western limb of the Estancia basin. Some of the Laramide faults of the Rio Puerco fault zone were reactivated during rifting (Machette, this guidebook). During later stages of rifting (Pliocene and Quaternary), volcanism occurred along the western margin of the rift to form the Jemez volcanic field. The Mount Taylor volcanic field is also contemporaneous with later stages of rifting, and it may form part of a northeast-trending lineament that also includes the Jemez volcanic field (Luedke and Smith, 1978).

REFERENCES

Armstrong, A. K., 1967, Biostratigraphy and carbonate facies of the Mississippian Arroyo Pefiasco Formation, north-central New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 20, 80 p.

Armstrong, A. K. and Mamet, B. L., 1979, The Mississippian System of north-central New Mexico: New Mexico Geological Society Guidebook 30, p. 201-210.

Bachman, G. O. and Mehnert, H. H., 1978, New K-Ar dates and the late Pliocene to Holocene geomorphic history of the central Rio Grande region, New Mexico: Geological Society of America Bulletin, v. 89, p. 283-292.

Black, B. A. and Hiss, W. L., 1974, Structure and stratigraphy in the vicinity of the Shell Oil Co. Santa Fe Pacific no. 1 test well, southern Sandoval County, New Mexico: New Mexico Geological Society Guidebook 25, p. 365-370.

Callender, J. F. and Zilinski, R. E., 1976, Kinematics of Tertiary and Quaternary deformation along the eastern edge of the Lucero uplift, central New Mexico: New Mexico Geological Society Special Publication 6, p. 53-61.

Chapin, C. E., 1971, The Rio Grande rift, part 1: modifications and additions: New Mexico Geological Society Guidebook 22, p. 191-201.

Fulp, M. S. and Woodward, L. A., 1981, Precambrian metallic mineralization in New Mexico: New Mexico Geology, v. 3, p. 33-42.

Hunt, C. B., 1936, Igneous geology and structure of the Mount Taylor volcanic field, New Mexico: U.S. Geological Survey Professional Paper 189-B, p. 51-80.

Kelley, V. C., 1951, Regional structure of the San Juan Basin: New Mexico Geological Society Guidebook 2, p. 101-108.

, 1952, Tectonics of the Rio Grande depression of central New Mexico: New Mexico Geological Society Guidebook 3, p. 93-105.

, 1955a, Monoclines of the Colorado Plateau: Geological Society of America Bulletin, v. 66, p. 789-804.

, 1955b, Regional tectonics of the Colorado Plateau and relationship to the origin and distribution of uranium: University of New Mexico Publications in Geology, n. 5, 120 p.

, 1972, Geology of the Fort Sumner sheet, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 98, 55 p.

, 1977, Geology of Albuquerque basin, New Mexico Bureau of Mines and Mineral Resources Memoir 33, 60 p.

, 1978, Geology of Espanola basin, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 48.

Kelley, V. C. and Clinton, N. J., 1960, Fracture systems and tectonic elements of the Colorado Plateau: University of New Mexico Publications in Geology, n. 6, 104 p.

Kelley, V. C. and Kudo, A. M., 1978, Volcanoes and related basalts of Albuquerque basin, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 156, 30 p.

Kelley, V. C. and Northrop, S. A., 1975, Geology of Sandia Mountains and vicinity, New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 29, 136 p.

Kelley, V. C. and Wood, G. H., 1946, Lucero uplift, Valencia, Socorro and Bernalillo Counties, New Mexico: U.S. Geological Survey Oil and Gas Investigations, Preliminary Map 47.

Lisenbee, A. L., Woodward, L. A., and Connolly, J. R., 1979, Tijeras-Cafioncito fault system-a major zone of recurrent movement in north-central New Mexico: New Mexico Geological Society Guidebook 30, p. 89-99.

Luedke, R. G. and Smith, R. L., 1978, Map showing distribution, composition, and age of late Cenozoic volcanic centers in Arizona and New Mexico: U.S. Geological Survey Map I-1091-A.

Myers, D. A., 1966, Geologic map of the Tajique quadrangle, Torrance and Bernalillo Counties, New Mexico: U.S. Geological Survey Map GQ-551. , 1967, Geologic map of the Torreon quadrangle, Torrance County, New Mexico: U.S. Geological Survey Map GQ-639.

, 1969, Geologic map of the Escabosa quadrangle, Bernalillo County, New Mexico: U.S. Geological Survey Map GQ-795.

Myers, D. A. and McKay, E. J., 1970, Geologic map of the Mount Washington quadrangle, Bernalillo and Valencia Counties, New Mexico: U.S. Geological Survey Map GQ-886.

, 1971, Geologic map of the Bosque Peak quadrangle, Torrance, Valencia, and Bernalillo Counties, New Mexico: U.S. Geological Survey Map GQ-948.

, 1976, Geologic map of the north end of the Manzano Mountains, Tijeras and Sedillo quadrangles, New Mexico: U.S. Geological Survey Map 1-968.

Myers, D. A., McKay, E. J., and Sharps, J. A., 1981, Geologic map of the Becker quadrangle, Valencia and Socorro Counties, New Mexico: U.S. Geological Survey Map GQ-1556.

Read, C. B. and Wood, G. H., Jr., 1947, Distribution and correlation of Pennsylvanian rocks in late Paleozoic sedimentary basins of northern New Mexico: Journal of Geology, v. 55, p. 220-236.

Ross, C. S., Smith, R. L., and Bailey, R. A., 1961, Outline of the geology of the Jemez Mountains, New Mexico: New Mexico Geological Society Guidebook 12, p. 139-143.

Ruetschilling, R. L., 1973, Structure and stratigraphy of the San Ysidro quadrangle, Sandoval County, New Mexico (M.S. thesis): University of New Mexico, Albuquerque, 79 p.

Slack, P. B., 1973, Structural geology of the northeast part of the Rio Puerco fault zone, Sandoval County, New Mexico (M.S. thesis): University of New Mexico, Albuquerque, 74 p.

Slack, P. B. and Campbell, J. A., 1976, Structural geology of the Rio Puerco fault zone and its relationship to central New Mexico tectonics: New Mexico Geological Society Special Publication 6, p. 46-52.

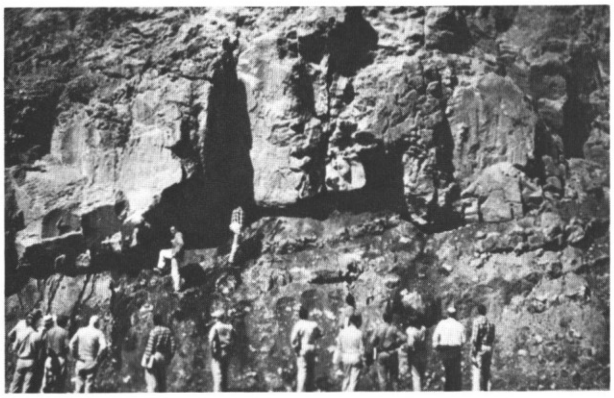
Smith, R. L., Bailey, R. A., and Ross, C. S., 1970, Geologic map of the Jemez Mountains, New Mexico: U.S. Geological Survey Miscellaneous Investigations Map I-571.

Woodward, L. A., Callender, J. F., Seager, W. R., Chapin, C. E., Gries, J. C., Shaffer, W. L., and Zilinski, R. E., 1978, Tectonic map of the Rio Grande rift region in New Mexico, Chihuahua, and Texas: New Mexico Bureau of Mines and Mineral Resources Circular 163.

Woodward, L. A., Callender, J. F., and Zilinski, R. E., 1975, Tectonic map of the Rio Grande rift, New Mexico: Geological Society of America Map and Chart Series MC-11.

Woodward, L. A., Kaufman, W. H., and Anderson, J. B., 1972, Nacimiento fault and related structures, northern New Mexico: Geological Society of America Bulletin, v. 83, p. 2382-2396.

Montosa thrust fault, Manzano Mountains (P. Bauer photo).



Some field trip geologists scale the shale slope of the Molas Formation to look at Pinkerton Trail limestones on the first day of the field trip. September 5. Coal Bank hill. Photo by K. F. Mather.

"Don't stand if you can sit, don't sit if you can lie down, etc., etc." to quote Queen Victoria's advice to her son the Prince of Wales. So here some of the 8th field trip gang awaits the buses on the morning of September 6th outside the Grand Imperial Hotel in Silverton. Gene Buell stands at right. Close by is his mathematician father, then UNM Professor Buell. Some read, and most just sit trying to recover from the party the night before.

They didn't believe me when I told the field trip gang that the top 30 feet of the Molas Formation at the type locality at Molas Lake and Pass had Des Moinesian fusulinids, crinoids, and brachiopods in marine red beds, so "chucking at the knappy stones," the gang tore up much of the Molas outcrop still left after the new widened highway really tore up the country. Frank "Little Jack" Frost and I trenched and collected the 116-foot Molas section at this locality on July 4, 1955, just before we were driven off Molas Pass by a 10-inch snowstorm! Stop #9, September 5.

If we didn't have pockets, where would we put our hands? The gang waits on buses after breakfast at the Grand Imperial Hotel in Silverton.

At an impromptu stop just south of Silverton, the late Kirtley Mather looks over the vast glaciated terrains of the San Juan Mountains which he and Wallace W. Atwood described in the classic 1932 Professional Paper 166 entitled "Physiography and Quaternary Geology of the San Juan Mountains, Colorado."

K. F. Mather, outside the Grand Imperial Hotel, talks to an old timer prominent in the early mining history of the Silverton region of the San Juan Mountains. This gentleman remembered Dr. Mather from the early days of mapping by Mather and Atwood for the U.S. Geological Survey. Photo by Martin Van Couvering.