



## ***Tectonics and general geology of the Ruidoso--Carrizozo region, central New Mexico***

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# TECTONICS AND GENERAL GEOLOGY OF THE RUIDOSO-CARRIZOZO REGION, CENTRAL NEW MEXICO

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## INTRODUCTION

The Ruidoso-Carrizozo region, as considered in this paper and in the accompanying tectonic map (in pocket), is about 75 miles wide and 100 miles long. It extends from near Corona on the north to near Tularosa on the south and from the edges of the Jornada del Muerto and the San Andres Range on the west to the eastern end of the Capitan Mountains on the east. It includes several prominent large mountain masses such as Gallinas, Jicarilla, Capitan, and Sierra Blanca and the edges of the great Sacramento and San Andres Ranges. The region also includes great table land areas such as Chupadera Mesa and a part of the High Plains along its western edge. All the Claunch to Carrizozo lowlands and the northern one-third or so of the Tularosa Valley are included.

Approximately the eastern one-third of the area drains to the Pecos Valley, and the western two-thirds is all interior drainage into the Carrizozo, Tularosa, or Jornada del Muerto basins.

Altitudes of the area lie mostly between 5,000 and 7,000 feet. The lowest part is in the Tularosa Valley, where it is about 4,200 feet; the highest altitude is 12,003 at Sierra Blanca Peak. It is perhaps of special note that the greatest relief in New Mexico is on the western escarpment of Sierra Blanca where it stands 7,800 feet above Tularosa Valley. This compares with some 7,100 feet off the Santa Fe Range; some 6,800 feet off Wheeler Peak near Taos; some 5,700 feet off the Sandia Mountains; and some 5,500 feet off Mount Taylor.

The tectonic map which forms the basis for the text was constructed especially for the Fifteenth Field Conference from numerous geologic maps and some additional field work by the authors. The map has many generalized areas owing to the small scale and to lack of adequate geologic maps or stratigraphic and structural control in places. Structure in the central part of Chupadera Mesa was virtually impossible to check owing to its inclusion in the White Sands Proving Grounds. At the scale of the map and with the 200-foot contour interval it is difficult to show accurately the dips of contour spacings at attitudes in excess of 15° (See "Contour Spacings" inset on the tectonic map).

## GENERAL GEOLOGY

Within the area rocks of nearly every system are present. Precambrian crystalline cores are exposed in the bold escarpments of the Oscura and San Andres Ranges with carbonate and clastic strata of Cambrian to Permian age in succession above. In the eastern part of the area several small Precambrian inliers, overlain by Permian strata, are scattered from the Gallinas Mountains on the north to the Sacramento Mountains on the

south. The most extensive strata are the San Andres and Yeso Formations of Permian-Guadalupe age, and together they surface at least 75 percent of the area, mostly in very low-dipping attitudes. Cretaceous Dakota, Mancos, and Mesaverde beds underlie some 750 square miles, or nearly 10 percent of the map area, and occupy an oval-shaped area between Ruidoso and Carrizozo. A lesser area of Late Cretaceous Paleocene McRae (Cub Mountain)<sup>1</sup> continental sediments and middle Tertiary bedded volcanic breccias and flows occupies the base and high ridges of Sierra Blanca. All the Cretaceous and Tertiary beds are preserved along a downwarp that has been referred to as the Sierra Blanca basin (Darton, 1938, p. 215).

Numerous stocks, laccoliths, plugs, and sills of various compositions and textures are scattered throughout the area. Many of the sills are diabasic, but the stocks and laccoliths are commonly syenitic to monzonitic. Saturated to undersaturated types are prevalent, but a few, such as Capitan and the northern Gallinas laccolith, are oversaturated. Dikes are numerous and occur in profuse swarms of composite and multiple associations, especially around the large Sierra Blanca stocks. Most of these are 20 feet or less in width and range in length from a fraction of a mile to as much as four miles. The Jones dike on Chupadera Mesa is as much as 575 feet wide and is about 10 miles in length.

## STRUCTURAL ELEMENTS

The structure of the Ruidoso-Carrizozo area consists of a diverse assemblage of basins, sags, slopes, uplifts, intrusive domes, laccoliths, stocks, faults, and lesser folds. The dominant structural element of the area is the broad Mescalero arch composed of the Pecos slope on the east

<sup>1</sup>There is little, if any, doubt that the so-called Cub Mountain of Bodine is the McRae Formation (Kelley and Silver, 1952, p. 115-120). The beds at Sierra Blanca are slightly more than 60 miles from the McRae exposures in the Jornada del Muerto. The general lithologies and stratigraphic successions are remarkably alike. The workers (Bodine, 1956, p. 8) who were responsible for the extra name in the Sierra Blanca country mention the similarity of the formation to the Baca and correlation with the McRae, whereas the situation is about the reverse. The Baca is different in many respects, whereas the McRae is practically identical. The responsibility of applying a new name to a sequence already named is with the proposer, and in this case it does not appear that the workers checked the McRae sections or the descriptions by Bushnell (1953, p. 22-45). The McRae was properly named in 1952; the name Cub Mountain was used in print in 1956 without adequately defining a type locality or giving a measured section with tops and bottoms. Since it still has not been properly introduced and as yet does not have formal status, the term McRae is used here for the sequence in the Sierra Blanca and Capitan areas that, with little doubt, were deposited in continuity with the McRae beds in what is termed here the McRae basin.

and declivities into the Claunch sag and Sierra Blanca basin on the west. This arch roughly follows the buried Permian Pedernal topography. Considerable modification of the arch occurs along the Lincoln County porphyry belt which also more or less follows the same course.

West of the arch the Claunch sag, Sierra Blanca basin, and Tularosa basin form a fairly continuous downwarp between the arch on the east and the Chupadera, Oscura, and San Andres line of uplifts on the west.

Faults consist of three principal types, 1) the large ones upon which the Oscura, San Andres, and Sacramento blocks are uplifted, 2) the lesser faults modifying these blocks or occurring singly or in groups near some of the igneous intrusions, and 3) those such as the Ruidoso fault zone, which somehow appear to be related to the Sierra Blanca basin. Crustal folds are not numerous, but small superficial folds in the incompetent Yeso Formation are very abundant.

The individual elements that make up the structure of the area are described and discussed below.

### **Claunch Sag**

The Claunch sag is a southward continuation of the Estancia basin to the north of the area. The sag is about 50 miles long and 10 to 22 miles wide. On the west the sag is bounded by the Chupadera platform and the Carrizozo anticline. The eastern boundary is irregularly formed by the Gallinas, Tecolote, Jicarilla, and Lone laccolithic domes (fig. 1A). The greatest width is midway, where an eastern reentrant occurs against the small Tecolote domes (See tectonic map in pocket). The narrowest part of the sag is at the southern end, where there is a constriction between the Carrizozo anticline and the Lone dome. The Claunch sag plunges southward throughout its length into the Sierra Blanca basin at an average rate of about 50 feet per mile. The boundary on the west is taken as a low escarpment formed by the long Chupadera fault. Throw on the fault appears to reach about 350 feet in the central part. Several southwesterly plunging narrow anticlines modify the central part of the sag as shown on the tectonic map.

### **Tularosa Basin**

The Tularosa basin is a northerly-trending depression 10 to 35 miles wide and about 130 miles long. It lies between two prominent uplifts, the westward-tilted San Andres uplift on the west and the eastward-tilted Sacramento uplift on the east. Fault scarps are especially evident along the bases of the middle parts of both uplifts.

Only the northern end of the basin is of direct concern here. In this part the basin turns from northerly to northeasterly and appears to merge with and plunge into the Sierra Blanca basin. The Tularosa basin, the Claunch sag, and the Estancia basin constitute a long regional depression despite modification by the Carrizozo anticline and the Sierra Blanca basin. In the northern end, fault boundaries to the depression either give way to downflexing or are covered by overlapping sediments. The relations are discussed further under adjoining

elements and under Tectonic History and Regional Relations.

### **Sierra Blanca Basin**

The Sierra Blanca basin is a north-northeasterly trending asymmetrical depression about 36 miles long and up to 24 miles wide. The area, as outlined by the Dakota Sandstone, is approximately 750 square miles. It lies adjacent to the Mescalero arch on the east and the Oscura uplift on the west. It is probably bounded on the southwest by a low nose or arch that may connect the Sacramento and Oscura uplifts in the subsurface beneath the Tularosa basin valley fill. On the north the basin is terminated irregularly by Lone dome and the White Oaks and Capitan faults and in part by the Mescalero arch. The northern portion of the basin has been modified locally by the Carrizo and Patos laccoliths. In a general way this basin forms a link in the regional Claunch-Tularosa depression, but the northeastern part presently forms an embayment into the Lincoln County porphyry belt.

The Sacramento uplift to the south merges with the basin through the northward-plunging Black Mountain and Cienegita anticlines. Structural relief of these folds approaches 5,000 feet.

The eastern limb of the basin gradually slopes away from the Mescalero arch to the Ruidoso fault zone, which has a throw of 1,200 to 1,400 feet. To the west of the fault zone a syncline and the Cienegita anticline are crossed prior to the final descent into the basin. The Sierra Blanca basin is the deepest depression within the area of the tectonic map. The westerly limb of the basin in T. 10 S. has an inclination of approximately 1°.

### **Jornado del Muerto Basin**

The Jornado del Muerto basin is a long depression west of the San Andres, Oscura, and Chupadera uplifts. In the latitude of the San Andres uplift it is a broad downwarp (Darton, 1922, p. 235). Against the Oscura uplift it is bounded by a large normal fault, and west of the Chupadera platform in the extreme northern end it again appears to be a synclinal downwarp (Torres syncline). Along its length it is somewhat arcuate following the combined curved configuration of the San Andres and Oscura uplifts.

### **Mescalero Arch**

The Mescalero arch extends from the Sacramento uplift, where the crest is in the escarpment, northeasterly to the central flank of the Capitan intrusive. North of the intrusive the arch is shifted to the west and passes through the Jicarilla intrusives and northward toward Tecolote and Corona where the crest is irregular owing to igneous intrusions and crossing of north-northeast trending folds and faults. The eastern limb of the arch consists of a gentle, more or less even, regional dip of 0.5 degree toward the Pecos Valley. Even from the crest of the Sacramento uplift to the Pecos Valley the overall regional dip of the Pecos (Sacramento) slope is only about one degree. The western limb of the arch descends or is faulted down into the Tularosa basin, into the Sier-

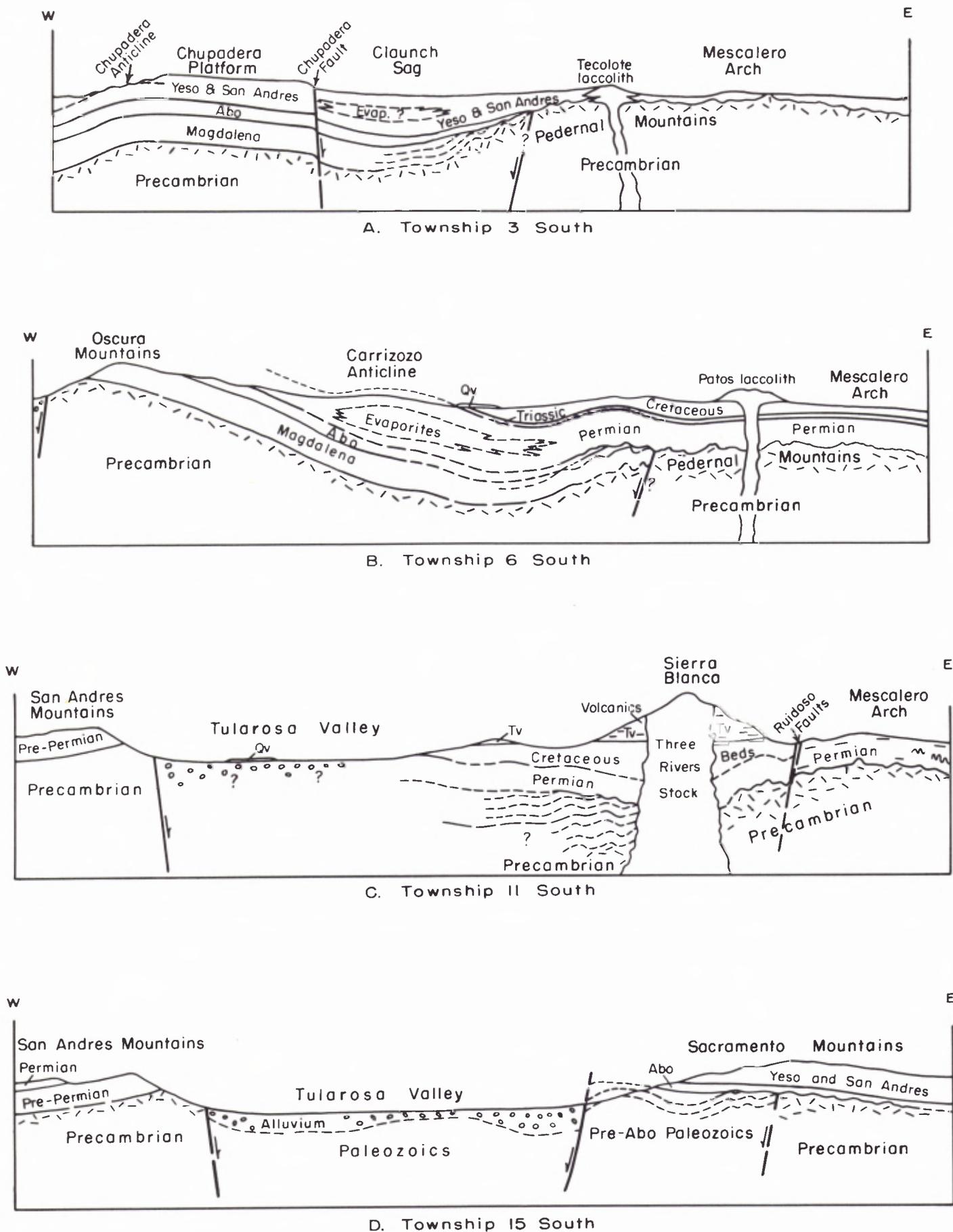


Figure 1. — Diagrammatic structure sections of the Ruidoso-Carrizozo region.

ra Blanca basin, and into the Claunch sag (fig. 1C). It is steeper than the eastern limb nearly everywhere and very irregular. The crest appears to be offset left across the Capitan intrusive and elsewhere lost in complications of irregular intrusive domes. The axis of the arch on the northern side of the Capitan intrusive is about 1,400 feet structurally lower than on the southern side. Some of the possible reasons for this are discussed under Tectonic History and Regional Relations. Where the arch is uninterrupted by modifying structures it is smooth and broad. Such places are found northwest of the Capitan intrusive, east of Capitan and Ruidoso, and north of the Gallinas uplift.

Northeast of the Sacramento uplift the crest is at about 9,000 feet on top of the Permian strata. It descends northward to about 7,500 feet south of the Capitan intrusive. Northwest of the Capitan Mountains, the crest is at about 6,300 feet at the same datum. It rises again toward Corona where, although considerably modified by the Corona syncline and other structures, it is about 7,000 feet.

### Chupadera Platform

The structural Chupadera platform is the north-south table land known as Chupadera Mesa. It is the source of Darton's term (1922, Bull. 726E) Chupadera (formation) which surfaces so large a part of the region.

The Chupadera platform extends from an arbitrary northwesterly-trending boundary with the Oscura uplift, near the Yeso-San Andres contact, northward to the southwestern corner of Estancia Valley. The bench is about 45 miles long and 10 to 15 miles wide. It is bounded on the west by the crest of the Chupadera anticline. This is the Oscura anticline of Darton (1922, Bull. 726E, p. 235), and the extension of the name northward along the bench reflected his belief that fault blocks like the Oscura were broken anticlines. It appears, however, that the anticline dies out straight southward against the homocline of the Oscura block, as shown on the tectonic map, instead of curving southwestward to the Oscura fault and the plunging drag of the uplift as Wilpolt and Wanek (1951) showed.

Its eastern boundary is the heretofore unmapped Chupadera fault scarp. The Chupadera fault extends from U.S. 380 northward around a nose from the Jones dike to almost the southern end of the Estancia Valley, a distance of nearly 50 miles. The throw may be as much as 350 feet in the central part.

The Chupadera platform probably has an over-all low dip of one degree or less toward the east or southeast. In the central part it appears to be essentially flat, and there is some suggestion that the eastern edge next to the Chupadera fault may be higher locally than to the west. The area is largely inaccessible within the White Sands Proving Grounds. Numerous superficial folds in the incompetent Permian beds occur throughout the central and southern parts. Many of these folds are probably due to solution collapse and some, like the anticline over the long Jones dike, may be due to igneous intrusions. Many additional small folds might have been shown in the area if photographs had been available at the time of preparation of the map.

### Oscura Uplift

The Oscura uplift is an eastward tilted fault block about 27 miles long and as much as 14 miles wide. It dips eastwardly on an average of 10 to 15 degrees (fig. 1B). The bold western escarpment at its middle maximum development is about half a mile high. It very much resembles the Sandia Mountains with its bold Precambrian granite escarpment surmounted by a relatively thin rimrock of Pennsylvanian beds. From a structural point of view it has affinities with the Sandia and Caballo uplifts in possessing a north-plunging nose at its northern termination without a similar termination at the southern end.

Maximum throw on the frontal fault may be as much as 7,000 feet, but this is distributed, in part, in at least one step fault. In the southern part of the uplift the frontal fault swings southeasterly and parallels the hinged Mockingbird Gap graben. In the southern part of the Oscura uplift several hinged faults within the range parallel the north-northwesterly frontal fault. These faults slice the southern end of the uplift into narrow blocks, and throws are both up and down to the east on individual faults. These faults, together with those in Mockingbird Gap and in the northern, north-easterly-trending part of the San Andres uplift, form a remarkable set that appears to be mechanically related in some manner to the swing in the San Andres-Oscura uplift line and the change in the direction of tilt of the uplifts. The Yates fault is different in trend and in some aspects of throw from the faults to the south. It is pivotal, having nearly 2,400 feet of throw in the central part near the small syncline in the southern block. These features are discussed further under Tectonic History and Regional Relations.

### San Andres Uplift

The San Andres uplift is nearly 80 miles long and only about 12 miles wide in its widest exposed part. It is a westerly-tilted block having generally low dips that extend beneath the valley fill of the *Jornado del Muerto* downwarped to the west. Precambrian rocks form the lower part of the eastern escarpment through most of its length, and in many places several thousand feet of Paleozoic rocks from Cambrian to Pennsylvanian surmount the basement up to the main skyline crest.

Local fan scarps follow the base of the uplift on the Tularosa side, attesting to the dominantly fault-block origin. Most of the southern part of the uplift is remarkably free of faults; but in the northern part they become rather numerous, especially from Rhodes Pass northward. The highest part of the uplift is Salinas Peak (altitude 9,040 feet), a prominent landmark in the region, which is held up by a large porphyry laccolith emplaced in the Pennsylvanian series.

The northern 26 miles of the uplift is crossed by a group of faults characterized by staggered offsets and pivotal movements. The tilt of the uplift decreases until at the northern end the Precambrian is exposed all the way around to the western side as in the eastward-tilted Mockingbird Gap graben and the Oscura uplift.

The Mockingbird Gap graben is about 7 miles wide. Its northwesterly-trending boundaries are covered by

panfans that connect with both the Tularosa and Jornada valley fill. The structural boundaries of the graben are buried by this alluvium and, owing to the prominence of the double pass, it appears that a zone of closely spaced faults may have marked the marginal zones of subsidence. The graben itself appears to represent a sort of torque axial zone of the wide band of crossing faults between Salinas Peak and the southern end of the Oscura uplift, all of which may be a part of the mechanics of twisting the San Andres-Oscura chain from a westerly to easterly tilt. Only a small corner of the San Andres uplift is shown on the map; therefore, for these details one must consult the Geologic Map of Southwestern New Mexico (Dane and Bachman, 1961).

### Sacramento Uplift

The Sacramento Uplift is a great cuesta with a bold western fault escarpment. Its over-all inclination eastward to the Pecos Valley is scarcely more than one degree. However, numerous gentle open folds, both crustal and superficial, modify the general structural slope. The western escarpment is modified by prominent folds which are, for the most part, pre-Permian and of greater structural relief than the younger folds (fig. 1D). The fault nature of the escarpment is clearly indicated by fan scarps and bedrock step faults along or near the rather even or regular base of the uplift. Pray (1961, p. 124-125) has described and mapped these faults and internal structures in some detail and has concluded

that throw on the Sacramento frontal fault or fault zone into the Tularosa basin is at least 7,000 feet in the central 15 miles of the uplift.

The tectonic map joins Pray's map on the north, and the northward plunge of the uplift which begins near High Rolls, about four miles south of the tectonic map, is shown east of Tularosa. It plunges in several noses and chutes into the Sierra Blanca basin in the western part and on to the Mescalero arch south and southeast of Ruidoso. The maximum crestal altitude of the top of the known Permian beds in the Sacramento uplift is probably near 10,000 feet, and the plunge to the bottom of the Sierra Blanca basin is on the order of 6,500-7,000 feet in a distance of 35 to 40 miles. The eastern nose of the broad northward Sacramento plunge becomes the Mescalero arch, but the descent to this arch is very gradual and in 10 to 15 miles is scarcely 1,000 feet.

### Lincoln County Porphyry Belt

Within the area of the tectonic map is exposed perhaps the greatest concentration of Tertiary intrusive centers in New Mexico. Between Corona on the north and Ruidoso on the south there are at least 9 stock and laccolith centers that range from about 5 to 25 square miles in outcrop area; and one, the Capitan intrusive, covers about 110 square miles. In addition, there are a number of smaller centers and countless dikes and sills.

The principal centers are as follows:

<i>Name</i>	<i>Composition</i>	<i>Area</i>	<i>Form</i>
Gallinas:			
North	Trachyte	16	Laccolith
South	Rhyolite	11	Laccolith
Tecolote	Syenite-diorite	5	Laccolith
Jicarilla	Monzonite(?)	25	Laccolith & stock(?)
Lone-Baxter	Syenite(?)	6	Stock & laccolith
Carrizo	Microgranite(?)	11	Laccolith
Patos	Monzonite(?)	7	Laccolith
Capitan	Microgranite	110	Stock & laccolith
Three Rivers	Monzonite to granite	24	Stock
Bonita Lake	Monzonite to granite	12	Stock

The Gallinas intrusives have been mapped by Kelley (1949, fig. 33) and Perhac (1961). They are dominantly two large laccoliths intruded into the Yeso Formation. The floor is locally exposed in the southern laccolith where Precambrian is found to underlie the intruded Yeso beds. In most places, however, the exposed sedimentary contact is the roof, and Glorieta and San Andres caps of the laccoliths are found on high ridges and peaks. The central part of the northern laccoliths appears to be about 1,600 feet thick. The thickest part of the southern laccolith may be no more than 800 feet. The emplacement of the laccoliths appears to have domed the general area for several miles around.

The Tecolote intrusions are a small cluster of elliptically shaped laccoliths of diverse trends. The largest one, under Tecolote Peak, is deroofed along a length of about three miles and has a principal width of about

one mile. It is at least 400 feet thick. The lesser laccoliths trend northeasterly and easterly and either adjoin or lie a short distance to the south of the main laccolith. The laccoliths that immediately adjoin the main mass on the south and east are multiple, in part consisting of an earlier, lower diorite laccolith that has been intruded and superposed by the later-prevalent monzonite porphyry. Several doubly-plunging anticlines and noses in the Permian country rock near the igneous exposures suggest the presence of other small, buried laccoliths. A few small dikes and sills are present. Rawson (1957) has mapped and studied the intrusions and associated structures in detail.

The Jicarilla intrusive appears to be a major exposure of a cluster of centers lying north of the White Oaks fault. The main Jicarilla intrusive may be mostly a stock, but some of its irregular protuberances and

nearby satellitic exposures may be laccoliths. Likewise, the domes and noses in Permian beds to the west in the vicinity of Ancho may be due to subsurface laccoliths that have not been deroofed. Some of these may be tongue-like or "half" laccoliths that branch in the subsurface from the main stock.

The Lone-Baxter intrusion has laccolithic and stock-like aspects. Beds are considerably disturbed next to the main contact (Kelley, 1949, p. 154), and the Baxter Mountain salient near White Oaks appears to crosscut the Permian and Mesozoic contacts.

The Carrizo and Patos intrusions are similar and circular in outline. They are boldly exposed in steep sides. The floor of the Patos laccolith appears to dip slightly to the southeast, whereas the Carrizo intrusive has a nearly level contact with the surrounding Cretaceous rocks suggestive of a laccolith. Neither of these laccoliths is known to have a sedimentary cap.

The Capitan intrusive is about 22 miles long and 4 to 6 miles wide. It is anomalous among the other large intrusive centers in size, shape, and trend. The smooth-topped range is cut in two about one-third the length from the western end by a deep wind gap. In general, Permian strata are turned up, often steeply along its sides. Where exposed there may be considerable irregularity of the contact due to offshoots of the intrusion and local incorporation of beds. Outcrops bow around the ends, and at the western end in particular the intrusive extends beneath the Permian strata in sill-like tongues. The smooth skyline of the mountain is remarkable, and this fact led the senior author to the discovery in 1943 of outlier caps of Permian sandstone and limestone on the western top. Similar caps very likely top the smooth crest in the eastern part of the mountains. The Capitan intrusive appears to have been emplaced along a fault or north-facing monocline, inasmuch as the general structural level north of the intrusive is considerably lower than to the south.

The Three Rivers stock is the largest intrusive in the Sierra Blanca basin and forms Sierra Blanca Peak. It is roughly circular and has a tongue that extends from the main body northward 2 miles near the head of Bonita Canyon. The rock type ranges from monzonite to granite. The stock intrudes andesite flows and volcanic breccias of the Sierra Blanca Volcanics and may well have been a locus of the volcanic extrusion vents. Numerous dikes and sills are injected into the surrounding volcanics from the stock. Dikes of intermediate composition also crosscut the stock.

The Bonita Lake stock is an irregular body in the Sierra Blanca basin that forms Mon Jeu Peak and occupies the surrounding area of Bonita Lake. The rock type varies from monzonite to granite and has been intensely altered and sheared locally. Numerous dikes occupy shear zones within the stock.

### Dikes

The area of the tectonic map contains a multitude of dikes. The intensity of occurrence ranges considerably, and the scale of the map and the current detail of mapping result in only the more prominent ones being shown. The greatest concentration of dikes occurs in the Sierra Blanca basin, which includes those of the well-

known Capitan swarm. The dikes range in composition but are predominantly mafic (See Elston and Snider, this guidebook).

The dominant pattern of the dikes is radial from Sierra Blanca basin and the large stocks therein. In the Three Rivers area there are some dikes that appear to be approximately concentric with the basin. In the southern part of the basin the dikes appear to parallel fold axes.

The total volume of dikes in this basin has caused a considerable extension. Jones (1951) has estimated an east-west extension of at least one mile within the Mesaverde belt of the southern part of the Capitan quadrangle.

The dikes crosscut sediments, volcanics, and, to a much lesser extent, stocks, making at least some of them the youngest rocks in the basin.

Several large dikes occur in the Chupadera platform area. The largest of these, the Jones dike, has been mapped in detail (Kelley, 1949). It trends west-northwesterly across the southern part of the bench. At Jones Camp the dike reaches a maximum width of 575 feet. The intrusion was multiple and/or composite. A central dike or part of the intrusion is hornblende monzonite about 225 feet wide. On both sides are marginal facies or perhaps separate dikes, each about 125 feet wide. The leucocratic, fine-grained marginal dikes are highly banded parallel to the steep dike walls and are intruded locally by the central dike. Numerous diabase sheets that were fed locally along the margin of the dike cut across upturned Yeso beds and spread as tongue-like sills in the Yeso to as much as a thousand feet or so from the dike. The sills are as much as 75 feet thick and occur in several horizons of the Yeso. Near the dike the Yeso is turned up at angles ranging from 50° to vertical, but the full zone of upturning is commonly 1,500 to 2,500 feet wide on either side, which fact suggests a larger, wider intrusive at depth.

Another large west-trending dike was mapped and described by Wells in 1931 (Bates, 1942, p. 291). This dike of monzonite porphyry cuts across the Chupadera anticline in T. 4 S. and is about 5½ miles long and up to 400 feet in width.

West of Gran Quivira about 15 miles along the northwestern edge of the Chupadera platform is a system of small hornblende diorite or syenodiorite dikes. These are up to 6 miles long and 500 feet wide. They have arched the Permian beds along their trends, and Bates and others (1947, p. 41-42) concluded that the dikes may have fed overlying laccoliths and sills.

### White Oaks Fault

The White Oaks fault is a curving fracture some 20 miles in length that bounds the Jicarilla-Lone cluster of intrusives on the south. It is downthrown on the south to a maximum of several hundred feet near White Oaks. The development of the fault and the upthrow of the northern side appear to be partly a result of the Jicarilla intrusions and partly due to later subsidence of the Sierra Blanca basin.

### Capitan Fault

The Capitan fault trends westward from the southwestern side of the Capitan intrusive. It is downthrown

on the south as much as 1,300 feet northeast of the town of Capitan but decreases to the west, where it probably turns southward between McRae beds downfaulted against Mesaverde beds. To the east, the fault appears to drop Permian beds against the Capitan intrusive for several miles. No similar faults are known to bound other parts of the intrusive, and it appears probable that the Capitan fault is related to the subsidence of the Sierra Blanca basin at a time after the emplacement of the Capitan intrusive.

### Ruidoso Fault Zone

The Ruidoso fault zone is a north-northeasterly trending fault zone between Sierra Blanca basin and the Mescalero arch, and it extends 25 miles from south of Ruidoso to the Capitan fault. The Capitan fault appears to be the northern boundary of the fault zone, and it is significant to note the eastward bow of the Mescalero arch, due possibly to basinward collapse along the fault zone. Along the Magado Creek fault in the central part of the zone the throw is as much as 1,400 feet, whereas to the south the zone dies out into flexures from the Sacramento uplift and into southeasterly-trending faults. In the vicinity of Ruidoso a north-northeasterly plunging syncline appears to have been formed by drag along the fault zone.

### Lincoln and Related Folds

Small folds related to the incompetency of the Yeso Formation are widespread in the region and, in general, are almost coincidental with the Yeso distribution or presence at shallow depth. Although generally related to incompetency of the Yeso, their origin is diverse and due to such causes as surficial gravity effects, intrusion, solution collapse, and compressive and gravity tectonics. Especially noteworthy areas of these folds occur south and east of Corona (Fischer and Hackman, 1964), in the Claunch sag west of Tecolote, on Chupadera Mesa, around the Capitan Mountains, and in the area of the Hondo drainage. The Corona ones appear to be in part tectonic and in part collapse folds. Those on Chupadera platform are in part tectonic, in part collapse, and in part intrusive in origin.

The folds in the Hondo drainage region have been termed the Lincoln fold system (Craddock, 1960). These folds appear to be most highly developed, and are certainly best exposed, in the triangle defined by Lincoln, Arabella, and Hondo. Most of the folds are disharmonically or incompetently confined to the Yeso. Many, however, are large, and involve the Glorieta and San Andres as well. These are exemplified by the McDaniel and Tinnie anticlines, which are a few hundred to two thousand feet wide and as much as 12 miles long. Craddock in 1960 and elsewhere in this guidebook describes and illustrates these folds in detail.

In general, the fold axes are arcuate or aligned convexly to the east, about the Hondo drainage, in part, and about the eastern end of the Capitan intrusive. Most of these folds are probably tectonic or gravity tectonic in origin, but the timing and motivating causes are still problematical.

### Carrizozo Anticline

The Carrizozo anticline is an elliptically shaped, doubly-plunging fold. It trends north-northeasterly and is about 17 miles long and 9 miles wide. It lies athwart the Tularosa basin-Claunch sag trend between the southern end of the Chupadera platform and the Sierra Blanca basin. The fold is broad and rather flat-topped. Closure appears to be limited by a short western limb to about 400 feet. The eastern limb is steeper than the western limb, especially along the easternmost outcrops near the Carrizozo lava flow. The fold was tested for petroleum by the Standard of Texas No. 1 J. F. Heard-Federal in 1951 to a depth of 8,050 feet. The hole was spudded in San Andres, bottomed the limestone at about 150 feet, and after drilling a Yeso section with many salt beds for about 4,300 feet, went through a more or less normal upper Paleozoic section to Precambrian gneiss.

It is said that the surface sections of Yeso thicken toward the area of the Carrizozo anticline; and, if so, the drilled thickness could indicate the presence of an evaporite basin. The lithologic logs of the well show a ratio of evaporite to clastics in the central 2,000 feet of the Yeso of about 1:1. This may be a rather low ratio for development of a salt anticline or roll. The diagrammatic relations depicted in figure 1B are intended to illustrate either a salt anticline or a primary thickness of evaporites. In either case the anticline might be nonexistent or only a terrace below the Yeso. There is also some possibility that the apparently thick section is due to folding or a low-angle fault which may have duplicated the section.

### TECTONIC HISTORY AND REGIONAL RELATIONS

The Ruidoso-Carrizozo region is situated across an east-west lower Paleozoic wedge-edge belt and a north-south Pennsylvanian mountain belt. During lower Paleozoic time the borderland of the ancient Sonoran geosyncline extended from east to west through the area. A sedimentary platform (New Mexico-Texas arch, Eardley, 1962, pls. 2-6) to the north was repeatedly elevated epirogenically along east-west hingelines that downwarped the region to the south. This caused stripping or restricted deposition to the north and preservation or increased deposition to the south. The present wedge belts of the several lower Paleozoic systems extend from the northern end of the San Andres Mountains (Tps. 9-11 S.), probably east-northeastward, beneath what is now the Sierra Blanca basin, toward Capitan.

The above postulations are for the most part based on projections of relations that may be observed in the San Andres, Oscura, and other ranges to the west. It is not possible to directly deduce the lower Paleozoic relations in the Ruidoso-Carrizozo region owing to incomplete exposures and borderland disturbances that began in Devonian and continued through Mississippian time. Beginning perhaps sometime in the Mississippian the earlier east-west lines of hinging appear to have given way to warping and truncation (Kelley and Silver, 1952, p. 88, 133) along northerly lines. By late Pennsylvanian time, and continuing through Early Permian time, the north-trending Pedernal mountains de-

veloped in full prominence along with other similar uplifts in northern New Mexico and southern Colorado. In New Mexico these have been referred to collectively as Pedernal ridge (Darton, 1922, p. 202; 1928, p. 279), Pedernal land mass (Thompson, 1942, p. 12), or Pedernal axis (Read and Wood, 1947, p. 226).

The evidence for the existence of such mountains in the Ruidoso-Carrizozo region lies in the existence of a marked unconformity at the bases of the Abo and Yeso in the area, in the conglomerate lithologies in the Pennsylvanian and Permian formations, and rapid thickness and facies changes. Continental detrital tongues in the Late Pennsylvanian (Virgilian) Holder Formation, abundant conglomerates in the Laborcita (Bursum) and Abo Formation, and local unconformities within and between these formations indicate considerable uplift and erosion to the east of the northern Sacramento escarpment (Otte, 1959, p. 92-93). Pray (1961, p. 92) also concluded that the lower Wolfcampian beds of the northern part of the uplift grade upward and eastward toward a source area into nonmarine red bed facies. Otte (1959, p. 61-62), together with Pray, found also that the abrupt thickening of the Abo, in the northern part of the Sacramento Mountains, from 500 to 1,400 feet was largely related to a sharp north- or northeast-trending eroded flex of Wolfcampian age wherein the Abo overlapped onto the highland to the east. It is difficult to determine from map and facies alone in so small an area the trend of the positive or source area. However, when viewed with the regional relations in the subsurface as well as at the surface it appears that the western escarpment of the Sacramento Mountains contains the lower western edge of the Pedernal mountains (fig. 1D). On the basis of regional exposures of the Precambrian from the Pedernal Hills in Torrance County to the Sacramento uplift, the western edge of the buried Pedernal mountains would project northward in the subsurface in Rs. 10 and 11 E. Pre-Abo folds similar to those in the Sacramento uplift with Precambrian possibly upfaulted on the east could be expected in the subsurface (fig. 1).

From Bent in Tularosa Canyon on the south to the vicinity of the Gallinas Mountains on the north several inliers of Precambrian have been found protruding nearly always through Yeso beds. In these places it is common for the Precambrian to protrude abruptly as "peaks" or "monadnocks" in middle or upper Yeso even though lower Yeso beds or Abo beds may be exposed nearby. Even in such exposures as close to each other as Red Cloud Canyon in the Gallinas Mountains and Chameleon Hill north of Corona there is considerable stratigraphic difference of position in the covering Yeso. If the Pedernal was an old age of peneplain surface, then once erosion had reached the general level of the Precambrian, the exposures would have been much more expansive than they are. It appears, therefore, that the Pedernal surface was not a peneplain but rather a mature or late-mature topography (fig. 1). As such, older strata (Permian or Pennsylvanian) may be expected in subsurface valleys or in channels or "straits" if the topography was flooded by transgressing Yeso waters. It appears that all the Pedernal topography was completely buried by the Yeso deposits with remarkably little coarse Precambrian clastics having contaminated the characteristically "clean" Yeso deposits.

The thick section of Yeso drilled in the Standard No. 1 Heard well on the Carrizozo anticline suggests that a subsiding Yeso evaporite basin existed west of the Pedernal mountains, possibly along most of the present extent of the Tularosa-Claunch sag.

During Late Permian time the region probably became emergent in the form of wide, low plains. By either very late Permian or Early Triassic time the emergence appears to have assumed the form of a westward-trending arch from near Tularosa to near Reserve in the western part of the state. Triassic and Jurassic red beds formed extensively to the north in a broad continental basin that was eventually lowered, accompanying sedimentation, by as much as two or three thousand feet. In the eastern part of the state the arch appears to have been crossed by Triassic sediments to form a connection with the Mexican geosyncline. The original Triassic and Jurassic southern sedimentary edges were eroded and removed by continued and expanded Jurassic and Early Cretaceous arching which culminated in the Dakota Formation truncating all previous Mesozoic deposits down to and through the Triassic.

Subsidence in the region continued at an accelerated rate through Late Cretaceous time. The east-west arch was obliterated or possibly retained only as a broad eastwardly-convex headland from the Cordilleran geanticline into west-central New Mexico. In Montanan time the region was dominated by floodplain conditions as represented by the Mesaverde beds. However, as indicated by Kelley and Silver (1952, p. 137) and Bushnell (1955, p. 86-87), Laramide disturbances began in this region in late Montanan time, and these caused shift from paludal-type floodplain environment of the Mesaverde to the drier depositional conditions represented by the thick McRae deposits. The similarity of the "Cub Mountain" to the more expansive and much better known outcrops of the McRae strongly suggests that the McRae basin extended across most of the region from the Rio Grande eastward to at least the Mescalero arch. The deposits of this basin are made up principally of Cretaceous and Triassic debris, but locally they derived material from sharply rising uplifts that contributed debris from rocks as old as Precambrian (Kelley and McCleary, 1960, p. 1419-1420). Furthermore, minor contemporaneous volcanism contributed at various times and places to the basin. The McRae beds reflect early Laramide deformation in their lithology, but except locally along the Caballo-Fra Cristobal uplifts to the west, they are not strongly involved in deformation that is typical of the late Paleocene of Eocene in the Rockies. Thus, the Ruidoso-Carrizozo region probably was out of the Laramide Rockies orogenic belt.

The thick Sierra Blanca Volcanics lie with considerable unconformity on beds from Mesaverde to McRae in age (fig. 2). The age of the Sierra Blanca Volcanics is not known for certain, but general relationships to the older McRae beds, on the one hand, and the intrusive stocks and regional geomorphology, on the other hand, make it fairly certain that they are not likely to be younger than Oligocene nor older than Eocene. The sequence is at least 3,340 feet thick as shown by Thompson elsewhere in this guidebook. The areal extent of the original eruptions was undoubtedly several times that of the present exposures. The base of the sequence is

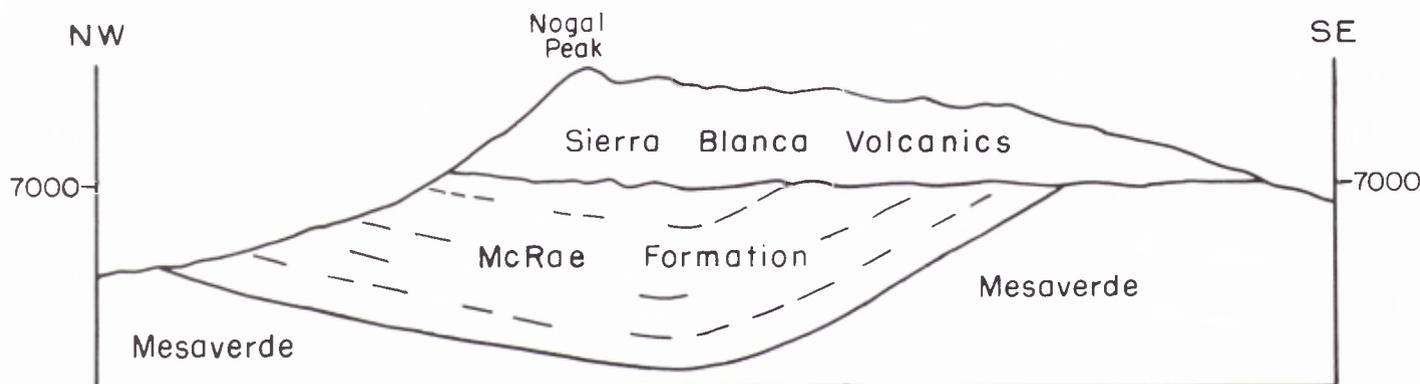


Figure 2. — Diagrammatic section through the Sierra Blanca basin showing the unconformity at the base of the Sierra Blanca Volcanics.

an irregular erosional surface having relief of a few hundred feet. The sequence is in general nearly horizontal and does not appear to have been involved in the basin as defined by the downwarping of McRae, Mesaverde, and older rocks. Except for the erosional irregularities, the general attitude of the contact with the underlying beds is rather uniform and reflects little if anything of the northeasterly-trending axis of the Sierra Blanca basin. Along the southern and southwestern margin of the volcanic pile the beds are tilted northward, apparently in continuation with the northerly plunge of the Sacramento uplift.

Beneath the nearly horizontal volcanic pile the Sierra Blanca basin axis trends northeasterly. The basin is slightly asymmetrical with the southeastern limb being steeper. The basin rims were bevelled before the volcanic eruptions, which probably issued through centers now masked and occupied by the large stocks.

If the volcanics are Eocene or Oligocene, then the principal subsidence of the Sierra Blanca basin could be late Laramide. It may be noted from the tectonic map that the Sierra Blanca basin indents or appears to deflect the Mescalero arch south of the Capitan intrusive and that similar north-northeasterly trending fold axes near Corona and Tecolote also appear to interrupt the arch trend. This relationship suggests that the Mescalero arch is older than the Sierra Blanca basin and therefore also Laramide. The regional extent of the arch and the Tularosa-Claunch sag, together with the rather obvious areal modification of both of these features by the Carrizozo anticline and the Sierra Blanca basin, serve to indicate their relative ages.

The Mescalero arch roughly follows the axis of the buried Pedernal mountains, and the Tularosa-Claunch sag appears to follow a mid-Permian Yeso downwarped evaporite basin (figs. 1A, B). Therefore, the Mescalero arch, the Tularosa-Claunch sag, and a gentle arch that probably followed the trend of the Chupadera-San Andres line of uplifts may have all formed as long, north-south, broad, open folds in Eocene (post-McRae) time. The Early Tertiary Chupadera arch was undoubtedly less prominent than the present structural platform and probably had not been modified by the Chupadera fault.

A second sag with broad and very gentle flanks may have coincided with the present Jornado del Muerto syncline.

As indicated above, the north-south arches and sags were probably followed in Eocene time by the north-northeasterly trending echelon folds including the Sierra Blanca basin, the Tecolote-Corona folds, and possibly also the Carrizozo anticline. The cause of the north-easterly-crossing structures is puzzling, but in the broader picture it is to be noted that they are parallel to, and undoubtedly part of, the turn to the northeast of the northern parts of the San Andres uplift and the Jornado del Muerto basin as well as the Rio Grande depression between the northern end of the Fra Cristobal and San Pasqual uplifts.

Volcanic eruption and intrusion of the "porphyries" probably followed the northeasterly folding. Although the porphyries may be of two or more distinctly different ages, the similarities in composition, texture, and tectonic setting appear to favor penecontemporaneous intrusion of the entire belt. If this is correct, then the key to the relative ages lies in the intrusion of the Sierra Blanca Volcanics by the stocks. Since the volcanics lie essentially unfolded above the Sierra Blanca basin, since the stocks intrude the volcanics, and since the laccoliths of the belt are correlatives of the stocks, then the intrusive centers in general are likely to be late Eocene or Oligocene. The numerous dikes in the Sierra Blanca region and, by analogy, the Jones and other large dikes, are probably also of about the same age. Some of the intrusives of the Tecolote and Jicarilla areas are shaped and aligned in a north-northeasterly direction, thereby suggesting some control by the earlier folds.

The tilted fault-block uplifts were the last of the major tectonic elements to form. The uplifting may have begun in late Miocene and continued to the present. The fault scarps of the Sacramento and San Andres uplifts appear to have followed the trends of the east and west flanks of the Laramide Tularosa sag, which in turn is thought to be controlled by a north-south sag of Yeso time. The Oscura fault probably developed along the western flank of the broad, gentle Laramide Chupadera arch. The uplifts appear to have formed out of the older

arches by accelerated rise and eventual faulting of sections of the old arch flanks. By this interpretation the Tularosa basin would be a sag whose limbs were flexed up and broken by high-angle faults. The Tularosa basin would not be due to "keystone" grabening of a collapsed arch as first proposed by Herrick (1904, p. 175).

Faults such as White Oaks, Capitan, and the Ruidoso zone are probably also late Tertiary in age, although perhaps in general somewhat older than the large Basin and Range faults. The evidence for the late age of faults such as the Ruidoso and Capitan lies in the down-faulting of the sediments along the southwestern boundary of the Capitan intrusive. Under "Lincoln County Porphyry Belt," the White Oaks fault was described as being mechanically related to the emplacement of the Jicarilla cluster of intrusions, thereby implying a late Laramide timing like the intrusions. The Capitan fault might have a similar relationship to the forcible rise of the large Capitan masses. The Ruidoso fault zone, on the other hand, might be older and a part of the subsidence mechanism of the Sierra Blanca basin. However, owing to the fact that the Ruidoso zone terminates at the Capitan fault rather than being offset by it, the younger interpretation for the zone is preferred by the authors at this time. The Chupadera fault is probably late Tertiary, and its position may have been determined by an evaporite-clastic ratio change. The beds of higher evaporite content in the Claunch sag to the east may have slumped along the fault owing to either flowage or solution.

At present it is assumed that the Ruidoso, Capitan, and White Oaks faults, even if they did originate early, suffered some movement in post-intrusive time and contributed to further lowering of the Sierra Blanca basin area. But movement on these faults was not accompanied by additional downbending of the basin flanks in the Sierra Blanca Mountains. Dropping on the Ruidoso and Capitan faults was, however, accompanied by additional downwarping in the Capitan area, and this operation may have shifted the Mescalero axis eastward in the Bonito drainage area. This is discussed below in connection with the cause of the convexity of the Lincoln fold belt.

The regional relationships resulting from this study throw some light on the problem of the Lincoln folds described by Craddock in this guidebook and elsewhere (1960). As indicated above, the sharp folds in the Yeso and San Andres display arcuate patterns partly about an axis roughly defined by the Hondo drainage and partly around the eastern end of the Capitan intrusive. The latter folds were either formed by longitudinal eastward push by the intrusive or, if of earlier age, simply deflected convexly eastward by the intrusion. The arcuate disposition of the folds across the Hondo drainage is more puzzling. There appears to be little doubt that most of the folds are shallow and bottom in the incompetent Yeso Formation. The folds in the Yeso are generally closed and more or less upright except that they are slightly asymmetrical to the west in places (Craddock, 1960, p. 37). Craddock has concluded that the folds are principally due to gravity detachment and movement in the direction of the regional dip. Of this there is little doubt; but our work reveals no "early" Sierra Blanca intrusions that created the eastward tilt,

but rather that the tilt preceded the intrusions. The "focus" of the Lincoln fold arc (Craddock, 1960, p. 42) in the Sierra Blanca intrusives is fortuitous, and there is no eastward crustal bowing that appears directly attributable to the intrusives. Instead, the arcuate arrangement of the Lincoln folds is nearly concentric with respect to the northeastern edge of the Sierra Blanca basin. The basin succeeded the Mescalero arch and appears to have moved it eastward, south of the Capitan intrusive, possibly both before and after the intrusion. It is possible that this "rolling" eastward of the Mescalero axis by encroachment of the basin may have added sufficient tectonic overpressure to the gravity stresses in the Lincoln-Hondo area to cause the convex bending of the folds.

One of the principal yet unnoted structural anomalies in the region is marked difference in position and structural altitude north and south of the Capitan intrusive. The left "offset" or shift in the axis of the Mescalero arch is about 9 miles, and the crest of the Mescalero arch south of the intrusive is about 1,600 feet higher than the Pecos slope directly to the north of the intrusive. It is also to be noted that the "shift" involves more than just the area near the intrusive, for the northerly-trending 6,200-foot structural contour along the southeastern border of the map is some 12 to 18 miles east of the same contour to the north of the intrusive. It is possible that the higher structure on the south is somehow related as a counterpart to the large downwarping of the Sierra Blanca basin. We have suggested above that the downwarping of the northern end of the basin "rolled" back the arch and caused its eastward shift. However, if the basin caused the general rise and shift of contours to the east, then the contours should shift westward again along the regional slope of the Sacramento uplift; and this does not seem to be the case. Therefore, it appears that the Capitan intrusive merely followed an easterly-trending fault or downflex to the north. This cannot be the Capitan fault, which is of opposite throw, unless pivotal movement is inferred. The strong structural anomaly across the Capitan intrusive lends greater importance to the regional alignment described below as the Capitan lineament.

The twist in the structure at Mockingbird Gap has been described above. The origin has long been puzzling to geologists who have observed it. It is to be noted on a geologic map of New Mexico that there is a large deflection of the San Andres uplift to the northeast north of Rhodes Pass. Similar or parallel deflections affect the Jornada and Tularosa basins, the northern Sacramento or Mescalero arch, and the course of the Rio Grande from the northern end of the Fra Cristobal Range to about 20 miles south of Socorro. Thus, the deflection of the San Andres uplift is part of a zone some 30 miles wide in a northeasterly direction that extends northwestwardly from near the northern end of the Sacramento uplift to the Rio Grande, a distance of about 80 miles. The zone of deflection may be due to a large, plastic, right shift in the subcrust.

Although the Mockingbird Gap could be related to the mechanics of the large deflection, it appears more likely that it is the result of longitudinal growth of two oppositely inclined flexes and tilt blocks to a junction zone where the pivotal faults and general structural

twist would develop. The "deflections" described above, if indeed they are deformational rather than the mere "following" of some older basement trend, probably formed prior to the late Tertiary uplifts which gave rise to the Mockingbird Gap structures.

Through the middle of the region there is a rather remarkable alignment of igneous features that has regional extensions considerably beyond the area. This alignment includes the Jones dike, the basaltic craters of the Carrizozo lava flows, the blunt northern end of the Carrizozo anticline, and the great Capitan intrusive with its included downflex. To the east, on more or less the same line, are long dikes east of Roswell and still farther in Texas, the Matador arch. This alignment, which may be referred to as the Capitan lineament, appears to have some coincidence and parallelism with the lower Paleozoic hinge zone. This zone of depositional trends was also evident throughout Triassic, Jurassic, and Early Cretaceous times when it served generally and broadly as the divide between the Mexican geosyncline to the south and the continental depositional basins to the north. The lineament is certainly old, perhaps even Precambrian, and has played an important role in the Ruidoso-Carrizozo region. The alignment of intrusives along the Capitan lineament suggests that the ancient hinge was in part a fracture zone. The strong structural decline to the north across the Capitan intrusive suggests this also. If this is an older feature, there may be stratigraphic and paleogeographic changes to the north of the intrusive that would be important to oil exploration.

The westerly-trending hinge has apparently been dormant or "crossed" at times by strong and persistent northerly trends. Such trends apparently started in Mississippian time along the Rio Grande to the west in the form of an arch. The Ruidoso-Carrizozo region did not experience the northerly-trending disturbances until Late Pennsylvanian time, when the Pedernal mountains developed from Colorado to the Mexican border. This great orogenic development set up north-trending folds and uplifts that, although deeply eroded or buried in succeeding times, still exerted a strong control upon the Tertiary and present tectonic features.

The following is a summary list of the order of tectonic and related geologic events which have affected the Ruidoso-Carrizozo region:

1. Periodic southward tilting into the Sonoran geosyncline. *Cambrian to Mississippian*.
2. Epeirogenic uplift and erosion. *Late Mississippian*.
3. a. Rise and folding of the north-trending Pedernal mountains. *Late Pennsylvanian*.  
b. Deep erosion and thick marginal continental deposition. *Late Pennsylvanian and Early Permian*.
4. Subsidence and complete burial of the mountain topography accompanied by some sagging on either side of the Pedernal uplift. *Middle Permian*.
5. Widespread stripping with probable return of the east-west arch. *Late Permian*.
6. Broadening and general rise of the arch across southern New Mexico. *Triassic*.

7. a. Overlapping from the north upon the southern source highlands. *Triassic and Jurassic*.  
b. Uplift and northward stripping followed by overlapping of Entrada beds. *Middle Jurassic*.
8. Broad uplift of the east-west arch followed by widespread southward truncation of beds down to Permian accompanied by overstepping of Lower Cretaceous beds. *Early Cretaceous*.
9. Deep burial by Cretaceous Mesaverde flood-plain deposits of regional expanse. *Montanan*.
10. Some disturbance and formation of the Tertiary McRae basin across south-central New Mexico. Local uplifts and volcanism as forerunners of Laramide orogeny. *Laramian and Paleocene*.
11. Warping along lines of the old Pedernal mountains with development of broad, open alternating anticlines and synclines which were from east to west: Mescalero arch, Claunch-Tularosa sag, Chupadera-San Andres arch, and the Jornada del Muerto sag. *Eocene(?)*.
12. Deep-seated plastic shift causing northeastward deflection in the Tularosa sag, Mescalero arch, San Andres arch, and Jornada del Muerto sag. Formation of the Sierra Blanca basin, Carrizozo anticline, and the Corona folds. Erosional truncation. *Eocene(?)*.
13. Eruption of the Sierra Blanca Volcanics. *Late Eocene(?)*.
14. Intrusion of stocks, laccoliths, and dikes. Some associated faulting. *Late Eocene or Oligocene(?)*.
15. a. Some growth of the Mescalero arch and other arches and sags to the west.  
b. Dropping of the Sierra Blanca basin on the Ruidoso and Capitan faults.  
c. Increased tilt of Pecos slope and Sacramento cuesta. Probable time of maximum development of Lincoln-type folds.  
d. Monoclinical flexing begins uplift of Sacramento, San Andres, and Oscura uplifts. *Miocene*.
16. a. Monoclinical flexes develop into Basin and Range faults and the major uplifts rise with reference to the basins.  
b. Wide pedimentation extends into the area from the east.  
c. Deep erosion of the fault scarps and the Sierra Blanca volcanic pile.  
d. Deposition of alluvial fill in the Tularosa basin. *Pliocene*.
17. a. Continued uplift of fault blocks; fan scarps.  
b. Minor glaciation on Sierra Blanca Peak.  
c. Accumulation of White Sands.  
d. Eruption of the Carrizozo basalt flows. *Quaternary*.

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