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THE LINCOLN FOLD SYSTEM*

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INTRODUCTION

In the walls of the valley of the Rio Bonito at Lincoln, New Mexico, the Yeso formation contains large folds that provide a startling contrast with the low dips of the formation prevalent in the surrounding region, and in the overlying San Andres Limestone. Field work revealed that these Permian formations show similar crumpling over an area of at least 3,500 square miles (fig. 1). The incompetent Yeso is generally folded where well exposed, but the San Andres Limestone is flat lying over most of the region and only locally buckled into sharp narrow folds. Previous investigations have dealt with these folds incidentally or have been confined to a few anticlines or localities. During this study a number of unmapped folds have been discovered. This paper summarizes the distribution and probable origin of all these folds, designated here the Lincoln fold system. An index map (fig. 2) shows the location of areas portrayed on the more detailed tectonic maps (figs. 3-7).

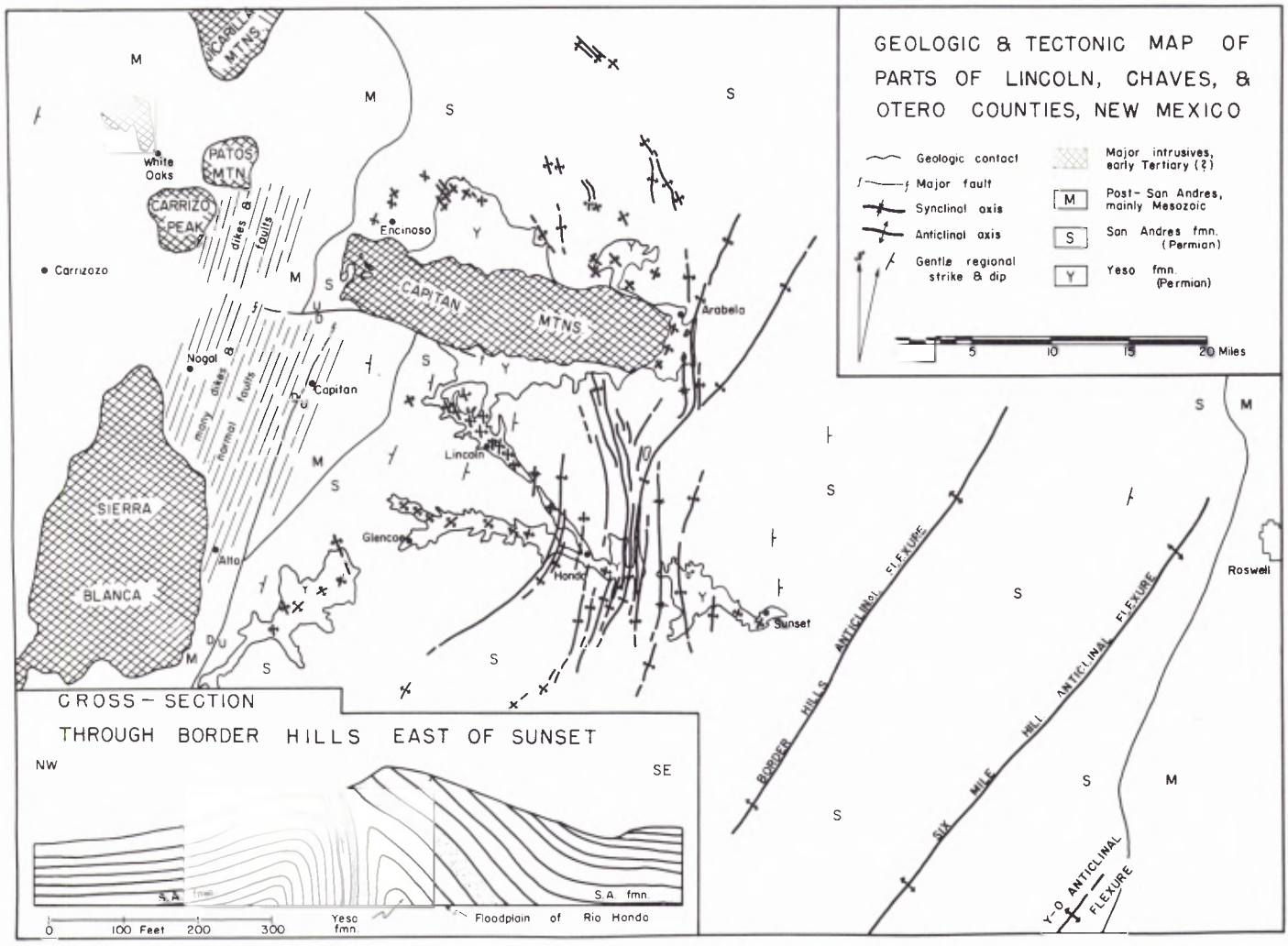


Figure 1. — Regional geologic and tectonic map.

*This article is an enlargement of a paper published in the Report of the International Geological Congress, 21st Session, Report, part 18, p. 34-44, Copenhagen, 1960.

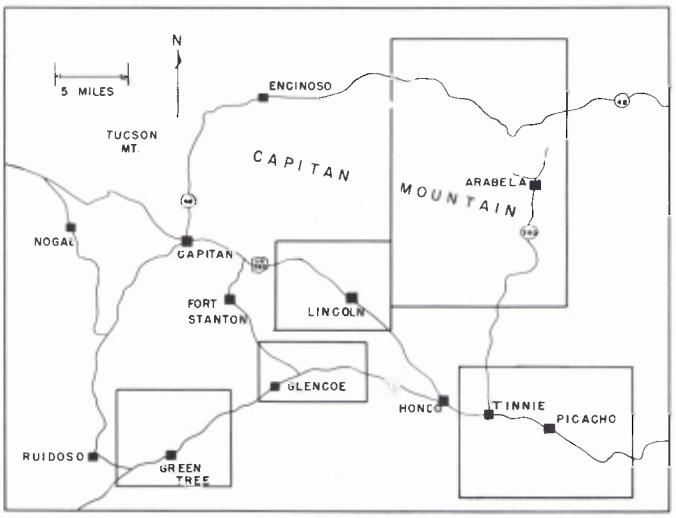


Figure 2. — Index map showing location of detailed tectonic maps.

The deformed region includes parts of Lincoln, Chaves, and Otero Counties and lies between the Great Plains to the east and the Cordilleran mountain system, expressed to the west in a series of north-south fault-block ranges. Over most of the map area the surface formations are Permian strata that dip almost 1° to the east or east-southeast. West of Lincoln these beds form a broad arch and descend westward with dips of 5 to 15° into a structural basin of middle Tertiary age with an igneous complex underlying its mountainous axis. South and southeast of Sierra Blanca is the Sacramento-Guadalupe Range, a gently eastward and northeastward dipping homocline separated from the desert basins to the west by major normal faults. Southeast of the map area is the important petroleum province, the Permian basin of west Texas and New Mexico. Throughout most of the west half of the map area lower Permian formations rest on a Precambrian basement, which indicates the existence of a south-trending rib of land in late Pennsylvanian and early Permian time. Lower Paleozoic formations occur east, south, and west of this buried landmass.

The writer learned of the Lincoln folds in 1954 and has worked on them intermittently since then. Preliminary reconnaissance on aerial photographs was followed by field study during the summers of 1957-59. Thanks are due Professor John Eliot Allen of Portland State College, Dr. Robert H. Weber of the New Mexico Bureau of Mines and Mineral Resources, and Mr. Walter A. Mourant of the U.S. Geological Survey for providing unpublished information from their work in various parts of the area and for help and encouragement during the field work. The writer expresses his gratitude to Harvey Meyer, Howard Stensrud, Neil Muncaster, John Anderson, and Jack O'Brien for assistance in the field. Mr. Mark D. Wilson has been both generous and helpful in sharing his broad experience in the regional geology of the area. This work was made possible by grants from the Graduate School of the University of Minnesota.

STRATIGRAPHY

Over most or all of the map area the Yeso Formation is separated from the basement by less than a few hundred feet of lower Permian red beds and locally some Pennsylvanian strata (Dunn, 1954). One of the Picacho wells, six miles southwest of Sunset, penetrated about 300 feet of pre-Yeso clastic rocks above the basement; farther north the Yeso lies directly on the Precambrian (Lloyd, 1949).

The Yeso is the oldest formation exposed in the map area and generally consists of 1,200 to 1,800 feet of siltstone, limestone, shale, mudstone, and evaporites (Pray, 1954). The lower Yeso does not crop out here, but where it is exposed to the southwest along the Sacramento escarpment red beds and evaporites are the predominant rocks. An incomplete section measured in the Bonito valley just east of Lincoln canyon (fig. 8) included 480 feet of Yeso, 65 percent siltstone and mudstone, 25 percent limestone, and 10 percent gypsum. The limestones form 14 to 35 foot units interbedded in the siltstone and their resistance to weathering causes the magnificient fold exposures at this locality. Above the uppermost limestone and below the base of the San Andres is a unit of red siltstone and gypsum of widely varying thickness. Seven sections measured through this interval ranged from 30 to 224 feet in thickness, and had a mean thickness of 100 feet. Single beds of gypsum as much as 40 feet thick occur in some of these sections, but evaporites are absent in others.

The San Andres Limestone consists of the Glorieta Sandstone Member and an overlying limestone member. The Glorieta, equivalent to the Hondo Sandstone Member of Lang (1937, p. 850), was measured east of state road 368 miles south of Arabela. At this locality it is 131 feet thick, and includes 60 feet of limestone and 71 feet of sandstone and siltstone. The upper unit is a 38-foot bed of massive, cross-bedded, fine-grained, yellow to buff sandstone which makes a distinctive key bed throughout the area. The overlying limestone member consists of rather uniform 3 to 24 inch beds of finely crystalline, medium to dark gray limestone and dolomitic limestone; beds of gypsum as much as 16 feet thick occur locally. The total thickness of the San Andres is about 1,000 feet.

No evidence of an unconformity between the Yeso and San Andres could be found in the field. At first glance the exposures near Lincoln (fig. 9) seem to exhibit such evidence but the contact was observed closely at 37 localities over the area and the two formations were found to be parallel and conformable in all cases.

Post-San Andres formations are preserved in the east near Roswell and in the west in the Sierra Blanca basin. These formations include the Chalk Bluff Formation of Permian age — 500 feet of siltstone, gypsum, sandstone, and limestone; the Dockum Group of Triassic age — 375 feet of variegated shale and coarse clastics; the Dakota Sandstone of upper Cretaceous age — 135 feet, the Mancos Shale, of upper Cretaceous age — minimum, 390 feet, and the Mesaverde Formation of upper Cretaceous age — minimum, 630 feet; Cub Mountain Formation of Bodine, 1956 — 2,200 feet of conglomerate, sandstone, siltstone, and variegated shales; and pediment surfaces of Pliocene(?) age veneered with ig-

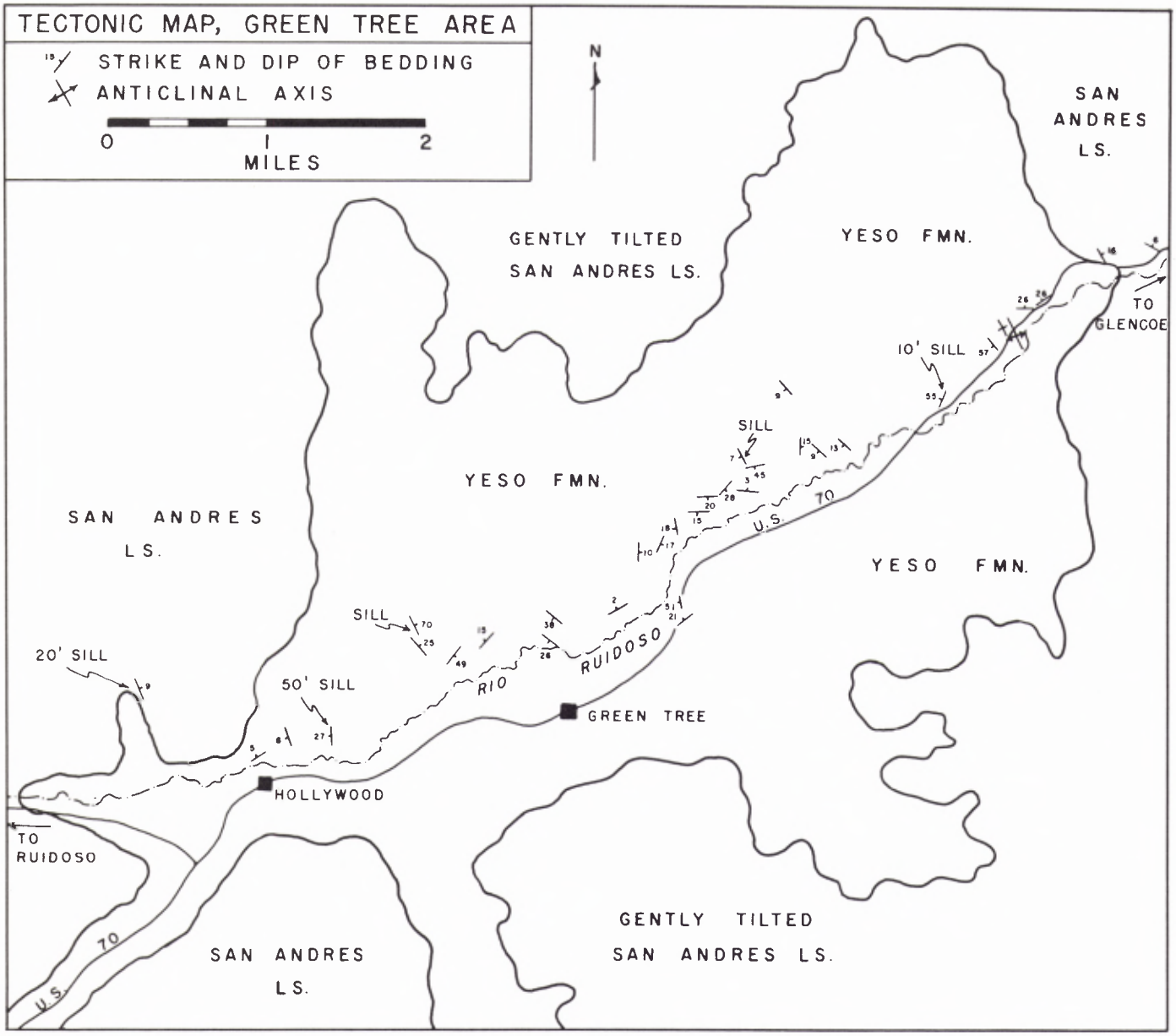


Figure 3. — Tectonic map, Green Tree area.

neous and limestone pebbles. The Cub Mountain Formation might be Upper Cretaceous (Bodine, 1953, p. 14; Kottlowski, and others, 1956) although reportedly it is separated from the Mesaverde by a substantial disconformity. Hence the section consists of a competent igneous and metamorphic basement, a 2,000-foot layer of incompetent fine-grained clastics and evaporite, a 1,000-foot plate of competent carbonate beds, and a cover of as much as 4,200 feet of younger formations — the lower 875 feet of which is mainly incompetent fine-grained clastics and evaporites.

CENOZOIC IGNEOUS ROCKS

The north-northeast trending axis of the Sierra Blanca basin is occupied by an igneous complex the detailed history of which has yet to be established. Geologists who have examined the area (Lindgren, 1910; Semmes, 1920; Knapp, 1933; Patton, 1951; Kelley, 1952; Bodine, 1953; Allen and Ferebee, manuscript) seem to agree however, that a widespread intrusive phase was followed by generally later volcanic activity which has continued into Recent time. Igneous rock fragments have not been reported in the Cub Mountain Formation, but it is crosscut by some of the intrusives in the main Sierra Blanca mass. On this basis the beginning of intrusive activity has commonly been dated as early Tertiary. It could have been late Cretaceous if the Cub Mountain should prove to be that old, or it might have been as late as middle Tertiary.

The intrusives of the early phase were emplaced as

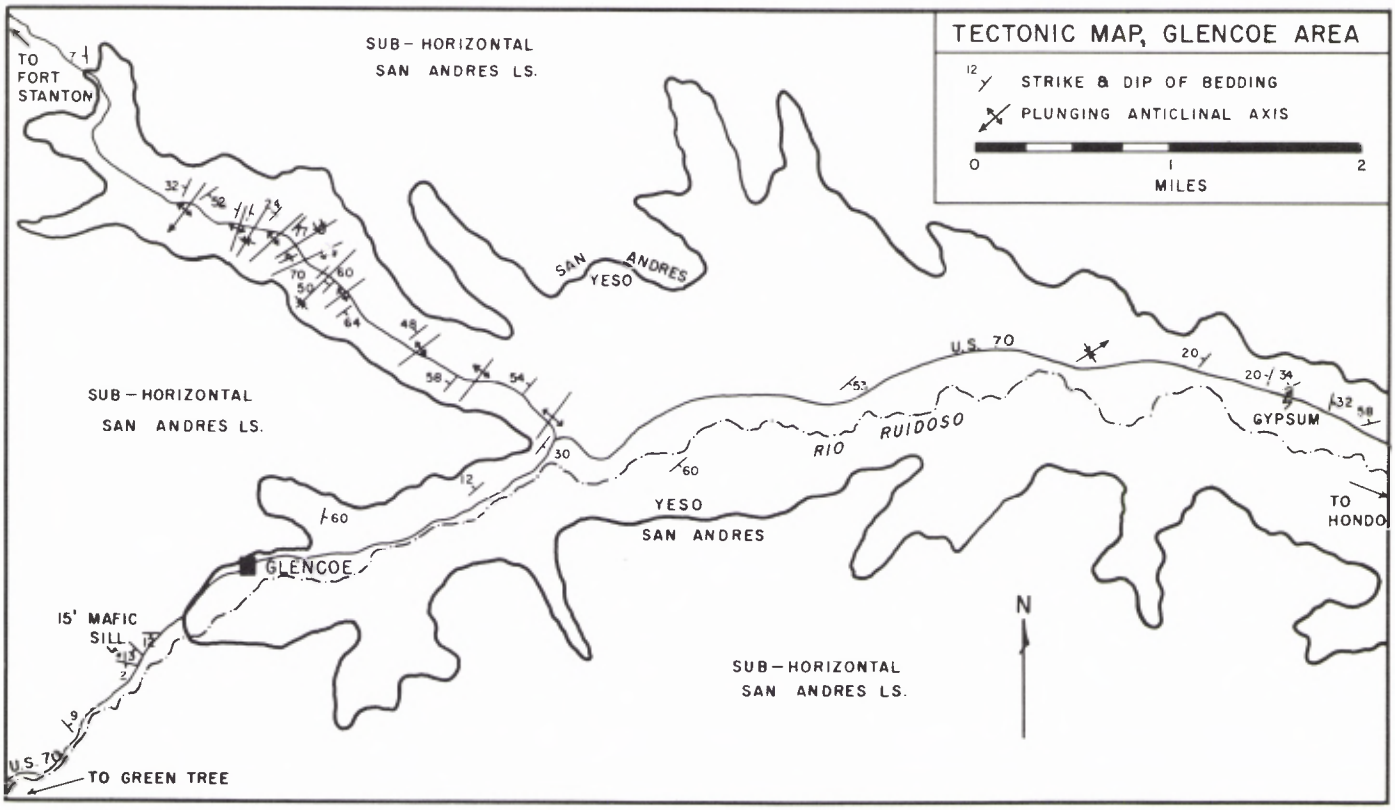


Figure 4. — Tectonic map, Glencoe area.

dikes, sills, stocks, and laccoliths, probably prior to the formation of the present structural depression. These rocks are of intermediate to felsic composition, and many are porphyritic; rocks reported from these intrusives include monzonite, diorite, syenite, and alaskite.

The main extrusives are a series of intermediate to felsic tuffs and agglomerates overlain by andesitic flows (Bodine, 1953, p. 16). The older volcanics are cut in many places by basic dikes, but few of these intrusives penetrate the upper flows. Bodine (1953) and Allen and Ferebee (manuscript) give conflicting interpretations of the relative ages for the dike swarm and the faults. This may be due to dike emplacement during both the intrusive and extrusive phases. Or it may imply that volcanism, subsidence, faulting, and dike emplacement all proceeded contemporaneously during the second igneous phase, or its early stages.

The area east of the Sierra Blanca basin contains scattered intrusives, similar in composition and probably in age to those in the main complex. The largest intrusive forms the Capitan Mountains, and is an unroofed pluton 4 to 5 miles wide and 21 miles long. It has been described by various writers as being composed of aplite, rhyolite, microgranite, and alaskite. The writer believes it is younger than the first intrusives in the main Sierra Blanca complex though it may be contemporaneous with some of the more felsic plutons. Eastward from Sierra Blanca to Arabela and almost to Sunset intermediate sills, described as andesite by Semmes (1920, p. 427) occur in the upper Yeso and the lower San Andres. At least some of these sills are older than the Capitan Mountains pluton, on the basis of truncation of the sills by the pluton south of Arabela.

DESCRIPTION OF THE FOLDS

The Yeso Folds

The Yeso Formation is exposed only in the valleys of the principal streams and along the margins of major plutonic bodies, especially the Capitan Mountains. Almost everywhere it crops out, the Yeso is moderately to strongly folded. Many details in the field attest to its mobility during deformation, particularly in the uppermost siltstone and gypsum unit. Three steeply-dipping clastic dikes 3, 5, and 15 feet in width were observed in the upper Yeso and the Glorieta Sandstone and consist of a siltstone matrix and subangular blocks of older sedimentary units. Since the first two occupy small faults and the last a fracture parallel to the crest of an anticline, it is probable they were injected from below during the folding and faulting. West of Lincoln many faults trend about N. 30° E. and offset the base of the San Andres 15 to 20 feet; the uppermost beds of the Yeso have flowed around the subsiding block and are nearly vertical. In the valleys northwest of Lincoln are some small, sharp east-west folds (fig. 7) which are probably younger than the larger main folds. The faults may be related to the formation of the Sierra Blanca basin and the east-west folds to the emplacement of the Capitan Mountains pluton; this suggests the Yeso may have been mobile over a considerable time span and not merely during the main folding.

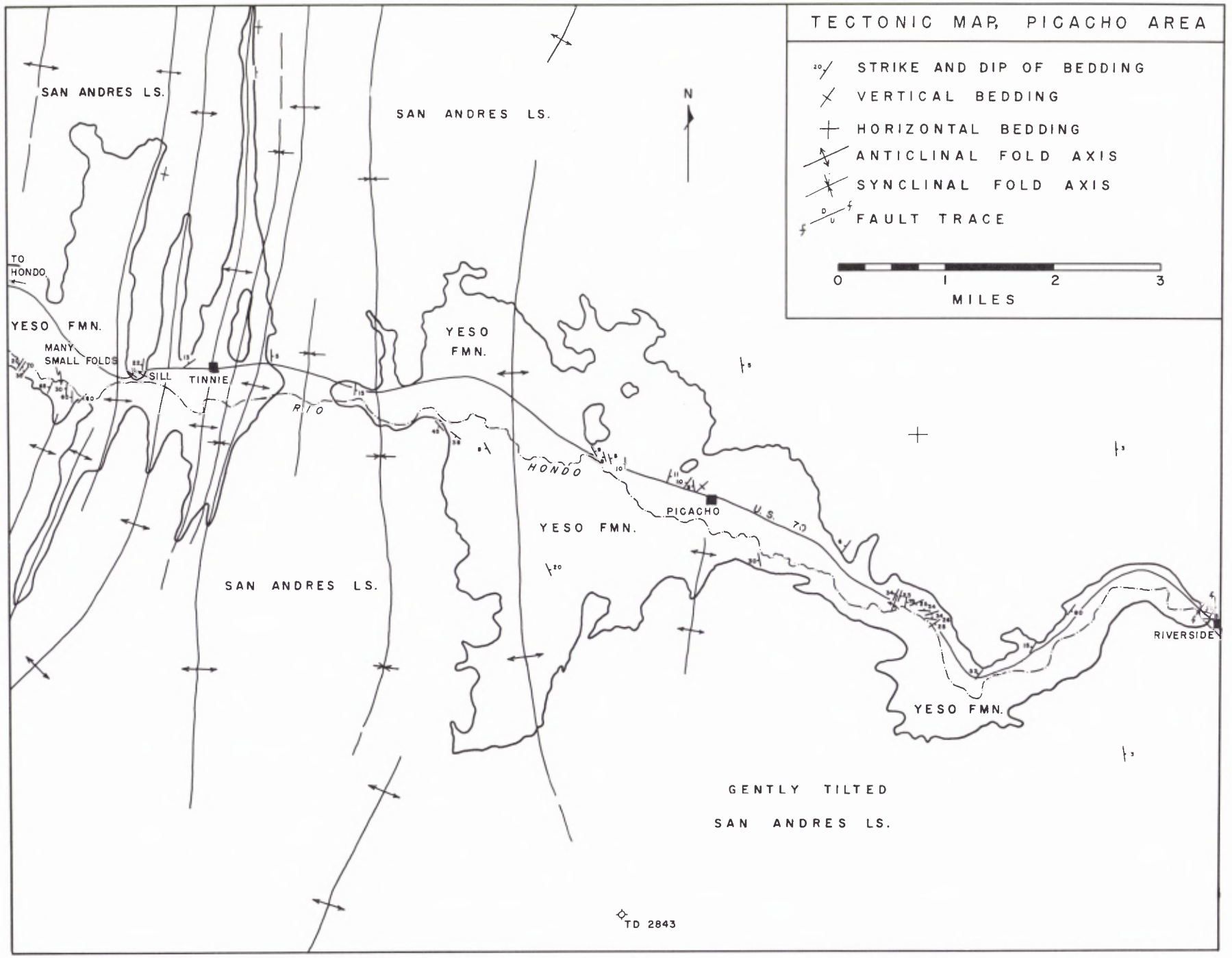


Figure 5.— Tectonic map, Picacho area.

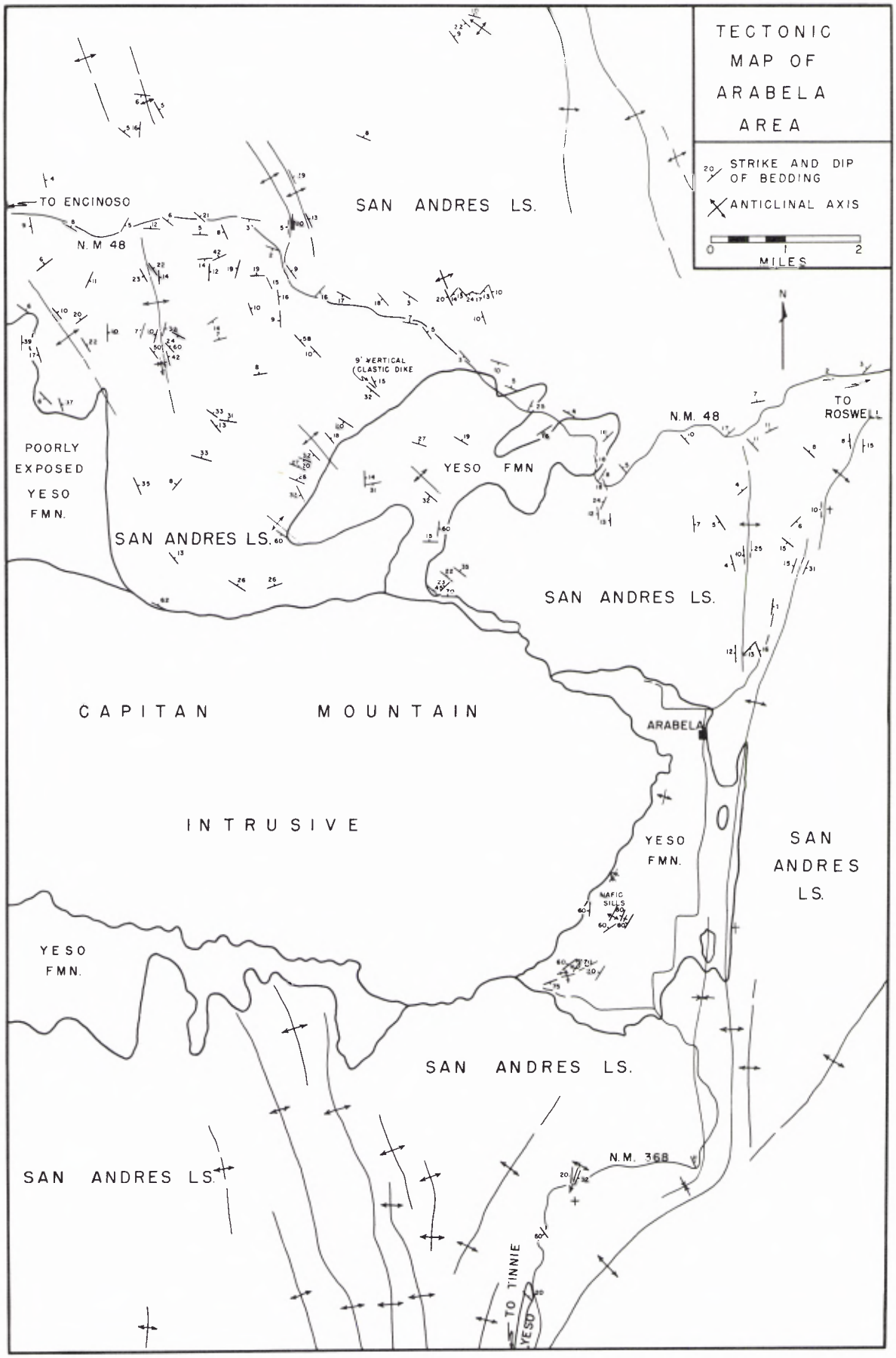


Figure 6. — Tectonic map, Arabela area.

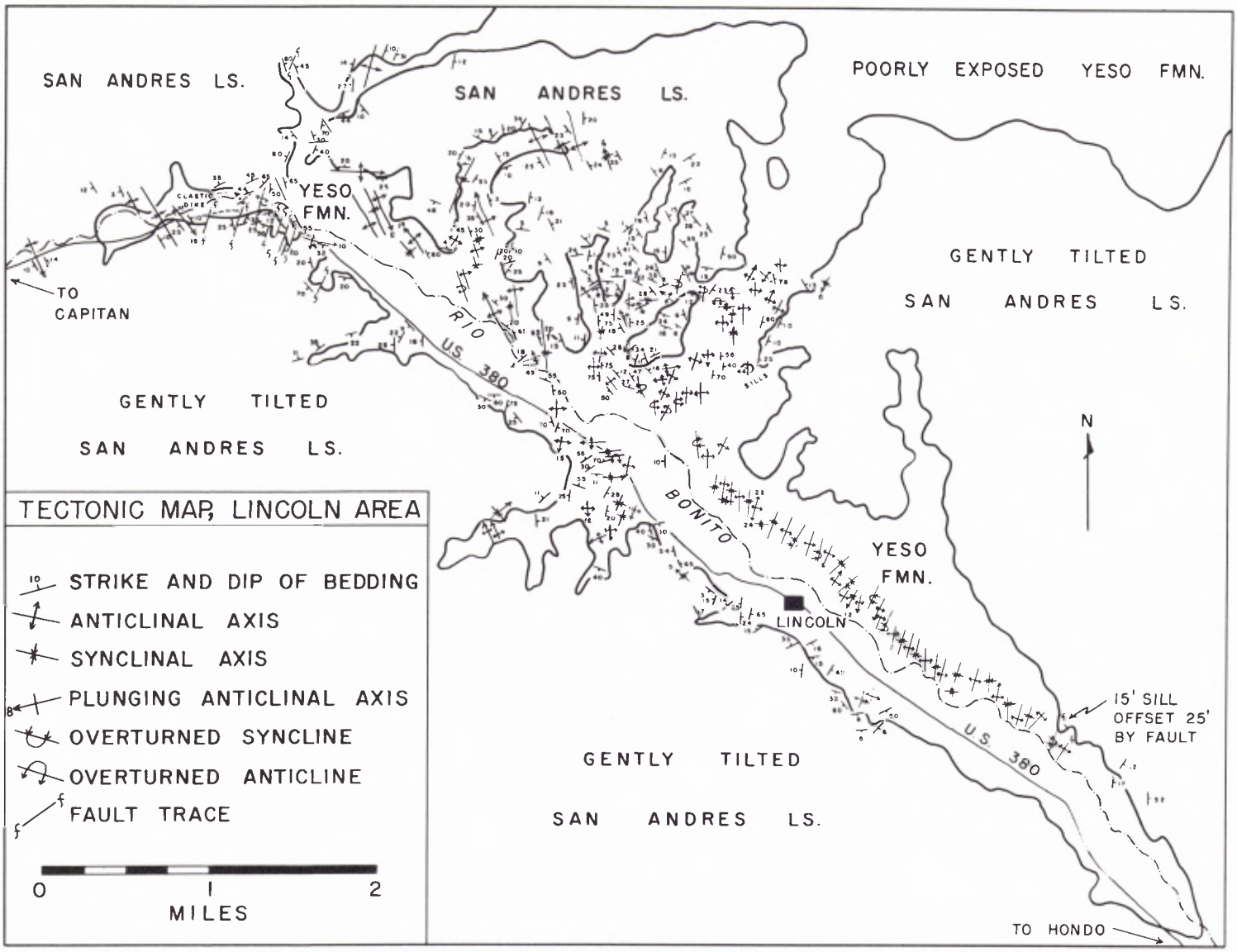


Figure 7. — Tectonic map, Lincoln area.

Despite local complications the overall pattern of the Yeso folds is quite regular and broadly symmetrical; axial planes are close to vertical in most folds, and the geometry is broadly that of parallel folding. The Yeso folds die out upward against the Glorieta in many places within a short vertical distance from very steep dips, a fact also noted by Semmes (1920, p. 429-430). This dying out is accomplished in the uppermost siltstone and gypsum unit, the thickness of which changes markedly in short distances. These folds are generally not faulted and tend to die out longitudinally; one well-exposed anticline measures 50 feet across and 150 feet long on a key bed and plunges 25° at both ends. The 22 folds shown in figure 9 have wave lengths varying from 325 to 1,200 feet, and all but three are between 510 and 1,000 feet; the mean is 713 feet. The apparent shortening of a key limestone bed in figure 9 is 5,600 feet or 25 percent.

Currie, Patnode, and Trump (1962) have analyzed the problem of the buckling of a competent layer embedded in a yielding homogeneous medium. For the case in which the thickness of the adjacent medium is less than the predicted fold wave length they find that

$$L = \pi \sqrt[4]{\frac{2\ J\ T^3}{3} \times \frac{E}{E_o}}$$

where L = predicted initial wave length, J = thickness of one enclosing layer, T = thickness of the buckling competent layer, E = Young's modulus of the competent layer, and E_o = Young's modulus of the enclosing layer. If the Yeso folds at Lincoln are considered to be caused by buckling and attendant lateral shortening, the mean initial wave length was about 950 feet. The uppermost siltstone unit in the Yeso represents the enclosing layer so J equals 100 feet. On the assumption that the remainder of the measured Yeso section comprises two-thirds of the competent layer, T equals 570 feet.

Predicted initial wave lengths were calculated for

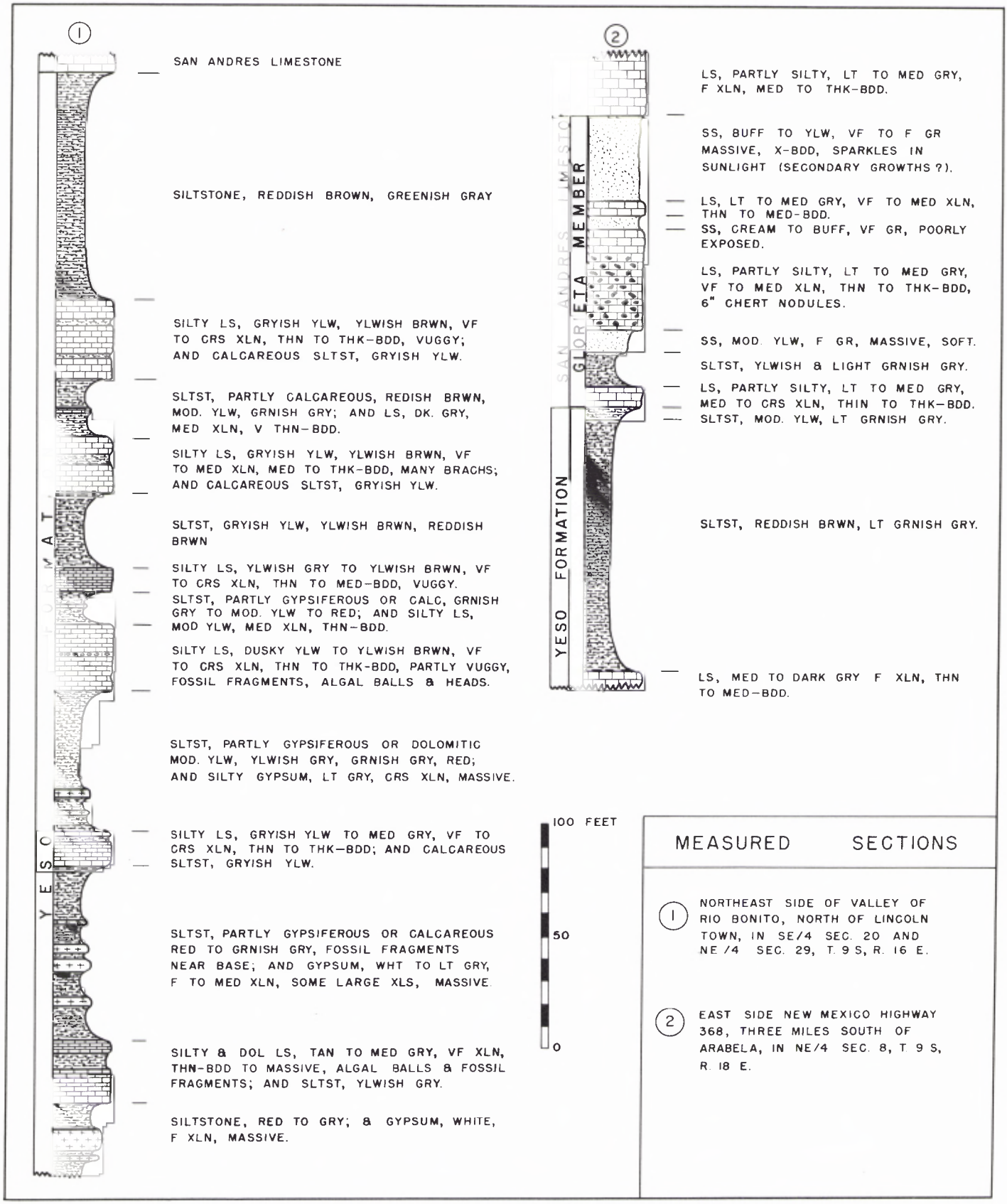


Figure 8. — Measured sections of Permian rocks.

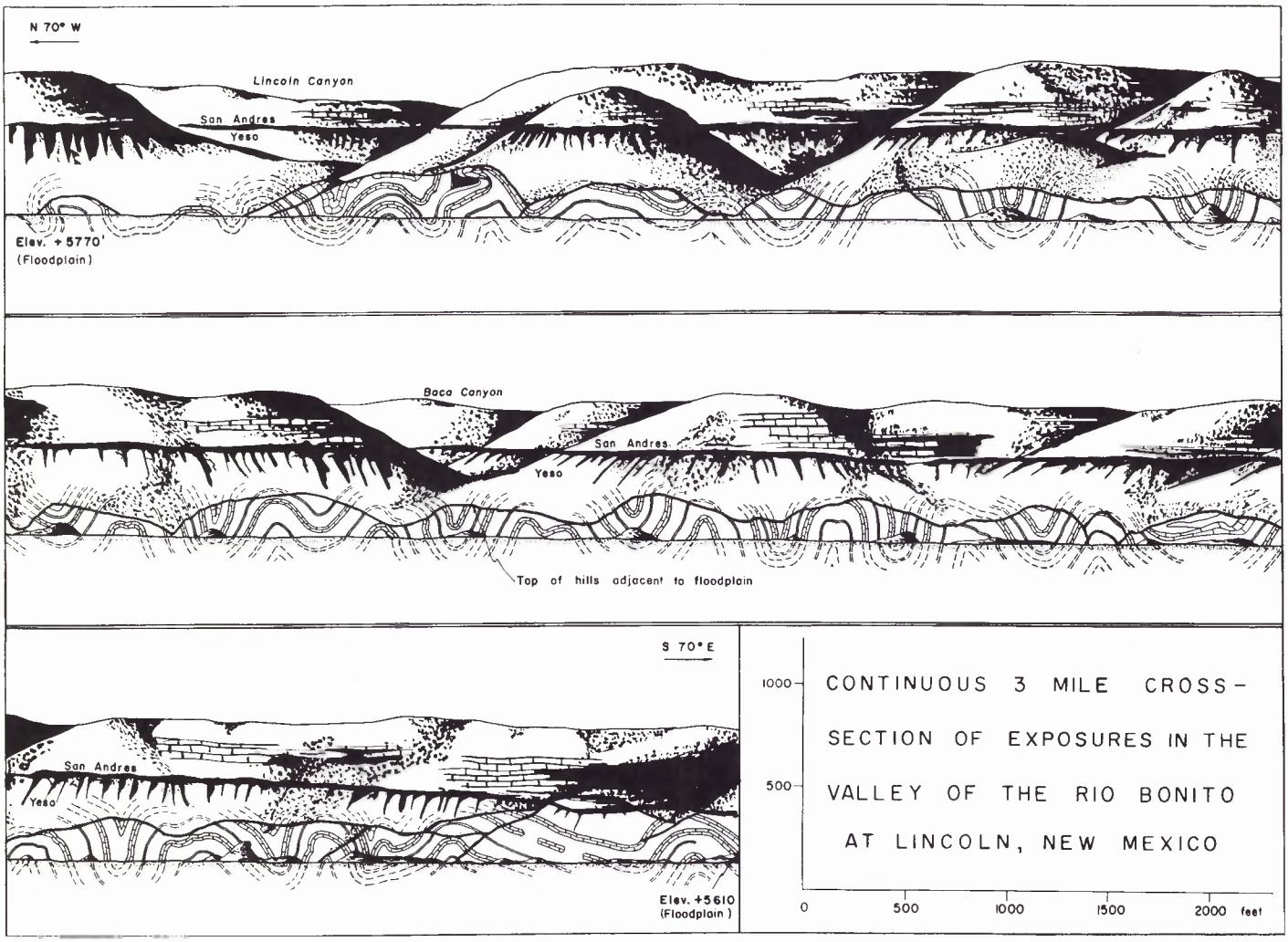


Figure 9. — View to NNE near Lincoln showing strongly folded Yeso formation and conformable overlying San Andres limestone.

various ratios between the elasticity of the layer and that of the enclosing medium. Values of E/E_0 equal to 10, 5, 3, and 1 yield values of L equal to 1,865, 1,565, 1,380, and 1,048 feet respectively. Since a good approach to the actual initial wave length is obtained only as the ratio E/E_0 approaches unity, it is awkward to account for these folds by a buckling process dependent on contrasting elasticity of the layers. This suggests that a more passive mechanism of folding may have been operative and that the apparent lateral shortening in these folded beds may exceed the true shortening.

The San Andres folds

Over most of the area the San Andres limestone is a gently warped plate though locally its basal beds are downfolded into the Yeso siltstone with dips as high as 70°. This prevailing gentle homoclinal structure is interrupted by sharp, narrow, long, and in many cases isolated buckles which tend to lift the Yeso-San Andres contact above its normal elevation. These also seem to be parallel folds and in some places show vertical or slightly overturned dips. The wave lengths of these folds are larger than in the less competent Yeso Formation; even in the zone of close folding east of Hondo successive anticlines rarely come within 1,200 feet, and in most places are at least 1,800 feet apart. Some of these folds are symmetrical, but many are not; some change their direction or asymmetry along strike as noted by Fiedler and Nye (1933, p. 78-81). An 11.3 mile section eastward across the main sheaf of folds from a point four miles west of Hondo reveals an apparent shortening of the Glorieta by 2.0 miles or 15 percent.

Although an independent origin is possible, the Border Hills, Six Mile Hill, and Y-O anticlinal flexures are here considered a part of the Lincoln fold system. These structures are narrow, sharp, locally faulted anticlines whose surface expression is almost confined to rocks of the San Andres limestone. Because distinctive units are rare in this thick carbonate section, it is difficult to determine if vertical displacement of the gently tilted strata on opposite sides of these flexures has occurred. However, if the Yeso-San Andres contact near Sunset is projected eastward five miles to the Border

Hills (fig. 1) using dips observable in the San Andres, the elevation of the contact is about the same below the flat-lying beds just northwest and just southeast of the flexure in this cross-section. This suggests that these structures are anticlinal buckles resulting from horizontal displacement of the San Andres strata; in this interpretation the observed reverse faults are a result but not a primary cause of the folding.

The general trends of all important axes in the Lincoln fold system have been plotted on figure 1. A sweeping arcuate pattern on the west passing eastward into more uniform, linear anticlines is evident. Some shallow dry holes near the projected trend of the northernmost folds on figure 1 suggest that this arc may continue farther northwest. Similar features extend southward; Renick (1926, p. 124-127) describes strongly folded Yeso beds beneath gently tilted San Andres 38 miles south of Glencoe.

AGE OF THE FOLDS

During the writer's early field studies near Lincoln it seemed probable that the Yeso folding represented a local Permian disturbance. However the discovery of conformable contacts between the Yeso and the San Andres, the local downfolding of the basal San Andres into the Yeso, and the large scale buckling of the limestone plate along axes parallel to those in the Yeso indicates a post-San Andres age. Merritt (1920) reports he has traced the Border Hills flexture into upper Permian red beds, which would argue for a post-Permian deformation.

The incomplete record of the Mesozoic in this area suggests that it was rather stable during that time, and that it was not until the emplacement of the early Tertiary intrusives that significant deformation occurred. One of these intrusives, the Capitan Mountains pluton, occurs in the folded area and provides important evidence on the chronology. Three lines of evidence suggest this pluton post-dates the main folding. First, the arcuate pattern of the folds, though possibly offset and locally deflected, continues obliquely across the Capitan Mountains; it is hard to conceive of this pattern developing after the emplacement of the pluton. Secondly, Kelley (1952, p. 69) reports clastic dikes in the lower San Andres on the west end of the Capitan Mountains in such a position that they could hardly have formed after the igneous intrusion. These clastic dikes may be the same age as those described above as essentially contemporaneous with the folding; if so, the Capitan Mountains pluton seems to post-date the folding. Finally, the complex cross-cutting and folding relations near Arabela indicate that the original folding and the intermediate sills in the folds are older than the pluton. The intense fracturing in the sills and the tightness of the folding suggest, but do not prove, that the sills preceded the pre-pluton folding.

Several localities near Arabela reveal small faults in the folded sills, but these may have been formed when the Capitan Mountains pluton was emplaced. However, southeast of Lincoln a 15-foot sill at the Yeso-San Andres contact is offset about 25 feet along a fault transverse to the fold axes. If this fault is related to the deformation that caused the folding, then this sill antedates the folding. This conclusion is consistent with the occurrence of sills in strongly folded Yeso beds elsewhere in the area, away from the Capitan Mountains; sills dipping 44°, 55°, and 70° have been observed. Thus, it is probable that the folding post-dates these earliest intermediate intrusions.

Northeast of Alto a major fault, the Cub Mountain Formation, and a flexure in the San Andres Formation all pass beneath a gently eastward-sloping gravel-covered surface having an elevation of about 7,000 feet. Between Hondo and Sunset another surface at about 5,800 feet altitude seems to bevel the folded San Andres formation (Fiedler and Nye, 1933, p. 13-14, pl. 5B). Bretz and Horberg (1949, p. 488) suggest that gravel of the Ogallala Formation of Pliocene age now capping the plains east of Roswell once covered most of the Sacramento-Guadalupe Range; Horberg (1949, p. 464-466) considers surfaces as high as 8,000 feet in the Guadalupe Range as remnants of this once continuous Ogallala surface. King (1942, p. 633), however interprets these high surfaces as portions of a pre-Cretaceous plain, and Kelly (1952, p. 70-71) considers similar surfaces near Capitan to be Pleistocene in age.

Although details of these surfaces have not been worked out, the surfaces west of Sunset and near Alto-capped with limestone and igneous pebbles — may well be remnants of a Pliocene pediment surface sloping eastward to the Ogallala Formation of the Great Plains. This places an upper time limit on the major subsidence of the Sierra Blanca basin and the folding, and reinforces the conclusion that the folding probably occurred in early Tertiary time.

IMPROBABLE HYPOTHESES OF ORIGIN

The following explanations for the fold system or for specific parts of it have been offered in the literature or suggested to the writer:

1) Intra-Permian deformation,
2) Movements on basement faults,
3) Lateral pressure from the emplacement of the Capitan Mountains pluton,
4) Drag effects during the formation of the arch west of Lincoln,
5) Tilting of the Sacramento Mountain block,
6) Volume changes during the recrystallization of evaporites,
7) Surface subsidence due to subsurface evaporite solution,
8) Landsliding or other local mass wasting processes,
9) Injection of sills.

Although some of these mechanisms may have played a local role, each is considered improbable as a general explanation of the Lincoln fold system for one or more of the following reasons: 1) the early Tertiary age of the folding, 2) the shape of the folds in cross-section, 3) the regional extent of the fold system, 4) the map pattern of the folds in relation to other geologic features, and 5) the lithologic composition and physical properties of the folded formations.

PROBABLE ORIGIN OF THE FOLDS

Before discussing the probable origin of these folds it is desirable to reconstruct the geologic conditions prevailing early in the Tertiary, the inferred time of folding.

The tectonic history of this area during the Mesozoic is incompletely known, but the widespread intrusive activity in the Tertiary terminated a period of relative crustal stability. The strata may have had a slight southeastward inclination inherited from their position on the northwest shelf of a depositional basin during Permian time. The San Andres carbonate plate was buried beneath at least 4,200 feet of younger beds and possibly more.

Folding of the Permian rocks is probably related to these plutonic intrusions. If the age is correctly established by the evidence discussed, the folding followed the injection of the early intermediate sills but preceded the emplacement of the acidic pluton of the Capitan Mountains. Folding followed the sill injection by enough time to allow solidification and faulting of some of the sills. Thus the great monzonite and diorite intrusions may not have directly caused the folding, but rather may have triggered it in some manner. Gravitational gliding of sheets of Cretaceous Dakota Sandstone resulting from doming due to Tertiary intrusions has been reported near Capitan by Allen and Ferebee (manuscript) and in the Jicarilla Mountains by Budding (1963).

The intrusions are also linked to the Lincoln deformation by the map pattern of the fold system. Whenever folds are exposed in both the Yeso and the San Andres, the trends are parallel and hence must be genetically related. The fold system forms a sweeping arc which measures at least 15 miles across, excluding the isolated anticlines to the southeast, and at least 50 miles in length. The focus of this arc lies near the main intrusive complex of Sierra Blanca.

Where significantly exposed, the Yeso is generally crumpled into a series of mainly parallel folds; in many localities these folds die out upward abruptly against the flat base of the San Andres. Attempts to project these folds downward are beset with the space difficulty inevitable for all parallel folds, and their shape seems to require a plane of "dying out" a few hundred feet below the deepest present exposures. The San Andres folds, on the other hand, are unusual in being sharp, generally upward-directed buckles which in some cases are separated by broad, flat areas.

A puzzling discrepancy exists in the amount of apparent lateral shortening from folding between the value computed from the San Andres limestone and that from the Yeso formation. An apparent shortening of about two miles was measured on the Glorieta member of the San Andres across the conspicuous family of folds near Hondo. With allowance for numerous minor warpings and the three anticlinal flexures to the southeast the maximum apparent shortening across a width of 50 miles is about 3 miles or 6 percent. However, in the well exposed transverse section of just over 3 miles at Lincoln the Yeso folds show an apparent shortening of 5,600 feet or about 25 percent. Thus in this short distance the apparent shortening in the Yeso equals one-third of the total calculated for the San Andres across the entire area. The universally folded character of the Yeso where exposed in the area suggests it is deformed throughout the area of San Andres folding. At the very least the Yeso deformation extends 25 miles transverse to the fold axes. Applying the 25 percent apparent shortening measured at Lincoln yields a minimum apparent shortening of 8 miles in the Yeso, clearly greater than the amount calculated from the San Andres.

The most satisfactory explanation for the known relations involves a decollement or slippage along a surface in the lower Yeso formation, as first discussed by Allen and Ferebee (manuscript) based chiefly upon observations in the vicinity of Capitan. Gravitational movement occurred when the area was tilted slightly by the early intrusions in the Sierra Blanca complex. This movement was directly southeasterly down the then-present regional dip; the modern more easterly dip probably results from later northeasterly tilting, most of which is late Cenozoic in age (King, 1948, p. 120-121). The present average eastward dip between Lincoln and Roswell is about 1°, and the surface slope is slightly less. Formational dip at the time of folding was probably about the same although somewhat higher eastward dips may have existed near Capitan before the collapse of the Sierra Blanca basin. Since the coarsely crystalline plutonic rocks on Sierra Blanca require a roof and since the present structural basin there is considered to post-date the intrusions, surface slopes at the time of folding may have been considerable.

The Yeso folds are thus interpreted as a mainly passive response to instability created by gravitational shifting the entire sequence above a bedding surface in the lower Yeso. The eastward movement of the San Andres limestone plate near Lincoln is limited to about 3 miles, and the actual slippage along the basal surface in the lower Yeso may be less. If the Yeso folds are considered passive, the true lateral shortening may be less than the value obtained by "unfolding" the folds. Such a mechanism also implies some attenuation of the units in the Yeso to permit the folds to form. Detailed sections were measured in a limestone and the overlying siltstone in a 2½-mile traverse across the folds at Lincoln. Sixteen limestone sections ranged between 24.6 and 35.3 feet, and 8 reliable siltstone sections between 14.4 and 23.0 feet. If the original thickness is assumed constant and equal to the maximum measured thickness for each unit, then attenuation has locally reduced the thickness of the limestone by 30 percent and the siltstone by 37 percent.

Bucher's (1956) scale model experiments on the role of gravity in deformation indicate that the proposed mechanism of folding is possible. Interbedding layers of stiff stitching wax and grease in a compression box were imparted a slight slope by pressure against the left end of the box. (See Bucher's Plates 1 and 3.) The true shortening, as measured on the lowest wax layer which bent only at the left end, was about 10 percent. As the entire sequence shifted to the right under gravity to eliminate the slope, a set of folds strikingly similar to the Lincoln fold system was formed. The middle wax layer was undeformed in the left half of the box but to the right buckled into long wave length folds analogous to those in the San Andres. The apparent shortening in the layer was roughly equal to the true lateral shifting. The underlying and overlying grease layers were deformed across the width of the box into shorter wave length folds analogous to those in the Yeso formation. The apparent shortening of these grease layers averages 31 percent, greatly in excess of the actual value. This writer considers the Lincoln fold system to have formed in a similar manner, except that the initial tilt probably resulted

more from arching due to intrusions rather than lateral pressure.

The main folds in the San Andres in the Hondo-Picacho-Arabela area may be compared to folds in two other regions. The Jura Mountains in France and Switzerland is the type area for decollement folding; lateral shortening there over most of the belt is 6-10 km or 25 percent (Umbgrove, 1948, p. 1055) but may increase to 17.5 km at the east end (Collet, 1927, p. 139). Reeves (1946) described an arc of faulted folds in the Cretaceous rocks of the plains surrounding the igneous Bearpaw Mountains in northern Montana; his interpretation has been confirmed by new subsurface data reported by Shouldice (1963). Lateral shortening there is as much as 3 miles and the plainsward dip is approximately 3°. The deformation in all three regions has been attributed by some to gravitational shifting, and the folds in each case have these characteristics:

1) Their geometry suggests the presence of a basal shear plane,
2) Sharp anticlinal folds are separated in some cases by broad, flat areas,
3) Many folds are slightly asymmetric and tend to change the direction of inclination of the axial surface along their axes,
4) The fold system has a broad arcuate pattern.

Faults are abundant in the Bearpaw folds, common in the Jura folds, but rare in these San Andres folds.

The writer has not studied the Border Hills, Six Mile Hill, and Y-O flexures in detail, but they are probably genetically a part of the Lincoln fold system. A case can be made for considering them the result of movements of basement blocks on the basis of 1) their straightness, 2) the presence of steep strike faults in the surface formations, and 3) the existence of monoclines elsewhere in the region. On the other hand, evidence relating them to the Lincoln fold system includes 1) their regular spacing, 2) their general parallelism with each other and with the folds in the Hondo-Arabela area, 3) the variable nature of their asymmetry and faults along the strike, and 4) the probable lack of vertical displacement of the flat-lying beds on opposite sides of these flexures. It is possible that minor basement faulting may have localized these flexures, but their geometry seems to require significant lateral shortening rather than monoclinal flexing.

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