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LARAMIDE EVAPORITE TECTONICS ALONG THE TEXAS-NORTHERN CHIHUAHUA BORDER

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INTRODUCTION

A major structural boundary lies approximately parallel to the present political boundary between northeastern Chihuahua and adjacent parts of Trans-Pecos Texas. It coincides with the northern and eastern margin of the Chihuahua Trough (DeFord, 1964), a narrow northwest-trending negative feature flanked by the Aldama Platform of western Chihuahua and the Diablo Platform of Trans-Pecos Texas. From the Late Jurassic until the Late Cretaceous, from 3600 to as much as 7600 m of sedimentary rock was deposited in the Chihuahua Trough while about 1000 m of sedimentary rock accumulated on the adjacent Diablo Platform (Gries and Haenggi, 1971). The accumulation of strata, including a thick basal evaporite sequence, was later complexly folded and faulted during formation of the Chihuahua Tectonic Belt. A zone of recurrent faulting along the western margin of the Diablo Platform marks the eastern limit of the Chihuahua Tectonic Belt. This zone of faulting separates the thick, complexly deformed rocks of the basin from the mainly block-faulted platform rocks to the east and north of the basin.

In relation to present geography, the eastern limit of this deformed belt lies immediately east of the eastern flanks of the various sierras extending from La Mula, Chihuahua to Sierra Blanca, Texas, referred to here as the La Mula-Sierra Blanca Range. The northern limit of the belt lies along a line extending from Sierra Blanca, Texas on the east through Sierra Juárez, Chihuahua on the west.

Stresses imposed during the Late Cretaceous-early Tertiary Laramide orogeny deformed the thick Mesozoic sequence and the underlying Paleozoic rocks. Evaporites acted as a décollement zone between Mesozoic and Paleozoic rocks. Major thrust faults, overthrust toward the east, developed along the eastern edge of the evaporite basin. Similar thrust faults and accompanying faults occurred along the northern margin of the basin with additional northward movement on the décollement zone. Complex disharmonic folding caused by evaporite, shale and marl flowage is present in thrust plates at all scales up to fold amplitudes of 3500 m. Diapiric injection occurred along three east-trending tear faults and in at least one place on the toe of the thrust complex. Normal faults in Cretaceous rocks developed over void areas left by evaporite flowage into anticlines and diapirs. During Laramide deformation there was probably reactivation of north- to northwest- trending faults that had affected Paleozoic rocks. Pre-Laramide fold-fault trends may have exerted control over Laramide structural trends, which determined the alignment of the front ranges of the Chihuahua Tectonic Belt.

Diapiric features that developed during Laramide deformation continued to be active after most faulting and folding had taken place. Collapse structures developed over diapirs as evaporites were removed by early Tertiary erosion. At several places, erosion removed nonresistant beds and gravity sliding resulted in flaps and detached flaps in adjacent beds of limestone on high-angle flanks of folds.

Late Eocene-early Oligocene volcanism deposited ignimbrites, lava and volcanically derived sediments over much of the area. Regional uplift and block faulting were superimposed on the Laramide structural features during the late Tertiary. Considerable evidence exists that late Tertiary and Quaternary structural features associated with the Rio Grande rift extend into the Chihuahua Tectonic Belt (Gries, 1979).

PRE-LARAMIDE GEOLOGIC HISTORY

Pre-Mesozoic geological history of the area of the Chihuahua Tectonic Belt must be inferred from exposures outside the deformed area. Figure 1 delineates exposures of Paleozoic units in areas surrounding the Chihuahua Trough.

Several lines of evidence indicate that the Chihuahua Trough was a Paleozoic depositional basin. To the north and east, on and adjacent to the Diablo Platform, surface exposures show Cretaceous rock resting unconformably on strata of different Paleozoic systems and also on Precambrian rock. In the northern Eagle Mountains (Underwood, 1963), Van Horn Mountains (Twiss, 1959), and Wylie Mountains (Hay-Roe, 1957), Permian strata unconformably overlie Precambrian igneous and metamorphic rocks of the Carrizo Mountain Group (King and Flawn, 1953). Miller (1957) reported that the N. B. Hunt No. 1 Toodle Trust (formerly No. 1 Presidio Trust), near San Carlos, Texas (in the central portion of the Sierra Vieja), penetrated 1.7 m of Cambrian-Ordovician rock below Permian strata and above Precambrian "granite."

In the Pinto Canyon-Chinati Peak-Presidio area (Amsbury, 1958; Rix, 1953; Dietrich, 1965), exposed Permian and Pennsylvanian rocks unconformably underlie Cretaceous rock. In the vicinity of Placer de Guadalupe, within the Chihuahua Trough, there are extensive outcrops of Paleozoic rock belonging to the Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian and Permian systems (Bridges, 1964). Paleozoic rock in this area is overlain unconformably by Jurassic rock, and the base of the Paleozoic section is not exposed.

On the western margin of the Chihuahua Trough near Aldama, metamorphosed Paleozoic rocks are unconformably overlain by Cretaceous rocks. Upper Wolfcampian fusulinids have been found in limestone lenses within the predominantly terrigenous section. One of the major features of the Aldama section is that the Paleozoic rocks are intensely deformed whereas the overlying Cretaceous rocks are not involved in the deformation. Flawn and others (1961) include the Aldama Paleozoic section in the frontal zone of the Ouachita structural belt.

Thus, it seems likely that rocks of a Paleozoic basin underlie the rocks of the Mesozoic Chihuahua Trough. Details of the tectonic features of the Paleozoic Diablo Platform are found summarized in Wiley (1972) and elsewhere in this guidebook.

LARAMIDE DEFORMATION

In early Mesozoic time the north and east boundaries of the Chihuahua Trough paralleled the earlier zones of recurrent uplift

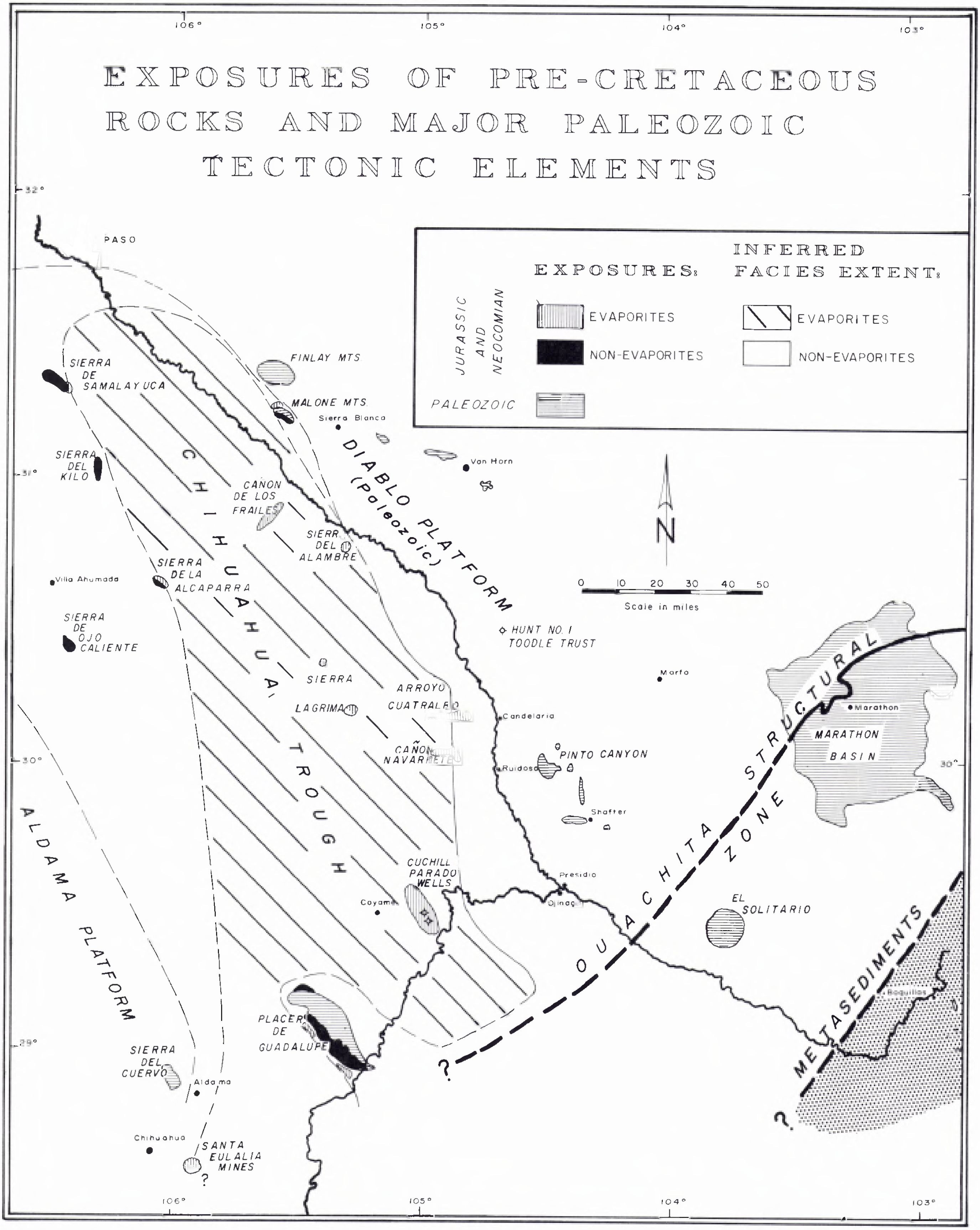

Figure 1. Exposures of pre-Cretaceous rocks, outline of evaporite basin, and major Paleozoic tectonic features of northeastern Chihuahua and part of adjacent Texas.

and faulting. Thus the trough took the form of a narrow north-south basin open to marine waters only on the south. The nature of this restricted connection is poorly known because of a lack of exposures and of detailed work. The resultant restricted marine environment was the site of thick evaporite deposition (fig. 1). All surface exposures of evaporite rocks are in diapiric areas and consist of gypsum, minor anhydrite and included fragments of younger rocks. Ramirez and Acevedo (1957) reported that Petroleos Mexicanos Cuchillo Parado No. 1 penetrated 2326 m of evaporite and associated rock near Cuchillo Parado on a diapiric anticline before being abandoned, still in evaporites. Of this thickness 80 percent was salt, 5 percent gypsum, 1 percent anhydrite and 14 percent claystone and limestone. Because all known data come from diapiric localities, no estimate of the thickness of the evaporite sequence can be made. No fossils have been found in the evaporites. The thick evaporites have been assigned a Late Jurassic or Neocomian age (Haenggi, 1966; Humphrey, 1964) Lower units in the evaporite sequence may represent late Paleozoic deposition. Evaporite exposures indicate that the eastern limit of evaporite deposition in the trough is approximately coincident with the west flanks of the La Mula–Sierra Blanca Range (Haenggi and Gries, 1970.

Up to 6000 m of carbonate and siliciclastic sediments were deposited conformably on the evaporites in the trough. Rocks of the same age are represented by about 1000 m of sediments on the adjacent Diablo Platform. DeFord and Haenggi (1971) present a detailed overview of the Cretaceous rocks of the Chihuahua Trough.

The rocks of the lower part of the Cretaceous are clastics with increasing carbonate deposits upward to the Upper Cretaceous rocks, which show a return to clastic deposition. Neocomian–Aptian formations are dominantly siliciclastic. Middle Albian formations are dominantly siliciclastic in the eastern and northeastern parts of the Chihuahua Trough, but are predominantly shallow-water carbonates in the western trough. Late Albian–early Cenomanian formations are limestone with lesser amounts of shale. During Cenomanian time siliciclastic deposition again became dominant.

Structural deformation occurring in Late Cretaceous through early Eocene is considered Laramide in this paper. The exact age of Laramide deformation in northeastern Chihuahua is unknown. Wilson (1965) has dated the Laramide in the Big Bend area as early Eocene (post-Hannold Hill Formation to pre-Canoe Formation).

Some form of Laramide stress system resulted in thrust-faulting away from the basin center, northward into southern New Mexico (Corbitt and Woodward, 1973) and eastward into extreme eastern Chihuahua (Haenggi and Gries, 1970). The evaporite sequence acted as a décollement zone with the thick Cretaceous sedimentary section moving eastward and northwestward until the limits of evaporite deposits were reached. At this boundary the overlying rocks no longer had the evaporite gliding surface beneath and were deformed into large folds with subsequent shearing and thrust-faulting.

Several possible configurations of the Paleozoic "basement" could form this structural belt. Haenggi (1966) suggested an arching that resulted in tilting of the basin edges away from the basin center. If the fault zone along the platform edge allowed the basin edge to subside, the thick succession of Cretaceous rocks overlying an evaporite layer would tend to move downdip toward the basin margin. The evaporite would serve as a décollement zone allowing the overlying rock to glide eastward.

A second possibility suggested by Haenggi (1966) was that regional compression formed deep-seated folds in the Paleozoic basement. Evaporite flowage toward the crests of these features amplified these folds in the overlying Cretaceous rocks. The formation of an amplified deep fold near the eastern limit of the evaporite basin, coupled with eastward gliding of the overlying rock on the evaporite, could produce a large overturned fold approximately coincident with the limit of the evaporite basin. With continued evaporite flowage and eastward gliding the fold would eventually be sheared and thrust faults would be formed along the eastern margin of the folds.

A third possibility is that the same structures were formed by regional extension. Extension would allow tilting of the Paleozoic basement by downdropping the basin margin along the platform-edge fault zone. Eastward gliding of the post-evaporite sedimentary rock would take place to the eastern limit of the evaporite basin. At this limit, folds with cores of evaporite would form and tend to overturn eastward. Shearing and thrust-faulting would take place as in the hypothesis of compression.

Sparse geologic data exist to support one hypothesis over another. One factor is the series of small thrust faults east of the main thrust faults near the limit of evaporite deposition. The Devils Ridge thrust fault near Sierra Blanca (Underwood, 1963), Dieciocho fault in the Rim Rock country (Twiss, 1959), Cerro Alto and Sierrita thrust faults of Gries and Haenggi (1971), subsurface thrust faults near Clint, Texas (Uphoff, 1977), and thrusting in the Quitman Mountains (Jones and Reaser, 1970) represent relatively small thrusts related to the major thrusts of the Chihuahua Tectonic Belt, but they are not known to be directly associated with evaporites. Cerro Alto thrust fault is about 15 km east of the supposed eastern limit of the evaporite basin. Other thrust faults are similar distances from the postulated basin-margin faults. This required low-angle, bedding-plane faulting east of the evaporite basin.

If folding took place in Paleozoic basement rocks, a similar rise would have formed in the evaporites prior to the development of the thrust faults. Therefore, the initial zone of faulting is also higher where the basement is folded than where it is not. The higher fault plane may steepen and break to the surface a short distance in front of the main sheared anticline. Consequently, the lower plate would be little affected by the faulting.

The lower fault plane associated with an unfolded basement would tend to produce low-angle, bedding-plane faults, disrupting more of the lower plate. This analysis would favor a relatively unfolded Paleozoic basement to produce the small "foreland" thrust faults.

Figure 2 shows a segment of the Chihuahua Tectonic Belt which includes both complex thrust-faulting and large-scale folds. North of the northwest-trending La Parra fault, the shortening of the Cretaceous strata is accomplished by major thrust faults, multiple imbricate thrust faults, and small-amplitude complex folding such as seen along the Comedor fault (fig. 3). South of the La Parra fault, the shortening is accomplished by large disharmonic folds of amplitudes up to 3,000 m (fig. 4). North of the La Parra fault the differential displacement between structural blocks is absorbed by tear faults such as the La Chiva and the Cuatralbo. South of the La Parra fault these differences are adjusted by complex folding as seen near the south end of Porvenir–Gaitán anticline (fig. 5).

POST–LARAMIDE FAULTING

Post-Laramide structures of the Chihuahua Tectonic Belt include diapiric activity, gravity tectonics and block faulting. Faulting associated with large-scale evaporite flowage began during Laramide deformation and continued well afterward. Haenggi mapped col-

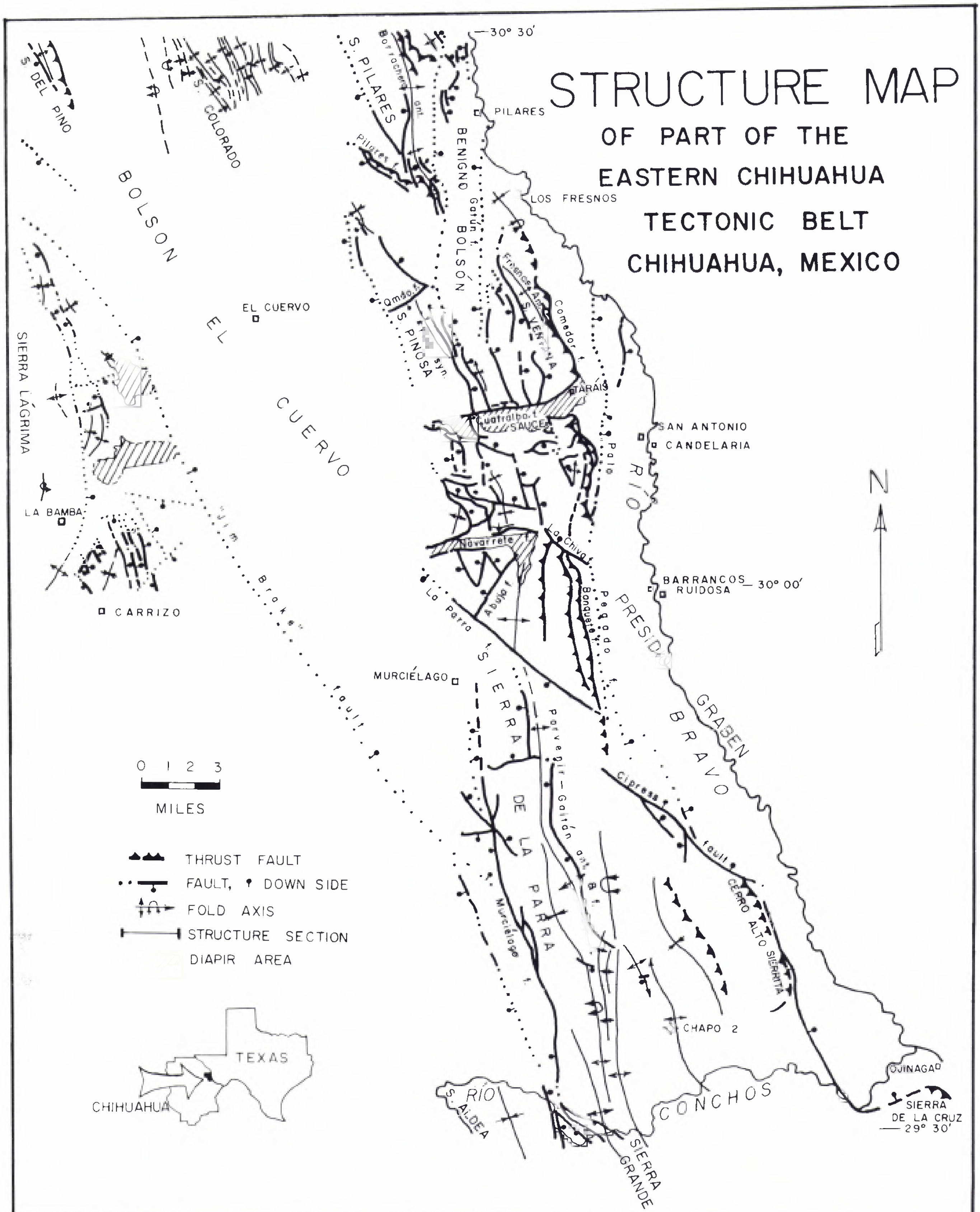

Figure 2. Structure map of a part of the eastern Chihuahua Tectonic Belt, Chihuahua showing location of major folds and faults. Shaded areas show the location of diapirs (after Gries and Haenggi, 1971).

Figure 3. Comedor thrust fault showing sheared fold in the upper plate and minor folds in the upper plate behind the thrust trace.

Figure 4. Overturned east limb of the Porvenir–Gaitán anticline. Topographic relief is about 900 m.

lapse features associated with salt diapirs intruding tear faults (Gries and Haenggi, 1971). Solution of the salt caused a depression, allowing blocks of Cretaceous and post-Oligocene sediments to collapse and founder in the core of the diapir.

In the La Mula–Sierra Blanca Range several large anticlines have a normal fault near the fold crest and parallel to it. The Fresno and Borrachera anticlines of Haenggi (1966) and the La Parra, Porvenir–Gaitán and Sierra Grande anticlines (Gries, 1970) all have crestal normal faults down to the west. Both the Murciélago fault on the Sierra Grande anticline and the Porvenir–Gaitán fault on that anticline displace Oligocene ignimbrite and tuff. The Murciélago fault has a total stratigraphic throw of 2000 m, of which 400 m represents post-ignimbrite displacement.

One hypothesis is that these faults and others associated with them were formed by evaporite flowage from the west limb into the crest of the fold. The Murciélago fault is 6 km east of the east limb of the evaporite core of the Cuchillo Parado anticline. It is possible that as the fold developed, evaporite from its west limb flowed into the Cuchillo Parado anticline.

The initial movement on these normal faults was Laramide, as the large diapiric anticlines overturned to the east and as thrust faults developed. Faulted Oligocene volcanic rocks indicate either slow continuous movement of the evaporites after Laramide deformation or post-Oligocene reactivation of the Laramide faults and, therefore, deformation during regional Cenozoic block faulting.

The Murciélago fault can also be explained as a normal fault affecting Tertiary, Mesozoic, Paleozoic and pre-Paleozoic rocks. Significantly, the major activity along the fault was prior to the early Tertiary volcanism which in turn predates most of the block-faulting superimposed on Laramide structure in Trans–Pecos Texas. Therefore, the fault seems to have formed during or even before Laramide deformation. The La Parra, Cipress, "Jim Brake" and La Chiva faults fit the northwest trend of the postulated Paleozoic structures and do not fit Laramide structures well. This may indicate that these structures had their origin during Paleozoic time and have experienced rejuvenation during Laramide and(or) Tertiary block faulting.

Post-Laramide erosion of steep anticlinal limbs has caused large-scale slide blocks and monoclinal overturning under the influence of gravity. Large-scale slide blocks near La Bamba were dated as post-Laramide and pre-Oligocene volcanic rocks by Haenggi (1966). A flap 8 km long occurs on the east limb of the Porvenir–Gaitán anticline (fig. 6). Figure 6 shows the gradually overturned flap from the south end of the structure. The north end is bounded by a tear fault and shows a flap rotation of 180° such that the limestones involved are upside down (fig. 7). No evidence of the time of overturning has been found.

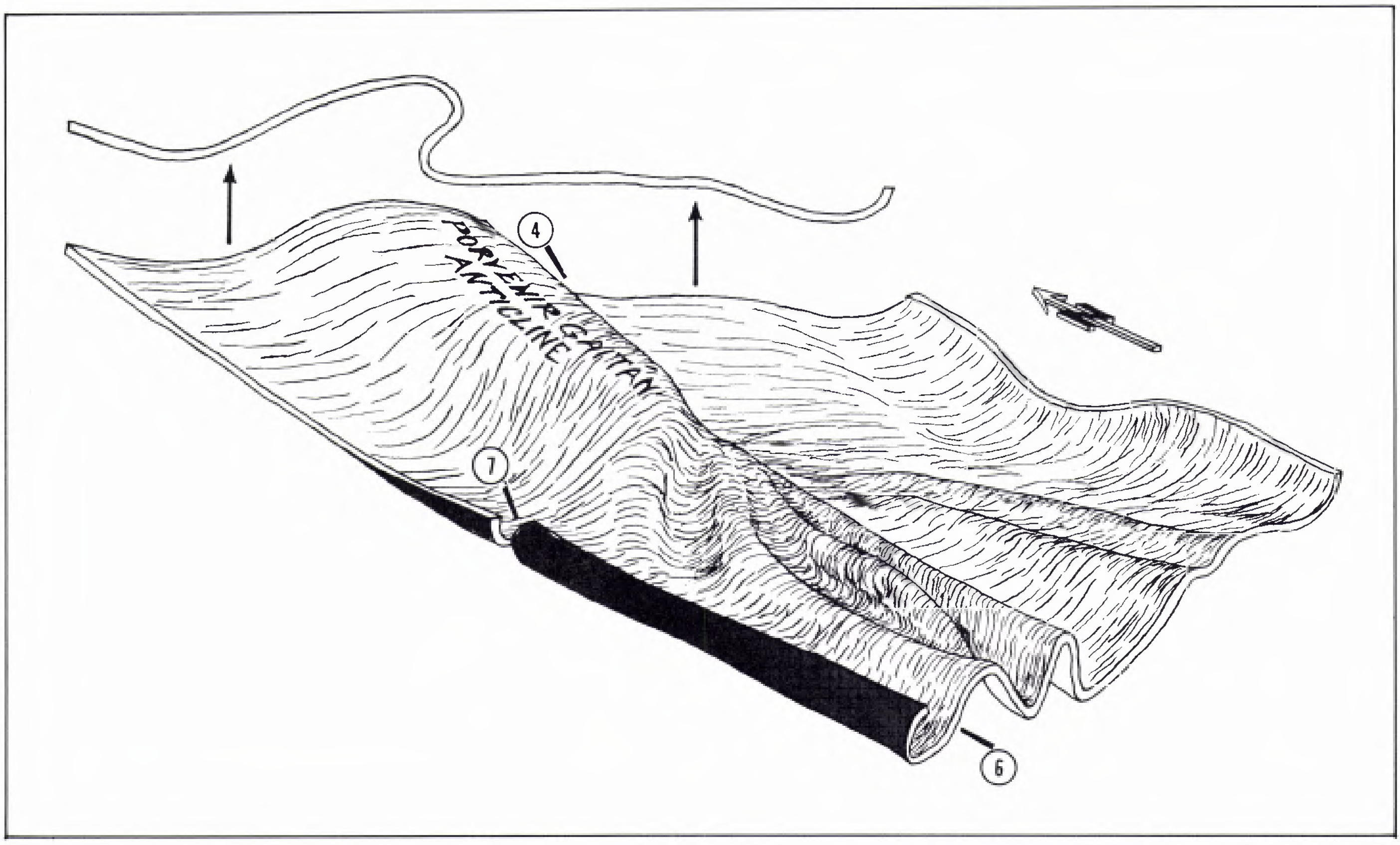

Figure 5. Sketch showing adjustment of differential movement between large overturned anticline and small multiple folds. Entire area represents the upper plate of one of the major thrust faults. Note the overturned "flap" on the west edge of the multiple folds. Numbers show the locations of photographs used in Figures 4, 6 and 7.

In addition to the post-Laramide movements on Laramide faults mentioned above, the following faults show evidence of high-angle, post-Laramide movements:

1. The Palo Pegado fault has offset Cenozoic bolson fill from El Villista south toward La Boquilla.
2. The Cipress fault has cut Cenozoic fill from near La Boquilla to Cerro Alto.
3. A fault trending S 20° E from the north end of Cerro Alto to Conejos places Cenozoic fill against Upper Cretaceous Ojinaga Formation.
4. A large number of relatively minor faults offset Oligocene volcanic rocks in the La Mula–Sierra Blanca Range.

The first three of the above faults form the western boundary of the Presidio bolsón, a well-documented graben (Amsbury, 1958; Dietrich, 1965; Dickerson, 1966; Groat, 1970). This block-faulting was accompanied by regional uplift of hundreds of meters (DeFord and Bridges, 1959).

The age of block-faulting in the Big Bend area is placed at post-early Miocene by Wilson (1965). The Rim Rock fault, the eastern boundary of the Presidio graben, offsets Oligocene strata and is intruded by a Miocene dike swarm 18 to 23 m.y. old (Dasch and others, 1969). It is reasonable to assume that the age of the block-faulting in the Chihuahua Tectonic Belt is post-early Miocene. Minor faulting probably started with the initiation of volcanic activity and has locally continued into the Quaternary. Quaternary fault scarps are present along the Tertiary fault trend at Sierrita.

The eastern edge of the Chihuahua Tectonic Belt has been suggested as the boundary between Basin-and-Range-type block-faulting to the north and east, and the Laramide décollement style of structure to the southwest (Haenggi, 1966; DeFord, 1969). Recent studies suggest the possibility that the Rio Grande rift continues into the Chihuahua Tectonic Belt (Gries, 1979). Tracing block-faulting related to either mid-Tertiary Basin-and-Range faulting or late Cenozoic Rio Grande rift features presents problems related to the evaporites.

A fault displacing "basement" blocks under a thick sequence of evaporites would probably not carry through the evaporites as a

Figure 6. Lower Cretaceous limestones on an overturned flap. Line of sight is north along the east limb of Porvenir–Gaitán anticline.

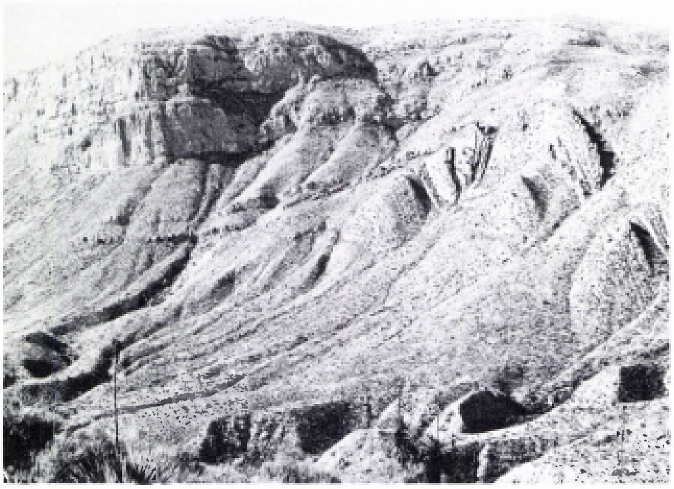

Figure 7. North end of 8-km flap of Porvenir-Gaitan anticline showing the tear fault between the nearly vertical beds of the anticlinal limb and the nearly horizontal (but rotated 180°) limestone units forming the prominent cliff. The section in the entire cliff is overturned.

fault. The displacement of basement blocks might be totally adjusted for by flowage of evaporite from above the upthrown block to the downthrown block, so that the overlying rock is not disrupted. It is more likely that partial adjustment by evaporite flowage would result in folds or lesser faults in the overlying rocks. These structural features would not necessarily be coincident with the underlying "basement" fault.

TECTONIC HISTORY

The following is proposed as the sequence of events in the tectonic development of the Sierra de la Parra area:

1. Nearby areas show a tectonically complex Precambrian history, but nothing is known of the Precambrian basement of the map area.
2. Tectonic movement took place along the boundary faults of the Chihuahua Trough during the Paleozoic Era and continued into the Late Jurassic. During the Cretaceous the Chihuahua Trough deepened with respect to the adjacent Diablo Platform—as much as 7600 m as the first evaporite, and then carbonate and siliciclastic sediments accumulated.
3. Sometime between Senonian and late Eocene the sub-evaporite "basement" was tilted to the east. This may have involved a broad arching from the center of the Chihuahua Trough and perhaps some relatively minor "basement" deformation.
4. Décollement on the evaporites induced an eastward gliding of the overlying Cretaceous rock. At the eastern limit of the evaporite complex, folding with subsequent shearing and eastward overthrusting developed where the overlying rock no longer had a gliding surface. Minor thrust faults developed in the rock as far as 15 km east of this limit. Simultaneously, evaporites flowed into the cores of the anticlines and intruded some fault zones to the north. A few older fault trends were reactivated.
5. Evaporite flowage into anticlinal crests resulted in continued uplift of crestal parts of the anticlines along normal faults; large blocks in the west limbs, in the hanging walls of the faults, foundered from loss of evaporite.
6. Post-Laramide normal faulting of basement blocks began with extensive volcanic activity and continued after it. Post-volcanic regional uplift of several hundred meters was accompanied by block-faulting. The effects of basement faulting are masked by evaporite flowage and by interaction with Laramide structure in the western half of the map area. At least one pre-Laramide fault was reactivated. Movement along the normal faults has continued into Quaternary times.

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Many of the ideas presented here originated from discussions with and previous studies by W. T. Haenggi, W. R. Muehlberger, W. R. Seager and C. E. Chapin, who have over a number of years provided data, discussion and constructive challenges to the above interpretations. Thanks given here should not be construed as an endorsement of these interpretations by the above colleagues.

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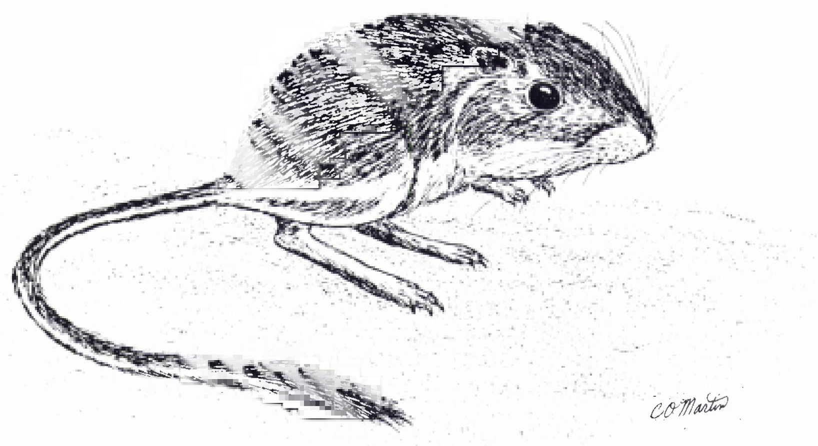

Ord's kangaroo rat, *Dipodomys ordii*.