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2-Ref. # 97, Wertz, J.B., 1970, The Texas Lineament & its Economic Significance in Southeast Ariz.........W/Maps & Diagr......

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ARIZONA PUBLIC SERVICE COMPANY
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August 22, 1975
ANPP-2913

Mr. Olan D. Parr, Chief
Light Water Reactors Project Branch 1-3
Division of Reactor Licensing
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

Re: Palo Verde Nuclear Generating Station, Units 1, 2 and 3
Docket Nos. STN 50-528/529/530

Dear Mr. Parr:

Submitted herewith you will find twenty (20) copies of the following references which were requested in NRC Question 323.58 (2A.94):

1. Reference 90; Turner, G. L., 1962, The Deming Axis, Southeastern Arizona, New Mexico, and Trans-Pecos, Texas.

2. Reference 97; Wertz, J. B., 1970, The Texas Lineament and its Economic Significance in Southeast Arizona.

Very truly yours,

Edwin E. Van Brunt

Edwin E. Van Brunt, Jr.
APS Vice President, Nuclear Services
ANPP Project Director

EEVBJr/JMA/pk

cc: Ms. Barbara E. Fisher, Esq.
Mr. Carmine F. Cardamone, Jr.

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[illegible]

THE DEMING AXIS

SOUTHEASTERN ARIZONA, NEW MEXICO AND TRANS-PECOS TEXAS

GREGORY L. TURNER
The Pure Oil Company, Houston, Texas

The Deming axis is a major linear tectonic element extending from southeastern Arizona to Trans-Pecos Texas. The trend of this axis is partially expressed by a chain of five lesser structural units; the Van Horn uplift in western Texas, the Florida and Burro uplifts in southwestern New Mexico, and the Graham and Florence uplifts in southeastern Arizona. The Deming axis seems to have been initiated during Mississippian time, and its presence has had a significant effect on the subsequent sedimentary and structural patterns of this area. These features are illustrated by paleogeographic maps of the Paleozoic and Mesozoic, and paleogeologic maps of outcrop patterns developed during intervals of major tectonism and erosion. The general north-south strike of Tertiary structures and present-day topographic features in this region are deflected to a northwest-southeast trend across the Deming axis, and this is the basis for the concept of the Texas lineament. Lateral continuations of the Deming axis beyond the area of investigation are open to speculation.

An analysis of the regional structure and stratigraphy of southern Arizona and New Mexico, western Texas and northern Sonora and Chihuahua, Mexico, has revealed the presence of a major linear tectonic element which is here termed the Deming axis. This feature can be traced from the vicinity of the town of Florence in south-central Arizona to the area of Van Horn in Trans-Pecos Texas, and has been named from Deming, New Mexico, which is near the center of the area of investigation. The Deming axis seems to have been initially developed during Mississippian time and its presence has had a significant effect on the sedimentary and structural patterns of the late Paleozoic, Mesozoic and Tertiary.

The evolution of the Deming axis can best be observed through the construction of paleogeologic and paleotectonic maps for critical parts of the stratigraphic sequence. The accompanying illustrations are generalized summaries of a series of maps that were prepared, for the most part, from a detailed survey of published and unpublished literature on this region, and an examination of available well control. Some segments have been compiled from field observations. For reference purposes, the trend of the Deming axis is indicated by a dashed line (D—A) extending across each map. A complete documentation of the control data used in assembling these maps would cover several hundred references. The appended bibliography has been selected to substantiate only the structural elements critical to the theme of this short note.

Figure 1 illustrates the regional trend of the Deming axis from south-central Arizona to Trans-Pecos Texas. An extension of this axis to the west of the map area has not been established, as the structural and stratigraphic history of southwestern Arizona is still imperfectly known. An eastward trace is likewise obscure due to the welter of Paleozoic, Mesozoic and Cenozoic structural events of western Texas and northern Mexico. Even along the known trend of the axis the complete understanding of its geologic history awaits the results of additional field work.

As indicated on Figure 1, the Deming axis seems to consist of a chain of five lesser tectonic features: the Van Horn, Florida, Burro, Graham and Florence uplifts. The individuality of these uplifts is only relative, although each seems to have become locally prominent during one or more intervals of geologic time. Structural and stratigraphic descriptions have been published for the Van Horn, Florida, and Burro uplifts (see bibliography). The features herein referred to as the Graham and Florence uplifts are previously undescribed.

The Graham uplift centers around the Precambrian mass of the Pinaleno Mountains and is named for Mt. Graham, the highest peak in the range. Significant local uplift and erosion occurred in the area of this element during the Late Jurassic "Nevadan" and Late Cretaceous to early Tertiary "Laramide" orogenies. The effect of Nevadan deformation has been mapped in the Dos Cabezas and northern Chiricahua Mountains, where Cretaceous sediments overlap eroded Paleozoic rocks and locally rest on Precambrian granite and schist. Renewed uplift and erosion during Laramide time is evidenced by the presence of Late Cretaceous and Tertiary volcanics resting unconformably on Mesozoic, Paleozoic and Precambrian rocks in the Dos Cabezas, Pinaleno, Santa Teresa, Turnbull and Mescal Mountains.

Nevadan and Laramide movement on the Florence uplift can be interpreted from field work in the ranges to the east and south of the city of Florence, Arizona. Nevadan tectonism is recorded by the occurrence of Cretaceous sediments and volcanics unconformably overlying Paleozoic and Precambrian beds in the Black, Santa Catalina, Waterman and Vekol Mountains. Broad uplift and erosion of Laramide age is evidenced in the Superior area, and the Tortilla, Black, Tortolita, Tucson, Silver Bell, Vekol and Silver Reef Mountains where the Cretaceous-Tertiary volcanic suite rests on older rocks of various ages. Sedimentary rock outcrops are rare in the region to the west and northwest of Florence, and the western limit of this uplift cannot be determined.

Separation between the Florence and Graham uplifts, and between the Graham and Burro uplifts, is a matter of conjecture. The proof is hidden beneath the piles of Tertiary volcanics forming the Galiuro and Peloncillo Mountains. Perhaps the best evidence is the mountains themselves, with the volcanic rocks in these ranges being topographically and structurally lower than the Precambrian on Mt. Graham.

Evidence for a Precambrian expression of the Deming axis is inconclusive. A zone of east-west trending Precambrian structures is certainly present in the core area of the Van Horn uplift in Texas. However, through southern New Mexico and Arizona the dominant lineations within Precambrian exposures are northeast-southwest. Probably the Deming axis is not underlain throughout its entire length by a significant basement structural element.

Figure 2 depicts the general paleogeology of early Paleozoic time. This region appears to have been a part

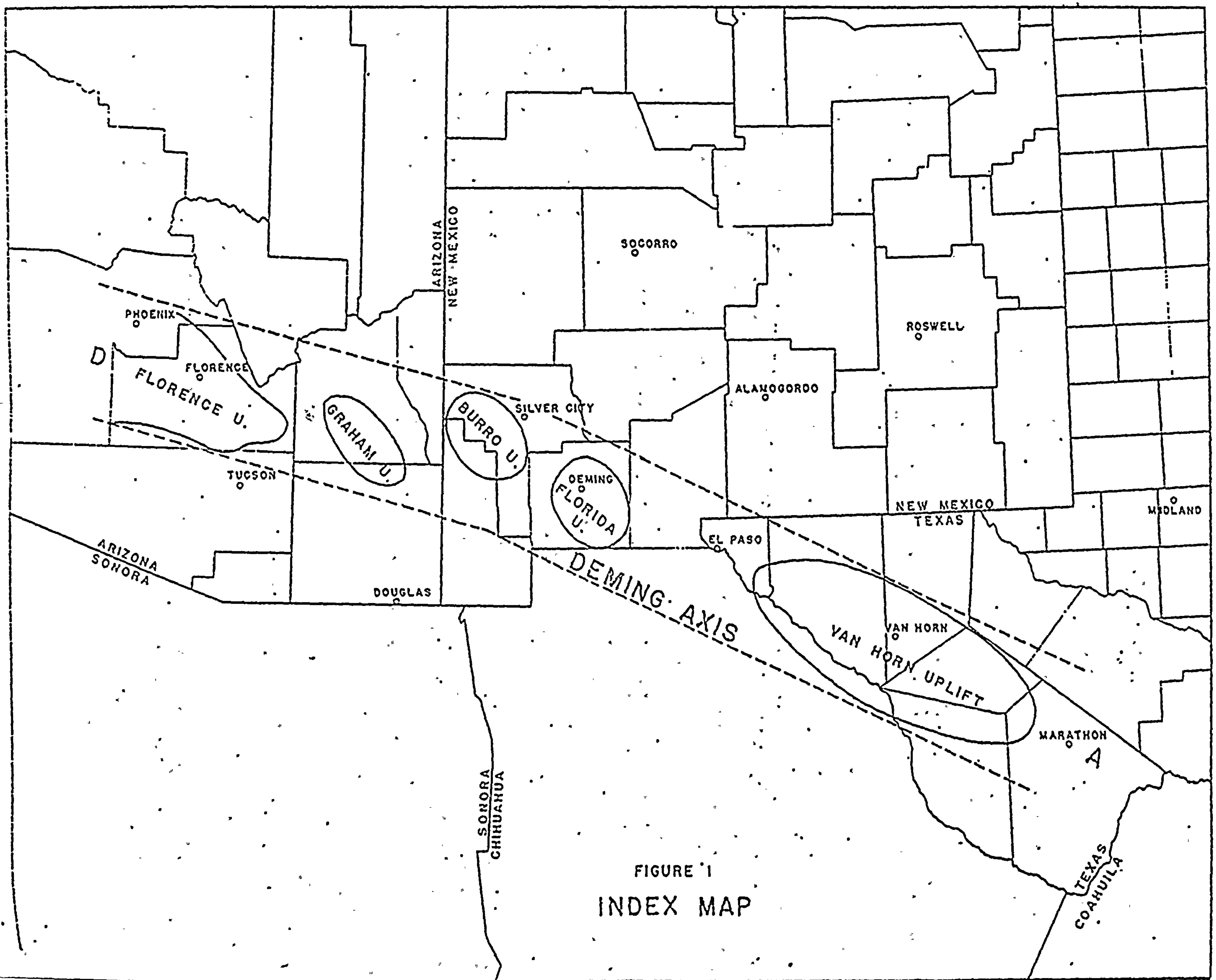

FIGURE 1

INDEX MAP

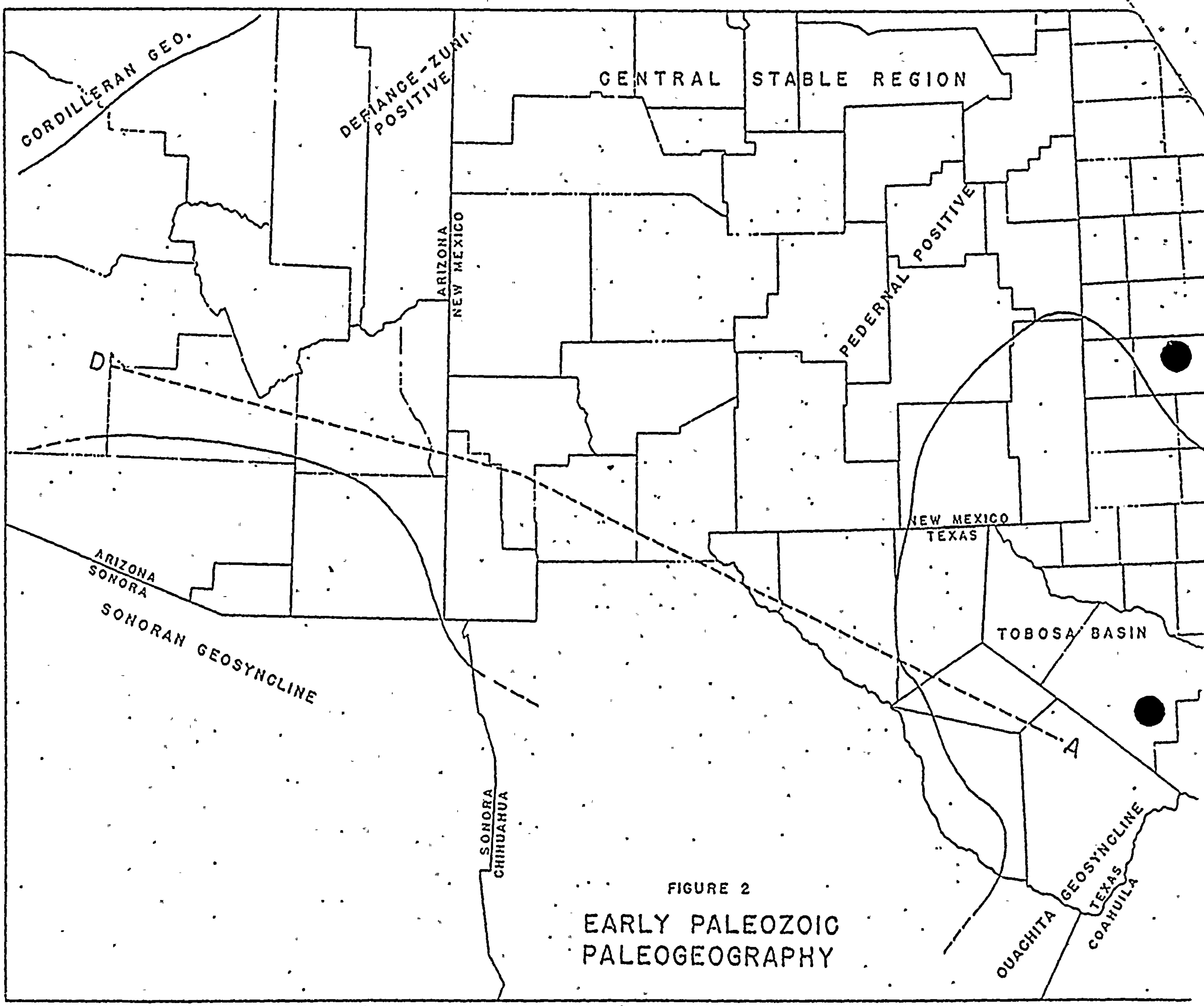

FIGURE 2

EARLY PALEOZOIC PALEOGEOGRAPHY

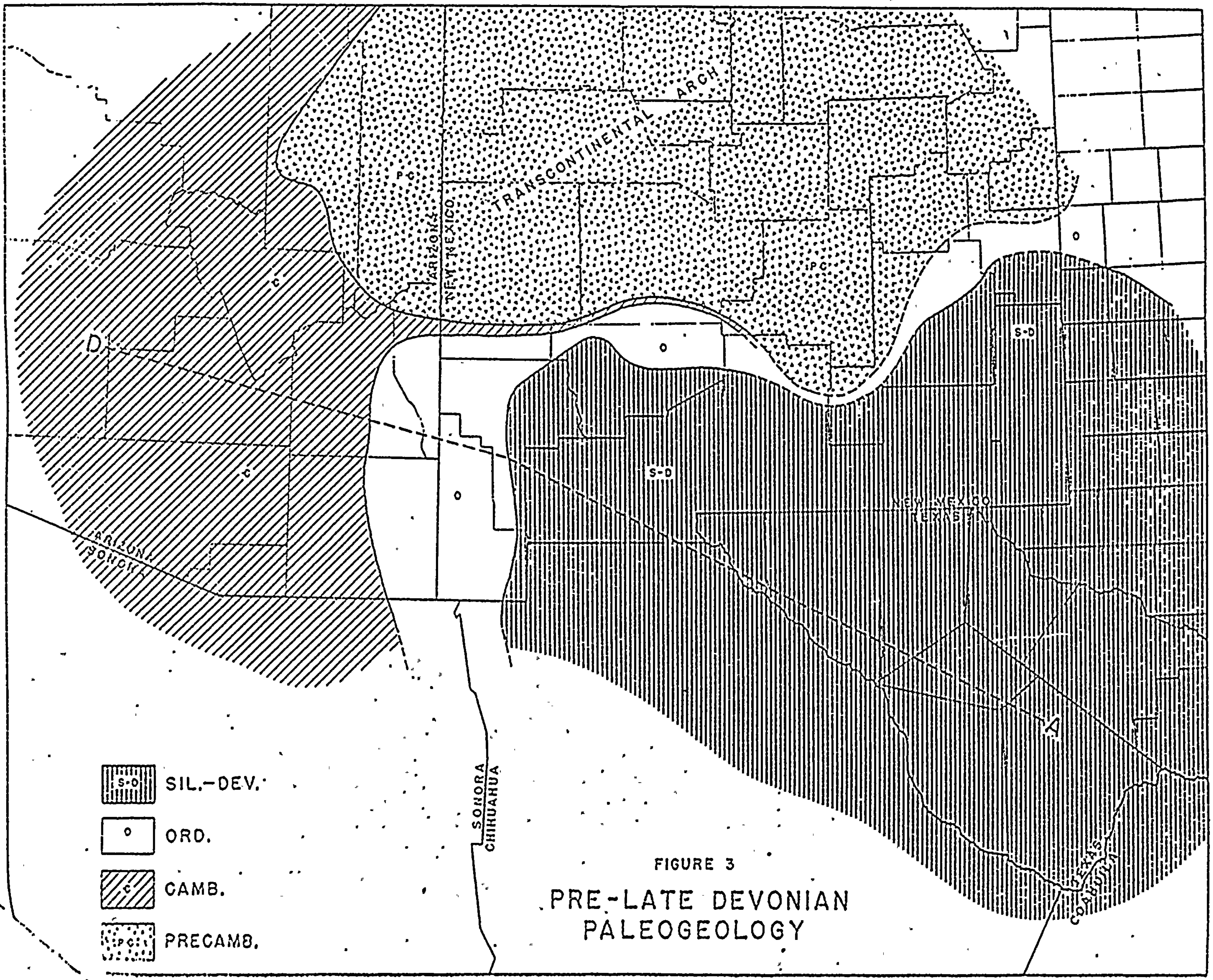

FIGURE 3

PRE-LATE DEVONIAN PALEOGEOLOGY

the southwestern extension of the Central Stable region of the North-American continent. The Defiance-Zuni and Pedernal positive areas may have been present as local upwarps on this platform, but this is by no means certain.

Cambrian deposits are thin or absent over most of southern New Mexico and western Texas. However, they thicken to the southwest across Arizona and Sonora towards the Paleozoic Sonoran geosyncline, and to the northwest toward the Cordilleran geosyncline. Cambrian beds also thicken to the southeast across Texas into a seaway possibly coincident with that of the late Paleozoic Ouachita geosyncline. Due to prelate Devonian erosion, the record of Early Ordovician sedimentation is obscure over the northern and western parts of the map area, but strata of this age are present across southern New Mexico and Texas, and thicken southeastward to the site of the Cambrian basin.

The history of later Ordovician, Silurian and Early Devonian sedimentation is likewise unknown through much of southern Arizona and northern Sonora, although beds representing parts of these time intervals are present in central and southern Sonora along the trend of the Sonoran geosyncline.

Another depositional feature of this period is the Tobosa basin, which was centered around the present site of the Central Basin platform of West Texas and southeastern New Mexico. The Tobosa basin seems to have been a persistent structural and depositional sag from Middle Ordovician through Devonian time.

Gaps in the fossil record suggest that during several periods in the early Paleozoic this region was subjected to epeirogenic upwarping, resulting in non-deposition of sediments and mild erosion. The first strong cycle of uplift and erosion occurred in Late Devonian time when the pre-Martin, pre-Percha, pre-Woodford and pre-Chattanooga unconformity was developed throughout the southern United States. During this time the broad Transcontinental arch was raised across northern New Mexico and central Arizona, and early Paleozoic beds were eroded off this arch to the approximate limits shown on Figure 3. Southwestern Arizona was broadly upwarped ("Mazatzal land") and post-Cambrian strata were stripped back to the vicinity of the Arizona-New Mexico boundary. Over most of central and southeastern Arizona Late Devonian beds rest on late Cambrian, with only a slightly discordant contact representing this extensive period of erosion. There is no definite evidence from lithofacies, thickness and structural studies in this region that a significant tectonic element was present along the trend of the Deming axis during early Paleozoic time.

Although separated from the older rocks by a major unconformity, the tectonic patterns of the Late Devonian generally reflect those of earlier Paleozoic. A limestone facies thickens to the southwest across southern Arizona into the Sonoran geosyncline in northwestern Sonora. The dark shale facies of southern New Mexico and western Texas thickens into a sag over-lying the earlier Tobosa basin. Again there is no stratigraphic or structural evidence of the Deming axis having been present during this time interval.

Although the record of Mississippian deposition has been obscured over much of this area by pre-Pennsylvanian epeirogenic upwarp and erosion, enough evidence remains to indicate that a significant change occurred in the regional tectonic framework during this Period. In southeastern Arizona and southwestern New Mexico, the northwest-trending Pedregosa basin began to form, and the alignment of its northeastern margin provides an expression of the tectonic development of the Deming axis (Figure 4). The effect of this axis on sedimentation is revealed by the thick, massively-bedded deposits of Early Mississippian limestone found in the Pedregosa basin which contrast with the thinner, somewhat more clastic, occasionally reef-bearing units found to the north and northeast of the axis. In south-central New Mexico, Kinderhook and Osage rocks are present in the San Andres and Sacramento Mountains, but have not been identified in the Hueco Mountains and Sierra Diablo outcrop areas of Trans-Pecos Texas. This absence is attributed to the initial appearance of the Van Horn uplift on the Deming axis. This uplift was evidently not active in Late Mississippian time, as Chester rocks are present in the outcrops of both Texas and New Mexico.

The second important cycle of uplift and erosion to affect this region occurred prior to Pennsylvanian deposition. Pre-Pennsylvanian paleogeologic mapping (not illustrated) suggests that over much of Arizona and New Mexico this movement was largely epeirogenic in nature. The Defiance-Zuni and Pedernal landmasses were developed at this time. A local, short-lived uplift occurred in the vicinity of the Caballo Mountains in south-central New Mexico; and in southeastern New Mexico and West Texas the Pecos uplift, the foundation of the Central Basin platform, also appeared. The tectonic behaviour of most of Trans-Pecos Texas during this time interval is unknown due to the widespread effects of the succeeding pre-Permian erosion period. The Deming axis does not seem to have played an important role during this interval of structural movement.

At the beginning of Pennsylvanian sedimentation, numerous structural changes occurred in New Mexico and western Texas, resulting in the development of the paleogeographic elements illustrated on Figure 4. During this time the Deming axis began to assume a more significant effect on the structural and sedimentary patterns of this region. The Pennsylvanian record is obscure in the mountain ranges of Trans-Pecos Texas, but the limited amount of data now available suggest that the Van Horn uplift (Diablo platform) may have been mildly positive and provided a separation between the Delaware and Marfa basins. To the northwest there is good evidence from thickness and lithofacies data that the Florida uplift (Florida islands) was developed on the trend of the Deming axis in and around Luna County, New Mexico. The trend of the Deming axis again seems to have provided a flexure controlling a zone of regional facies change for Pennsylvanian sedimentation in southeastern Arizona and southwestern New Mexico. Thick units of relatively clastic-free carbonates accumulated in the Pedregosa basin in contrast to the much more clastic sections deposited in the Central New Mexico basins, and on the flanks of the Defiance-Zuni landmass. The relatively stable Deming axis provided a favorable environment for late Pennsylvanian reef development along the northeastern margin of the Pedregosa basin in New Mexico.

The third significant pulse of Paleozoic orogenic movement in this region occurred prior to, or early in, Permian time. The result of this tectonism is illustrated on the paleogeologic map of Figure 5. Through southeastern Arizona, most of southwestern New Mexico, and in the depositional

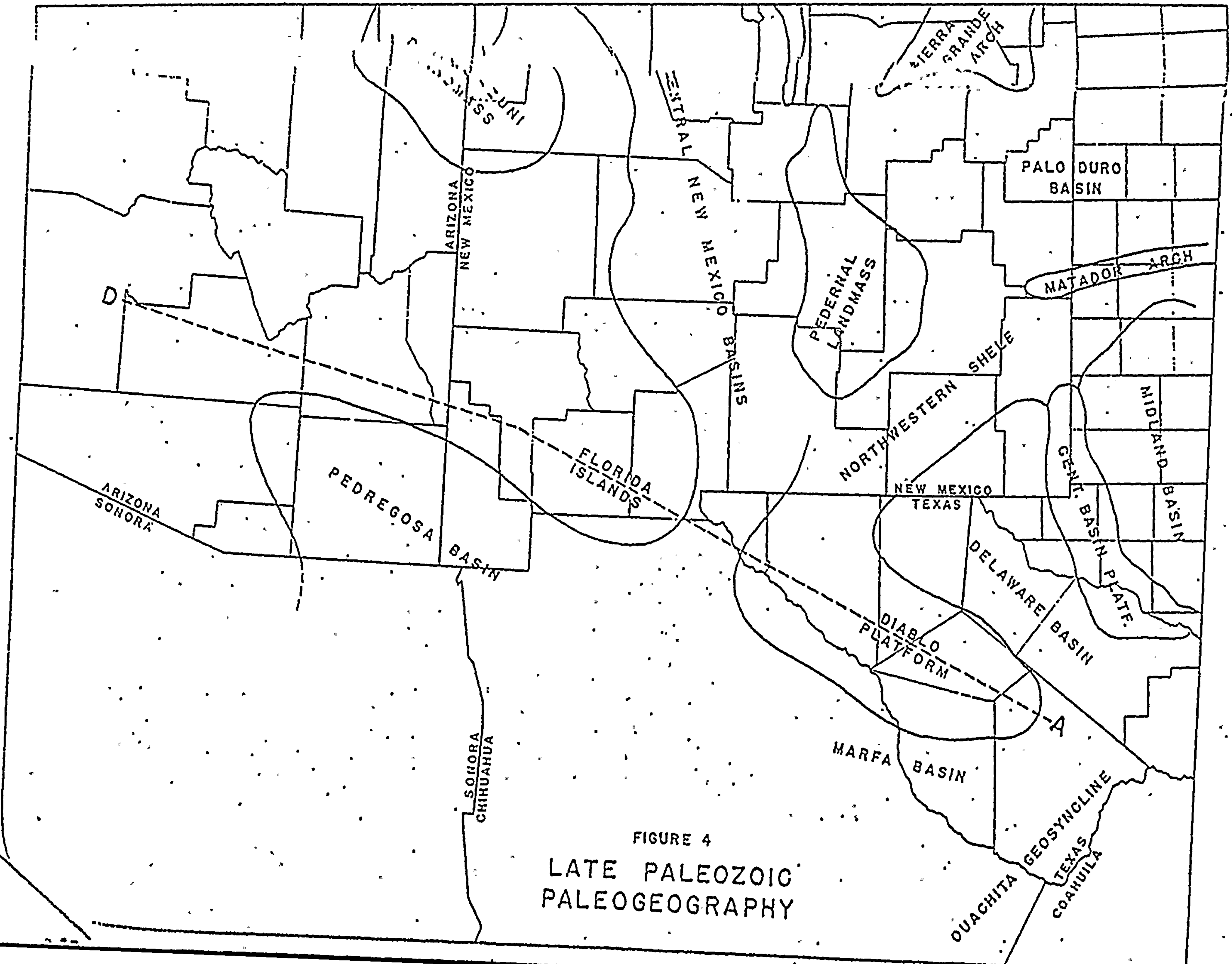

FIGURE 4

LATE PALEOZOIC PALEOGEOGRAPHY

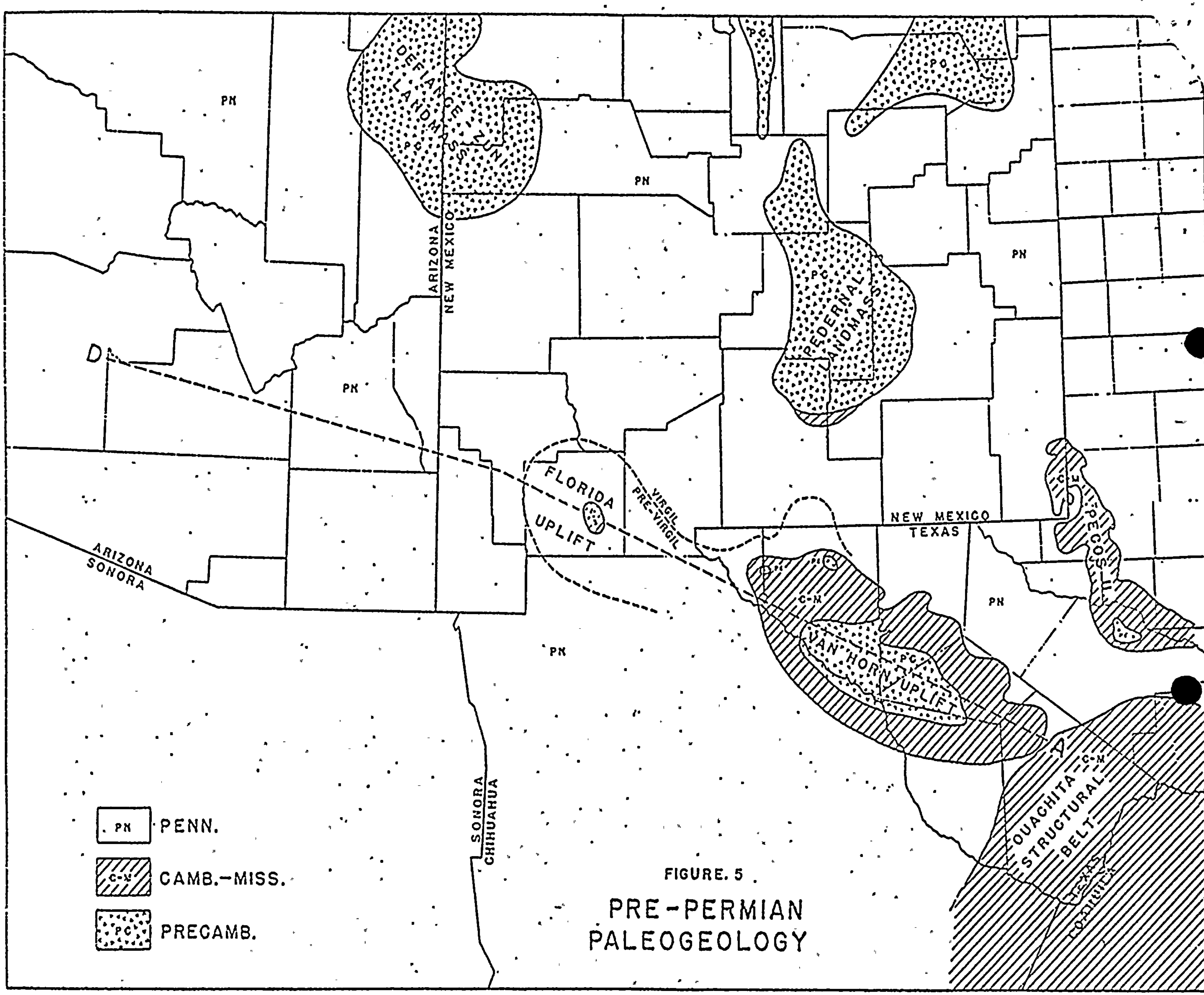

FIGURE. 5

PRE-PERMIAN PALEOGEOLOGY

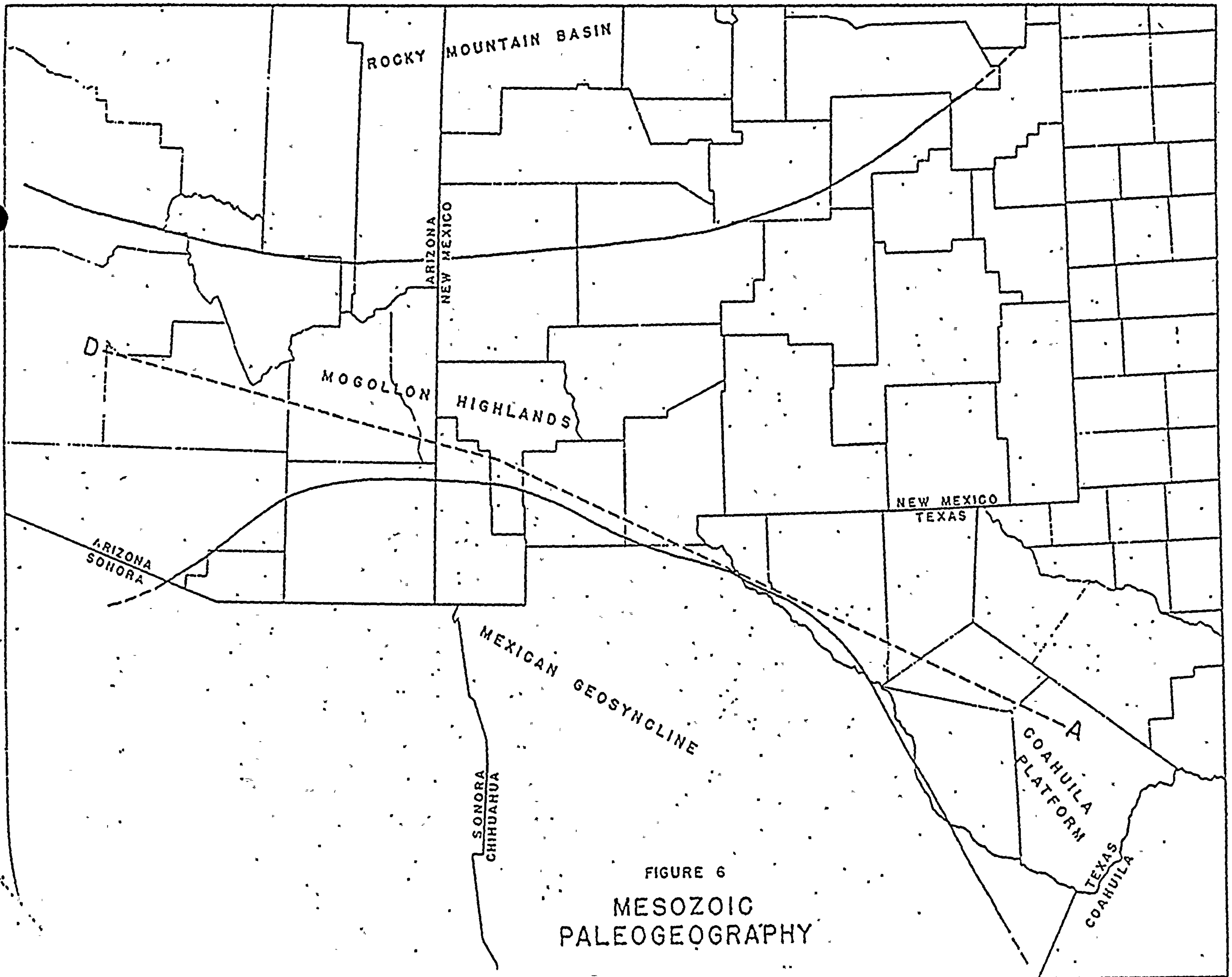

FIGURE 6

MESOZOIC PALEOGEOGRAPHY

of southeastern New Mexico and western Texas, there is little evidence for a break in sedimentation between Pennsylvanian and Permian times. However, the complex tectonic elements of the Ouachita structural belt reached their culmination at this time, and subsidiary deformation is recorded on the positive structural features to the northwest of this trend. At the southeastern end of the Deming axis, the area of the Van Horn uplift was upwarped and deeply eroded, with all pre-Permian sediments being stripped off its crest. To the northwest, the deformation was less severe in the area of the Florida uplift. All Pennsylvanian strata were removed in the vicinity of the Florida Mountains, and beds of Virgil age are missing over a somewhat broader region. Similarly, the Pecos uplift was rejuvenated and deeply eroded; however, this tectonism is significantly recorded on the Pedernal landmass only around its southern margin.

During Permian time the region of the Van Horn uplift provided a stable environment (Diablo platform) for extensive reef development, as did the Pecos uplift (Central Basin platform) to the east. To the west the flexure along the trend of the Deming axis continued to provide regional environmental control for Early Permian sedimentation. The Pedregosa basin on the south continued to sink and receive predominately carbonate deposition, again accompanied by reefing in southwestern New Mexico. To the north, the Early Permian is largely represented by an extensive clastic redbed shelf facies. The record of the late Permian is obscured by the effects of extensive post-Paleozoic erosion. However, there is a similarity between Late Permian strata preserved on either side of the axis, suggesting that this feature was not a particularly significant tectonic element during this time.

The regional paleogeography of Mesozoic time (Figure 6) is much simpler than that of the late Paleozoic. The character of the Deming axis was generally positive through this period, and it appears to have acted as an intermittent barrier (Mogollon highlands) between depositional basins to the north and south. Sediments of Triassic and Jurassic age are found on either side of this structural trend. However, the present limits of their occurrence are due to pre-Cretaceous uplift and erosion, and consequently there is some question as to whether or not these widely-separated rock units were once connected over the Deming axis.

The regional effects of the Nevadan orogeny is depicted on the paleogeologic map of Figure 7. In contrast to the late Paleozoic tectonic events, which were more severe along the eastern part of the Deming axis, the Nevadan movements were more strongly expressed toward the west; and the Florence, Graham and Burro uplifts were developed at this time. In each of these areas the Paleozoic rock column was removed, exposing sizeable terrains of Precambrian. To the east, this upwarping resulted in the erosion of only the post-Wolfcamp Permian section, although Precambrian rocks were re-exposed in a small area on the crest of the Van Horn uplift. Just to the south of the Deming axis, a sharp uplift in the vicinity of the Mule Mountains was also eroded to the Precambrian.

The regional control of deposition and structure by the Deming axis was well-expressed during the Cretaceous. During most of Lower Cretaceous time, sedimentation was confined to the Mexican geosyncline lying immediately to the south of the axis. Only during Washita time were appreciable amounts of sediment deposited over the eastern end of the axis in West Texas and southeastern New Mexico. A significant tectonic shift occurred during the Upper Cretaceous, and rocks of this age were probably deposited only in the Rocky Mountain basin encroaching from the north. The few deposits of very Late Cretaceous age found to the south of the Deming axis in Arizona and northern Sonora (Figure 8) may be attributed to local pockets of debris resulting from early Laramide movements.

Marine sedimentation within the area of investigation was terminated by the widespread deformation of the Laramide orogeny. The history of this orogeny is quite complex and it seems to have developed in several stages extending from Late Cretaceous into early Tertiary time. A detailed discussion of this progression of events is beyond the scope of this paper, and reference is made here only to the earliest movement. The result of this period of uplift and erosion is summarized on the paleogeologic map of Figure 8, the title of which may be somewhat misleading. In southeastern Arizona and part of southwestern New Mexico this "pre-Tertiary" map is drawn at the base of the volcanic section, part of which is considered to be late Cretaceous in age. In Trans-Pecos Texas and some areas in New Mexico, where the volcanics are thought to be entirely Tertiary in age, this map more nearly reflects a true pre-Tertiary picture.

As shown on Figure 8, the earliest expression of Laramide movement consisted of the rejuvenation and re-erosion of the tectonic features associated with Deming axis. Upwarping appears to have been more or less regional in nature and preceded the extensive folding, faulting, volcanism and intrusive igneous activity that are usually considered to be characteristic of Laramide time. In Trans-Pecos Texas, a subsidiary fold was developed in the vicinity of the Chinati Mountains south of the main trend of the Van Horn uplift. In addition, there is good evidence that a long, possibly boomerang-shaped, trend was developed to the north of the Deming axis in southwestern New Mexico. This feature, here termed the Hillsboro uplift, can be traced through the Lemitar, Magdalena, San Mateo, Cuchillo, Black and Mimbres ranges where the Cretaceous is absent and Tertiary rocks rest on Paleozoic beds locally as old as Ordovician. The southeast-trending arm of this uplift is quite conjectural, but has been postulated in order to tie in areas of pre-Tertiary erosion in the southern Caballo, Robledo, Tonuco, Dona Ana and (possibly) Organ Mountains.

A study of structures known to have been primarily developed during the Laramide orogenic period has indicated that the persistent Deming axis had a significant effect on the strike trends of these elements. Similarly, this axis was also instrumental in determining the strike directions of the Basin and Range structures developed during the late Tertiary Cascadian orogeny. Figure 9 is a plot of the strikes of major Laramide and Cascadian structures present in the area of investigation. With supplementary reference to the recently-published tectonic maps of the United States and Mexico, it can be seen that the dominant structural grain of this region is north to north-northwest. However, across the Deming axis this grain is sharply deflected to a west-northwest trend. This deflection is also obvious on an examination of the present topographic trends and is the basis for the concept of the Texas lineament (see bibliography). An analysis of lineament recognition and lineament tectonics is also beyond the scope of this paper. However, it is thought that the structural and topographic strike deviations along the Tex-

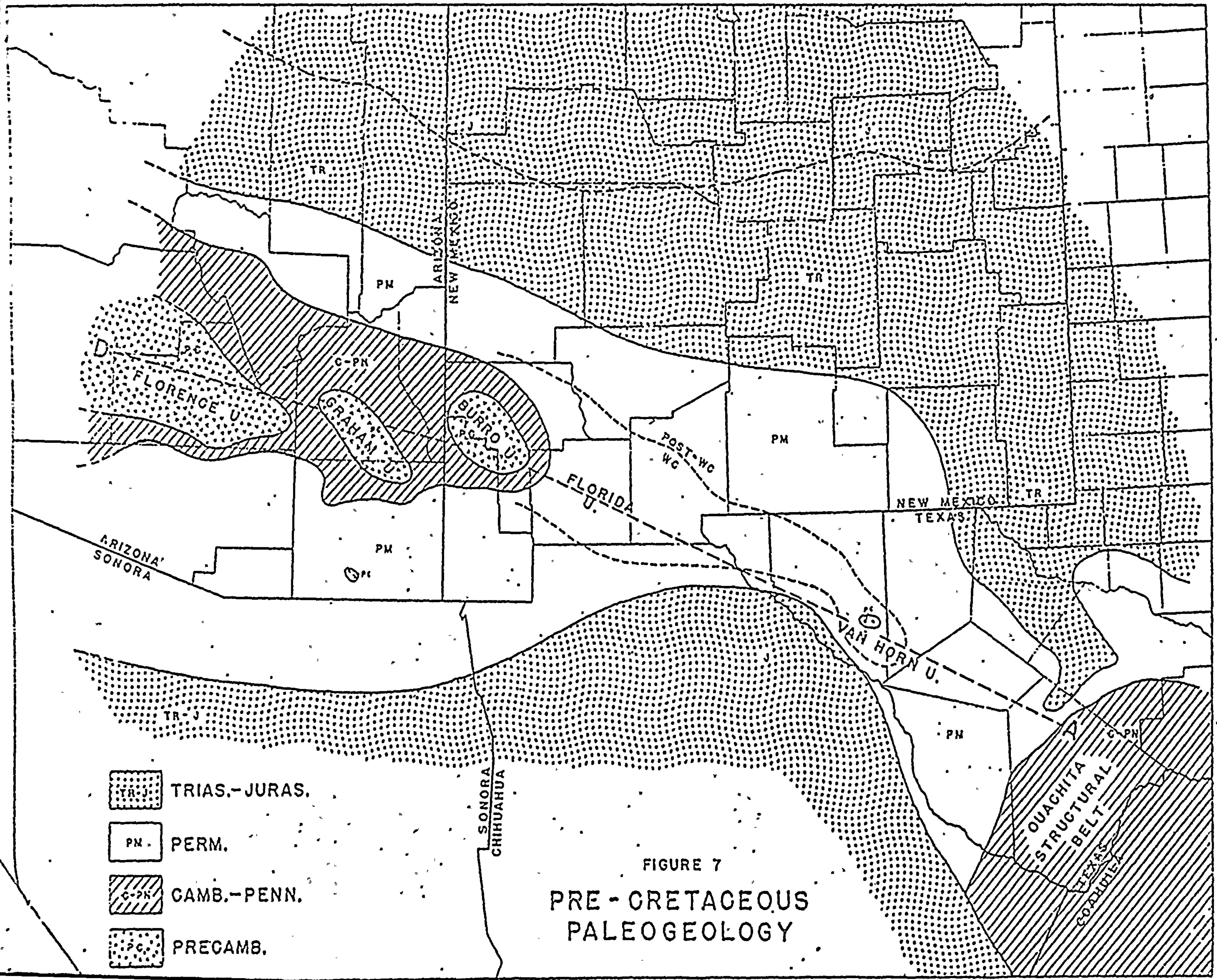

FIGURE 7

PRE-CRETACEOUS PALEOGEOLOGY

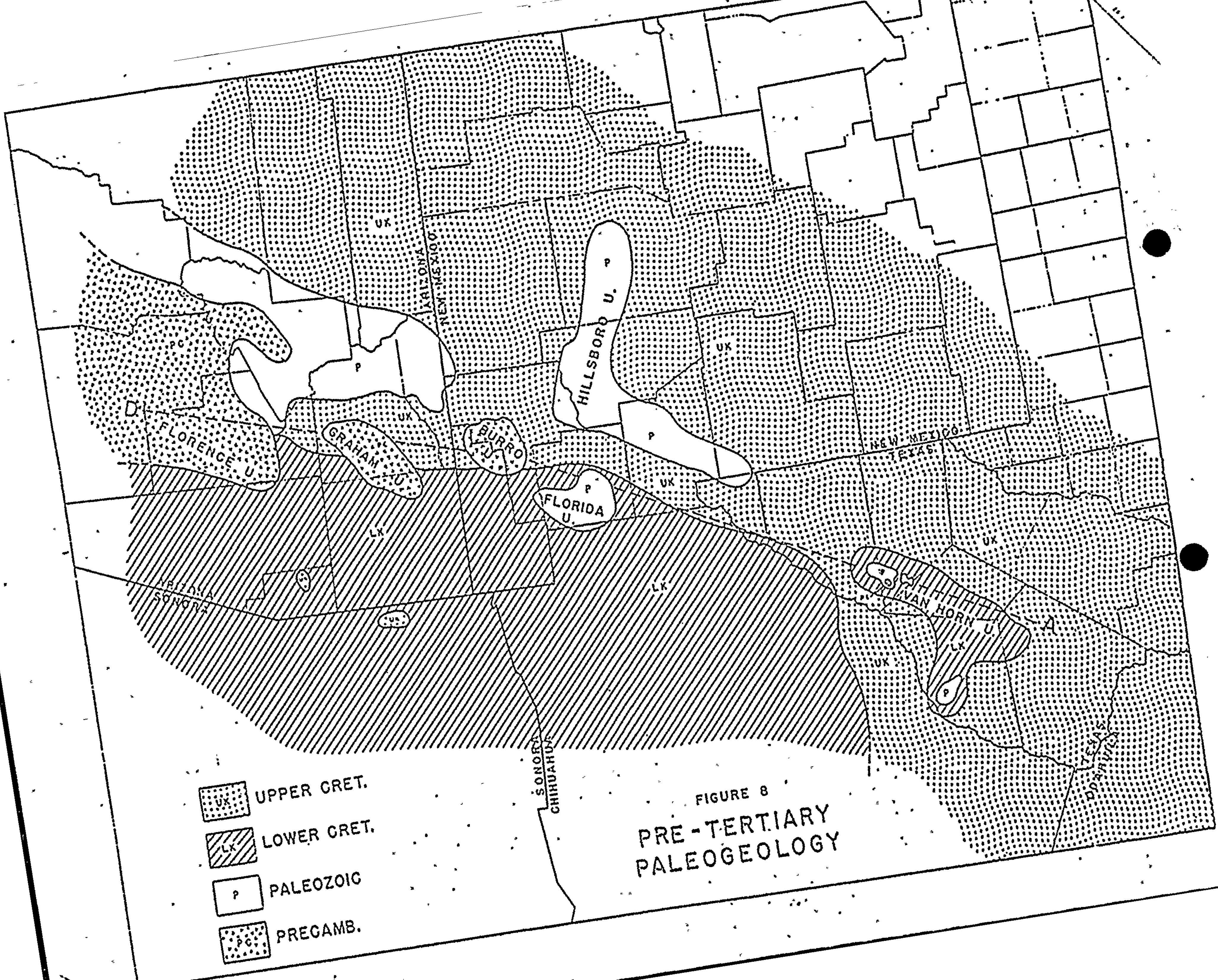

FIGURE 8
PRE-TERTIARY
PALEOGEOLOGY

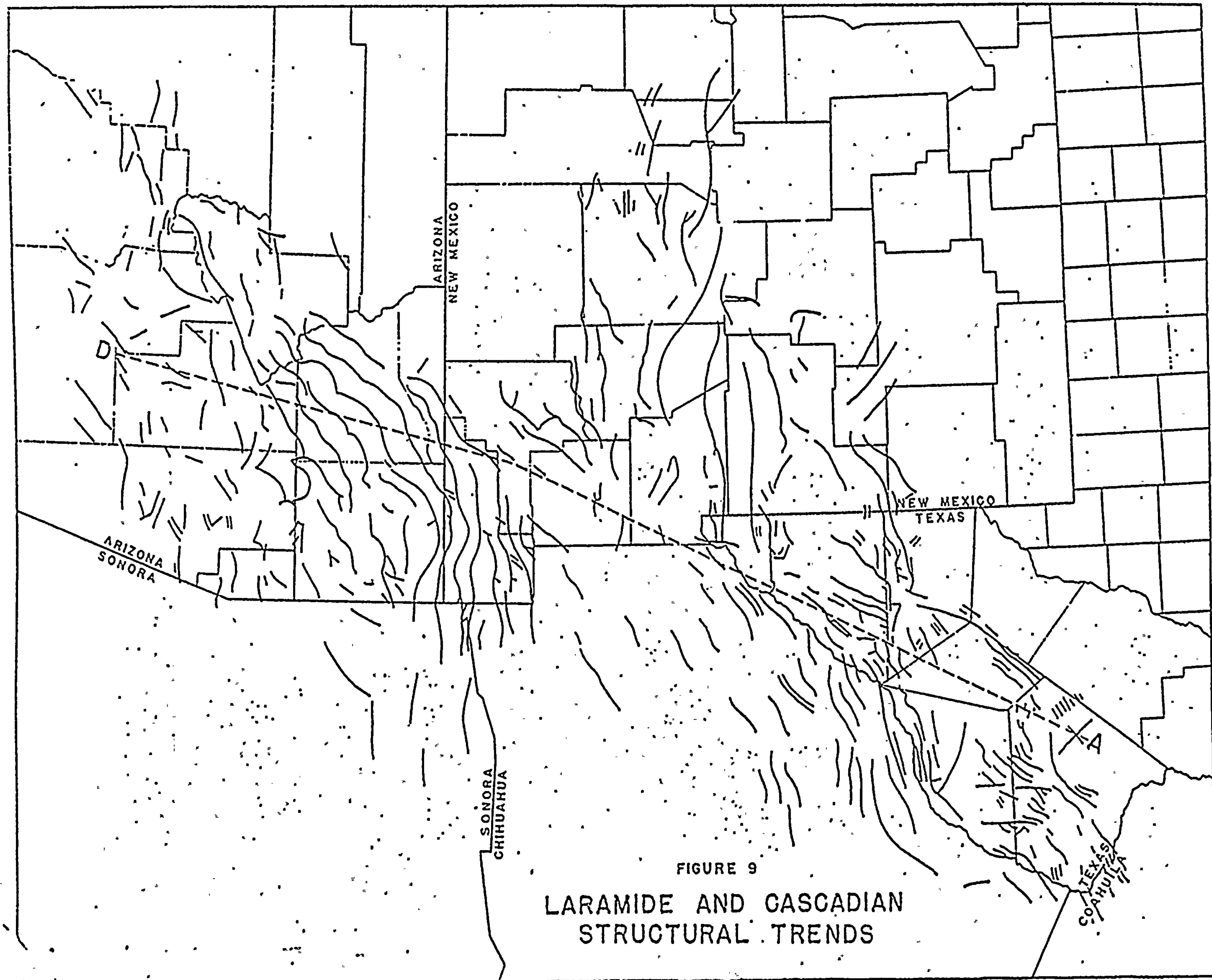

FIGURE 9

LARAMIDE AND CASCADIAN STRUCTURAL TRENDS

as lineament are more likely due to refraction effects across the ancient Deming axis than to some form of regional shear or wrench-fault tectonics.

Lateral continuations, if any, of the Deming axis beyond the area of the present study are open to question. However, if the definition of the Texas lineament is of significance it might extend to the west through the Transverse ranges of southwestern Arizona and southern California. To the east, cogent arguments could be made for extending it: (1) along the trends of the Fort Stockton high, Yates-Todd (Ozona, Pecos) arch, Llano uplift and San Marcos arch; (2) along the trend of the Ouachita structural belt and Devils River uplift; (3) past the Marathon uplift to the Burro uplift and Tamaulipas peninsula of Mexico; or (4) southward along the axis of the Coahuila peninsula. It may also be speculated that unstable eastward branchings of the Deming axis may have successively established each of these trends during different intervals of geologic time.

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The Texas Lineament and Its Economic Significance in Southeast Arizona

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Abstract

Within a broad structural framework construed in southeast Arizona, attempt is here made to: (1) give further evidence on the location and relative movements of the roughly parallel components to the Texas lineament, (2) analyze the structural setting of the major fracture centers, mainly the mineralized ones that occur inside or out of the lineament belt, and to (3) bring out the apparent economic significance of this important structural belt.

In this area, the components or strands of the Texas lineament appear to have been broken, thereby following slightly differing directions (S50E to S75E in the eastward direction) suggesting a mild, irregular bend within the whole belt, with a slight concavity to the northeast. Those places, where the successive changes in direction occur, generally coincide with intersections of the north-northwestern fractures, although some northeastern ones also join these same centers.

Recurring movements, remotely connected with the Murray transcurrent deep-seated fracture and the San Andreas fault complex, causing increased torsional tangential effects, must somehow have affected the components of the Texas lineament as a whole, exerting a structural impact on all fracture centers that exist within its confines in southeast Arizona. Seemingly, this influence could have been much more intense along the convex or southern fringe of the lineament through accrued tangential tensional stresses inherent to the incipient drifting of Baja California.

Although the north-northwestern and, probably to a greater extent, the northeastern sets of fractures generally are accepted as propitious to or partly responsible for mineralization, it is postulated here that the Texas lineament has increased the potentialities for ore throughout the area by additional perturbance and fracturing, slightly jarring loose, so to speak, some of the major fracture intersections, allowing for better ground preparation, as evidenced in Ajo, Tombstone, Bisbee, and several other major mining centers. New mining districts, certainly could be uncovered some day within this important structural belt.

Introduction

A LARGE number of local fracture arrangements occurring in southeast Arizona have been previously analyzed (Wertz, 1966a; 1968a; 1968b) and the importance of the orientation trends of elongated batholiths has been emphasized in an effort to detect some of the ancestral breaks in the upper earth's crust, although exceptions will arise (Krauskopf, 1968). The conjunction of fracture intersections and domes was recognized to be generally a useful guide in mineral exploration. These structural arrangements were expanded, next, into the regional dimension through interpolation and extrapolation of both known and inferred local structure trends occurring within outcrop areas, aided by studies of aerial photographic mosaics to help bridge the gaps within the alluvial plains, and further supported by second- and third-order evidence revealed by stratigraphic and geomorphologic means.

In order to further consider the fundamental breaks that cut through the upper crust, in a regional context, following assumptions are considered necessary:

(1) Secondary faults (Wertz, 1966a; 1968a) are omitted in this regional study leaving only for consideration the primary fractures or ancient breaks now generally concealed; it is not the intent, however, to minimize the importance of these secondary faults in later search for mineralization.

(2) Being relatively local features, all domal structures (Wertz, 1968a, b) are temporarily set aside, again without the intent to minimize their economic importance at places (Wisser, 1960).

(3) Unless they happen to fall along some regional trends, all block-faults are disregarded as a rule, no matter how large or important, as they usually are undecipherable and accompanied by chaotic effects.

(4) The very long sinuous fault boundaries, shown on maps to occur alongside chains of mountains, are misleading and are also disregarded because they represent only "surface structures" that follow Laramide or later trends, often without any rapport with the ancient deepseated structure (Hunt, 1963, page 139).

(5) Quaternary and Tertiary-Quaternary lavas, as indicated on State geological maps, are also omitted in this study as assimilated, to a certain extent, to alluvium cover.

Many long and important fractures, some economically quite interesting and supported by strings of numerous pieces of evidence (Wertz, 1966a),[1] were revealed throughout southeast Arizona (Fig. 1). From the relatively large number (more than 180) of papers, theses, government reports compiled onto maps at the scales of one mile to the inch and six miles to the inch, analyzed and interpreted, and from added evidence from state geologic maps and aerial photographic mosaics, it is hoped that the resulting maps, although certainly far from perfect, may presently be a reasonable attempt at representing some of the major, deep-seated breaks that crisscross southeast Arizona.

Much remains to be done, however, to weed out those relatively insignificant or local breaks from the important and regional ones. To determine and define the weighing factors for that purpose and, in addition, to introduce the time element will be the necessary tasks ahead. Cailleux (1958) certainly made a useful and well-documented step in that direction.

Attention to these fractures is now focused on their orientation and importance in length, on their intersections and relationships with each other, on the configurations and patterns that they display, and also on some of their coincidence with mining centers. Three main sets of fractures are acknowledged and confirmed in this study:

(1) a north-northwestern group, assumed to follow the Wasatch-Jerôme orogenic belt and the overall trend of an Arizona anticlinorium—part of the Cordilleran geanticline (Schmitt, 1959, Fig. 1), seems to have guided the general orientation of many chains of mountains in Arizona;

(2) a northeastern group, broadly emphasized by Landwehr (1967, p. 499), shows here a convergence to the northeast, occurring in western New Mexico; and

(3) a west-northwestern set, behaving as a continuous and well-defined group of roughly parallel fractures, about 60 to 80 miles wide as a whole, without any trend of this nature to the north nor to the south, as far as known, is assumed to pertain to the Texas lineament. Such a wide group of more or less parallel structural features should really be referred to as a belt (Kelley, 1955, p. 58). In addition, the strands of this lineament definitely appear to be broken (Fig. 2) exhibiting a slight concavity to the northeast (Hunt, 1953, Fig. 5, p. 135).

[1] The relative amount of inference that necessarily intervenes in this kind of regional work will undoubtedly leave the door open to errors, at places, on account of the rather weak scatter of detailed pieces of information.

The various downthrow situations shown in Figure 1 suggest that several long breaks have been affected by scissor movement, displaying a downthrow on one side of a fracture, at one place, then a downthrow on the other side some hundred miles away or, similarly, a horst structure in one area then a gradual reversal to a graben in another area along the same primary fault. While Moody and Hill (1956, p. 1214) suggested that such deep-seated faults may be of the wrench type, Goguel (1952, p. 62) found them to be common and added that this reversal of apparent dip-slip displacement occurs wherever a transcurrent movement cuts obliquely into existing folds. This is exactly what happens in southeast Arizona to a large majority of the primary fractures that transect the anticlinorium, resulting in "incomplete" or "partial" horsts and graben, as shown in Figure 1. Later block faulting, tilting, and differential erosion certainly complicated these situations, making many structural problems difficult to solve.

Lineaments

Ancestral structural elements of large magnitude, the tectonic lineaments (Kelley, 1955, p. 58), in later years simply referred to as lineaments, are characterized by a remarkable alignment of geological or topographical features, too precise to be fortuitous (Brock, 1957, p. 130). They can be compared with the geofractures or geosutures of Hans Cloos (1948) and their paths would coincide (Brock, 1957, p. 130) with fracture zones or geological barriers, with straight stretches of rivers or elongated lakes, with rifts or volcanos, with a seismic epicenters (Richter and Gutenberg, 1954) or thermal sources.

Either magnetic, gravity or geothermal anomalies may be encountered at places along a lineament (Robert, 1968, p. 746–47) and also thick halite deposits, not necessarily related to sedimentary sequences nor to diapiric domes, can occur along these deep fractures (Robert, 1968, p. 744). A possible case in point in southeast Arizona, within gravity lows, are some halite occurrences several thousands of feet in thickness that seem to coincide with deep-seated breaks, some possibly within or north of the fracture system that composes the Texas lineament. Of economic importance, however, are magma occurrences in the form of elongated intrusions or isolated stocks emplaced along the lineament trend, with the probability of metallic deposits in their vicinity.

Lineaments which consist of a conspicuous grouping of important, parallel, primary breaks that cut through the surface of the earth's crust preferably should be called a lineament belt (Kelley, 1955, p. 58). These belts are essentially straight for long

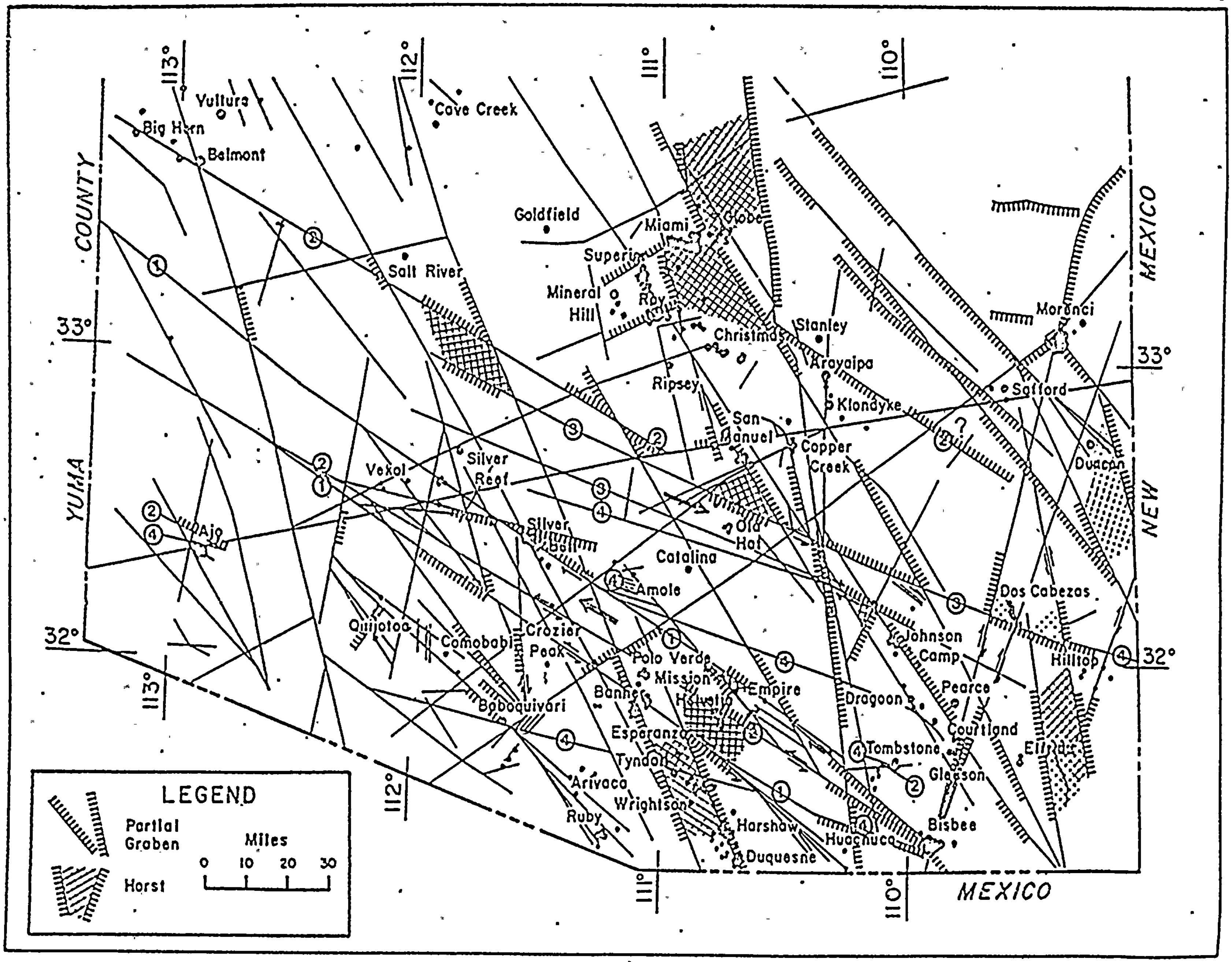


FIG. 1. Structural net through southeast Arizona showing horsts and graben as well as major tear faults.

distances, measured in hundreds and in some cases thousands of miles, with an almost constant orientation but without prominent curvature nor the sinuous trend of subsequent surface structure mentioned in the above assumption 4. Indeed, the relative rectilinear characteristic of lineaments studied by Robert in Europe, Central America and North Africa, and by Brock (1956, 1957, 1959) in South Africa reflects an apparent mechanic homogeneity of the rocks at great depth, without much, if any, rapport with surface structure. Also, there does not seem to be any correlation or coincidence in orientation between the deep-seated structure as indicated here and the broad tectonic trends or basement highs or lows shown on regional structural maps. Indeed, Cloos maintained, and Osterwald (1961, p. 223) concurred, that geofractures can retain their individuality even where surrounded or engulfed into younger geosynclines and that an active geofracture can even "underpass" an active geosyncline (Cloos, 1948, p. 99). Hills (1956, p. 339) called the effects of such structural rejuvenation "resurgent," implying not so much the continuity of tectonic movements over a period of time as their reappearance along old trends after a period of quiescence and stability. The straightness and continuity of most deep-seated breaks, as opposed to local fractures and faults, would thus not tolerate any obstacle, deflection nor offset along the way, and locally important disturbances such as doming and tilting, for instance, should certainly be of no significance whatsoever.

However, if an instance were to occur where a whole system of breaks may appear to have been slightly disturbed by stresses of very large magnitude, as seems to have happened in southeast Arizona, and if this contention of slight disrupture or bending along the trend were established and confirmed, one would particularly want to investigate the economic impact and implications of such an unusual accident.

The Texas lineament (Albritton and Smith, 1956; Moody and Hill, 1956; Turner, 1962) has become accepted as traversing the southwest part of the United States. Transgressing all known structure, it coincides throughout much of its length in Arizona, New Mexico, and Texas with the northern margin of the Mexican geanticline (Osterwald, 1961, p. 233), but its breadth as well as the contention that it is composed of a number of strands or important breaks still remains somewhat debated. The individual components (as represented on Figure 1 for instance), each one made to coincide for sake of simplicity with individual axes without the necessary implication of clear-cut fractures, may in reality correspond to a wide fracture or shear zone, up to several miles wide at places, be elsewhere reflected on the surface by an en echelon pattern (Moody and Hill, 1956, p. 1215; Schmidt, 1956, p. 443; Osterwald, 1961, p. 231), or be discontinuous (Kelley, 1955, p. 58) for hundreds of miles, and this latter peculiarity probably is the best distinction between a lineament and a fault (Brock, 1957, p. 131). Lineaments on the North American Continent should of course be just as old, deeply-rooted and active throughout a number of tectogenetic periods of the earth's history as their European counterparts described by Cloos (1948).

The Texas Lineament and Its Economic Significance in Southeast Arizona

Initiated in the northeastern Pacific Basin through the Murray fracture zone (Menard, 1955, p. 1166–67), a transcurrent movement (Moody and Hill, 1956, p. 1217–21; Vacquier et al., 1961) extends eastward apparently as a large fracture belt into Arizona and New Mexico (Albritton and Smith, 1956, p. 507 and Fig. 4, p. 511). This is the Texas lineament which is composed of a number of segments inferred from these studies and shown on Figure 2.

The preponderance of right-lateral slip along the Andreas fault, resulting in the relative displacement of the whole Northeast Pacific Basin with regard to the continent (Hill, 1965) has caused a serious east-west tension situation to the south as compared to compressional effects farther north. Some repercussions of these movements undoubtedly should have affected parts of southeast Arizona with tangential, torsional stresses. Renewed movements within the whole San Andreas fault complex, and relayed through their eastern Garlock-Pinto Mountains fault extensions, must have therefore strongly disturbed the Texas lineament belt and very plausibly could have been responsible for the slight change in course observed in the latter from S50E to S75E in the eastward direction throughout the crossing of the Arizona anticlinorium. Concurrently, all the intersection centers belonging to the Texas lineament must have been slowly strained and disturbed because the motions represented in these centers were once the local phases of crustal movements of the continent, as indicated by Billingsley and Locke (1941, p. 47), and the tensional and torsional effects must apparently have been felt more intensely toward the southern part of the lineament belt.

The slow, progressive northwestward rift of Baja California from the mainland (Hamilton, 1961, p. 1314; Rusnak and Fisher, 1963, p. 153; and Yeats, 1968) which presently becomes more and more menacing, has not been responsible in any way to the tension incurred to the southwest of the United States as it was only initiated much later in Miocene time.

Fig. 1. Structural net through southeast Arizona showing horsts and graben as well as major tear faults.

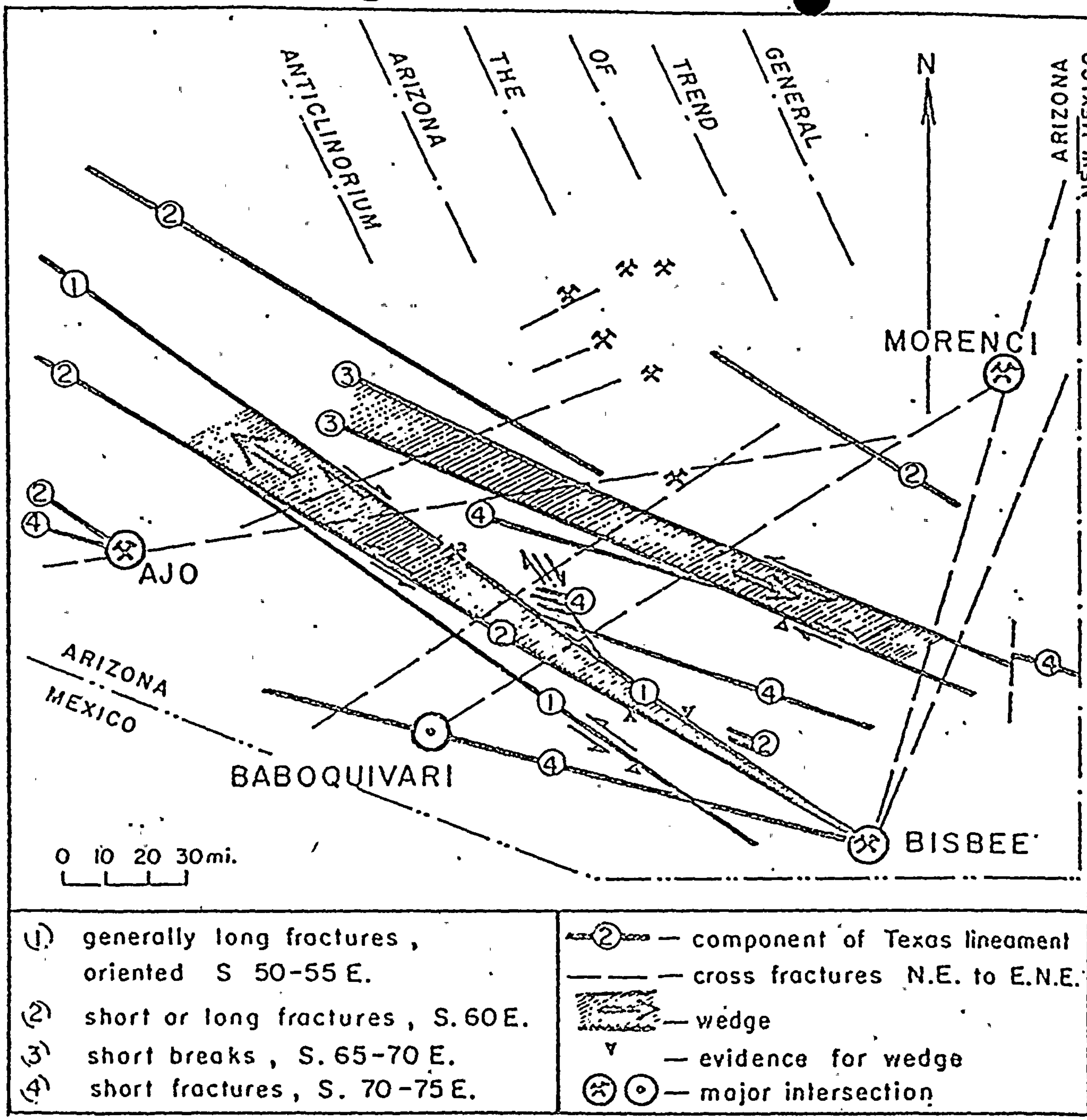


FIG. 2. Broken segments of fractures pertaining to the Texas lineament, as it curves while crossing the Arizona anticlinorium in southeast Arizona.

According to the arrangement of inferred fractures, the slight change in course that seemingly affected the Texas lineament did not seem to have happened very smoothly, and the components of this broad structural belt were broken and dislocated at a number of places, (Fig. 2) allowing for stretching and elongation of the area, as evidenced by a number of tear faults and especially by two narrow "wedges"[2] that stretch in a direction parallel to the lineament.

[2] Wedges are here defined as regional, narrow and very elongated "slivers" or strips of land bounded on both sides by major, well recognized faults affected by such lateral, complementary movements (one mile or more) on each side that a relative displacement of the wedge could happen.
Major evidence for the wedges (shown shaded on Fig. 2) are: a/ for the northern one: the left-lateral Mogul fault

The lateral displacements, represented by these two wedges, each having moved in the opposite direction with at least one mile of offset, and by tear faults, definitely correspond to tangential, torsional stresses or to torsional effects resulting in a differential stretching that accompanied the irregular, jagged bending now evidenced by the broken segments of the Texas lineament.

The various strands that compose this lineament within southeast Arizona show four preferred directions: (1) generally long breaks, 150 to 200 miles of inferred length, oriented S50–55E; (2) some long (150–200 miles) and some very short breaks (20 miles) oriented S55–60E; (3) somewhat shorter breaks (100–150 miles of inferred length) oriented S65–70E; (4) short breaks (15 to 50–100 miles) oriented S70–75E. These four sets of fractures follow one another from west to east in irregular, disconnected fashion, forming a very broad curve slightly concave to the northeast, as shown on Figures 1 and 2, and are to be subsequently referred to as No. 1, 2, 3, and 4 trends, respectively.

Some observations from the map can already lend credence to the hypothesis of a regional distortion of some sort or to a regional tensional strain (Gilluly, 1946, p. 58) that resulted from or at least accompanied the apparent bend of the Texas lineament: (1) pronounced vertical displacement with a strong downthrow to the north occurred north of the Huachuca block, north of the Whetstone block, and also north of the Ajo structural block, along a direction parallel to the Texas lineament and along the southern fringe of the lineament, where the strain may have been the strongest; (2) the strong disturbance suffered by the Ajo block, hinged upon a component of the Texas lineament and tilted 50 degrees to the southwest and away from the belt, further supports the hypothesis; (3) steep, multiple vertical displacements are to be observed parallel to the Texas lineament at Bisbee and in the Baboquivari Mountain area, together with transcurrent movements at right angle (as will be shown in detail); (4) a great structural disturbance that upheaved the Ajax Hill block in Tombstone for several thousands of feet must have witnessed the tangential stresses involved at the junction of two major component directions of the Texas lineament.

When the available magnetic information (Dempsey et al., 1963a, b, c, d) is placed in overlay on part of the present structure picture, the interpretation seems to confirm the importance of the Texas lineament as an ancient and profound zone of rupture and also emphasizes the validity of some of its strands as now construed on the map. Those of its major components showing a lateral displacement, such as the Antelope Tank, are found to coincide with a very steep, conspicuous slope in magnetic contours as if the shear were reflecting a sudden drop in magnetic intensity. Offsetting effects seem particularly strong wherever all three sets of fractures meet (as in the Dragoon and Cochise quadrangles) although, by themselves, the northwestern and northeastern fractures do not seem to be necessarily reflected in the aeromagnetic results. However, the northwestern ones, very conspicuous from Bisbee to Jerome, and particularly in the San Manuel area, show a very strong parallelism in the aeromagnetic ridges and valleys.

Wherever fractures with different orientations came together and met (such as in Ajo, Tombstone, Bisbee), the entire vicinity of these intersections must certainly have been shattered and shaken, allowing for numerous openings of all sizes and all types: these were therefore ideal places with the right ground preparation for mineralization to develop. Although the northeast and the north-northwestern fractures may really be the ones along which mineralization is to be recognized, the Texas lineament most certainly must have accentuated this propensity by imparting additional favorability to the fracture centers and helping to bring forth the occurrence of orebodies through its recurring and perturbing actions.[3]

Previous investigators (Mayo, 1958; Schmitt, 1966) have already suggested that the Texas lineament must have influenced the presence of some orebodies in southeastern Arizona, and this was recently reasserted in stronger terms by Guilbert and Sumner (1968). However, the economic contribution of this important structural belt cannot easily be ascertained, being overshadowed by the north-northwestern and mainly by the northeastern (Landwehr, 1967, Fig. 3, p. 499) fracture belts which, rightfully it seems, could be accepted as the main avenues for mineralization in this part of the Southwest.

on the north side with almost one mile displacement (Ludden, 1950; Wallace, 1955; Pilkington, 1962) and the Antelope Tank faults with a right-lateral displacement on the south side (Silver, 1956; Cooper, 1959) regarded as elements of the Texas lineament (Cooper, 1959); b/ for the southern wedge: the Andrada fault with an 8,000-foot right-lateral displacement (Alberding, 1938) on the north side, and the Sycamore fault on the south side (Johnson, 1941; Jones, 1941) with a 5,000-foot left-lateral displacement; c/ with additional tear faults at the Saw Mill Canyon (Lutton, 1958), composed of four sub-wedges forming a left-lateral shear, parallel to the Texas lineament, and at the Noscut and Long-Mile faults, slightly oblique to the lineament (Lee and Borland, 1935; Browne, 1958) with almost one mile of right-lateral movement.

[3] The term "perturbance," as applied here, has remotely the broader connotation used in astronomy of a great physical disturbance exerted by an outside force upon a body, causing the latter to be deviated from its normal course of orientation.

Far from minimizing this contention, it is here postulated that southeast Arizona has become such an extraordinarily mineralized province by the additional shattering of fracture centers and for the opportunity for tensional gaps that developed at a number of angular discontinuities of the strands of the lineament, especially along the southern fringe of the Texas lineament. It appears that most of the angular discontinuities generally correspond to the major fracture centers or, in the words of Billingsley and Locke (1941, p. 59), ore districts became clustered at nodes determined either by the presence of superimposed orogenic movements or of intersecting lines of successive motion, or of persistent deep-seated breaks.

From the study of mineralization occurrences within the fracture net in southeast Arizona, it could tentatively be predicted that a long, important fracture that cuts through a sizeable orebody somewhere along its strike may possess some intrinsic qualities as mineralizer and is likely to indicate more occurrences at other places.

Major Fracture Centers Connected with the Texas Lineament Belt

Whether mineralized or not, the major fracture centers assumed to occur within the Texas lineament, are to be analyzed next in structural sketches that will bring about the relationship with some of the four differing directions of the components of the lineament.

Bisbee (Ransome, 1904; Trischka, 1928; Bryant and Metz, 1966; Bryant, 1968)

A rather spectacular intersection stands out in the southeast corner of the map, at Bisbee (Figs. 1 and 2). It is a hub-like center toward which several very large fractures converge, some parallel to and part of, the Texas lineament, others cutting at right angles. A closer look (Fig. 3) shows a north-northeast set of cross-fractures that constitute an important trough which appears to exert its influence over a 5-mile width in this vicinity. This trough cuts almost at a right angle through the Texas lineament trend, the components of which exhibit here a series of important downthrows to the south-southwest, amounting to a total vertical displacement of more than a mile.

The actual intersection resembles a rectangular, box-like depression, approximately four by two miles in size, limited to the north by the Dividend fault. Observing to the west the parallelism between the existing synclinal axis and the horst (both trending N55–75W, in an eastward direction, and both found to occur within and west of the depression), one concedes the existence farther north of an ancient, parallel structural break extending along the southern boundary of the anticlinal dome (Juniper Flat Granite Mountain) to merge into the Dividend fault. It seems, therefore, most unlikely that the Quarry fault would be the continuation of the Dividend, as speculated by some, because it could only be a part of the west flank of the northeast-trending graben.

The Sacramento stock, center of mineralization at Bisbee, became emplaced almost exactly at the important junction formed by the axis of the N25E graben with a No. 2 strand of the Texas lineament. Emplaced where the Dividend fault appears to change its orientation, this stock suffered multiple intrusions with a diversification of intrusive breccias, intense fracturing and strong alteration. With the proximity of the proper limestone formations as well as a rather complex horse-tailing as occurs where the east branch of the Dividend fault splits the stock, the conditions were obviously perfect and ideal for an orebody to be present at Bisbee. As is often the case (Schmitt, 1935, p. 42), these ore deposits were found on the downthrow side within the depression.

If one were to expect a southwestward extrapolation from a rather important, deep-seated fracture that cuts its way through western New Mexico, from Lordsburg probably then through Tyrone (with a 5-mile width) then through Santa Rita (with a 6-mile width) straight in the direction of Bisbee, one would feel somewhat disappointed not to detect any northeast trend through the Chiricahua Mountains or at Bisbee, or farther southwest, through Cananea.

As a matter of interest, Bisbee, which is found at the intersection of No. 2 and 4 trends, is located along the bisectrix of two sets of double angles as is Tombstone), forming a very symmetrical arrangement (insert, Fig. 3). Could this imaginary bisectrix represent a possible unexpressed trend such as an incipient rupture belonging to the anticlinorium setting? This coincidence is here reflected upon because these exist similar examples of deposits occurring along a bisectrix within this province but not necessarily along the anticlinorium (Safford, Cananea, and other parts of the continent).

Baboquivari Mountain Area (Wargo, 1954; Donald, 1959; Fair, 1961)

Following westward the southern boundary of the Texas lineament, one encounters the Baboquivari Mountain area which also presents a fascinating intersection of fractures (Fig. 4) that in many ways resemble the Bisbee center.

Although apparently barren, the Baboquivari Mountain area is a particularly dense intersection that is characterized, as in Bisbee, by a similar set of three faults more or less oriented in the same

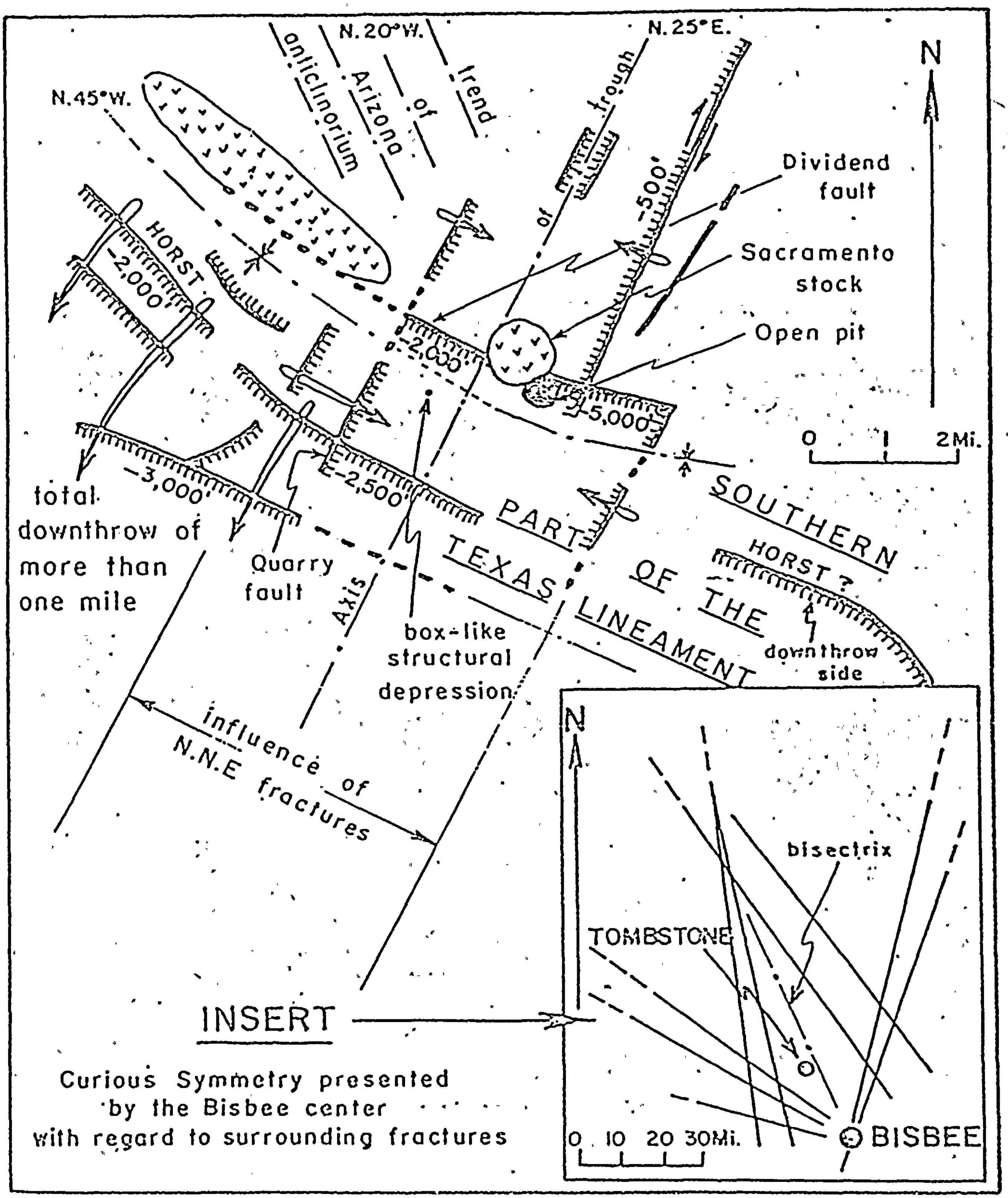


FIG. 3. Structural sketch of Bisbee illustrating the intersection of a southern component of the Texas lineament with a north-northeast cross-fracture.

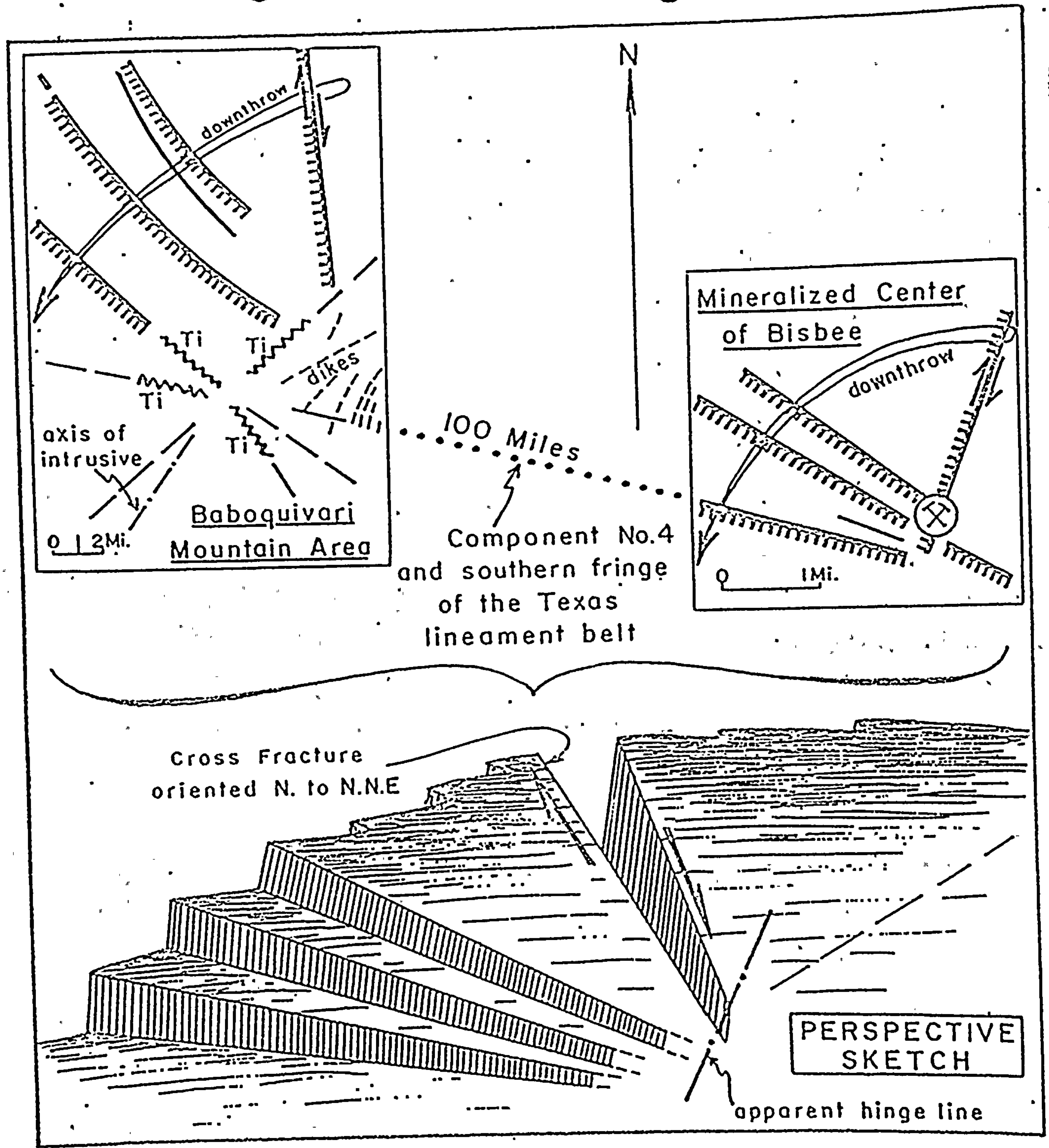


FIG. 4. Striking resemblance between the barren Baboquivari area and the mineralized Bisbee center.

direction and similarly downthrown to the southwest, and also by a strong right-lateral fault occurring at right angles which is similarly downthrown to the west. Only 100 miles apart, both the Baboquivari and Bisbee centers are located along a No. 4 component of the Texas lineament belt. The northeast fracture is additional here, whereas perhaps incipient in Bisbee (with the Tyrone-Santa Rita axis in mind), as are the numerous dikes that crisscross the center.

With this amazing structural similarity, the geological setting is of course quite different: many more volcanics and flows, many Tertiary intrusives, more metamorphics, together with a spectacular plug in the midst of the Baboquivaris contrast with the Precambrian granites and schists, the limestones and other sedimentary formations, displayed in the Bisbee area. Although the basic, primary structural arrangement may seem most propitious, the necessary ingredients for an economic mineralized target to occur somewhere within the Baboquivari center center must have been deficient or missing (or the potential orebody could have been eroded away or still be deeply buried).

Such homologous structural arrangements as those of Bisbee and the Baboquivari Mountain build up the hypothesis of a torsional strain effect in this part of the province. Indeed, the subtle change in orientation observed by both the north-northwest and the northeast fractures at these two centers, which are only 100 miles apart, certainly appears compatible with the slight curvature inherent to the Texas belt. Although their regional relationship cannot clearly be appraised at present, both centers seem to represent hinge-like nodes, or key tangential-tensional stress situations pertaining to the southern fringe of the Texas lineament, and they could perhaps be considered as keystones within the framework of the lineament belt.

Ajo (Gilluly, 1946; Dixon, 1966; Wadsworth, 1968)

Continuing the examination farther westward along the southern edge of the lineament, the next fracture center of interest occurs at Ajo. There is, however, very little information to be found on the area surrounding this intersection to allow for broad yet safe inferences within the Ajo structural setting.

The present Cornelia orebody was considered since 1946 (Gilluly, 1946, p. 105) and is now confirmed (Wadsworth, 1968, p. 101) as being the downfaulted cupola of the Chico-Shuni quartz monzonite pluton, located two miles to the southwest. This cupola (Wadsworth, 1968, Fig. 2, p. 103) represents a textbook example of multiple, differentiated intrusions that disclose a definite orientation expressed in the later stages of an intrusion. The general axis, accepted as a primary fracture (Wertz, 1968a and b), is oriented N55W and follows a No. 2 component of the Texas lineament which, again, implies the definite economic contribution offered by the lineament to some highly mineralized centers in southeast Arizona.

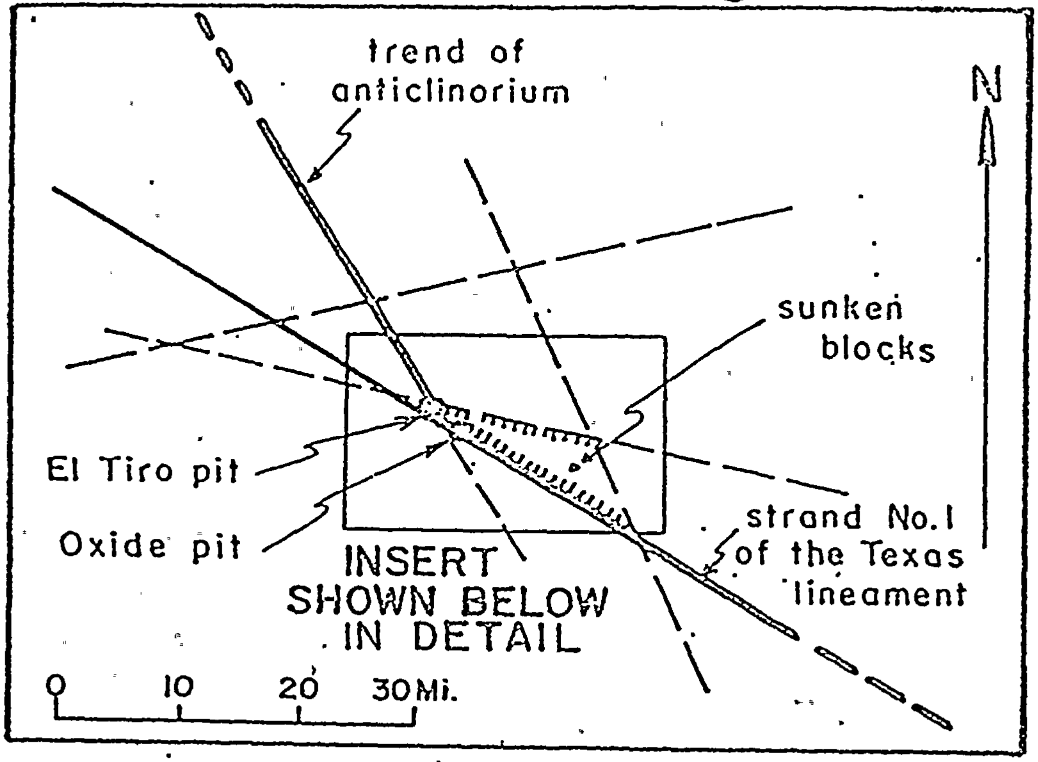
The 50-degree tilt to the southwest undergone by the Ajo block and hinged upon the Little Ajo Mountain fault (which also coincides with a No. 2 component of the Texas lineament) seems to be a resultant of the tangential effects that induced the slight curvature to the general belt. It is remarkable, indeed, to compare Ajo with Bisbee in spite of their large geological dissemblances: both of these mines which follow the southern fringe of the lineament, and simultaneously, occur at the intersection of No. 2 and No. 4 trends and also along a major cross-facture that extends northeastwards into the general Morenci area. An apparent but not necessarily major flaw in this tentative comparison is the fact that Bisbee and Ajo are porphyry coppers belonging to radically different ages: the emplacement at Bisbee being approximately 165 million years as against 60 to 65 for 17 other orebodies in this mineralized province, Ajo being one of these seventeen (Livingston et al., 1968).

The Ajo orebody, which thus far remains a structural puzzle, could plausibly constitute a third keystone to the southern edge of the lineament belt. Gilluly stated that "the trends of the faults that brought about vertical displacements were controlled by tangential forces and not by the grain of the exposed geologic formations. The differential support of the crustal blocks was presumably the primary cause of the faulting but, in general, the regional tangential forces governed the orientation of the surface of the shear" (Gilluly, 1946, p .58).

Silver Bell (Richards and Courtright, 1954; 1966)

The central part of the Texas lineament belt in Figure 2, with its upheaved and its downthrown blocks, brings out quite conspicuously two areas that sunk notably with regard to the adjacent blocks, as far as present structural knowledge can tell. Instead of being relatively planar and narrow grabens, these rather large areas appear much more important because they are three-dimensional downthrown areas, that is structural windows or broad negative blocks that relatively sank by gravity and tension for several thousands of feet. One major mining area, Silver Bell, occurs within one of these lows and along a No. 1 trend (Fig. 1) and, on the basis of a predicate enounced prior to Chapter C, could perhaps lead to the expectation of economic importance because this No. 1 strand of the lineament is quite long and trends straight toward the Bisbee orebody.

Comparison of the generalized structural map (Fig. 5-a) with the actual location of the two mineral deposits at Silver Bell (Fig. 5-b) generally shows good agreement. The two major directions of interest at Silver Bell (emphasized by heavier lines on Fig. 5) are the component No. 1 of the Texas belt and a trend that pertains to the Arizona anticlinorium. This contention, which does not agree with previous investigations, is based on the fact that numerous small monzonite masses follow these



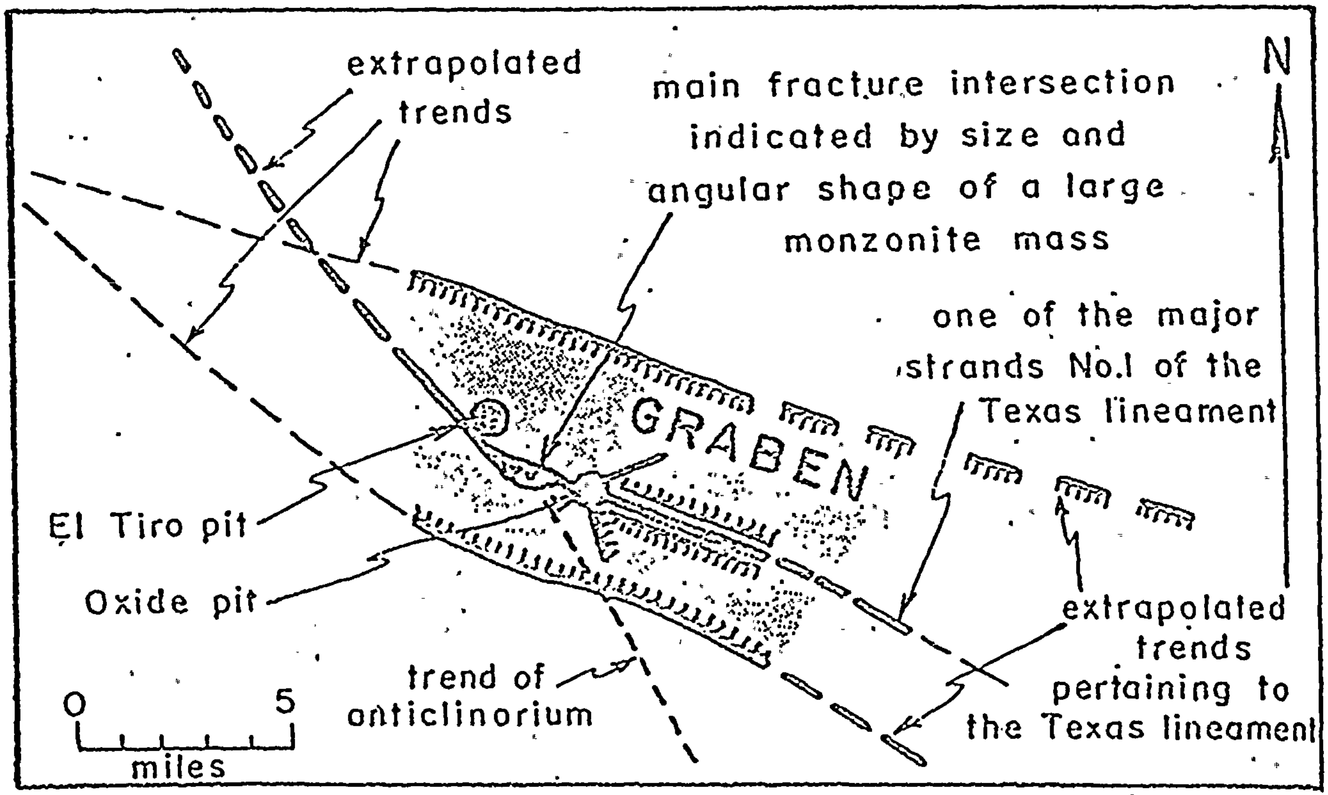


FIG. 5. The Silver Bell area within the regional structural framework. Insert adapted from Richards and Courtright (1954).

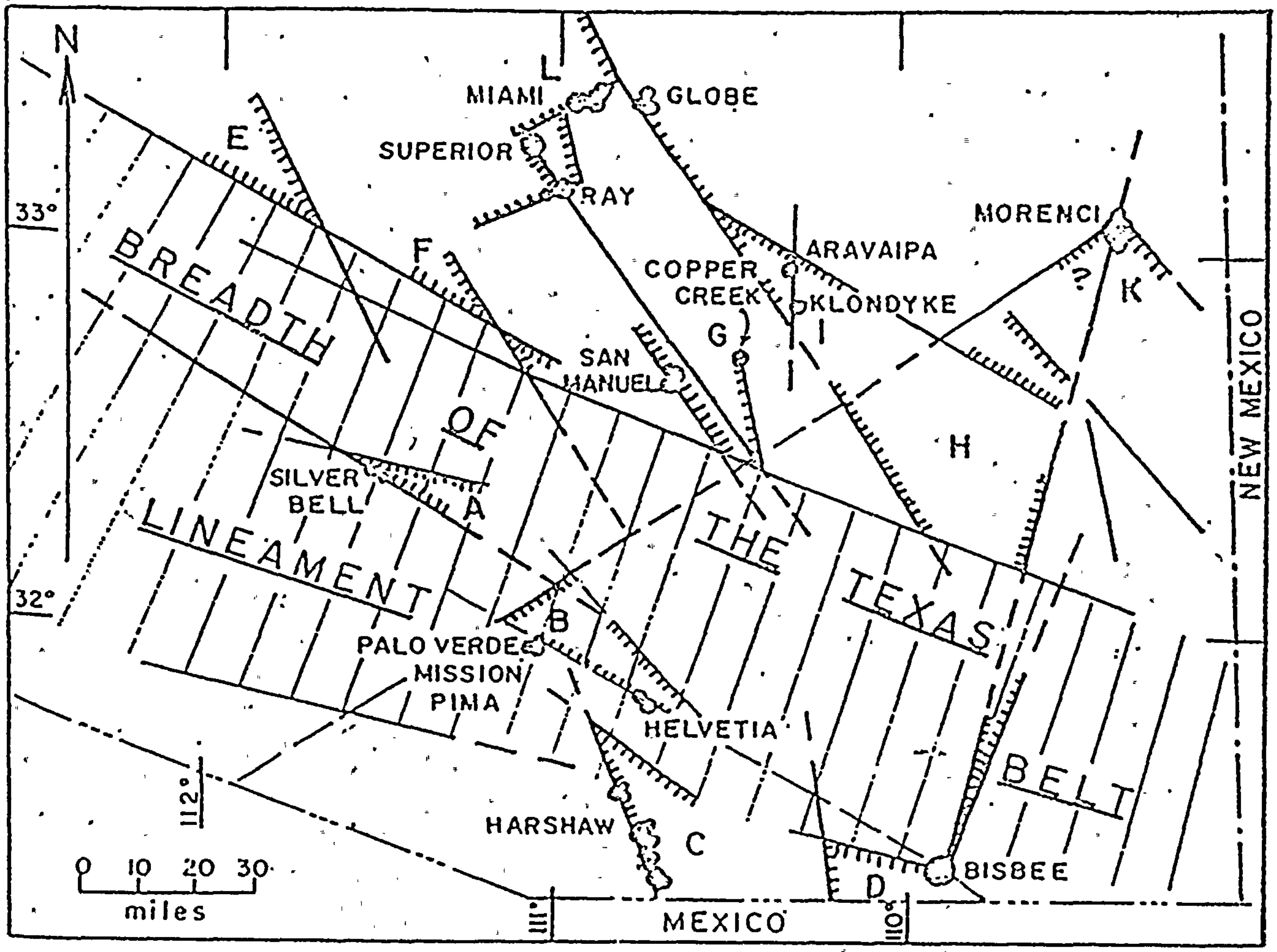


FIG. 6. Configuration of the various structural "lows" inferred within the Texas lineament in southeast Arizona.

two trends rather faithfully and that the largest monzonite body (Richards and Courtright, 1954), by its broader size and by its angular shape that embraces both trends, definitely marks the main fracture intersection, somewhat reminiscent of the similar key position held by the Sacramento stock in Bisbee. The difference is that here both mines are located within one mile or so from the junction, one mine along each direction. Indications of a northeast break, conformable with the structural background, that is, toward San-Manuel, Copper Creek, and Morenci, certainly could confirm the position of Silver Bell as one of the major fracture centers inside the Texas lineament belt.

Northeast and Southeast of the General Sierrita Area
(Silver, 1956; Cooper, 1960; Lacy and Titley, 1962)

In addition to the structural low at Silver Bell (*A* in Fig. 6) within and parallel to the Texas lineament belt, there is another elongated, regional low (*B*) that occurs north of the Palo Verde-Mission-Pima and of the Helvetia mineralized areas. Both these mining centers seem to be found on the upthrown, southern side of the long Sycamore fault, southern boundary of this low. However, the Palo Verde-Mission-Pima group should most likely be disregarded presently because it occupies, structurally speaking, an artificial, out-of-place position in the area (Cooper, 1960; Lacy and Titley, 1962), leaving the Helvetia group alone to follow a strand of the Texas lineament. This regional low is mostly covered by alluvium except toward the southeast corner.

Farther to the south and straddling the southern fringe of the Texas lineament, there is a large low (*C*) oriented crosswise and rather toward the anticlinorium. Its western boundary shows a good number of small mines and prospects all along and east of the Patagonia Range, but these string out

similarly along the anticlinorium trend, implying the lack of influence from the lineament here.

Near and southwest of Bisbee, there is another structural low (*D*) for which there is not enough information available and no study made so far, due perhaps in part to the proximity of the Mexican border. North of Bisbee, although not directly connected with a low, is Tombstone, a famous mineralized center (Butler, 1938; Gilluly, 1956) which occurs where an ancient north-south fracture (along which the Schieffelin granodiorite was emplaced) encounters an apparent intersection of inferred No. 2 and 4 trends. The former of these trends parallels a number of major fractures oriented N60W southeast of the Ajax Hill horst whereas the latter trend follows, it seems, a short wedge-like basin or graben that relatively moved westward along a N75W averaged direction, north of the horst. The latter was upheaved as much as 6,500 feet on its western edge, perhaps through the interaction of the two components of the Texas lineament, acting as a couple, with the north-south fault.

Northern Fringe of the Texas Lineament Belt (Schwartz, 1953; Pelletier and Creasey, 1965; Lowell, 1968)

To the northwest, the information generally becomes more scanty. Two small angular lows (*E* and *F*) which are only partial grabens, are located outside and north of the lineament belt, in homologous arrangement and tied up with a No. 2 component: occurring entirely in alluvium, there is no mineralization to be readily expected.

Farther east and abutting against a northern component of the Texas lineament, there is a partial graben (*G*) that economically is particularly important. The western boundary of this low is recognized for seven miles as the Mammoth fault, parallel to the anticlinorium and strongly emphasized by longitudinal, aeromagnetic patterns. It seems entirely possible (as indicated on Figure 1) that the Laramide monzonite-porphyry dike swarms that brought about the original, unfaulted San Manuel-Kalamazoo orebody (Lowell, 1968, p. 647) was emplaced along this ancient, primary fault. Among the regionwide structural disturbances that followed, crosscutting and tilting the area, some without doubt could reflect recurrent effects of the Texas lineament belt, namely the important Red Rock fault, implying that the lineament could conceivably occur this far north. The eastern boundary of the graben (*G*) is characterized by the numerous mines of the Copper Creek area (Kuhn 1941; Creasey et al, 1961).

Concerning the large low (*H*) there is not enough information to make a conjecture at this time.

Fracture Centers Outside of the Texas Lineament Belt

In order to better assess the apparent structural influence of the Texas lineament belt throughout southeast Arizona in terms of mineralization, it would seem necessary to compare such effects with similar situations occurring outside and away from this belt. One would very probably expect more interesting structural features accompanied with ore to occur within the lineament belt than outside because of the additional disturbances that it created and of the renewed tangential-tensional stresses involved.

To the north, there are three more lows (Fig. 6). The Aravaipa-Klondyke area (Ross, 1925; Creasey et al, 1961; Simons, 1961) (*I*) is also a partial graben that may perhaps still belong to the main belt. An apparent low at Morenci (Lindgren, 1905a and b; Moolick and Durek, 1966) (*K*) could exist south of the mining center, but there may not be enough evidence for interpreting its presence. As to the Safford orebody (Cook and Robinson, 1962; Robinson and Cook, 1966), it is rather symmetrically located along another virtual bisectrix, between two important structural belts: a shear zone, 3,000 feet wide, passing through the San Juan mine to the north and a shear zone 5,000 feet wide, practically coincident with the Trojan fault to the south.

The group of mines that includes Christmas, Ray, Superior, Miami, Castle Dome, Copper Cities, and Globe, farther north seems as a whole to be intersected solely by the northeastern and north-northwestern fractures, seemingly remote from the influence of the Texas belt (with the possible exception of a No. 2 strand, oriented in the general direction of these mines, "coming from the southeast). This important agglomeration of mines exhibit complex, square-shaped partial-graben situations (low *L*) north and away from the Texas lineament belt.

Structure, as rationalized thus far in this study, does not explain the occurrence of these mining centers. It does not explain either why certain parts of this area were so intensely disturbed as to display at numerous places the regional brecciation long ago described as terrazo pavement (Ransome, 1904; Baker, 1934; Peterson, 1954). The hypothesis of a broader, wider version of the lineament belt as a possible explanation for this brecciation on such large scale, this far north, does not agree with the present findings, and it may be appropriate to consider the intervention and effects of another parameter to understand the perplexing fragmentation that eventuated over such large areas. Another hypothesis, to be expounded in a subsequent paper, is related to several Paleozoic basins which once existed

in this part of the state. Their flanks, weakened and shattered through compaction, coincide rather well with the presence of those mines now found to be strung all around the basins (as far south as San Manuel and Christmas) and also correspond to some of the places where the terrazo pavement was described.

Outside and south of the belt, in Mexican territory, two major mines, Cananea (Valentine, 1936; Velasco, 1966) and Pilares, at Nacozari (Wade and Wandtke, 1920) do not apparently fall on extrapolated structural trends (not illustrated here). This could be explained by the fact that trends loose much of their evidence outside of the area under scrutiny, unless constantly reinforced by additional field data farther along the way. Such efforts toward the south are indeed hampered by an almost complete lack of information as well as rather scanty correlatable data pertaining to the structure of the few mining centers occurring in northern Sonora.

Cananea is mainly characterized by a multiple-intrusion granite enclosed within an earlier, complex fault system, both oriented northwest. Evidence of late wide fractures and shear zones striking northward, together with the similar orientation shown by the Cananea Ranges, gives some weight to the impression that Cananea also occurs along an imaginary, incipient north-south bisectrix passing through the San Antonio and Terranate prospects, north of Cananea. There is presently no indication that a northeastern trend joins Cananea to Bisbee, to later join the Lordsburg-Tyrone-Santa Rita alignment.

All the above considerations certainly indicate that the fracture centers that occur within the Texas lineament belt are as a whole more mineralized than those centers located outside. The economic significance of this belt should certainly be recognized, as it must have significantly contributed to the formation of a richly mineralized province.

Conclusions

Attempt has been made to indicate by induction those broad, regional parameters possibly responsible for the occurrence of major mines, then to examine the local structural setting in which some of these occur. For instance, the mineralized stock at Bisbee occurs exactly at the intersection of a strand of the Texas lineament with the axis of an important northeast fracture or trough, while at Silver Bell the largest monzonite body occurs exactly at the intersection of the same lineament trend with a north-northwest fracture, the Texas lineament being the common denominator, so to speak. Although in both cases the stock happens to occur close to or within [illegible] and although the distance from one to the stock varies from contiguity to one to two miles, the broad influence of the Texas lineament belt is undeniable. A predicate, enounced earlier, that a long fracture, along the trend of which occurs already one orebody is more likely than another, so-called barren, trend to bring out a mineralized center elsewhere, as if possessing some inherent favorability of a sort, still seem acceptable.

The validity of the ancient primary breaks, as determined, will have to be reinforced, or corrected as the case may be, with the gradual updating and addition of field data. Confirmation of these breaks will also come about through an increasing number of techniques soon to become available. These techniques may comprise the following: detailed and general gravity determinations, aeromagnetic and seismic work (Zietz et al., 1968; Zietz, 1969), thermal gradient and heat flow studies, infrared and radar investigations, and photogeologic analysis (Harman, 1967; Parmenter, 1968), not to forget satellite photography (although much surface structure is expected to blur the awaited results). Whereas some of these techniques will or may not necessarily bring out convergent results, nor even compatible ones, some will nevertheless remain rewarding. Indications of depth, width, and continuity of fractures as interpreted from their patterns and contiguity to known mines should also reveal anomalies along some of the trends, as indicated through computer methods and statistical analyses. Further studies by various geophysical means, the use of geochronologic data, geochemical investigations and deep-well log analyses should be pursued and confirmed, of course, in conjunction with repeated field work. More locally, the geomorphologic implications, as the obvious elongation of lakes and of stretches of rivers, even in semi-arid areas, the more subtle controls of erosion mechanisms and effects, and channel behaviour (Wertz, 1963; 1964–65; 1966b; 1970b), etc., cannot be neglected.

From exhaustive structural studies within the district considered for exploration, together with the stratigraphic and alteration settings, and also the eventual response to a number of new techniques, those unexplainable anomalies along certain trends or close to specific intersections should require close investigation. The sum of these procedures and ideas will some day yield a valuable key to the localization of future mines and mining districts, many of these being still buried under lava or alluvium.

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August 25; November 20, 1969

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