STRUCTURE OF BASIN AND RANGE PROVINCE IN ARIZONA

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INTRODUCTION

The following paper has two main objectives: (1) to discuss briefly some tectonic events which influenced the development of the existing Basin-and-Range structure; (2) and to point out problems which invite attention.

PHYSIOGRAPHY

The Arizona portion of the Basin and Range province lies southwest of the Colorado Plateau (figs. 10, 11, 12) and includes an area of more than 50,000 square miles. It is characterized primarily by approximately 150 individual mountain ranges alternating with broad plains, valleys, or basins.

In general, the basins and ranges are distinguished as follows: (1) they are relatively short and more or less parallel; (2) they consist of fault blocks which generally though not invariably have been tilted; (3) their internal structure may be simple or complex.

The Arizona basins and ranges trend broadly parallel with one another only in particular belts (Fig. 12), and a considerable number of them lie transverse to the north-northwest trends commonly ascribed to them.

The mountain masses rise sharply to altitudes of a few hundred feet to more than 10,000 feet above sea level. They measure from a few miles to more than a 100 miles in length, and some are more than 20 miles wide. In general, the longest, highest, and widest are within a belt 60 to 100 miles broad which borders the Plateau from the northwestern corner of the State to the New Mexican boundary north of Morenci and swings southward into Sonora as part of the Mexican Highland. Ransome (1923) termed this belt the Mountain Region, and the province southwest of it the Desert Region (fig. 10).

The boundary separating the Basin and Range province from the Plateau is sharp in northwestern Arizona but in the central and southeastern parts of the State the structural features by which the two provinces are differentiated cannot be so clearly defined. Ransome (1923) drew the boundary along the Mogollon rim from Longitude 111° 30' to 110° and thence southeastward (fig. 10). We have delimited a transitional belt (fig. 12) within which the strata, although locally folded, tend to be relatively flat.

Some of the intermontane valleys form closed basins, bolsons, or playas, but most of them are dissected by drainage systems tributary to the Colorado River. They attain widths of a few miles to more than 30 miles, with the widest generally in those areas west of Longitude 111°. The valley floors rise from approximately 100 feet near Yuma to 5,000 feet above sea level in the Sulphur Springs Valley; many of them show maxima of 1,200 to 2,000 feet of relief between axis and margin.

In cross section, the margin of a mountain range in southwestern Arizona may be a pediment, cut on hard rock and with or without alluvial cover, which merges

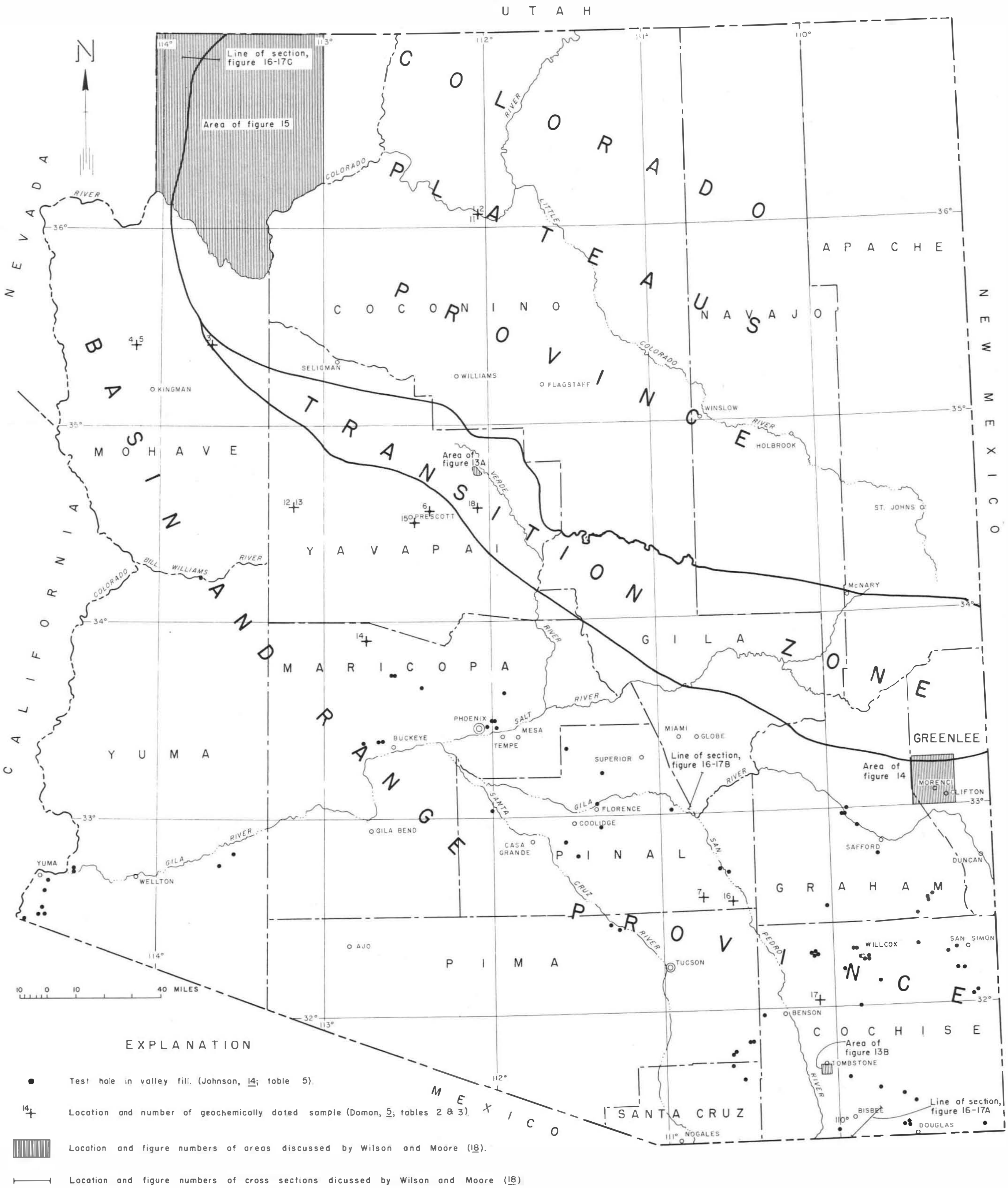


FIGURE 10. Map of Arizona showing structural provinces and location and figure numbers of areas and cross sections discussed by Wilson and Moore (18), location and number of geochemically dated samples (Damon, 5), and locations of test holes (Johnson, 14).

imperceptibly into the alluvial valley floor. Commonly the pediment drops off abruptly into a deep valley trough which presumably formed by folding and/or faulting. Unfortunately, not much is known regarding the profiles, widths, or depths of these numerous valley troughs.

ROCK UNITS

The Basin and Range province in Arizona is made up of metamorphic, igneous, and sedimentary rocks of older Precambrian to Recent age (table 6). Throughout much of the region, unfortunately, paleontologic evidence is lacking, and in many areas the age classifications, as given on the Geologic Map of Arizona (Darton, Wilson, and Hansen, 1924) and on the new County geologic maps issued by the Arizona Bureau of Mines, are based tenuously upon lithologic characteristics, stratigraphic succession, and known or deduced structural history; here is a most worthy place for geochronological research.

REGIONAL PERIODIC DEFORMATION

General Statement

Structurally, the Basin and Range province in Arizona tends to be complex rather than simple as the result of periodic deformation and igneous activity which occurred most notably during older Precambrian, at the close of younger Precambrian, between Permian and Cretaceous, during Cretaceous and early Tertiary, during middle and late Tertiary, and during Quaternary times.

Older Precambrian

Our general knowledge of the older Precambrian in Arizona is rather fragmentary and limited. Understanding of complexities inherent within the ancient terranes is further limited by the fact that large tracts of igneous and metamorphic rocks of unknown age have been assigned to the era.

Information regarding some occurrences of older Precambrian rocks in Arizona has been analyzed comprehensively by Anderson (1951; Anderson and Creasey, 1958, pp. 1-45). Anderson noted that the metamorphosed Yavapai series of this age in the Jerome region is 40,000 to 50,000 feet in total thickness, and largely volcanic but partly sedimentary in nature. In other Arizona localities, the Yavapai and Pinal series likewise are generally composed of thick sequences of both sedimentary and volcanic rocks. Anderson and Creasey (1958, p. 33) concluded that the Yavapai series may be marine and/or nonmarine. The record of extensive volcanic activity suggests an orogenic belt, and the great thickness of rocks, totalling perhaps 7 to 10 miles, probably accumulated in a geosyncline. Cooper and Silver (1954) suggest that older Precambrian sediments accumulated in a geosyncline which included the Dragoon quadrangle (Cooper, 23) and that the geosyncline may have been the locus of the Mazatzal revolution.

The principal orogeny recognized for the older Precambrian in Arizona was the Mazatzal revolution (Wilson, 1939). It resulted in the following: (1) East-west and north-south shear faults; (2) folds of prevailingly northeast, but also some north-south, northwest, and east-west trends; and (3) thrusting north-northwestward. The deformation culminated with invasion by batholiths of granite and smaller masses of other plutonic rocks. Schist and gneiss were developed in the vicinity of intrusive bodies, but elsewhere the regional metamorphism was of a relatively low grade.

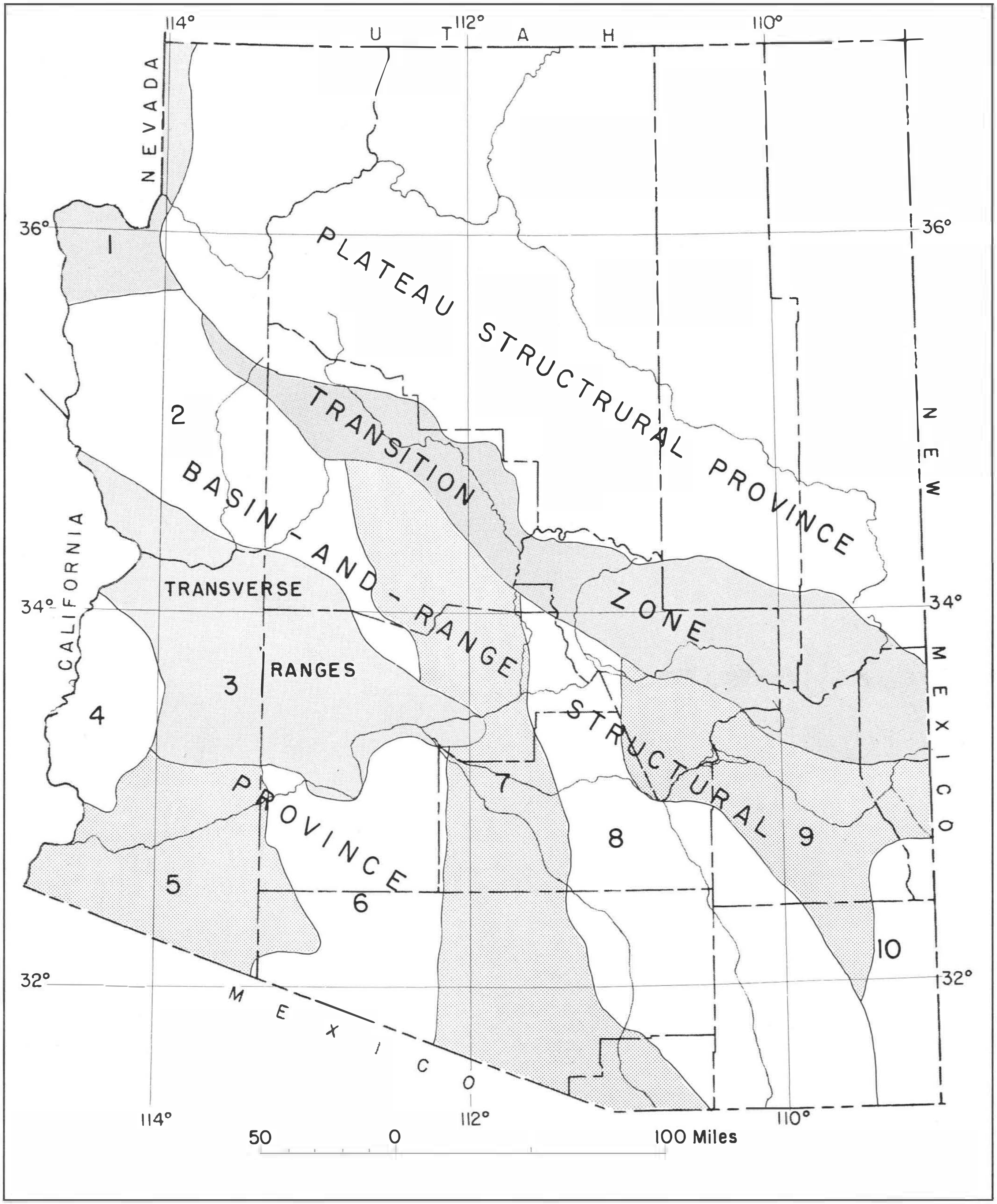


FIGURE 11. Map of Arizona showing areas of similar topographic trends of Basin and Range mountains. Area 1, north-south to N. 15° E. trends; Area 2, north-south to N. 15° W. trends; Area 3, area of transverse ranges trending north-south, east-west, N. 60° W., N. 60° E.; Areas 4, 7, and 10, north-south trends; Area 5, N. 30°-40° W. trends; Area 6, north-south, east-west, and N. 30°-35° W. trends; Area 8, N. 30°-45° W. trends; Area 9, N. 50°-60° W. trends.

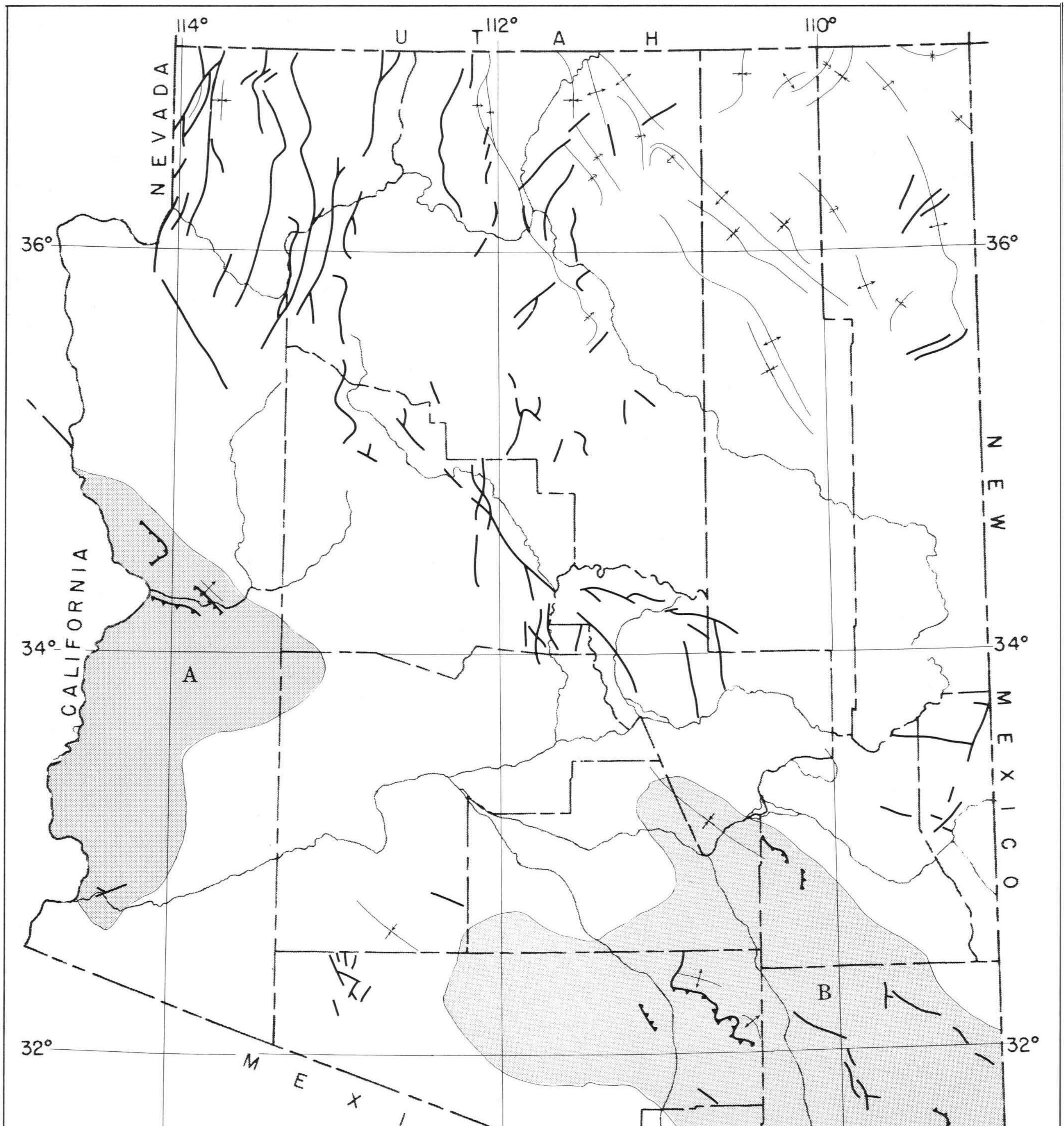


FIGURE 12. Tectonic map of Arizona showing known folding and faulting as described in published literature. Areas A and B are areas of strong deformation characterized by folding and thrusting of younger than Precambrian age.

In regard to other possible orogenies during older Precambrian, we have mapped in southern Arizona numerous areas of granitic gneiss intruded by granite of supposedly older Precambrian age. Further speculation regarding age relations of these rocks awaits geochronological work.

It has become increasingly evident, with geologic work in Arizona during recent years, that the structure of the older Precambrian basement rocks has influenced fundamentally the subsequent structural development.

Younger Precambrian

Younger Precambrian (Darton, N. H., 1925, 1932; Stoyanow, 1936) is represented in southeastern Arizona by the Apache group, which comprises a series approximately 1,400 feet thick of quartzite, shale, conglomerate, and limestone. It was intruded extensively by diabase of at least two ages (Shride, 1952), pre-Middle Cambrian and Laramide. The earlier intrusion was locally associated with flexing of the Apache group along north-northeast trends and may have occurred during the younger Precambrian, or Grand Canyon, orogeny.

Paleozoic

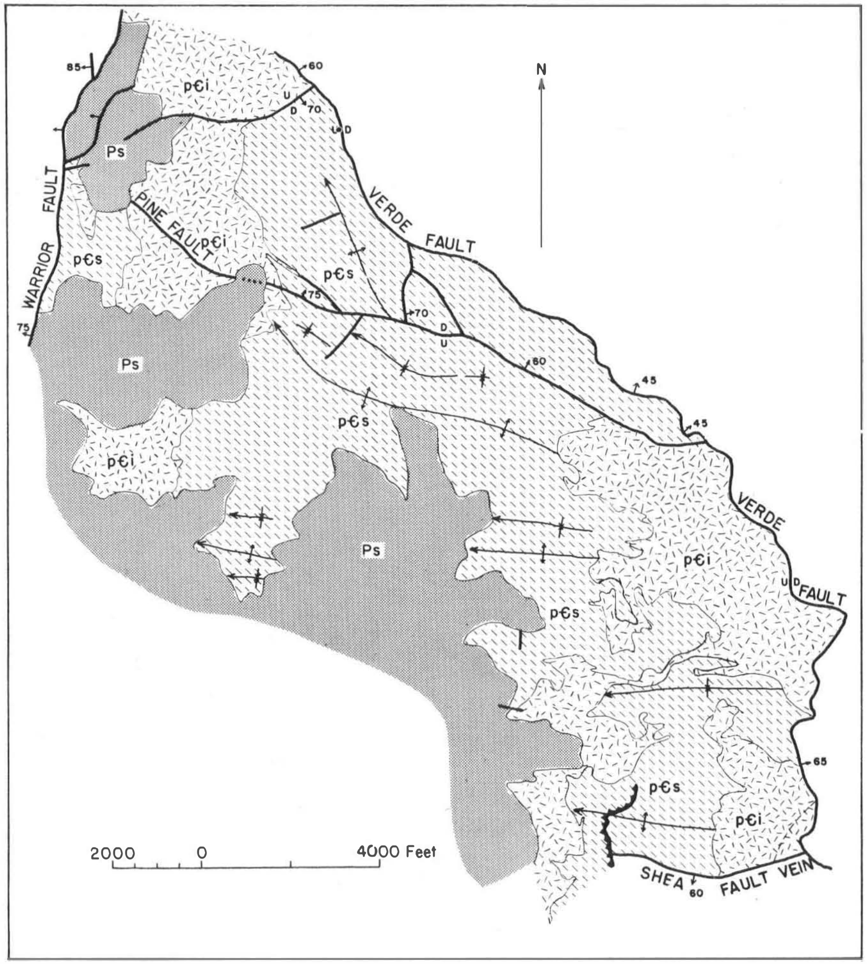
McKee (1951) has shown that by Cambrian time a general pattern of structural trends had been initiated, and that it continued to develop throughout the Paleozoic. Thus, by the end of Permian, the main elements in Arizona were: (1) Positive areas in the northeastern and southwestern portions, with a sag between them; (2) in northwestern Arizona a segment of the northeastward-trending Cordilleran geosyncline deepening northwestward from this sag; and (3) in southeastern Arizona, a segment of the Sonoran geosyncline trending and plunging southeastward from the sag. Marine limestone and dolomite, together with subordinate sandstone and shale, were formed during Cambrian, Devonian, Mississippian, Pennsylvanian, and Permian to a total combined thickness of 6,000 feet in southeastern Arizona and 9,000 feet in northwestern Arizona, but the Paleozoic rocks were thin, if not absent, on the aforementioned positive areas.

So far as is known, igneous activity was lacking in Arizona during Paleozoic time.

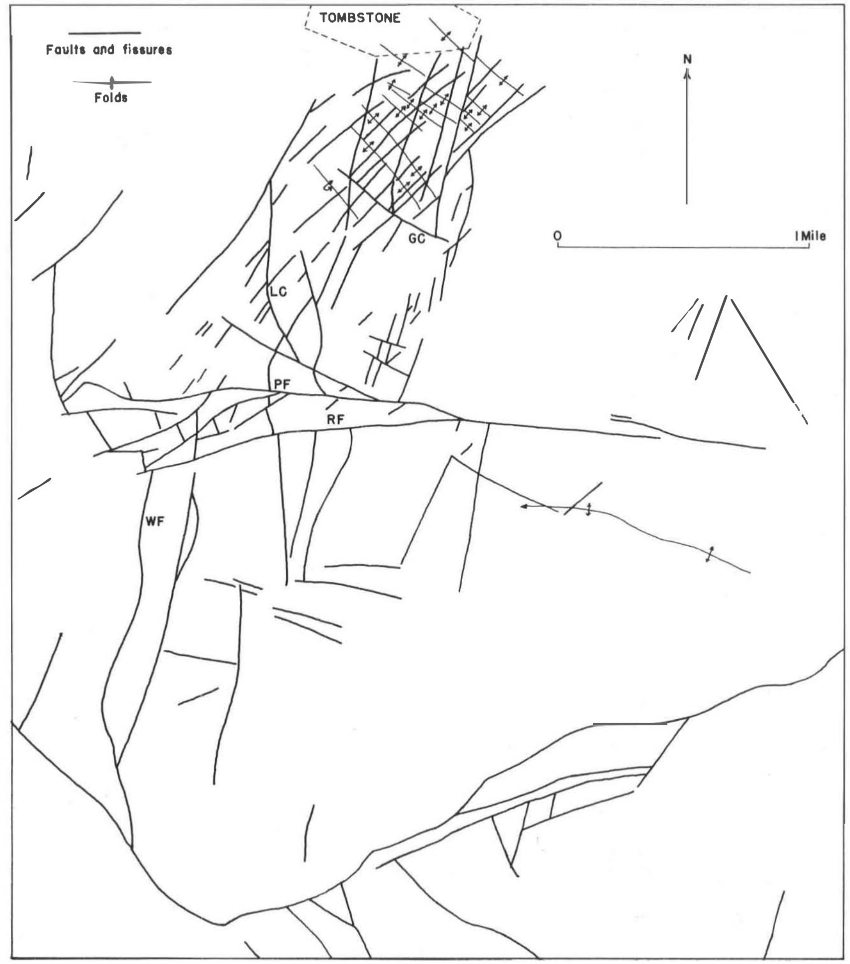
Permian-Cretaceous Interval

Between Permian and Triassic, regional uplift occurred in central and/or southern Arizona, according to McKee (1951). Triassic and Jurassic sediments were laid down in the Plateau region but have not been identified in the Basin and Range province of Arizona.

The Triassic and Jurassic Barranca formation is thick in the Caborca area of Sonora (Cooper and Arellano, 1946) and more than 7,200 feet thick in Sierra de Santa Rosa (Keller, 1928), less than 100 miles from the Arizona boundary. King (1939, p. 1659) concluded that the western marine portion of the geosyncline, in which the Barranca formation was deposited, probably was linked with the marine Triassic and Jurassic basins of Nevada and California; if so, it would have crossed southwestern Arizona, somewhat as suggested by Tenney (1930) and by Eardley (1949, Figs. 10, 12). Possibly it is represented in the thick series of locally metamorphosed sandstone, shale, conglomerate, and impure limestone which occur in several mountain ranges west of Longitude 113° 30'. This series has been considered



A. Tectonic map of a part of the Jerome area, Arizona (after Anderson and Creasey, 1958). Precambrian intrusive rocks (pЄi); Precambrian sedimentary and volcanic rocks (pЄs); Paleozoic sedimentary rocks (Ps).



B. Tectonic map of Tombstone area, Arizona (after Butler, Wilson, and Rasor, 1938). Grand Central fault (GC); Lucky Cuss fault (LC); Prompter fault (PF); Rattlesnake fault (RF); West boundary fault (WF).

FIGURE 13. Tectonic maps of parts of the Jerome and Tombstone areas, Arizona.

as Lower Cretaceous (?) on purely lithologic grounds (Wilson, 1933, p. 80; McKee, 1947), although much of it strongly resembles portions of the Barranca formation, and its slate and limestone suggest resemblance to Middle Triassic in west-central Nevada (Muller and Ferguson, 1936).

Evidence of the Appalachian revolution in Arizona is expressed on the Plateau by angular unconformity between the Permian Kaibab and Lower Triassic Moenkopi formations. In the Gunnison Hills of southeastern Arizona, J. R. Cooper discovered an unconformity of major importance between Permian and Lower Cretaceous. Within the zone of this unconformity are andesitic rocks, evidently a remnant of a much larger blanket, which he presumes to be of Triassic or Jurassic age (in Gilluly, 1956, p. 68).

Vulcanism presumably was active within the Basin and Range province to provide the widespread accumulation of volcanic ash present in the Upper Triassic Chinle formation of the Plateau; much of the Upper Triassic sediments came from the south, as shown by McKee (1951). Although no expression of this igneous activity has been indicated in southern or south-western Arizona outside of the Gunnison Hills, the volcanic rocks of several other areas are of unknown age and could be Triassic. The relation of the vulcanism to the pre-Cretaceous Juniper Flat granite of the Bisbee district is not known. This granite invaded Permian beds and was overlapped by Glance conglomerate; Gilluly (1956) mapped it, and also large areas of intrusive rocks in the Dragoon Range, as Triassic or Jurassic. The Glance has been assumed to be Lower Cretaceous, although as suggested by McKee (1951), there is no real proof that it is younger than Triassic.

The orogeny exemplified by the Juniper Flat granite resulted in mountain-making uplift locally, as at Bisbee and in the Santa Rita Mountains, where Lower Cretaceous overlaps formations ranging in age from Precambrian to late Paleozoic. This uplift was accompanied by compression; the Juniper Flat granite apparently occupies the zone of the Dividend fault, a westward-trending shear. This disturbance has been regarded as post-Jurassic or Nevadan, but like the Glance conglomerate which overlies the Juniper Flat granite, it may be of earlier Mesozoic age.

Cretaceous

Lower Cretaceous sedimentary rocks in Arizona, so far as known, are limited to the area of the Sonoran geosyncline east of Longitude 112°15' and south of Latitude 32° 30'. The succession thickens southeastward to 10,000 feet, or possibly more, in southeastern Cochise County. Marine deposits of this age are not known west of Longitude 111° (McKee, 1951; Stoyanow, 1949); elsewhere the beds are continental. As stated on a previous page, a thick sedimentary series, which may be Triassic, Jurassic, or Cretaceous, occurs west of Longitude 113°30'.

Upper Cretaceous rocks occur in the Basin and Range province of Arizona south of Latitude 33°15' and east of Longitude 111° (Stoyanow, 1949). They thicken southeastward to a maximum of possibly 7,000 feet.

During Cretaceous time, structural unrest was expressed by vulcanism in areas south of the Plateau. Typically, the eruptions were andesitic. This vulcanism became more intense during the latter part of the period; within the Christmas-Deer Creek area, for example, approximately half of the Upper Cretaceous section is volcanic (Ross, 1925).

Laramide Interval

During the Laramide interval, embracing part of Upper Cretaceous and extending into Tertiary, diastrophism developed further and increased to revolutionary intensity. How long it continued into the Tertiary and Quaternary is not known. This great revolution resulted in the following: (1) East-west and north-south shear faults parallel to those in the older Precambrian; (2) folds of prevailingly northwest, but also of north-south, east-west, and northeast trends; and (3) thrusting commonly northeast or eastward, in contrast to the northwestward thrusts of the older Precambrian. The Laramide culminated with emplacement of batholiths and stocks of granitic to monzonitic composition with which many great ore deposits of the Southwest are genetically associated.

The known areas of intense Laramide deformation and igneous activity are confined to the southeastern portion of the Mountain Region, including the head of the Sonoran geosyncline, and a part of the Desert Region southeast from Topock; in the latter, Paleozoic and Mesozoic sedimentation is very thin. Possibly this diastrophic belt is continuous from northwest to southeast, but the intervening segment shows chiefly crystalline rocks in which structural details are unknown.

Tertiary and Quaternary

During middle and late Tertiary and down to Recent time, the southern Arizona region has undergone intermittent faulting, flexing, erosion, deposition of sediments, and volcanic activity. Thus in the Globe-Ray region, a period of erosion and sedimentation exemplified by the Whitetail conglomerate was sufficiently long to expose considerable areas of the porphyry stocks and bring about most of the supergene enrichment of the copper ore bodies. Following its deposition the Whitetail was covered by extensive Tertiary dacite flows, succeeded by Gila conglomerate, more volcanics, and recent alluvium.

Loosely to firmly consolidated gravel, sand, and silt of Cenozoic age, in part analogous to the Gila conglomerate (Heindl, 1952), fill the intermont valley troughs to maximum depths of at least 7,000 feet. So far as is known, these deposits are continental except for Pliocene or Miocene marine beds along the Colorado River near Latitude 33°20' (Wilson, 1931, 1933).

The Tertiary rocks of the Basin and Range province in Arizona have been deformed extensively by compressional stresses. For example, along the southern base of the Santa Catalina Mountains, beds of presumed Miocene age are thrust over earlier rocks. At San Manuel, Tertiary conglomerate is cut by a great low-angle thrust fault (Wilson, 1957). West of Ray, the dacite and younger rocks are sharply folded in the Spine syncline, which carried the zone of oxidation down almost to sea level. East of Yuma, probable Pliocene beds are cut by large reverse shear faults. In the Artillery Mountains, Lasky and Webber (1949) determined that thrust faulting affects probable Eocene beds, and folding continued probably through Pliocene. Possibly this general orogeny marked the close of Tertiary time.

Associated with, and in part later than, the compressional deformation are normal faults which, as discussed on subsequent pages, have been presumed to be primary features of Basin and Range structure. This faulting is believed to have continued into Pleistocene (Bryan, 1925; Lasky and Webber, 1949).

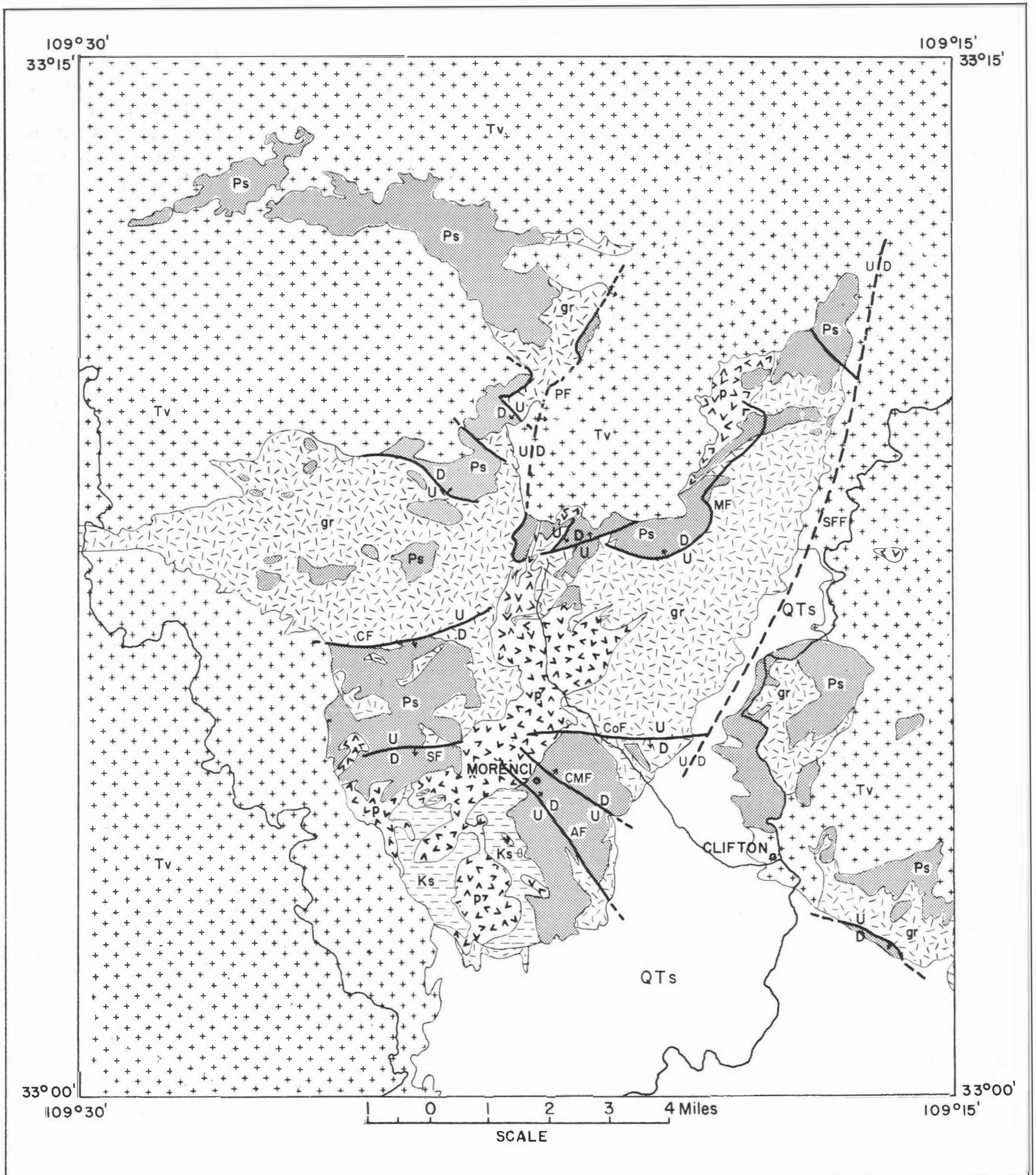


FIGURE 14. Tectonic map of Clifton quadrangle, Arizona (after Lindgren, 1905b); Valley fill (QTs); Tertiary volcanic rocks (Tv); porphyry intrusive rocks (p); Cretaceous sedimentary rocks (Ks); Paleozoic sedimentary rocks (Ps); Pre-cambrian granite and schist (gr); San Francisco fault (SFF); Malapais fault (MF); Pinal fault (PF); Coronado fault (CF); Soto fault (SF); Concentrator fault (CoF); Copper Mountain fault (CMF); Apache fault (AF).

ORIGIN OF THE BASIN AND RANGE STRUCTURES

Review of Principal Theories

The origin of the mountains and valleys in our Basin and Range province has long been a subject of speculation among geologists. Opinions developed as exploration revealed additional facts.

The topographic features have been considered by some as wholly erosional and by others as partly tectonic and partly erosional. The evolution of the earlier thought was summarized by Gilbert (1928), who himself first enunciated a fault-block theory of Basin Range structure (Gilbert, 1874).

Ransome (1919, 1923) concluded that the mountains and valleys of central and southern Arizona are tectonic, with complex fault blocks rather than folds predominating. Bryan (1925) found that many of the mountain ranges and plains in southwestern Arizona are fault blocks of post-lava age, but also that some mountains of uncertain origin existed prior to the volcanic activity.

The status of knowledge regarding basin and range structure prior to 1946 was analyzed constructively by Gilluly (1946) whose conclusions in part may be summarized as follows:

1. Faults are reflected at least by the larger topographic features.

2. The trends of the faults that brought about vertical displacement were controlled by tangential forces and not by the grain of the exposed geologic formations; in general the regional tangential forces governed the orientation of the surfaces of shear.

3. Gilbert's hypothesis (that the ranges are due to vertical adjustments of the brittle surface rocks to folds in the lower zones, brought about by regional compression) would require considerable shortening of the crust. The deformation possibly was caused by subcrustal flow and associated frictional drag, as postulated by Vening-Meinesz (1933).

The development of ideas regarding regmatic shear patterns has been summarized by Moody and Hill (1956). Their concept of wrench fault tectonics presupposes that a regmatic shear pattern with eight directions of shearing and four directions of folding and/or thrusting, (Moody and Hill, 1956), was developed throughout the entire outer crust of the earth early in its history. The concept is based upon horizontal movement along these shears or strike-slip faults, brought about by compressive forces. The principal elements of the system include major boundary shears, which may be either left-lateral or right-lateral wrenches, and second-order features resulting from movement along the major or first-order wrench faults. Within limits, the orientation of the various features is controlled by the direction of the compressive forces and the stresses and strains associated with the force. Thus, the first-order wrench faults form at approximately 30 degrees to the compressive force, and the first-order folds and/or thrusts form at right angles to the force. The second-order faults, folds, and/or thrusts are oriented in a similar fashion about the reoriented stresses which result from movement along the first-order wrench faults.

In general, second-order fold and thrust-fault systems brought about a reduction

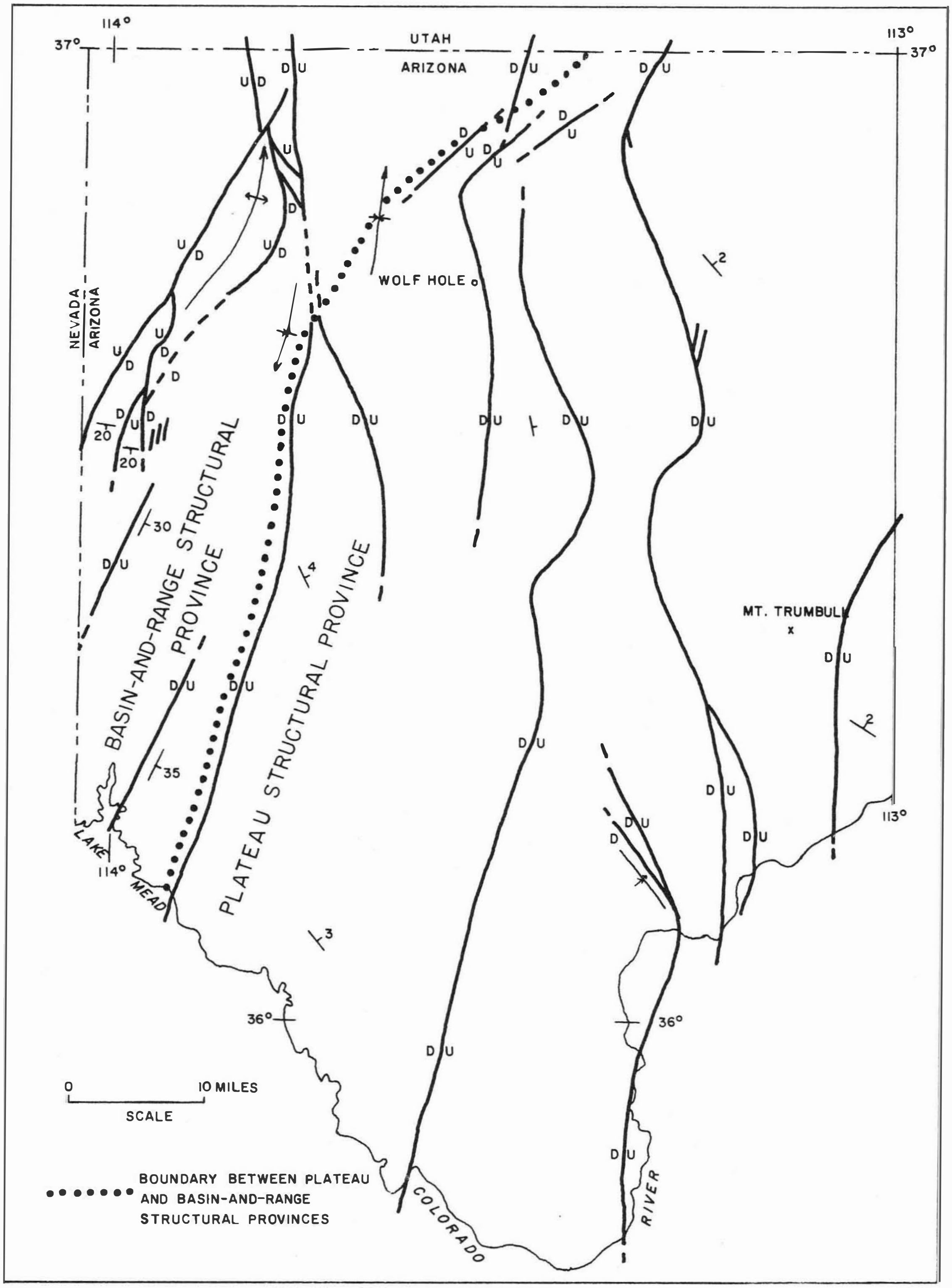


FIGURE 15. Tectonic map of northwestern Mohave County, Arizona (after Moore, 1958).

in area along the edges of the blocks.

Four of the principal trends have been discussed recently by Mayo (1958).

Normal faults are accounted for by Moody and Hill (1956, p. 1242) as follows:

> "In the event shifting of the major blocks resulted in unstressing (in a horizontal compressional sense) a given block, that block would then collapse by dominantly vertical movement along the pre-existing shear pattern comprised of lower-order wrench faults. Thus, it should be fairly common to see vertical-fault systems which satisfy the directions of a theoretical wrench-fault system but on which the later increments of movement have been essentially vertical. Such faults, having the appearance of high-angle normal or reverse faults, may have originated as wrench faults in response to horizontal compressive stresses."

SOME TECTONIC FEATURES IN ARIZONA

Evidences of the compressional forces which have acted intermittently since early Precambrian time are ample throughout Arizona (Butler, 1933; Schmitt, 1933; Wilson, 1950). We offer here a few samples of the structure (figs. 11-17) together with some possible applications of the Moody and Hill concept of wrench fault tectonics.

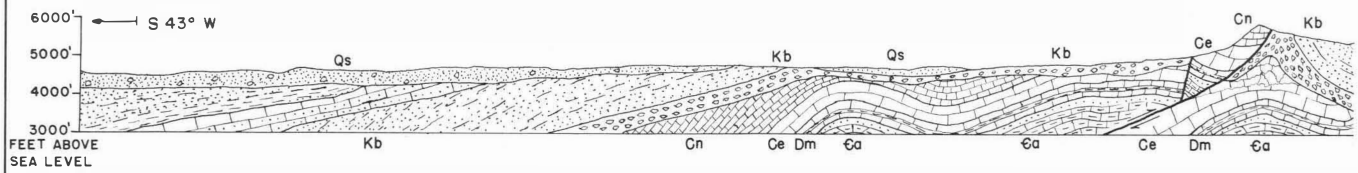
General features of the Precambrian structures have been mentioned on previous pages. Specific examples are found in the Jerome area. There the northwestward-trending Verde fault zone (fig. 13A) marked a vertical separation of 1,000 feet in Precambrian, and 1,500 feet in subsequent time; evidence for this figure, as well as for considerable lateral displacement, is discussed by Norman, Anderson, and Creasey (Anderson and Creasey, 1958, pp. 145-159), Reber (1938), and Ransome (1932). Also, the north-south Shylock fault, west of the area of figure 13A, had a minimum stratigraphic throw of 20,000 feet, all in Precambrian time (Anderson and Creasey, 1958). The Precambrian Pine fault effected considerable right-lateral displacement of an anticline (fig. 13A). The Shea fault of uncertain age appears to have caused right-lateral displacement.

It is believed that the boundary separating the Plateau from the Basin and Range province in Arizona was related to the Sonoran and Cordilleran geosynclines. It is further believed that these geosynclines have been marked by wrench faults, together with associated folds and thrusts, since older Precambrian time.

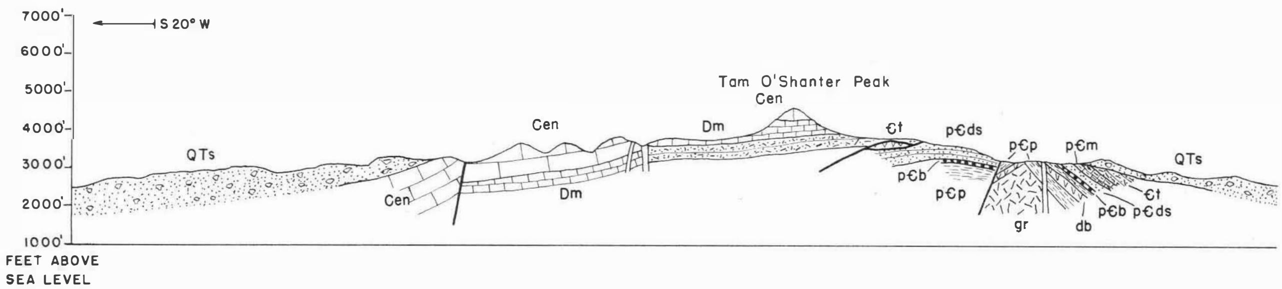
Both Nolan (1943) and Longwell (1949) demonstrated that deformation of middle Mesozoic to early Tertiary age profoundly affected the Cordilleran geosyncline. Moore (1958) has shown that this orogeny extended into the northwestern corner of Arizona, where it developed folds and faults of considerable magnitude (figs. 15, 16-17C) along the western margin of the Plateau.

As pointed out by Suess (1904) and by Butler (1949), the formations in the area adjacent to the Plateau have been uplifted many thousands of feet relative to those in the Plateau, and locally folded and thrust faulted.

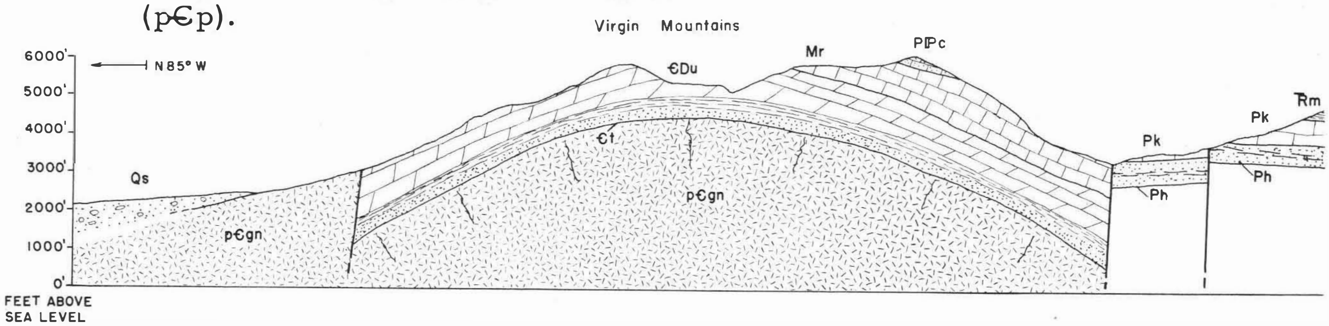
The southeastern Arizona belt of folding and thrust faulting (fig. 11) coincides with part of the area of the Sonoran geosyncline.



A. Cross section in Bisbee district, Arizona (after Ransome, 1904). Valley fill (Qs); Cretaceous Bisbee group (Kb); Pennsylvanian Naco limestone (Cn); Mississippian Escabrosa limestone (Ce); Devonian Martin limestone (Dm); Cambrian Abrigo limestone (Ꞓa).



B. Cross section of Dripping Springs Valley, Arizona (after Ransome, 1923). Valley fill (Qts); Carboniferous Naco and Escabrosa limestones (Cen); Devonian Martin limestone (Dm); Cambrian Troy quartzite (Ꞓt); diabase (db); younger Precambrian Apache group -- Mescal limestone (pꞒm), Dripping Spring quartzite (pꞒds), Barnes conglomerate (pꞒb); granite (gr); older Precambrian Pinal schist (pꞒp).



C. Cross section in northwestern Mohave County, Arizona (after Moore, 1958). Valley fill (Qs); basalt (Qtb); Triassic Moenkopi formation (TRm); Permian Kaibab formation (Pk); Permian Hermit shale (Ph); Permian and Pennsylvanian Supai formation (IPPs) and Callville limestone (IPPc); Mississippian Redwall limestone (Mr); Cambrian and Devonian limestone and dolomite (ꞒDu); Cambrian Tonto group (Ꞓt); older Precambrian granite and gneiss (pꞒgn).

FIGURE 16. Left half of cross sections of the Bisbee district, Dripping Springs Valley, and northwestern Mohave County, Arizona.

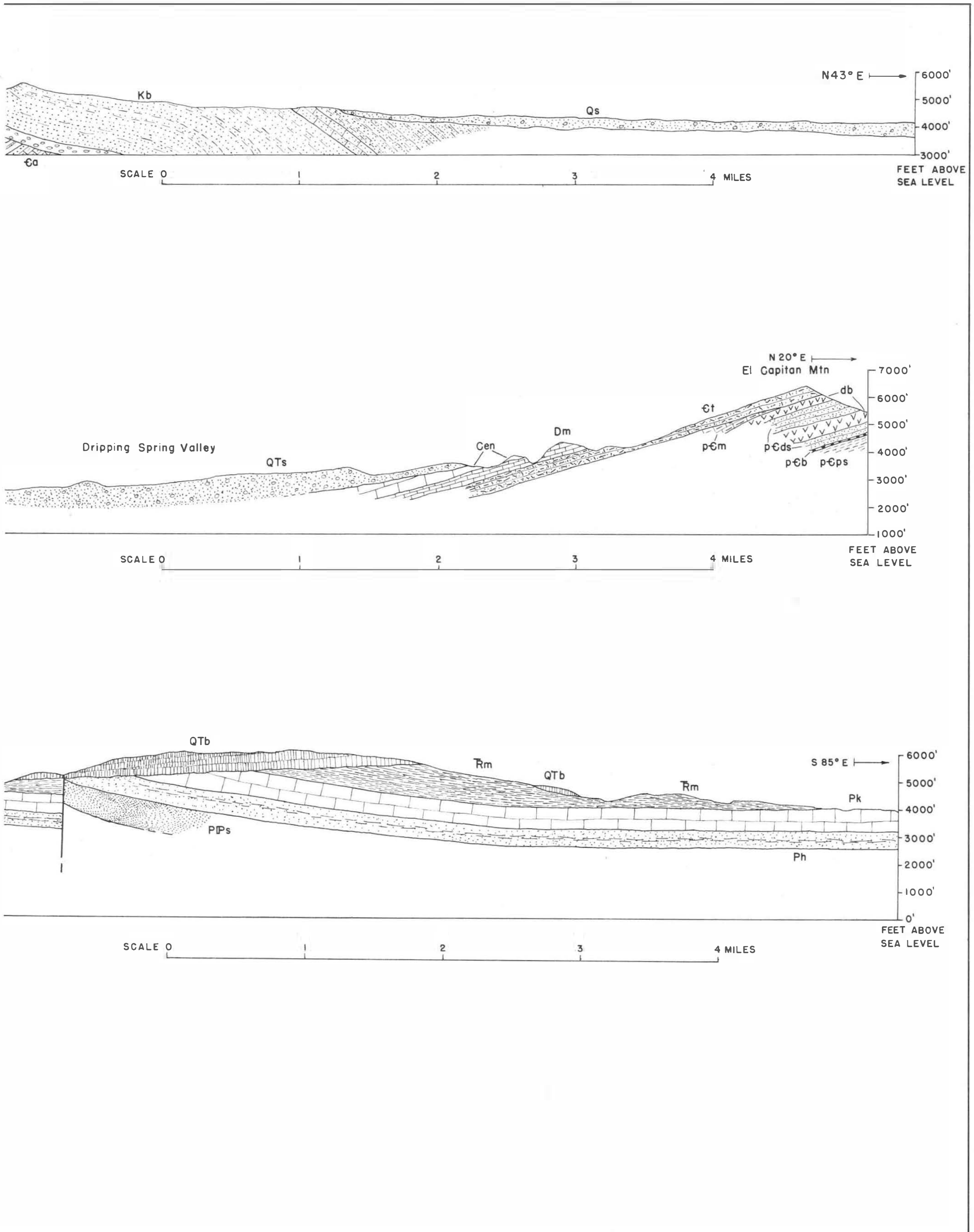


FIGURE 17. Right half of cross sections in the Bisbee district, Dripping Springs Valley, and northwestern Mohave County, Arizona.

In general, the folding is most obvious where Cretaceous shale and sandstone form a large proportion of the sedimentary succession. In districts where limestone, volcanic, or crystalline rocks predominate, folds of relatively small amplitude may be present, but the large, mountain-making folds commonly have been broken by the compressive forces and also by the later faulting; their crests and troughs, removed by erosion or concealed by later rocks, are generally not apparent, and their faulted limbs may resemble blocks tilted by basin-range faulting. Evidence for this conclusion is seen in the Deer Creek-Dripping Spring Valley, southeast of Globe (fig. 16-17B). Its southeastern portion is a well-known syncline in upper Cretaceous beds. In its northwestern segment, the trough is floored by late Tertiary and early Quaternary conglomerate; the bordering limestone mountain ranges are much faulted, but northeastward thrusting and a prevailing synclinal structure are suggested by cross sections (Ransome, 1923).

Folding, thrust faulting and normal faulting, partly pre-Cretaceous and partly post-Lower Cretaceous, are exemplified in the Bisbee district (fig. 16-17A; Ransome, 1914; Trischka, 1938; Hogue and Wilson, 1950).

At Tombstone, 20 miles northwest of Bisbee, a southeastward-plunging syncline has been deformed by northwestward-trending folds and northward-trending dike fissures (fig. 13B; Butler, Wilson, and Rasor, 1938; Gilluly, 1956). The east-west Prompter reverse fault separates it from the Ajax horst of east-west trend. The Prompter fault has a maximum stratigraphic throw of 4,000 feet, plus notable left-lateral displacement. The Tombstone deformation is regarded as Laramide.

Thrusting and overturning to low angles, together with presumably Laramide reverse faulting with great displacement, occur between Ray and Superior (Wilson, 1953, pp. 96-105).

Globe and Miami appear to be near the margin of the southeastern Arizona deformed belt; Peterson (1954) found but little folding and thrust faulting there.

Morenci seems to be outside the belt of folding and thrust faulting. According to Lindgren (1905), faults later than the Laramide intrusions have divided the strata into blocks with gentle west, northwest, or northerly dips. The principal faults trend east-west, N. 10^{o}-30^{o} E., N. 60^{o} W., and N. 30^{o}-45^{o} W. (fig. 14). The blocks south and east of each fault are relatively downthrown. Maximum vertical displacement amounted to 3,000 feet on the San Francisco fault and 2,000 feet on the Pinal fault. Notable right-lateral displacement is indicated on the Copper Mountain fault.

An area of intense folding and thrusting, of late Tertiary and possibly earlier age occurs in western Arizona between Topock and Yuma (fig. 11). Part of it coincides with the area of transverse ranges (fig. 12).

It is suggested that broad, open folding of dominantly northwest to northward trend possibly was developed over other portions of the Arizona Basin and Range province during Laramide time. Within the 180 miles between the Tucson Mountains and Yuma, the tilted block-mountain ranges show periodic reversals in dip suggestive of three major anticlines and synclines. The indicated broad folds in part are limited on the north by the aforementioned transverse ranges. As a rule, the observed easterly dips of the blocks are markedly steeper than the westerly dips; thus these suggested faulted folds would resemble the Plateau folds in asymmetry as well as breadth.

In summary, analysis of the structural pattern in Arizona indicates that a wrench-fault zone, accompanied by folding, trends approximately N. 60° W. along the Basin and Range-Plateau boundary from Longitude 109° to 111°30'; another, apparently not accompanied by folding, trends N. 45° W. along the Plateau boundary from Longitude 111°30' to 114°; and one accompanied by folding trends North to N. 15°E. along the western margin of the Plateau in the northwestern corner of Arizona (figs. 15, 16-17C).

The relatively high belt, which extends from the Kaibab Plateau southward along Longitude 112° (fig. 12) into Mexico, possibly represents a first-order fold. Second-order features include the northwest-trending folds of the Plateau and the more complex set of folds, thrust faults, and strike-slip faults found in the Basin and Range province. The zone of faulting, which trends North to N. 15° E. in the northwestern corner of Arizona (figs. 15, 16-17C), apparently represents a second-order right-lateral wrench-fault zone. Its prominence, however, suggests that it may be controlled in part by a pre-Paleozoic structure, possibly an older Precambrian wrench fault. Also, the eight-directional fracture pattern at San Manuel (Wilson, 1957) corresponds very closely with the first-, second-, and third-order shear directions.