Arizona Geological Society Digest, Volume X, March 1976

ELEMENTS OF PALEOZOIC TECTONICS IN ARIZONA

by

H. Wesley Peirce

Arizona Bureau of Mines, Geological Survey Branch
University of Arizona, Tucson, Arizona

Abstract

Available evidence suggests that the Paleozoic Era in Arizona was notably deficient in severe deformational tectonism. Instead, regional characteristics of the Paleozoic sedimentary rocks indicate that they were affected and controlled by movements broadly classed as epeirogenic, which includes mild tilting, arching, and sagging. Movements tended to be repetitious in space often reflecting similar directional components, especially northeast, northwest, and northerly trends. The definable tectonic elements approximate the spatial distribution of younger, regionally prominent Laramide structures shown on contemporary geologic maps. Even Cenozoic trends reflected in the present physiographic margins of the Colorado Plateau province in Arizona are parallel to tectonic elements active during Paleozoic time.

Paleozoic tectonism might not have been dramatic, but it appears to hint at a connecting linkage between more conspicuous pre- and post-Paleozoic deformational tectonism. If true, this suggests that there is a thread of commonality that runs through the entire tectonic history of Arizona, a thread that perhaps warrants consideration when applying the "new" tectonics to Arizona.

The purpose of this presentation is to provide a brief summary of the highlights of the Paleozoic tectonic habit as discerned from a review of the Arizona Paleozoic general geologic record.

General Statement

Paleozoic time is usually cited as evidencing relative tectonic stability, a conclusion that stems from observations that Paleozoic rocks were not noticeably deformed (changed in form or volume) by Paleozoic events. What is evidenced are vertical movements that broadly can be classed as epeirogenic, which includes minor tilting, regional arching and sagging, and conventional non-distorting vertical adjustment.

The Paleozoic rock record is a record preserved in sedimentary rocks, rocks that owe their characteristics, compositional and geometrical, to tectonic influences. In Arizona, the evidence for Paleozoic tectonic adjustment tends to come from gross geometrical considerations because these are the manifestations most readily detected. There was Paleozoic tectonism and the record indicates that its general habit reflects fundamental patterns present in both pre- and post-Paleozoic

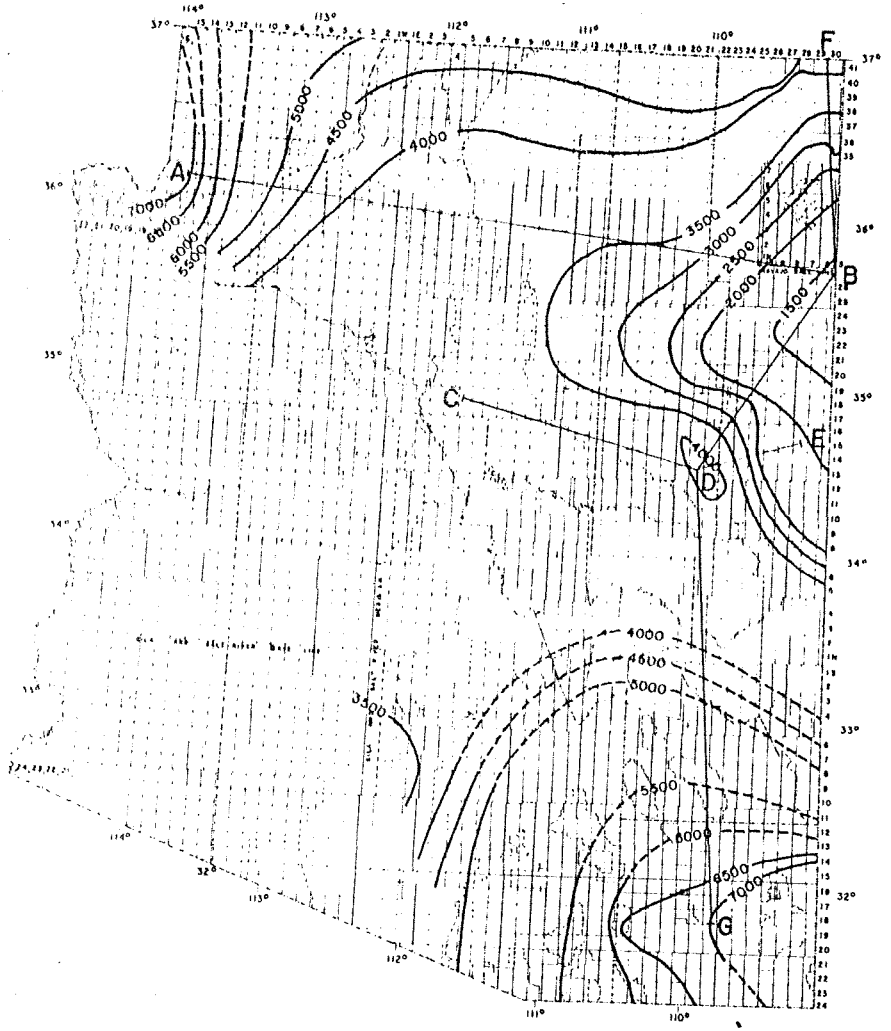

Figure 1. Total Paleozoic isopach map and index to thickness sections shown in Figure 2.

rocks, some of which are evident in major contemporary str ral subdivisions.

Nature of the Record

The Paleozoic Era occupies a time span of about 345 m.y. that begins at the close of the Precambrian about 570 m.y. ago and ends with the beginning of the Mesozoic Era about 225 m.y. ago. It is this time period that is so elegantly displayed in the walls of the geographically limited Grand Canyon. In Arizona, the Paleozoic rock record, as presently known, consists wholly of rocks that accumulated in sedimentary environments.

Although the Grand Canyon is noted for complete exposure of rocks representative of the Paleozoic Era, the remainder of the plateau is not so noted. Elsewhere, most of the plateau record, though complete, is buried beneath the surface where data are a by-product of unequally spaced exploration drilling (Peirce and Scurlock, 1972).

In contrast, the record in the Basin and Range region of the southwestern half of Arizona has been rendered incomplete largely by post-Paleozoic geologic events that have left the rock sequences not only in shreds but absent over much of the western and southwestern section of the state.

Discussion

The general geometry of the Paleozoic Erathem is shown in Figures 1 and 2. These strata reflect a thickness differential of at least 1,500 meters (5,000 feet). The maximum contrast occurs between the thicker sections of both the northwest and southeast corners and the thinner sections preserved in eastern Arizona between Canyon de Chelly and Springerville in Apache County. An analysis of this thinning suggests that over half, and perhaps more, should be attributed to Paleozoic tectonic manifestations. The remainder is the result of various combinations of thinning by onlap onto elements inherited from Precambrian events and erosion in late Paleozoic to Early Triassic time.

Figure 2 clearly shows that Pennsylvanian-Permian (upper Paleozoic) strata constitute from 50 to 100 percent of the Paleozoic Erathem whereas Cambrian-Mississippian (lower Paleozoic) rocks are relatively thin to absent over much of the state. Even though geologic subtlety renders a precise reconstruction of the tectonic history obscure, these significant differences are indicative of a contrasting Paleozoic tectonic history.

The larger regional Paleozoic tectonic framework includes: (1) the Cordilleran miogeosyncline in Nevada, (2) an adjacent shelf zone in northern Arizona, (3) a positive region in central and eastern Arizona, and (4) a basining tendency in southeastern Arizona extending northward from the Sonoran geosyncline and limited to the north and northeast by the shoaling and positive tendencies mentioned above.

In northwestern Arizona, the locale of more rapid thickening toward the miogeosyncline is often called a hinge line. The persistence of this feature, as well as its near-coincident position with the present boundary zone between the Basin and Range and Colorado Plateau provinces, is of fundamental tectonic significance (Moore, 1972, p. 58).

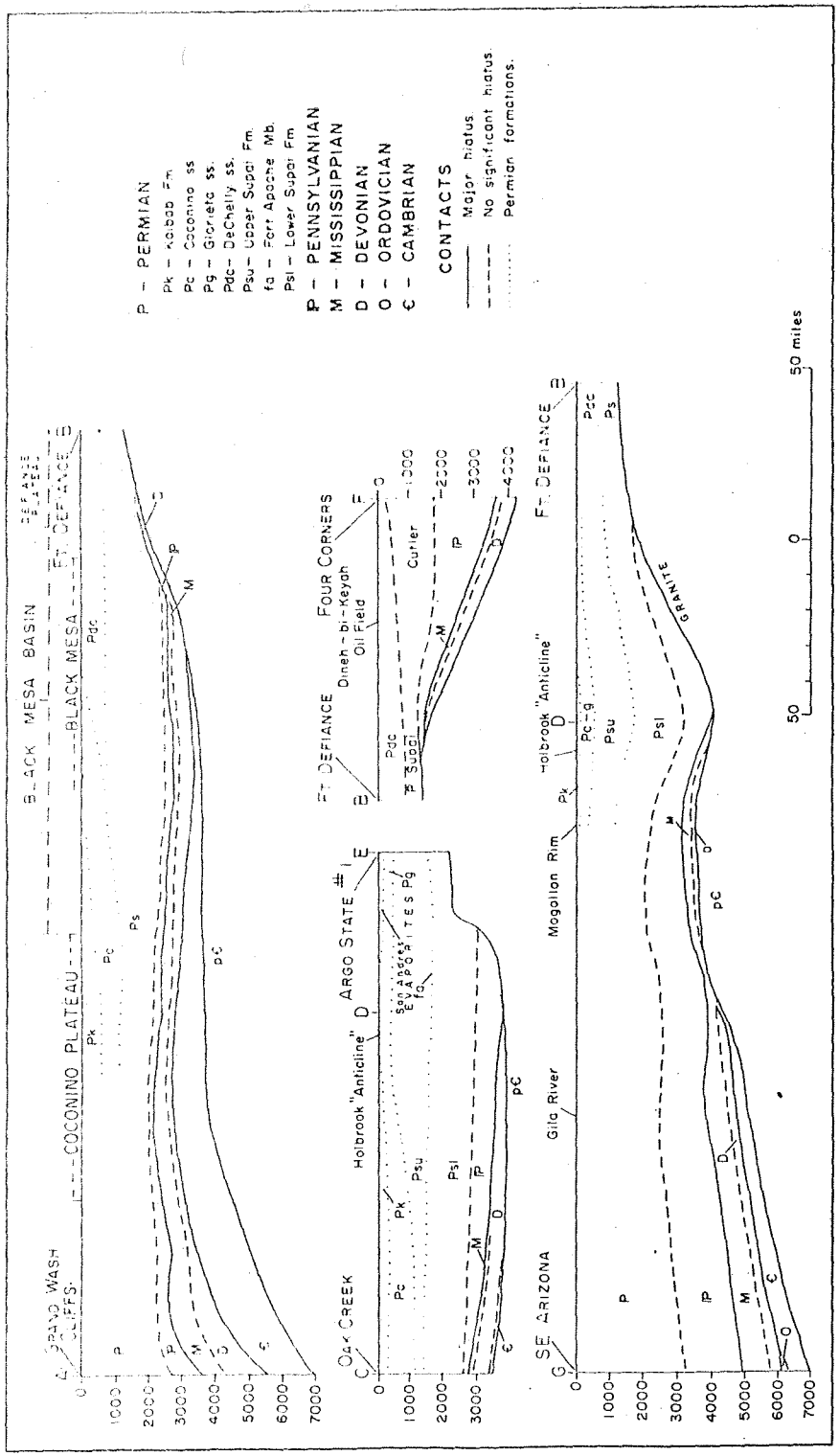

Figure 2. Thickness profiles of the Paleozoic strata of Arizona. See Figure 1 for orientation.

The positive and shoal region of northern, central, and eastern Arizona is frequently depicted as being a southwestward extension of the Transcontinental Arch (Eardley, 1963, p. 20; Lessentine, 1960, p. 97).

Lower Paleozoic

The early Paleozoic, for discussion purposes, is here defined as including Cambrian-Mississippian time. Flooring this relatively thin sequence is a profound hiatus that apparently represents more time than the Phanerozoic Eon of about 570 m.y. Also, within the sequence, there is a widely reported major hiatus between Upper Cambrian and overlying Upper Devonian strata such that Ordovician-Silurian strata are largely nonexistent in Arizona. Although the implications suggest a time break in excess of 100 m.y., the strata on either side of the hiatus appear conformable. The tectonic history of this hiatus constitutes a classic example in geologic subtlety. Was the Arizona region at relative stillstand or was significant depositional activity followed by epeirogeny and erosion? Subtlety stems from the remaining relatively thin stratal thicknesses that are spread over a large area combined with apparently conformable relationships, at least locally.

The "arching" sense of the so-called Transcontinental Arch is manifested by the geometry of Cambrian, Ordovician, and Silurian stratal distribution, in which both to the northwest into Nevada and to the southeast into New Mexico, the wedge-outs of succeedingly younger strata are farther from an inferred axial position in central Arizona. The gross relationship is that of offlap and/or erosion during the post-Cambrian–pre-Late Devonian interval. Whatever the details, this suggests early Paleozoic epeirogeny or mild warping along a northeast axis.

Cambrian. Cambrian strata wedge out to the east and southeast (Fig. 2, Sec. A-B; Fig. 3) along a N 55°-60° E trend in northern Arizona. These rocks are believed to be transgressive (McKee, 1969, p. 81) toward the southeast; thus, the wedge-out direction might be viewed as an element already present in Cambrian time that approximates the sedimentary strike. However, it is also possible that the wedge-out was erosionally adjusted in pre-Late Devonian time along reactivated trends that were present during Cambrian and earlier times.

The Cambrian of the southern province appears to occupy a south-plunging embayment. Assembling the pieces suggests a transgressive wedge-out to the northeast (Hayes, 1972) and onlap to the north (Krieger, 1968, p. 25).

Another classic question relates to the age or ages of thin, generally unfossiliferous, often channel-filling, conglomeratic sandstones in central Arizona. These sandstones crop out between Salt River Canyon and Jerome along the general Mogollon Rim trend where they are overlain by Middle to Upper Devonian carbonates. Teichert (1965, p. 29), on the basis of Early to Middle Devonian plant fossils at one locality in Salt River Canyon, assigned a Devonian age to these basal Paleozoic channel sandstones of the region. However, in my opinion, the fossil data cannot legitimately be extended to these sandstones because the plants occur in a thin shale that directly overlies Precambrian rocks in an area where the channel sandstones are not immediately present. I believe that these sandstones are older than the shale and therefore could represent remnants of a stream system that connected pre-Early Devonian (Cambrian?) seas with a granitic source not far distant to the east.

Wedge-out toward the northeast of lower Paleozoic strata of the southern region is of interest because it helps to define the geometry of

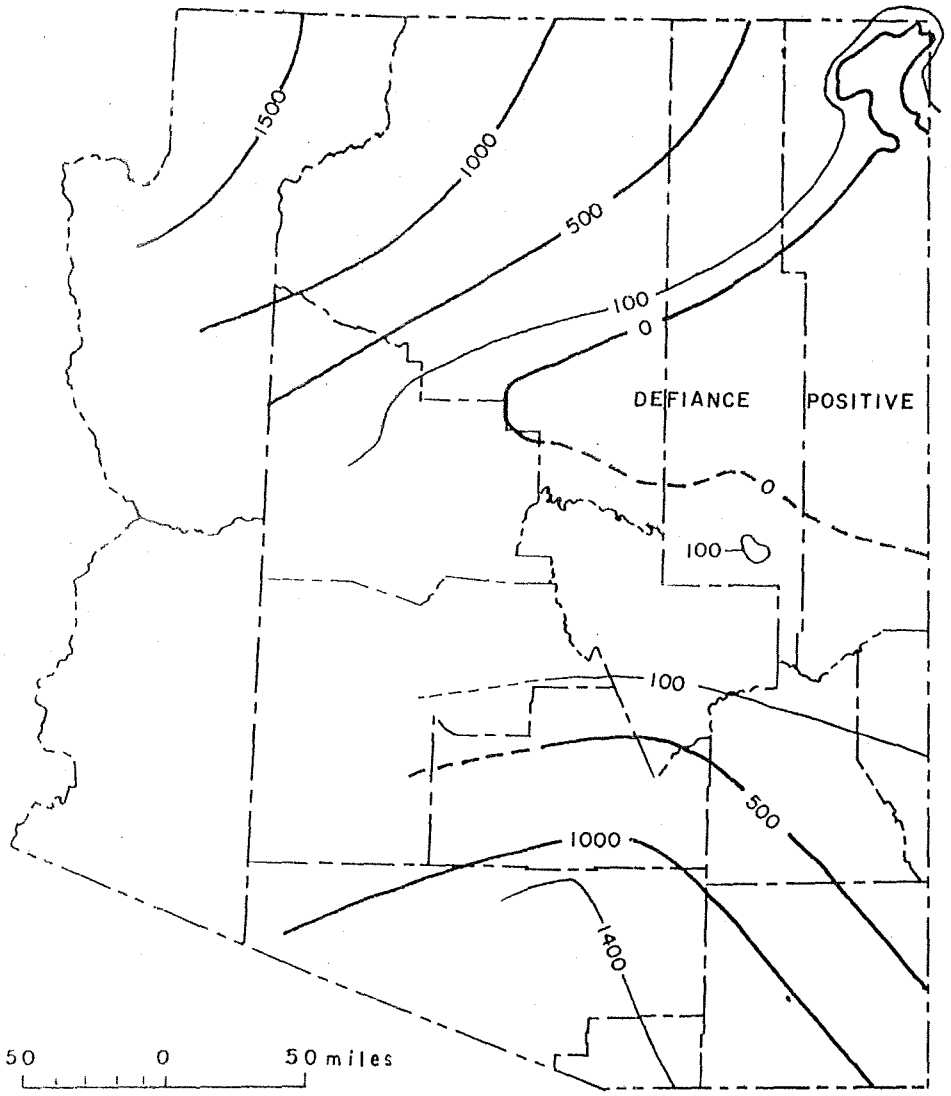

Figure 3. Generalized isopach of the Cambrian System.

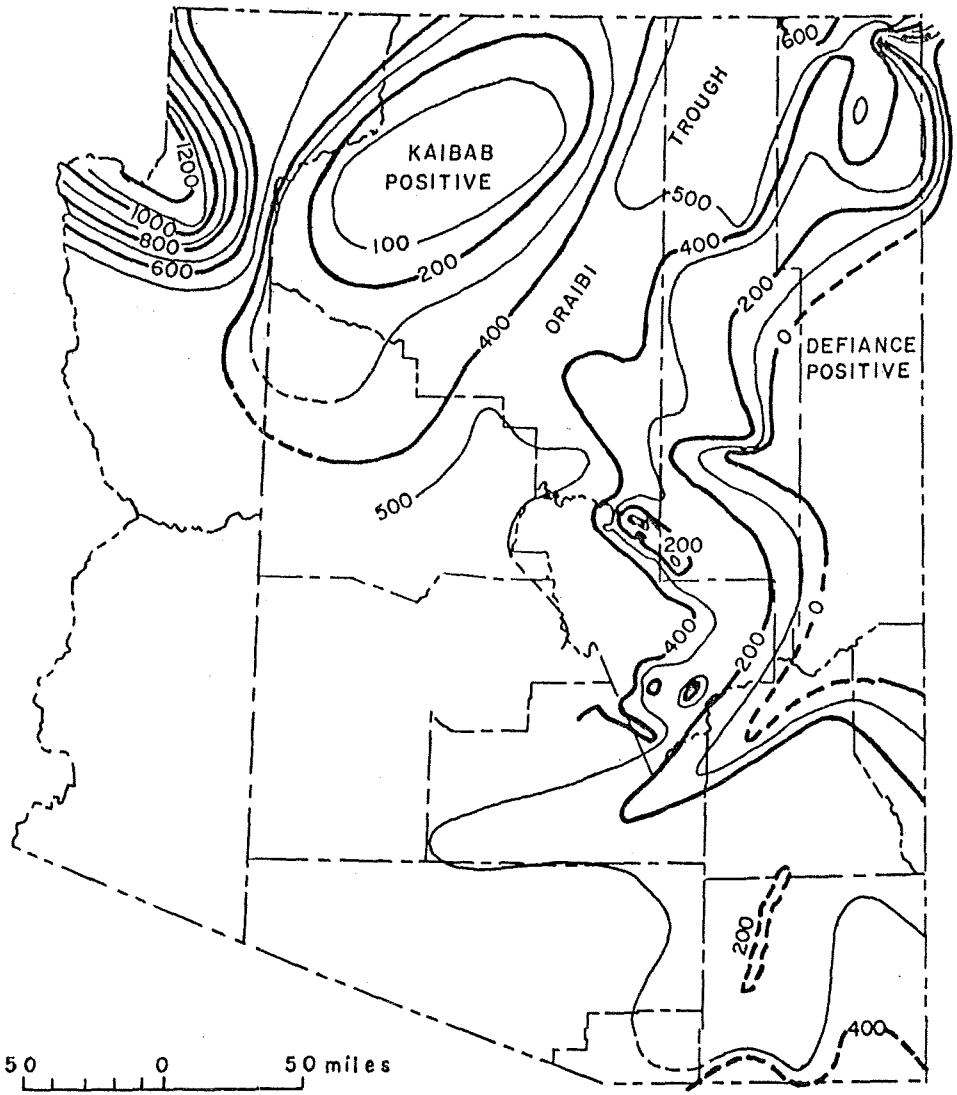

Figure 4. Generalized isopach of the Devonian System.

the structurally high element in east-central Arizona that has come to be known as the Defiance Positive area (McKee, 1951, p. 484). This northwesterly edge trend, combined with the southwesterly edge trend in the more northerly region, defines a nose that tends to close in central Arizona. This expression of a northwesterly element also is of interest, although generally not emphasized, because it embraces a zone that approximates the Plateau-Basin and Range interface—the Mogollon Rim of east-central Arizona. The record in southwestern Arizona remains obscure, although meager evidence suggests that Cambrian seas may have been shoal in this region.

Ordovician. Ordovician strata are known in Arizona only in a north-south strip east of Willcox and south from Morenci. North of Morenci, these and other Paleozoic strata disappear beneath younger rocks and are believed absent beneath the Permian Supai Formation in a well section near Springerville in southern Apache County (Peirce and Scurlock, 1972, Well No. 376, p. 122). Eastward into New Mexico, Ordovician strata are thicker than Cambrian rocks, a reverse relationship suggestive of eastward migration of basin capacity. Too, the Cambro-Ordovician aspect of strata near the state line (Gillerman, 1958, p. 23; Hayes, 1972, p. 12) is supportive of such a hypothesis. A narrow southwestward projection from the Defiance Positive appears to have affected Devonian deposition (Fig. 2, Sec. C-D-B; Fig. 4). Perhaps this element, if real, was present as an earlier influence on Ordovician deposition.

Ordovician rocks have not been recognized in northern Arizona, although they are known a short distance to the northwest in Nevada. Ordovician strata are not known in either eastern or extreme southwestern Utah and Hintze (1963, p. 57) suggests that Silurian and Devonian erosion is a likely explanation for their absence.

Silurian. Silurian representation is unknown. Arizona is believed to have been emergent during this time, thus providing an opportunity for erosion of unknown proportions.

Devonian. Krieger (1968, p. 25) notes that Devonian strata overlie progressively older rocks (Ordovician to Cambrian) from the Chiricahua region westward to the Whetstone Mountains where the Cambrian section is thickest. From the Whetstones north to the Galiuro Mountains there is generally conformity on Cambrian strata that range in thickness between 800-1,300 feet. Before reaching Globe, still farther north, the Devonian rocks overlie Precambrian rocks. Krieger attributes some removal of Cambrian section to pre-Late Devonian erosion. Whether Ordovician and/or Silurian strata once extended into this region is not known.

Devonian strata, though relatively thin, are more extensively developed areally than are the Cambrian sedimentary rocks, especially in the plateau region. Too, they reflect a contrasting tectonic setting. Although wedge-out occurs in the Defiance Positive area, the zero line displays a more varied and complex geometry (Fig. 4). Whereas the Cambrian System records an overall wedge shape, Devonian strata begin to express features that might be considered incipient or ancestral to those mapped on the surface today. These rocks are 1,200 feet thick in extreme western Grand Canyon and thin eastward to 100 feet beneath the Coconino Plateau in the central Grand Canyon region. At the east edge of the Coconino Plateau, which is also the approximate west boundary of the Black Mesa Basin, they thicken into a trough (Oraibi Trough) before wedging out on the Defiance Positive area (Fig. 2, Sec. A-B; Fig. 4). The Laramide Kaibab Uplift of the Grand Canyon region, like the Laramide Defiance Uplift along the Arizona-New Mexico border, lends its name to a larger paleogeographic positive tendency in the Grand Canyon country. Although it is usually applied to Pennsylvanian paleogeography, it seems evident that the Kaibab area was inclusively active along a probable northerly trend in post-Cambrian-pre-Mississippian time. Similarly, the northeast-trending Devonian Oraibi Trough can be construed to reflect a negative tendency at least partially coincident with the Laramide (in part) Black Mesa Basin.

Relationships of Devonian rocks to the Defiance Positive area are more intricate and varied than those envisioned for the Cambrian. Overall, the Defiance Positive is elongate in a northerly direction, but, in detail, it reflects northwesterly oriented promontories, embayments or sags, and edges, as well as a suggested southwesterly extending promontory and a northeasterly trending northern edge that tends to parallel the Oraibi Trough.

In the central Mogollon Rim region, Devonian strata exhibit a distinctive southwest to northeast onlap relationship that is, in part, coincident with the present-day Mogollon Rim, both in position and trend (Teichert, 1965, p. 47). In the northwestern corner of Arizona, an embayment plunges approximately N 45°-50° W into adjacent Nevada. To the southeast, I interpret the existence of a low narrow protrusion extending S 60° W from the Defiance Positive. To the east of this suggested feature, Devonian strata are referred to the Morenci Shale and appear to have thicknesses on the order of 200 feet. However, to the west of this feature, a carbonate-bearing sequence ranges around 500 feet in thickness and is designated the Martin Formation.

It seems likely that there are diverse reasons for Devonian strata pinching against the Defiance Positive. North of the position of the Holbrook "anticline," Devonian rocks extend about 50 miles east of the inferred Mississippian zero edge where they are unconformably overlain by the Pennsylvanian section that, in turn, thins to the east above Precambrian crystallines. It seems likely that both Devonian and Mississippian strata were once more extensive and that their present zero edges were erosionally produced in Late Mississippian-Early Pennsylvanian time. South of the Holbrook "anticline" relationships are obscured by volcanic cover, but projections suggest that Mississippian rocks overlap Devonian strata toward the northeast. This, coupled with Devonian onlap toward the northeast, hints at non-depositional reasons for absence.

In the subsurface beneath the Holbrook "anticline" (a surface feature expressed by deformed Permian and Triassic rocks), the zero edges for Devonian and Mississippian strata are nearly coincident. These and other data yet to be developed suggest the existence of a fundamental northwesterly trending tectonic zone.

In southeastern Arizona there is a suggestion of a slight embayment that trends north to slightly west of north in eastern Cochise County (Fig. 4). This appears to coincide with the position of Ordovician strata in southeastern Arizona. Too, Schumacher (this Digest) reports mid-Late Devonian uplift that shifted late Late Devonian deposition toward the east.

Mississippian. Fledgling tectonic elements reflected in Devonian strata apparently are not widely duplicated by the Mississippian distribution. In gross fashion, the Mississippian resembles the Cambrian in that beneath the plateau surface the overall form is that of a wedge with a zero edge to the southeast against the Defiance Positive and an embayment in southeastern Arizona that pinches to the northeast against the Defiance Positive (Fig. 5). In the Plateau, the zero edges of both the Cambrian and Mississippian are in part nearly coincident. As in earlier times, the younger representatives of the period are to the northwest

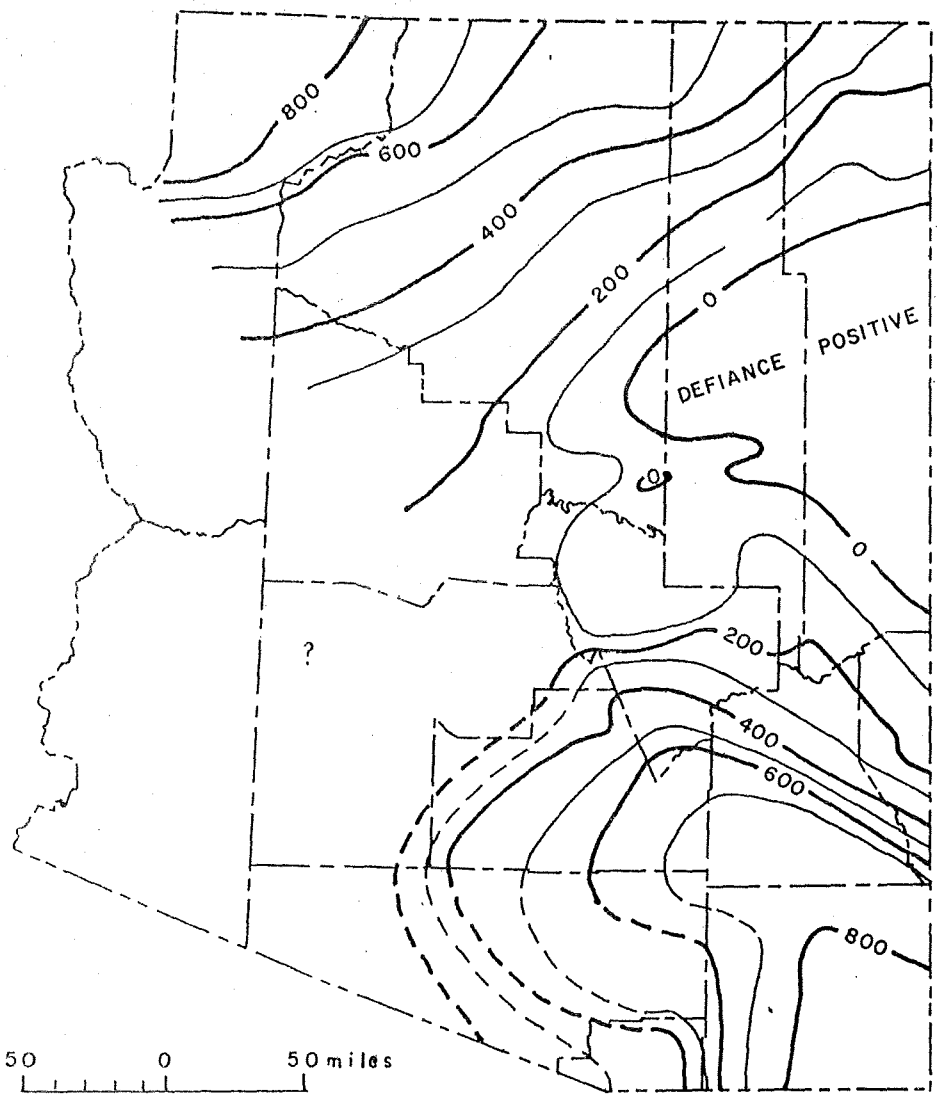

Figure 5. Generalized isopach of the Mississippian System.

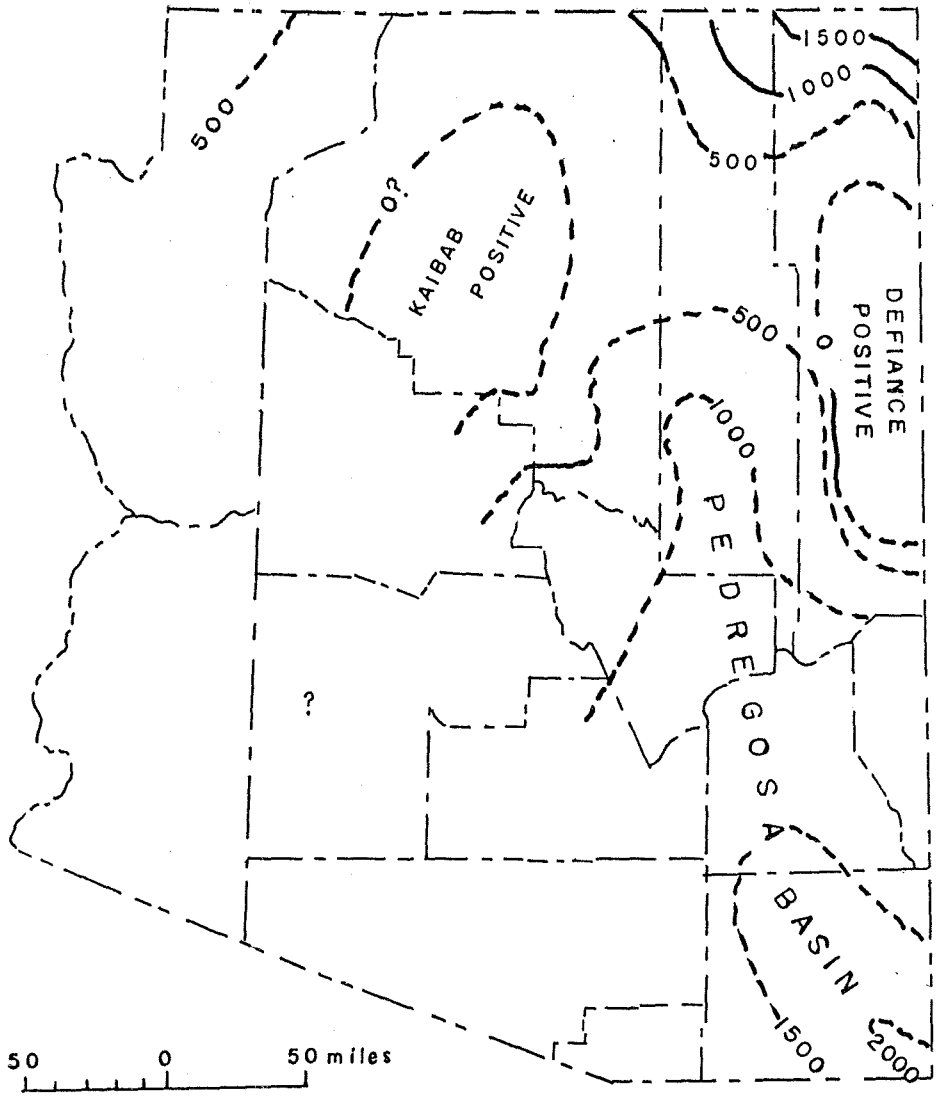

Figure 6. Generalized isopach of the Pennsylvanian System.

of Arizona and in extreme southeastern Arizona. In later Mississippian and earlier Pennsylvanian, most of Arizona is thought to have been emergent. This surface was subjected to subaerial processes in which carbonates were dissolved and an insoluble chert residuum accumulated, at least locally. Again, the tectonic habit, overall, is suggestive of epeirogeny. It is likely that Mississippian strata were stripped from some of the Defiance Positive as indicated by Devonian and Mississippian strata disappearing to the northeast beneath Pennsylvanian rocks of Missourian-Virgilian age. Lokke (1962, p. 84) demonstrates that Desmoinesian strata thin from Salt River to the northeast by non-deposition, an onlap relationship indicative of Late Mississippian to Early Pennsylvanian tectonic activity. The coincidence of the Devonian and Mississippian zero edges in the vicinity of the Holbrook "anticline" is suggestive of erosion. The expression "anticline" arises from considerations expounded by Bahr (1962, p. 118) and by Peirce and Wilt (1970, p. 72).

Upper Paleozoic

The tectonic history evidenced in Pennsylvanian-Permian rocks appears to be more varied and complex than that which preceded in the early Paleozoic (Fig. 2).

Pennsylvanian. Pennsylvanian strata range in thickness from about 2,000 feet to pinch-out on the Defiance Positive. The thickest sections occur in the Four Corners area and in the extreme southeastern corner of the state (Fig. 6).

The southern Arizona section accumulated in a north- to northwest-trending embayment that is usually called the Pedregosa Basin. It is thought to have plunged to the south or southeast with closure in the plateau subsurface in southern Navajo County. It is sharply limited to the northeast where well sections indicate that Pennsylvanian strata are in depositional contact with Precambrian crystalline rocks (Fig. 2). North and northwestward, the section thins, and carbonates and shales seem to give way to red-bed clastics that overlie Mississippian strata in the Jerome–Oak Creek–Grand Canyon area. This pinching or shoaling takes place on the Kaibab Positive. This feature contains a link with the Defiance Positive via a mildly negative saddle that trends east-west in central Navajo County. Fetzner (1960, p. 1375) defines a northwest lineament that extends from the Zuni Mountains of New Mexico through the Defiance–Kaibab region into southern Utah and calls it the Kaibab-Zuni uplift. He reserves Defiance for a northward projection from this lineament, a projection that is strikingly similar in geometry to the Laramide feature that we map at the surface today. The saddle is a less negative region that marks the northward termination of the Pedregosa Basin and also the southwestern end of a minor embayment off the Paradox Basin of southeast Utah. The overall tectonic configuration for the Pennsylvanian in the Arizona plateau region is, in some respects, similar to that envisioned for the Devonian Period.

The manner of Pennsylvanian thinning is an interesting and classic question. It has become customary in the Mogollon Rim area to have the marine shales and carbonates give way both northward and northwestward to red beds assigned to the Supai Formation such that an indefinite lower portion of the Supai is Pennsylvanian in age. This picture derives largely from the occurrence of Desmoinesian fusulinids beneath "red beds" at Fossil Creek to the west, whereas younger, Virgilian fusulinids underlie red beds to the east at Carrizo Creek south of Show Low. Although it seems clear that the youngest Pennsylvanian carbonates and shales are to the east, the overall explanation for this pattern might involve generally unrecognized unconformity and not just simple westward replacement of carbonates and shales by red-bed clastics. This question needs additional study. As indicated previously, Lokke (1962, p. 8) finds evidence of northward onlap of Pennsylvanian strata and says that "fusulinid data suggest that significant thinning of Pennsylvanian sediments must be recognized in addition to the previously described interfingering of red-bed clastics with Naco surface equivalents."

Also, Peirce and Wilt (1970, p. 61) point out that in an east-west direction, where the Pennsylvanian Naco is thickest, the Supai tends to be thickest but that to the south the Naco thickens where the Supai thins. However, this Supai thinning, for the most part, takes place within the upper Supai (above the Fort Apache Member) and therefore is not largely a result of interfingering of lower Supai with the Naco Formation.

Relative to this problem is another question that needs additional attention; it relates to the significance of widely distributed conglomeratic units that occur both in the upper Naco and the lower Supai as they are now defined. These generally have been called "intraformational," but more intensive research might reveal other possibilities that would assist the evaluation of the role of mild post-Desmoinesian–pre-Permian regional uplift or tilting and erosion of the Kaibab Positive and the subsequent spreading of thin, locally discontinuous conglomerates over a wide region of central Arizona. Within the conglomeratic zone of the Mogollon Rim region are carbonaceous, plant-bearing horizons. Work by Blazey (1971, p. 50, 53) on macro- and micro-botanical aspects suggests that the sediments are latest Pennsylvanian to Early Permian, most likely Wolfcampian in age. The larger sedimentary interval that embraces the conglomerates has been called the Oak Creek member by Jackson (1952, p. 144) and designated a Pennsylvanian part of the Supai Formation. However, the new data suggest the possibility that the Pennsylvanian-Permian boundary might be lower than general custom has tended to place it.

Heylmun (1958, p. 1790), in discussing the Kaiparowits region of southern Utah, says: "Since orogenic movements were taking place during the deposition of the Hermosa (roughly Naco equivalent), intraformational unconformities are numerous" and that "the most profound of these unconformities is the one at the base of the Permian. . ."

The east and west sides of the northern end of the so-called Pedregosa Embayment (Fetzner, 1960, p. 1375) are notably different (Fig. 2, Sec. C-D-E). To the west, the Naco Formation thins gradually above Mississippian strata, whereas to the east it pinches out relatively abruptly against Precambrian crystalline rocks. Between two drill holes about eight miles apart in southern Apache County, there is a loss to the east of an estimated 1,200 feet of Pennsylvanian-Permian section (Peirce and Scurlock, 1972, Well Nos. 362, 366). The nature of this structure is not known, but it is probably Late Mississippian–pre-Permian in age and might represent north-south faulting of the then west margin of the Defiance Positive. Closer spaced studies are required if additional details are to be gained. Pennsylvanian subsidence in the Rim region could have been asymmetrical such that offlap relationships developed from west to east, while onlap occurred to the north and east.

Pennsylvanian thinning from Four Corners southward onto the Defiance Positive (Fig. 2, Sec. B-F) is similar in style to that which takes place from east to west along the Mogollon Rim. In spite of notable thinning, in both cases the underlying Mississippian-Devonian strata tend to persist, suggesting that these rocks were not exposed above base level for any significant length of time during periodic Pennsylvanian

tectonic adjustments. The thinning of the Pennsylvanian section from the Paradox B[illegible] of southern Utah into the Black Mesa region of northeastern Arizona is thought to have been caused by marine offlap (Fetzner, 1960, p. 1408; Lessentine, 1969, p. 105) in response to movements on the Kaibab-Zuni northwest-trending lineament of Fetzner.

Pennsylvanian tectonic history in Arizona likely has facets in common with the tectonic history of the Uncompahgre region of southwestern Colorado, especially as regards the probable removal of pre-Pennsylvanian strata from parts of the Defiance Positive area (Elston and Shoemaker, 1960, p. 54).

Permian. The Permian System in Arizona is thicker than the rest of the Paleozoic combined. It contains a varied lithologic assemblage that is reflected in a relatively extensive stratigraphic nomenclature (Fig. 2). In broad aspect, the plateau Permian is a composite of lenses of regional extent which are composed largely of clastics but contain marine carbonates and evaporites. Red beds dominate the lowest three-fourths or so, but give way locally to interbeds of marine carbonates and evaporites (Supai Formation). Overlying these is a sequence of eolian sandstones (Coconino Sandstone to the west and part of the De Chelly Sandstone to the east). These sandstones are overlain by interbedded marine sandstones and carbonates (Toroweap-Kaibab formations to the west and south and Glorieta Sandstone and San Andres Limestone east of Holbrook). Permian strata are thickest (3,500 feet) near Holbrook and thinnest on the Defiance Positive (1,500 feet).

In the Basin and Range region, the Permian System consists largely of carbonate rocks that approach 4,000 feet in thickness (Butler, 1971, p. 72). This latter record is confined to the southeastern corner of the state. There is a gap of at least 100 miles in central-eastern Arizona where there is no known preserved Permian record between the southernmost outcrops of the Plateau Permian and the northernmost outcrops of the Basin and Range Permian (Fig. 7). Various authors have suggested tentative correlations across this gap, which, to reemphasize, is dominantly clastic to the north and dominantly carbonate to the south.

In the Plateau province, the change to a relatively thick clastic sequence during the Permian markedly contrasts with the carbonates that characterize much of the pre-Permian. This, combined with the tendency for major Permian units to pinch out, as well as the lithologic contrast with southern Arizona, is indicative of a relatively diverse and complex tectonic history during Permian time.

Some of the larger scale aspects of Permian stratal characteristics indicative of a diversity of tectonic activity include:

1. Inclusion of a widely scattered "red" chert-pebble conglomerate near the base of the Permian section in southeastern Arizona—the chert is believed to have been derived from chert characteristic of Pennsylvanian rocks north of the depositional region and south of the Mogollon Rim (Rea and Bryant, 1968).

2. Some of the thin, so-called intraformational conglomerates in the lower portions of the Supai Formation along the Mogollon Rim might actually be extraformational in origin (Brew, 1965; Finnell, 1966) and perhaps were related tectonically to the chert and limestone pebble conglomerates in the Basin and Range province. These latter conglomerates usually are within 100 feet or so above an inferred Pennsylvanian-Permian boundary as determined by fusulinid control in southern Arizona. Conyers (1975) presents additional data on Supai conglomerates.

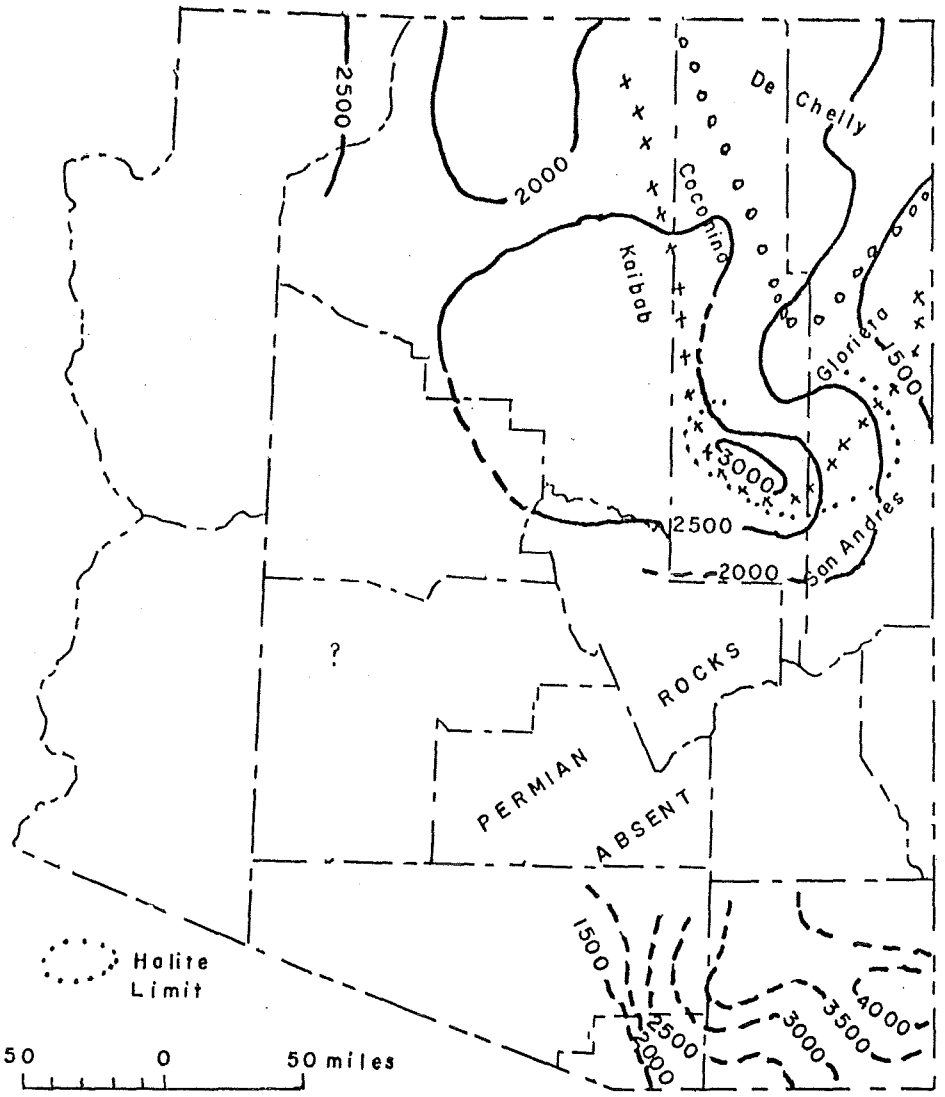

Figure 7. Generalized isopach of the Permian System.

3. Northwest isopachous trends within the Supai Formation cross the north[illegible]h trends of the Pennsylvanian.

4. The isopach trend of the Fort Apache Member of the Supai Formation, the southwest edge of the upper Supai evaporite basin, and the pinch-out of the Kaibab "Limestone" along the Holbrook "anticline" segment (Wilson and others, 1960), are all essentially northwest trends that parallel the southern edge of the Plateau province.

5. The Coconino Sandstone thins and undergoes facies changes to the east and southeast along the Mogollon Rim (Peirce and Wilt, 1970, p. 69).

6. De Chelly Sandstone pinches out in all directions; in particular, the entire type section, in outcrop, pinches out to the south along the Defiance Plateau (Peirce, 1967, p. 59).

7. The Supai Formation thickens internally by about 1,000 feet in the Holbrook Basin.

8. The Fort Apache sea transgressed northwest.

9. The Kaibab-Coconino-Glorieta-San Andres units pinch out in northeastern Arizona. This might involve Early Triassic erosion from a south-plunging arch (Fig. 2, Sec. A-B, C-D-E; Fig. 7).

10. The southern Arizona Permian section records intermittent transgression and regression and remote uplifting and clastic influx. Butler (1971, p. 74) states: "During Colina and Epitaph time, a seaway extended north to the Holbrook Basin." It is tempting to consider the Fort Apache Member as a tongue of one of the Basin and Range Permian formations, e.g., Colina Limestone (Winters, 1962, p. 88), but the form of the Fort Apache suggests west to northwest transgression from New Mexico (Gerrard, 1969, p. 176) not northward transgression from southern Arizona. This, along with the large area of no Permian record, tends to render such ideas rather casual and therefore debatable.

Two of the more extensive works dealing with Arizona Permian stratigraphy and tectonics (Baars, 1962; McKee, 1967) contain gross errors in correlation that lead to faulty conclusions. These fundamental inaccuracies have been pointed out elsewhere (Peirce and Gerrard, 1966, p. 5; Peirce, 1967, p. 60; Peirce and Wilt, 1970, p. 61; Peirce and Scurlock, 1972, p. 152).

One of the more basic problems is that Baars, and then McKee, misplaced over 1,000 feet of Supai stratigraphy because they failed to recognize the subsurface stratigraphic position of the Fort Apache Member of the Supai Formation relative to the principal Supai evaporite basin. Both workers place the principal evaporites beneath the Fort Apache Member when, in fact, they are unequivocally above it. This is important because the correct relationships emphasize post-Fort Apache (Leonardian) tectonism and place major Supai thickening at a time much later than is required to support the traditional unsubstantiated general concept that the Supai thickens as the underlying Pennsylvanian Naco Formation thins.

The Kaibab and Defiance positive areas were complexly influential during Permian time, especially as evidenced by stratigraphic manifestations in the Defiance region of northeastern Arizona. The story has yet to be assembled in detail, but it will vary with each worker's concept of stratigraphic correlation, both in outcrop and the subsurface. Part of the problem with the distribution of units that overlie the Supai Formation is the question of the influence of erosion beneath Triassic

sedimentary rocks. The time represented in this unconform[illegible]ncreases from west (Coconino Plateau) to east (central Defiance Plat[illegible]) with the hiatus containing both Late Permian and Early Triassic time. The present distribution of the Kaibab–San Andres, Coconino–Glorieta, and De Chelly units beneath Triassic rocks (Moenkopi Formation and the overlying Shinarump Conglomerate Member of the Chinle Formation on the highest part of the structure) suggests a south-plunging arch that occupied much of the northern two-thirds of Navajo and Apache Counties and extended into Utah to the north and New Mexico to the northeast. The southern closure point of the Kaibab–San Andres, Coconino–Glorieta contact is the southeast end of the exposed Holbrook "anticline." Whether or not this larger feature should be considered a ramification of the Defiance Positive area is not clear, nor is it known if it was active in Late Permian time such as to have affected deposition and/or erosion.

In addition to the already mentioned concept of the existence of a source of limestone and chert pebbles south of the Rim, McKee (1934) and Baars (1962, p. 212) have suggested that the Older Precambrian quartzites of central Arizona served as sand sources for the Permian Coconino Sandstone of the plateau region to the north. If true, parts of central Arizona would have been dramatically positive in Coconino time. However, I do not believe that their basic concept is valid because the quartzites in question were nonporous before the deposition of the Devonian Martin Formation and probably even before the accumulation of the Younger Precambrian Apache Group sedimentary rocks. As such, these quartzites were not and are not sand makers because they were and are solidly cemented with secondary quartz. Sandstones of the Coconino Sandstone do not contain composite sand grains nor do the present clasts contain any hint of remnant secondary quartz. I think that the sands were derived from the real sand makers of this world, the crystalline rocks, especially granitic types that were probably not significantly exposed in central Arizona during Coconino time. In addition, these eolian sands were transported and deposited by winds blowing from northerly directions.

The extreme southernmost exposures of the largely clastic Supai Formation of the Plateau province indicate that the Pedregosa Basin, at least as a site of carbonate deposition during Permian time, was considerably south of its position during Pennsylvanian time. According to Butler (1971, p. 77), the axis of the Permian basin trended northwest through central Cochise County with positive or shoal regions to the northeast. Bryant (oral communications) suggests that relative highs along the Deming Axis of Turner (1962, p. 59) may have been undergoing erosion in at least Early Permian time. This axis is between the present south margin of the plateau and the axial position of the Pedregosa Basin in Permian time as envisioned by Butler. The full extent of its influence on stratigraphic continuity between the plateau region and southern Arizona in Permian time is not known. Tectonically, the suggestion is that, as during other parts of the Paleozoic, northwest trends were in effect, trends that tend to parallel whatever southern boundary is selected to separate the Plateau geologic province from the Basin and Range geologic province.

Details regarding the Permian history of northwest Arizona are presented by Bissell (1969). The "shelf to basin" transition, with the exception of the westward change from basal Supai (Pennsylvanian) red beds to marine carbonates, takes place in Nevada. McKee (1969, p. 85), in discussing the Supai Formation, makes reference to "a distinctive conglomerate that contains rounded pebbles of gray limestone and red siltstone and attains a thickness of as much as 14 m (45 ft) occurs throughout Grand Canyon at the base of the Wolfcamp rocks."

Conglomerates also are present in the lower part of the Supai Formation [illegible]k Creek Canyon south of Flagstaff and along the Mogollon Rim in central Arizona all the way to Whiteriver. As previously suggested, Supai conglomerates offer opportunities for additional research that could shed considerable light on Late Pennsylvanian–Early Permian tectonic activity in Arizona.

Conclusions

Considerable emphasis has been given to the relatively sharp north-south boundary between the Colorado Plateau and the Basin and Range provinces in northwestern Arizona and the relationship of this geologic boundary to Paleozoic stratal characteristics (Lucchitta, 1974, p. 351). It would seem as though considerably less emphasis has been given to the northwest so-called Mogollon Rim trend which marks the present southwest edge of the Colorado Plateau province in central Arizona. Although actual definition of a structural boundary with the Basin and Range province is debatable, it seems clear that numerous Paleozoic stratal trends are northwesterly and thus tend to parallel this structural grain. Also, Paleozoic highs and lows are notably quasi coincident with the major Laramide structural units expressed on the present plateau surface.

North, northwest, and northeast controls on sedimentation and erosion are most prominent. These directions, of course, are well manifested in the Precambrian history of Arizona (Wilson, 1962) and numerous authors ascribe many post-Precambrian tectonic trends to these zones of weakness that were established during Arizona's oldest recognized geologic history.

Much of the Paleozoic tectonic history is obscured by the absence of a preserved rock record. Nevertheless, enough is known to suggest that although the Paleozoic time interval is preceded and succeeded by severe deformational tectonism, sufficient manifestations show through to provide a connecting tectonic linkage with that which went before and after.

Epeirogeny appears characteristic of Paleozoic tectonics. The present plateau position reflects Cenozoic epeirogeny with exhumation of older tectonic features. However, this epeirogenic event, in Arizona, was not exclusively restricted to what we now call the Plateau province. This is to say that unilateral uplift of the plateau, so-called "Plateau uplift," is a "myth" (Shakel, 1975, p. 1265).

The present is the key to the past, or is it that, in the context of this paper, the past is guideline to the present? Although the "new" tectonics is both revolutionary and exciting, it seems sensible to ask that its application be sensitive to all that needs explanation. There was tectonism in Arizona during the Paleozoic Era. It seems reasonable to wonder as to why its geometry appears to contain similarities to that which preceded and that which came after.

References

Baars, D. L., 1962, Permian System of Colorado Plateau: Am. Assoc. Petroleum Geologists Bull., v. 46, no. 2, p. 149-218.

Bahr, C. W., 1962, The Holbrook anticline, Navajo County, Arizona, in New Mexico Geol. Society, Guidebook 13—Mogollon Rim region: p. 118-122.

Bissell, H. J., 1969, Permian and Lower Triassic transitio[illegible]m the shelf to basin (Grand Canyon, Arizona to Spring Moun[illegible]as, Nevada), in Four Corners Geological Society, Guidebook 5—Geology and natural history of the Grand Canyon region: p. 135-169.

Blazey, E. B., 1971, Fossil flora of the Mogollon Rim: unpublished Ph.D. thesis, Arizona State University, Tempe, Arizona, 169 p.

Brew, D. O., 1965, Stratigraphy of the Naco Formation in central Arizona: unpublished Ph.D. thesis, Cornell University, 230 p.

Butler, W. C., 1971, Permian sedimentary environments in southeastern Arizona: Arizona Geol. Society Digest, v. 9, p. 71-94.

Conyers, L. B., 1975, Depositional environments of the Supai Formation in central Arizona: unpublished M.S. thesis, Arizona State University, Tempe, Arizona, 85 p.

Eardley, A. J., 1963, Structural evolution of Utah, in Oil and gas possibilities of Utah, re-evaluated: Utah Geol. Mineral. Survey Bull. 54, p. 19-29.

Elston, D. P., and Shoemaker, F. M., 1960, Late Paleozoic and early Mesozoic structural history of the Uncompahgre Front, in Four Corners Geol. Society, Guidebook 3—Geology of the Paradox Basin Fold and Fault belt: p. 47-55.

Fetzner, R. W., 1960, Pennsylvanian paleotectonics of the Colorado Plateau: Am. Assoc. Petroleum Geologists Bull., v. 44, no. 8, p. 1371-1413.

Finnell, T. L., 1966, Geologic map of the Cibecue quadrangle, Navajo County, Arizona: U.S. Geol. Survey Map GQ-545.

Gerrard, T. A., 1969, Stratigraphy of the Fort Apache Member, Supai Formation, east-central Arizona, in Four Corners Geol. Society, Guidebook 5—Geology and natural history of the Grand Canyon region, p. 174-180.

Gillerman, E., 1958, Geology of the central Peloncillo Mountains, Hidalgo County, New Mexico, and Cochise County, Arizona: New Mexico Bureau of Mines and Mineral Resources Bull. 57, Socorro, New Mexico, 152 p.

Hayes, P. T., 1972, Stratigraphic nomenclature of Cambrian and Lower Ordovician rocks of easternmost southern Arizona and adjacent westernmost New Mexico: U.S. Geol. Survey Bull. 1372-B, 21 p.

Heylmun, E. R., 1958, Paleozoic stratigraphy and oil possibilities of Kaiparowits region, Utah: Am. Assoc. Petroleum Geologists Bull., v. 42, no. 8, p. 1781-1811.

Hintze, L. F., 1963, Summary of Ordovician stratigraphy of Utah, in Oil and gas possibilities of Utah, re-evaluated: Utah Geol. Mineral. Survey Bull. 54, p. 51-61.

Jackson, R. L., 1952, Pennsylvanian-Permian facies of the Supai Formation in central Arizona: Guide book for field trip excursions in southern Arizona: Arizona Geol. Society, p. 143-146.

Kriegel, M. C., 1968, Stratigraphic relations of the Troy Quartzite (youn Precambrian) and the Cambrian formations in southeastern Arizona, in Titley, S. R., ed., Southern Arizona Guidebook III: Arizona Geol. Society, p. 23-32.

Lessentine, R. H., 1969, Kaiparawits and Black Mesa basins: stratigraphic synthesis, in Four Corners Geol. Society, Guidebook 5—Geology and natural history of the Grand Canyon region, p. 91-113.

Lokke, D. H., 1962, Paleontological reconnaissance of subsurface Pennsylvanian in southern Apache and Navajo Counties, Arizona, in New Mexico Geol. Society, Guidebook 13—Mogollon Rim region, p. 84-86.

Lucchitta, I., 1974, Structural evolution of northwest Arizona and its relation to adjacent Basin and Range province structures, in Geology of northern Arizona, Part 1, Regional studies for Geol. Soc. America Meetings, Flagstaff, Arizona: p. 336-354.

McKee, E. D., 1934, The Coconino Sandstone—its history and origin: Carnegie Inst. Washington Pub. 440, p. 77-115.

_____1951, Sedimentary basins of Arizona and adjoining areas: Geol. Soc. America Bull., v. 62, p. 481-506.

_____1967, Arizona and western New Mexico, in Paleotectonic investigations of the Permian System in the United States: U.S. Geol. Survey Prof. Paper 515-J, p. 201-223.

_____1969, Paleozoic rocks of Grand Canyon, in Four Corners Geol. Society, Guidebook 5—Geology and natural history of the Grand Canyon region, p. 78-90.

_____1974, Paleozoic rocks of Grand Canyon, in Geology of northern Arizona, Part 1, Regional studies for Geol. Soc. America Meetings, Arizona: p. 119-154.

Moore, R. T., 1972, Geology of the Virgin and Beaverdam Mountains, Arizona: Arizona Bureau of Mines Bull. 186, University of Arizona, Tucson, 65 p.

Peirce, H. W., 1967, Permian stratigraphy of the Defiance Plateau, Arizona, in New Mexico Geol. Society, Guidebook 18—Defiance-Zuni-Mount Taylor region: p. 57-62.

_____, and Gerrard, T. A., 1966, Evaporite deposits of the Permian Holbrook Basin, Arizona, in Second symposium on salt, Vol. 1: Cleveland, Ohio, Northern Ohio Geol. Society, p. 1-10.

Peirce, H. W., and Scurlock, J. R., 1972, Arizona well information: Arizona Bureau of Mines Bull. 185, Tucson, University of Arizona, 195 p.

Peirce, H. W., and Wilt, J. C., 1970, Oil, natural gas, and helium, in Peirce, H. W., Keith, S. B., and Wilt, J. C., eds., Coal, oil, natural gas, helium, and uranium in Arizona: Arizona Bureau of Mines Bull. 182, Tucson, University of Arizona, p. 43-101.

Rea, D. K., and Bryant, D. L., 1968, Permian red chert pebble conglomerate in Earp Formation, southeastern Arizona: Am. Assoc. Petroleum Geologists Bull., v. 52, no. 5, p. 809-819.

Shakel, D. W., 1975, "Colorado Plateau uplift"—persisten th of Arizona geology (abs.): Geol. Soc. America Annual Me ngs, Salt Lake City, p. 1265.

Teichert, C., 1965, Devonian rocks and paleogeography of central Arizona: U.S. Geol. Survey Prof. Paper 464, 181 p.

Turner, G. L., 1962, The Deming axis, southeastern Arizona, New Mexico, and Trans-Pecos Texas, in New Mexico Geol. Society, Guidebook 13—Mogollon Rim region: p. 59-71.

Wilson, E. D., 1962, A résumé of the geology of Arizona: Arizona Bureau of Mines Bull. 171, University of Arizona, Tucson, 140 p.

_____, Moore, R. T., and O'Haire, R. T., 1960, Geologic map of Navajo and Apache Counties, Arizona: Arizona Bureau of Mines, University of Arizona, Tucson.

Winters, S. S., 1962, Lithology and stratigraphy of the Supai Formation, Fort Apache Indian Reservation, Arizona, in New Mexico Geol. Society, Guidebook 13—Mogollon Rim region: p. 87-88.