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PENNSYLVANIAN ROCKS OF THE MOGOLLON RIM AREA, ARIZONA

FRANK E. KOTTLOWSKI[1] and KAY C. HAVENOR[2]

Early Pennsylvanian strata rest unconformably on a karst surface of Mississippian limestones in much of the Mogollon Rim area in east-central Arizona. The Pennsylvanian-Permian boundary, in contrast, is within a broad zone of interbedded red beds and sparse nodular limestones somewhere in the lower part of the Supai Formation. Thicknesses of the Pennsylvanian are thus merely estimates, based on conjecture as to how much of the lower part of the Supai is of Pennsylvanian Age. To the northwest, and perhaps to the north, the lower, dominantly marine limestones of the Pennsylvanian, grouped in the Naco Formation, are progressively older beneath predominant red beds, being of Desmoinesian Age near Fossil Creek but of Virgilian Age along the Mogollon Rim near Salt River Canyon and Carrizo Creek.

North of a line drawn from Globe to Morenci, Pennsylvanian rocks crop out only along the Mogollon Rim and eastern reaches of Salt River, erosion apparently having stripped off most of the Paleozoic rocks in the intervening region. The relationships are complex in this area because of facies changes from the predominant limestone typical of the south in southeastern Arizona to the Supai-type red beds of the north. Reworked residual soil marks the Mississippian-Pennsylvanian contact. The lower Pennsylvanian is contained in the Naco Formation, consisting of nodular fossiliferous limestones interbedded with red beds; the upper Pennsylvanian is within the lower part of the red-bed sequence called the Supai Formation.

To the south, thick sections of Pennsylvanian rocks are exposed near Superior in Queen Creek Canyon and near Coolidge Dam of San Carlos Reservoir. Along Queen Creek Canyon, the Naco Limestone disconformably overlies the Mississippian Escabrosa Limestone (Harshman, 1939) or Redwall Limestone (Huddle and Dobrovolny, 1945), the name applied to the Mississippian rocks depending on whether the problem is approached from the south (Escabrosa) or from the north (Redwall). From 1,100 to as much as 1,390 feet of Pennsylvanian has been reported from this area, but the Pennsylvanian strata are overlain with deep erosional unconformity either by Tertiary conglomerates or by Tertiary dacite flows and tuffs. Northward from Queen Creek, the Naco Limestone is thinned by erosion and is absent at King's Crown Peak, where dacite flows overlie the Escabrosa Limestone. Southward, the Naco Limestone is in places only 200 feet thick beneath the Tertiary volcanic rocks and volcanic sediments.

The basal beds of the Pennsylvanian, 30 to 45 feet thick, are dark-red to purplish sandy shales and chert conglomerate, which appear to have been derived under karst conditions from the underlying Escabrosa Limestone and thus are, in part, a reworked regolith on the Escabrosa. Above are 40 to 45 feet of thin-bedded cherty light-gray to pink limestone that is overlain by conglomerate lenses. Rounded pebbles in the conglomerate are of jasper, quartzite, limestone, and schist, the percentage of schist pebbles increasing northward; this suggests a source from the north, where Precambrian rocks probably were exposed to erosion. This lower clastic sequence is similar in origin and lithology to the Molas Formation of the Four Corners region.

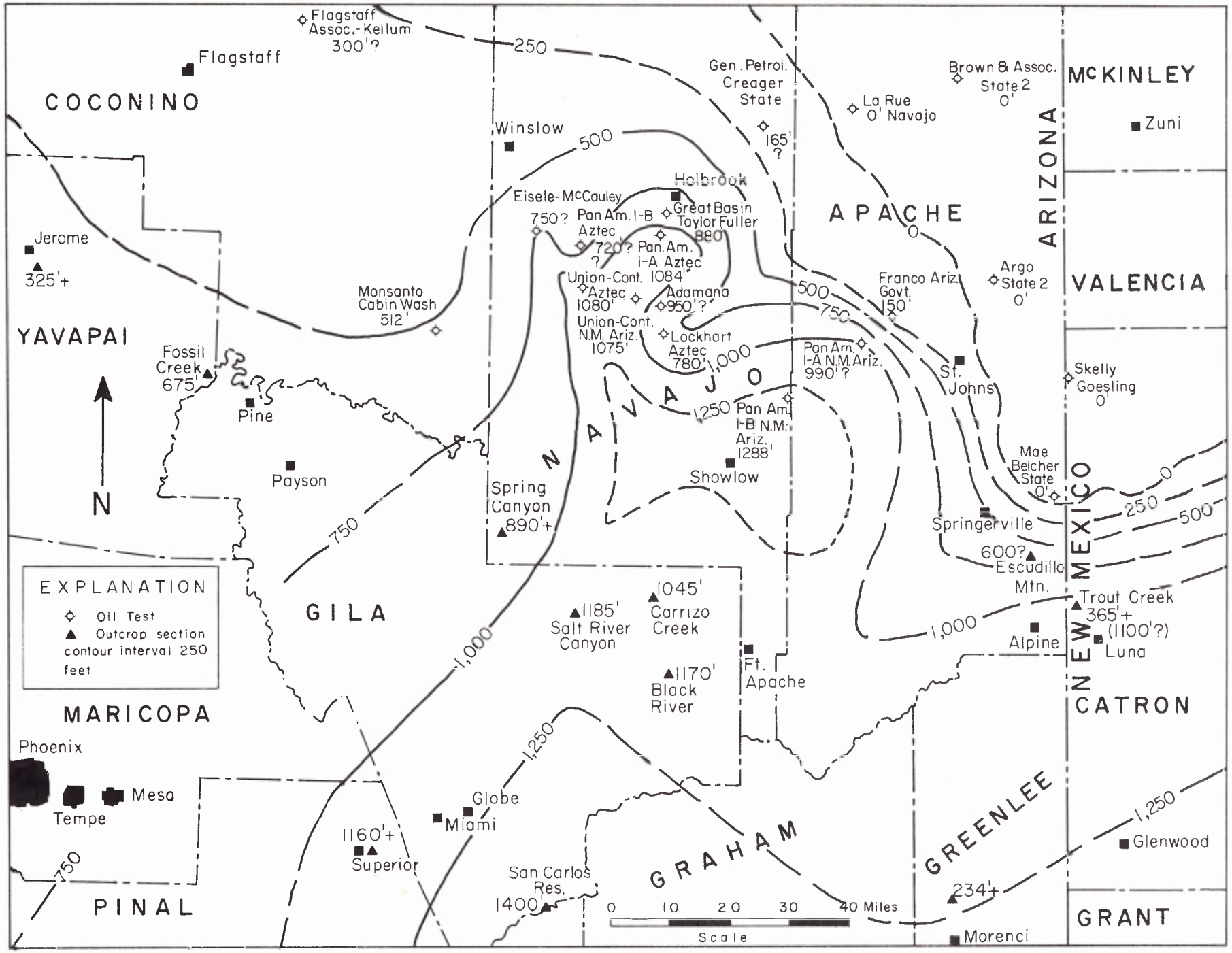
This Queen Creek Canyon section contrasts with the Pennsylvanian sections to the south (in southeastern Arizona) because of the large amount of clastic rocks. The lower 780 feet of the Pennsylvanian barely includes more limestone than siliciclastic beds and, therefore, could be termed a lithic equivalent of the Horquilla Limestone. The upper 390 feet of the section resembles the unit mapped as the Earp Formation in Cochise County to the south, with shales and sandstones more numerous than limestones, and with a relatively high percentage of sandstones. The amount of shaly nodular limestone and limy shale varies considerably along the strike, most of these beds being a hard to soft marl cementing lenses of fossil coquinas. Many of the beds have a reddish to pinkish tint, but the coloring is more pastel than to the north along the Mogollon Rim, where this type of bed is dark red, a coloring more typical of the Pennsylvanian Supai red beds.

The most complete section of Pennsylvanian rocks reported from the Gila River area was measured by Harold R. Wanless, Illinois University, east of Coolidge Dam of San Carlos Reservoir. The upper 155 feet of the measured section is of red shale and light-gray to brown sandstone. The highest fusulinids were found 250 feet below the top, the lowest fusulinids 1,310 feet from the top. There appears to be no distinctive break with the underlying Mississippian limestones, but the Pennsylvanian part of the section probably is about 1,400 feet thick. The beds dip about 30 degrees, and crop out as alternating ledges and slopes, the concealed intervals being deeply covered by slope wash and talus, preventing a complete picture of the lithology; thus it is not known whether the many concealed beds are nonresistant limestone, shale, siltstone, or sandstone. Trenching several of the thick concealed intervals with a shovel and pick revealed marly limestones and shales; namely, an intimate intercalation of pinkish limy shale and of nodular gray argillaceous limestone. The clastic rate (about 0.7) is considerably lower than that for the Queen Creek section (clastic ratio about 1) to the northwest, and higher than the Gunnison Hills section (clastic ratio 0.2) to the south.

North of Morenci, near the village of Granville, the Pennsylvanian is probably more than 235 feet thick (McKee, 1951) and is unconformably overlain by Tertiary volcanic rocks. Near Morenci and Clifton, a thin sequence of fossiliferous Late Cretaceous beds overlie Mississippian limestones with erosional unconformity. Possibly erosion during Tertiary and (or) Mesozoic times may not have cut so deeply into Pennsylvanian strata in some parts of the volcanic region of northern Graham and northern Greenlee Counties, so that there may be sizable areas north of Morenci wherein thick sections of Paleozoic strata are concealed beneath the volcanic rocks.

To the north along the Mogollon Rim, the Mississippian Redwall Limestone underlies the Pennsylvanian strata. In Spring Canyon along the upper reaches of Canyon Creek, the Redwall Limestone is only about 30 feet thick but thickens eastward to 210 feet in Salt River Canyon, thickens

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ISOPACH MAP OF PENNSYLVANIAN ROCKS IN MOGOLLON RIM AREA

westward to 280 feet south of Jerome (McNair, 1951), and thickens southward to 420 feet near Superior (Harshman, 1939). The top is a pronounced erosion surface, Huddle and Dobrovolny (1945) having reported relief of 30 to 50 feet in many places, with cavern breccia and fillings of reddish sandy silts locally extending through the entire Redwall Limestone.

Basal Pennsylvanian beds are reworked residual materials, red clays, silts, and cherts, typical of karst conditions that were prevalent in late Mississippian and early Pennsylvanian time. This karst residuum is more common than has been reported, Wanless (personal communication) having seen it in situ as far southeast as the Granville area, and Havenor (1958) reported chert conglomerate farther to the south, both east and west of Tucson.

Huddle and Dobrovolny (1945) measured many sections in a regional study of the Paleozoic rocks exposed in central Arizona; their material is the only relatively detailed published account of Paleozoic stratigraphy in the Mogollon Rim area. McNair (1951) reported on the Paleozoic rocks of the region to the west, Jackson (1951, 1952) studied the Supai Formation along the Mogollon Rim, and Winters (1948) measured sections of the Supai red beds near Fort Apache. Wanless (personal communication to Eldred Wilson, Arizona Bureau of Mines) measured many sections along the Mogollon Rim and near Salt River Canyon and collected fusulinids from significant horizons. Fetzner (1960) and Brown and Lauth (1958) used this published material, as well as data from oil tests north of the rim, to draw isopach maps of the Pennsylvanian of northwestern Arizona. Regional tectonics of the Mogollon "slope" were discussed by Kelley and Clinton (1960).

South of Jerome, McNair (1951) measured more than 300 feet (the top an erosion surface) of lower Supai red beds unconformable on the Redwall Limestone. Similarly, Anderson and Creasey (1958) reported a maximum of 370 feet of the lower Supai near Jerome and noted considerable limestone and limestone-breccia conglomerate amid the red siliciclastic beds. To the northwest, the lower part of the Supai red-bed facies intertongues with the upper part of the Callville Limestone, which has yielded Virgilian fusulinids; near Peach Springs the Pennsylvanian part of the Supai Formation is at least 325 feet thick.

Of considerable note is McNair's (1951) observation that crossbedding in the Supai in most places dips south or southeast, indicating that the currents bringing the sediments came from the north and northwest. Similar measurements made by McKee (1940), Hughes (1952), and Jackson (1952) showed south and south-southeast trends of crossbedding within the lower Supai of the Grand Canyon area northwest of Flagstaff and along the Mogollon Rim, but south and south-southwest trends near Ashfork about 50 miles west of Flagstaff. These data suggest that much of the Pennsylvanian lower Supai originated from the north, from the vicinity of the Kaibab uplift, a positive feature postulated by Heylmun (1958). The Kaibab uplift, with its highest points along the Arizona-Utah state line north of Flagstaff, may have been a northwest extension of the Zuni-Defiance arch, and appears to have been initiated in late Derryan (Atokan) or early Desmoinesian time. Intermittent uplifts during middle and late Pennsylvanian time are believed to have caused the cyclic deposits of the Hermosa Formation northeast of the Kaibab uplift, along the southwest border of the Paradox basin. The lower, Pennsylvanian-Age Supai red beds in the Jerome and western Mogollon Rim areas, that probably were derived by erosion of the Kaibab uplift, include a minor amount of limestone lenses, but are composed principally of quartz silt and calcite, stained by hematite — sediments suggestive of derivation from preexisting sedimentary rocks. McNair (1951) believed the Supai in the area west of Jerome to be shallow-water marine deposits; at least locally along the Mogollon Rim, part of the lower Supai red beds resemble some present-day delta deposits. The original sediments, rich in hematite, were either dumped so rapidly that the red pigment was not reduced, or the shifting of environments from shallow marine to delta and back did not permit significant reduction of the iron oxides.

Havenor suggests that deltaic beds are only a minor part of the Supai sequence, believing that the lower Supai red beds and carbonate rocks are predominantly shallow-water marine deposits, laid down in a shallow ephemeral sea — where a lowering of sea level by only a few feet may have exposed several hundred square miles of the sea bottom.

Separate studies by Havenor (1958), prior to publication of Heylmun's (1958) article, indicated the existence of the Kaibab uplift. It was a very low, gentle feature that perhaps was never extensively exposed to erosion. The Redwall Limestone appears to thin slightly in the area of the Kaibab uplift (George Thomas, personal communication), and the uplift probably caused the cyclic and reefoid deposits of the Hermosa Formation to the northeast. The uplift may have had more than local effects; it may have restricted waters coming directly from the west from the Cordilleran geosyncline, thereby assisting in the isolation of the Paradox basin during the time of salt deposition in early Desmoinesian time. The Kaibab uplift was a tectonic control on Pennsylvanian sedimentation throughout northern Arizona, as shown by the general thinning of the Paradox basin Pennsylvanian strata to the southwest, the lower Supai to the west, and then the Callville-Supai to the east, and the Naco-Supai to the north.

The Kaibab uplift may have resulted in a sequence of regressive marine deposits lasting through the remainder of Pennsylvanian time (post-early Desmoinesian) and into the Permian, with the effects of the uplift felt far to the southeast, to be lost only in the Pedregosa basin area of southeasternmost Arizona and southwestern New Mexico. Actual dating of the uplift does not appear to be possible, but it is feasible that the uplift may have taken place about the time the Manhattan geanticline was formed to the west. The scattered, isolated patches of Devonian strata preserved in parts of northern Arizona may suggest uplift in pre-Redwall time.

In their study of sections in central Arizona, Huddle and Dobrovolny (1945) divided the Pennsylvanian-lower Permian sequence into a lower, predominantly carbonate-rock unit, the Naco Formation, and an upper red-bed unit, the Supai Formation. The contact between the two formations was drawn by them at the horizon where the gradational sequence changed from one dominated by limestones and limy beds to a dominance of red-bed clastic rocks. They noted the northward and westward gradation of the upper limestones of the Naco Formation into the lower clastic beds of the Supai Formation, but the Pennsylvanian-Permian boundary appears in all cases to be within relatively unfossiliferous sequences of red beds.

The Naco Formation as designated by Huddle and Dobrovolny (1945) is 475 to 785 feet thick along the

Mogollon Rim, thickening eastward from Fossil Creek to Salt River Canyon. Where the Naco Formation is thick, as in Salt River Canyon, fusulinids ranging from Derryan to Virgilian in age were collected; at the thin section along Fossil Creek, the upper beds assigned to the Naco Formation yielded Desmoinesian fusulinids, the field relationships suggesting that westward the carbonate-rock Missourian and Virgilian beds intertongue with unfossiliferous Supai red beds.

The limestones of the Naco are for the most part aphanitic, dense, and light gray to tan, but in the upper part of the formation tend to be reddish, purplish, and greenish. The carbonate beds vary greatly in thickness within a few score feet along the strike; many are nodular, shaly, and silty, grading laterally in one direction into limy shale containing numerous limestone nodules, and into massive bioclastic limestone in the opposite direction. As in the Pennsylvanian limestones of the Gila River region, many nodules, lenses, beds, and stringers of chert, weathering pinkish to reddish brown, occur in the limestones.

Many beds of light-colored argillaceous nodular marls and limy shales are present and contain numerous fossiliferous lenses. The shales included in the Naco Formation are varicolored, ranging from almost white through shades of gray and green to pink, red, and purple; most of the shales are calcareous and silty, grading laterally into siltstone. Conglomeratic lenses are common, although not persistent along the strike, and consist of angular to subrounded pebbles and cobbles of limestone and siltstone in a shaly limy matrix, which in many places is a fossil-fragment hash.

Of interest to petroleum geologists, is the lithologic similarity of the Naco strata to the "Bough" zone in Roosevelt and Lea Counties of southeastern New Mexico. This zone produces oil from the Bluitt, Bough, and Allison fields and appears to have similar relationships to the Matador arch as the Naco has to the Kaibab and Zuni-Defiance uplifts.

Huddle and Dobrovolny (1945) reported a sequence of gray limestones that weather tan and contain fossils of late Desmoinesian Age. These limestones are silty and arenaceous, laminated to crosslaminated, thin bedded to nodular, and marked by nodular masses of brown limestone in which the centers are replaced by pinkish to reddish translucent chert. The thickness of the Pennsylvanian strata below this marker zone is almost constant in the area, ranging from 225 to 300 feet, the thicker sequence being to the west, not to the east, as would be suggested by the westward thinning of the Naco Formation facies.

The Supai Formation was divided by Huddle and Dobrovolny (1945) into three members, which are in part contemporaneous and grade laterally into each other, being more easily recognized by their topographic expression and color from a distance than by close examination of the outcrop. The lower member is 200 to 540 feet thick and is composed of siltstone, fine-grained sandstone, and shale, with some limestone interbeds; it crops out typically as a gentle slope broken by a few resistant ledges. The member ranges in age from Desmoinesian to perhaps as young as Wolfcampian, and interfingers with the underlying Naco Formation and overlying middle member. Contact with the middle member was drawn arbitrarily at the top of the highest bed of gray limestone, or at the base of the first massive bed of crossbedded sandstone.

Individual beds are highly irregular in thickness, varying as much as 12 feet within a lateral distance of several hundred feet. The limestones are for the most part silty, reddish, and nodular, containing reddish-brown chert nodules and lenses, as well as scattered coquina lenses. To the east, in west-central New Mexico, on the east and northeast sides of the Zuni-Defiance arch, red chert appears to be typical of the younger part of the Pennsylvanian (Roy W. Foster, personal communication), although it may occur sparsely in beds as old as Desmoinesian.

The shales of the lower member are intercalated with siltstones, are calcareous to highly limy, contain many limestone nodules, and vary in color from red and purple to green and gray. Sandstones are lenticular, commonly laminated, crosslaminated, and crossbedded on a small scale. They are mainly fine grained and silty; sieve analyses would probably classify many of the beds labeled sandstones as siltstones. The siliciclastic beds are calcareous and contain nodules and lenses of dense limestone and reddish chert. Whereas the weathered color is predominantly reddish, many of the sandstones and hard siltstones are gray, olive, and greenish gray on fresh fractures and in drill cuttings. Lenses of limestone-siltstone pebble conglomerate occur here, as in the underlying Naco Formation. Some of the beds are gypsiferous and contain numerous veinlets and laminae of recrystallized gypsum.

McKee (1951) and others have suggested that this part of the Supai, as well as its younger beds, were derived from the Uncompaghre uplift, far to the northeast. Rivers that carried red sediments southwestward from the Uncompaghre uplift, however, couldn't have crossed the seas that occupied the Paradox basin.

The middle member of the Supai is 250 to 400 feet thick and consists of dark reddish-brown siltstone, sandstone, and shale, which crop out as cliffs and steep slopes. The lithology is very similar to that of the Abo red beds of New Mexico. Apparently on the basis of plant fossils, the middle member is believed by Huddle and Dobrovolny (1945) to be of "Leonardian Age but may include Wolfcampian beds." The highest limestones of the lower member of the Supai red beds have yielded Virgilian fusulinids near Fort Apache, suggesting that the middle member of the Supai more likely is predominantly of Wolfcampian Age. Baars (1962) also correlated this part of the Supai with the Abo, and noted that the Abo red beds interfinger southward with marine carbonate rocks of Wolfcampian Age (Thompson, 1942, 1954; Kottlowski et al., 1956).

The upper member of the Supai Formation of the Mogollon Rim area is not present at the Supai type section in the Grand Canyon, thus Baars (1962) suggested restricting the term Supai to the lower, typical Supai strata. The upper member of the Supai of Huddle and Dobrovolny (1945) is correlated with the basal Meseta Blanca Member of the Yeso Formation and with the De Chelly Sandstone by Baars (1962), and appears to be of Leonardian Age. Pierce (1958) suggested that the De Chelly Sandstone thins southward from the Defiance Plateau due to a rapid lateral change to Supai lithology of the lower part of the De Chelly, and a thinning of the upper part.

Precise thicknesses of the Pennsylvanian or Permian cannot be calculated from the available data. Winters (1951) in his study of sections and fossils from the Fort Apache area concluded that the lower member of the Supai Formation, as measured by Huddle and Dobrovolny (1945) near Fort Apache, should be included in the Naco Formation, and raised the contact between the Naco and Supai

formations to the top of the highest fossiliferous limestone in which he identified Virgilian fusulinids (Jackson, 1952).

Jackson (1951) measured sections along the Mogollon Rim northwestward from Spring Canyon and called the lower member of the Supai red beds the Packard Ranch Member, and the middle member of the Supai the Oak Creek Member. He correlated both the Packard Ranch and Oak Creek Members as measured along Fossil Creek with the upper part of the Naco Formation of Winters in the Fort Apache area, which was called the lower member of the Supai Formation by Huddle and Dobrovolny! Detailed mapping and tracing of outcrops — a difficult task in the rugged, wild country below the Mogollon Rim — appears to be the only way to solve the complex relationships of the interfingering red beds and carbonate rocks, and to determine the approximate location of zones. Whereas the units used by Huddle and Dobrovolny appear to cross time planes, the best approximation to be gained from the available data is to consider the lower member of the Supai as uppermost Pennsylvanian, as it is near Fort Apache, and calculate thicknesses and lithologic ratios on this basis.

Along Fossil Creek west of Pine, Huddle and Dobrovolny (1945) assigned 475 feet to the Naco Formation and 200 feet of strata to the lower member of the Supai. Jackson (1951) measured 414 feet of the Naco Formation and 211 feet of the Packard Ranch Member of the Supai Formation. In this area, and eastward and southeastward to Pine and Payson, even the beds assigned to the Naco Formation are dominantly clastic rocks. The basal 10 to 40 feet is of reddish sandy shale and chert breccia unconformable on karst Redwall Limestone. The rest of the Naco is chiefly of red to gray limy siltstone and fine-grained sandstone, with a few interbeds of gray to pink, arenaceous limestone. Huddle and Dobrovolny's (1945) marker zone of Desmoinesian strata is about 100 feet below the top of the Naco, and consists mainly of limy siliciclastic beds with nodules of silty brown limestone and red chert.

To the east, near and along Salt River Canyon, Pennsylvanian beds are crossed by the field conference route in the upper reaches of Salt River Canyon and along Carrizo Creek. The Naco Formation thickens eastward in this area, being 530 feet thick along Spring Canyon, 770 feet thick in Salt River Canyon, 745 feet thick along Carrizo Creek, and 785 feet thick along Black River near its junction with White River. Desmoinesian and older Pennsylvanian rocks, however, appear to thicken only slightly in a southeastward direction, being about 375 feet thick along Fossil Creek, 390 feet along Spring Canyon, and 440 feet along Salt River and Black River. Thinning of beds in the Naco Formation to the northwest is almost entirely in the post-Desmoinesian sequence, and this thinning is mostly due to lateral and upward interfingering with Supai red beds.

Along Spring Canyon, beds assumed to be of Pennsylvanian Age are more than 890 feet thick, have a clastic ratio of nearly 3.3, and a sand-shale ratio of 0.24. This contrasts with the Fossil Creek section's clastic ratio of about 5 and sand-shale ratio of about 0.2. To the southeast, along Carrizo Creek, possible Pennsylvanian strata are about 1,045 feet thick, have a clastic ratio of 3.6, and a sand-shale ratio of 0.13. On the north edge of Salt River Canyon, the Pennsylvanian rocks as interpreted by Huddle and Dobrovolny (1945) and by Harold R. Wanless (personal communication), are 1,115 to 1,185 feet thick; the clastic ratio is about 2 and the sand-shale ratio 0.08. Along Black River, the Naco Formation and lower member of the Supai total 1,170 feet thick; they have a clastic ratio of 1.2 and a sand-shale ratio estimated as 0.12.

Again, in the Salt River Canyon and Carrizo Creek area, the basal Pennsylvanian is of red sandy shale and chert breccia derived from weathering and solution of the underlying Redwall Limestone. The lower third of the Naco Formation is gray to pink limy shale, with thin interbeds of silty argillaceous limestone, and sparse lenses of pebbly sandstone. The middle third of the unit, dated as Desmoinesian in age, is mostly gray calcareous shale with interbeds of gray cherty limestone and some red limy siltstone. These beds are marked by tan-weathering silty arenaceous limestone containing red chert, and by brown cherty limestone nodules amid the shale beds. The upper part of the Naco Formation consists of interbedded red to pink shales and gray limestone. The overlying lower member of the Supai Formation is chiefly red to gray siliciclastic rocks, with thin interbeds of gray to pink, siliceous silty limestone.

North of Salt River Canyon, and north of the south-facing scarp of the Mogollon Rim, Pennsylvanian strata are known only in the subsurface. Evidence of age is even more obscure in data from drill cuttings. The "Naco" and "lower Supai member" appear to be present in the oil tests drilled within the general area from Show Low to Holbrook, but again the exact Pennsylvanian-Permian boundary is unknown, being somewhere within the lower part of the Supai. Test holes drilled south of Holbrook reportedly found shows of oil and gas in the lower Supai and in the Naco Formation; however, a series of five oil tests by Pan American and Monsanto during 1959 failed to develop any producing zones, and were discouraging to petroleum exploration in the region. Three of the older test holes are interpreted by Huddle and Dobrovolny (1945) as having encountered 385 to 545 feet of the Naco Formation, with thinning to the northeast, and 495 to 590 feet of the lower Supai member, also thinning to the northeast. These possible Pennsylvanian beds are 1,080 feet thick in the Union Oil Co. and Continental Oil Co. Aztec Land and Cattle Co. No. 1, where they have a combined clastic ratio of 2.6 and a sand-shale ratio of 0.07. Some gypsum beds occur in the lower member of the Supai, as they do in the Union Oil Co. and Continental Oil Co. New Mexico-Arizona Land Co. No. 1, which penetrated a combined thickness of 1,075 feet of Naco and lower Supai, with a clastic ratio of 3.2 and sand-shale ratio also of 0.07. About 15 miles to the north-northeast, the Great Basin Oil Co. Taylor-Fuller No. 1 went through 880 feet of the Naco and lower Supai, which had a clastic ratio of almost 2 and a sand-shale ratio of almost 0.5; the changes reflect a decrease of shale to the north and increase of fine-grained sandstone.

Relatively thin sections of interbedded limestone and red beds, possibly of Pennsylvanian Age, were penetrated both to the west and to the east of this "Holbrook Gulf" in the Eisele McCauley No. 1 (750 feet?), Monsanto Cabin Wash No. 1 (512 feet), Adamana Oil Co. No. 1 (950? feet), and Kelly and Weiss (formerly Lockhart) Aztec No. 1 (780 feet). There is the possibility that part of the overlying red-bed sequence in these wells may also be of Pennsylvanian Age. The Pan American Aztec No. 1-A,

drilled about 7 miles south-southwest of Holbrook, encountered 1,084 feet of "Naco" but the Pan American Aztec No. 1-B, located about 14 miles to the west, penetrated only 720 feet of "Pennsylvanian" rocks. Southeast of Holbrook and northeast of Show Low, two oil tests abandoned in 1959 showed eastward thinning of the Pennsylvanian carbonate-rock section onto the Zuni-Defiance arch; the Pan American New Mexico-Arizona No. 1-B encountered (see isopach map) 1,288 feet of Naco, and perhaps considerably more Pennsylvanian rocks in the overlying thick Supai red beds, whereas the Pan American New Mexico-Arizona No. 1-A, about 15 miles to the northeast, cut only 990 feet of Naco. About 7 miles farther northeast, in the Franco-Arizona Government No. 1 test, the Naco is absent, and the lower member of the Supai is about 150 feet thick, resting on Precambrian granite. Thin red-bed Pennsylvanian or no Pennsylvanian rocks are reported from oil tests drilled up on the Zuni-Defiance arch in the General Petroleum Creager State, LaRue Navajo No. 1, Brown and Assoc. State No. 2, Argo State No. 2, and Mae Belcher State No. 1 in Arizona, and Skelly Goesling strat test (Foster, 1957) in New Mexico. The results of this drilling suggest that the Pennsylvanian and lower Permian strata lap onto the Zuni-Defiance arch from the southwest, but that the positive area had a relatively small relief as most of the shoreline clastic rocks are shales, calcareous siltstones, and silty limestones.

Similar abrupt thickening of the Pennsylvanian appears to occur on the south flank of the Zuni-Defiance arch along the New Mexico-Arizona state line. Any Pennsylvanian unit in the Mae Belcher State No. 1 is within unfossiliferous red beds overlying the Precambrian, and is thin if not entirely absent. About 12 miles to the south on the north side of Escudilla Mountain, however, poorly exposed Pennsylvanian strata crop out, broken by faults; they consist of interbedded reddish-brown shales amid massive to nodular fossiliferous limestones. Identification of fusulinids by Wendell J. Stewart, Texaco, Inc., suggests that the various fault slices are mostly of Missourian and upper Desmoinesian Age. Wrucke (1961) believed these rocks are xenoliths in andesite, although andesite, which locally overlies the limestones, was not seen beneath the Pennsylvanian rocks. He collected fusulinids that were identified by Lloyd G. Henbest as Virgilian to early Wolfcampian in age. Whether these limestones are scattered float blocks or huge xenoliths within the Tertiary andesite, or whether they are high remnants of prevolcanic outcrops does not matter in interpretation of the Pennsylvanian sedimentational history. They do suggest that a relatively thick marine Pennsylvanian sequence was deposited in the Escudilla Mountain area, and it should be present beneath the Tertiary volcanic and sedimentary rocks, at least locally.

To the southeast along Trout Creek in west-central New Mexico, similar but less faulted Pennsylvanian rocks crop out (Kottlowski, 1960). The partial section exposed is 350 to 400 feet thick, and consists of fossiliferous calcarenite and algal oolitic limestone, with minor interbeds of pink calcareous shale and brown lenticular arkosic sandstone. Fusulinids in the limestones are chiefly of Desmoinesian Age. The limestone was originally mapped by Robert H. Weber (Weber and Willard, 1959). The limestones appear to be in fault contact with andesitic-latitic rocks near the base of the Tertiary volcanic sequence; Weber believes the Pennsylvanian outcrop is a float block in the volcanic rocks, in parallel with relationships to underlying andesite of a smaller block four miles to the south-southeast. Although the beds dip somewhat steeply, they are relatively unbroken and are not baked or intruded by the igneous rocks, and no fragments of the Pennsylvanian limestones were found within the nearby volcanic outcrops.

If a similar partial section were found to the east on the southeast flank of the Zuni-Defiance arch, in the Magdalena-Socorro area, one could postulate 200 to 400 feet of early Pennsylvanian below the exposed section, and at least 300 feet (plus?) of late Desmoinesian, Missourian, and Virgilian strata above. The total Pennsylvanian section in the Trout Creek area, therefore, may be or may have been 1,100 or more feet thick.

The Pennsylvanian in this east-central Arizona region of the Mogollon Rim shows (1) thickening (see isopach map) and an increase in marine limestone to the south, (2) thinning and a facies change to calcareous red beds to the north and northwest, (3) abrupt thinning onto the Zuni-Defiance arch to the northeast and perhaps onto the Kaibab uplift to the northwest, (4) relatively uniform thickness of the Desmoinesian and older Pennsylvanian strata in the outcrop belt along the Mogollon Rim, (5) possible erosion of post-Desmoinesian limestones on the edges of the Zuni-Defiance arch or onlap of the Pennsylvanian strata onto the arch, with little or no deposition on the arch during late Pennsylvanian time, (6) existence of a north-trending "Holbrook Gulf" southwest of Holbrook extending southward to the thick marine section near San Carlos Reservoir, and (7) relatively fine-grained nearshore marine and minor deltaic deposits on the edges of the Zuni-Defiance arch and Kaibab uplift, indicating that these positive areas were lowlands, not mountains, and often may have been awash amid the shallow Pennsylvanian seas.

A connection with the San Juan basin between the Defiance and Zuni positive areas, as suggested by Wengerd (1962), may have been through shallow tidal channels barely beneath sea level; a similar connection northward from Holbrook into the Paradox basin of the Four Corners region, if it existed, also was probably an intermittent and ineffective marine passageway. Northwestward, the thin Pennsylvanian red beds grade into the thick Callville Limestone, a shelf facies on the flank of the Cordilleran geosyncline (Bissell, 1962). Southwestward, post-Paleozoic episodes of erosion have all but eliminated the record of Pennsylvanian sedimentation. To the south (Havenor, 1959), marine Pennsylvanian sediments are continuous (where not partly removed by post-Pennsylvanian erosion) into the Pedregosa basin (Kottlowski, 1962) of southwestern New Mexico and southeastern Arizona.

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