Stratigraphy of Outcropping Permian Rocks in Parts of Northeastern Arizona and Adjacent Areas

GEOLOGICAL SURVEY PROFESSIONAL PAPER 374-H

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By C. B. READ *and* A. A. WANEK

SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

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A discussion of the stratigraphy and correlation of Permian rocks in the northern part of the Zuni Mountains, Defiance uplift, and Monument Valley

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1961

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington 25, D.C. - Price 65 cents (paper cover)

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STRATIGRAPHY OF OUTCROPPING PERMIAN ROCKS IN PARTS OF NORTHEASTERN ARIZONA AND ADJACENT AREAS

By C. B. READ and A. A. WANEK

ABSTRACT

Rocks definitely or tentatively classified as Permian in age crop out in a number of uplifts in the Colorado Plateaus Province in northeastern Arizona and adjacent parts of New Mexico and Utah. This report specifically treats of these rocks in the Zuni uplift, the Defiance uplift, and the Monument Valley upwarp.

In the Zuni uplift, New Mexico, the sequence, in ascending order, consists of the Abo formation, the Yeso formation, the Glorieta sandstone, and the San Andres limestone. The Yeso formation is divided into the Meseta Blanca sandstone member and the San Ysidro member.

Thirty miles northwest from the northernmost outcrops of Permian rocks in the Zuni uplift, generally equivalent strata are exposed in Arizona in the southern part of the Defiance uplift. In ascending order this sequence consists of the Supai formation and the De Chelly sandstone. In tracing the sequence northward a lower tongue or member of the De Chelly sandstone appears and becomes progressively more prominent until in Bonito Canyon the two members merge to form the two-ledged De Chelly sandstone that is characteristic of the northern part of the uplift.

It is apparent that the Supai formation in the southern part of the Defiance uplift is the equivalent of both the Abo and the Yeso formations in the Zuni uplift and that the upper member of the De Chelly sandstone is correlative with the Glorieta sandstone. In the northern part of the Defiance uplift, however, the lower member of the De Chelly sandstone is equivalent to the upper part of the Yeso formation of the Zuni uplift.

The Permian sequence in the Monument Valley upwarp consists of the Rico formation, which in this particular area is very tentatively classified as Permian(?), overlain by the Cutler formation. The Cutler formation has been divided in ascending order into the Halgaito tongue, the Cedar Mesa sandstone member, the Organ Rock tongue, and the De Chelly sandstone member. Overlying the Cutler is the Hoskinnini member of the Moenkopi formation which is now classified as Triassic(?).

The Halgaito tongue, the Cedar Mesa sandstone member, and all the Organ Rock tongue except its uppermost beds are believed to correlate with the Supai formation of the Defiance uplift. The uppermost beds of the Organ Rock tongue appear to be equivalent to the lower member of the De Chelly sandstone in the Defiance uplift and the De Chelly sandstone member of the Cutler formation in Monument Valley correlates with the upper member of the De Chelly sandstone in the Defiance uplift. Available data suggest that the Hoskinnini may be Triassic (Moenkopi) in age but are inadequate to demonstrate it conclusively. In consequence, the Hoskinnini is classified as Triassic(?).

INTRODUCTION

In the spring and early summer of 1950 the writers undertook an investigation of the outcropping Permian rocks in northeastern Arizona, northwestern New Mexico, and parts of southern Utah. This work had as its specific objective the establishing of correlations of Permian rocks in the Zuni uplift, Defiance uplift, and Monument Valley upwarp. The determination of these relations, it is believed, will be of aid in the current activities of the Geological Survey in the Navajo Reservation which have as objectives the investigation of the mineral fuels and water resources of the area.

AREAS STUDIED

The three areas studied are uplifts in the Colorado Plateaus province (fig. 1). One of these, the Zuni uplift, is entirely in the State of New Mexico. The Defiance uplift lies along the New Mexico–Arizona line and is in both States, but the areas of Permian outcrop are mainly in Arizona. The Monument Valley upwarp lies athwart the Arizona-Utah line although the area in which Permian rocks crop out is mainly in Utah.

The Zuni uplift is an elongate structural dome that trends northwest and occupies parts of McKinley and Valencia Counties, N. Mex. The uplift is locally complicated by normal faulting, but at no point are these complications severe. A variety of plutonic, igneous, and metamorphic rocks considered to be of Precambrian age crop out in several areas in the core of the Zuni uplift. Permian(?) strata, or, locally, rocks of putative Pennsylvanian age, are disconformable on these old rocks (Darton, 1928, p. 137–142; Baker and Reeside, 1929, p. 1430–1433). On the southeast, east, and northeast flanks of the uplift these strata dip gently into

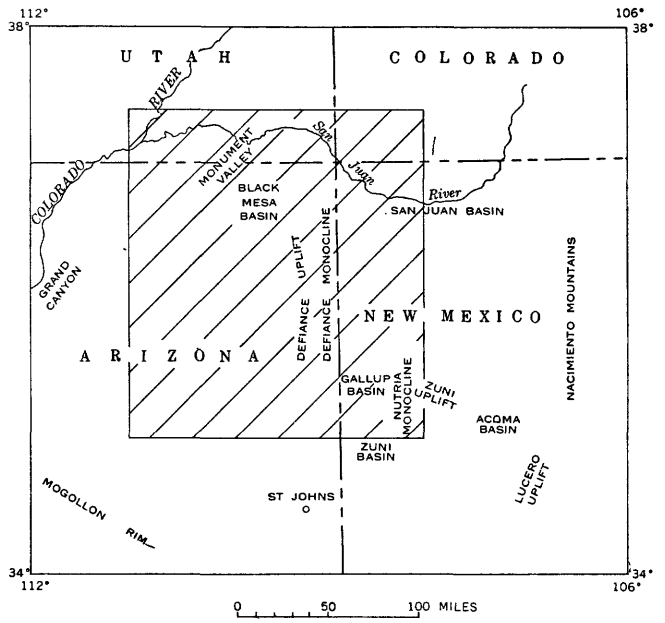

FIGURE 1.—Index map showing the location of features described in this report and the area shown in plate 1.

the Acoma and San Juan basins. On the southwest flank where the strata pass under the Gallup and Zuni basins, the dips are steep to vertical along an anticlinal bend that has been called the Nutria monocline.

The Defiance uplift is a great asymmetrical anticline that trends north-northwest through parts of Apache County, Ariz., and McKinley and San Juan Counties, N. Mex. Like the Zuni uplift, this fold is locally faulted, but the structural complexities are slight. The west limb of this anticline is moderately to gently dipping, but the east limb is steep and locally overturned. The anticlinal and synclinal bends of the east limb of the Defiance uplift have been termed the Defiance monocline. Rocks believed to be of Precambrian age are exposed in two canyons in the uplift and at both points are overlain by Permian strata. Higher Permian strata crop out over considerable areas (Darton, 1925, p. 85, 91, 207; Baker and Reeside, 1929, p. 1427–1428).

Monument Valley is part of a complex upwarp that lies in Navajo and Apache Counties, Ariz., and San Juan County, Utah. Steeply dipping strata flank the upwarp on the east and southeast; the dips on the north, west, and south are moderate. Minor folds complicate the structure and expose strata that range in age from Pennsylvanian to Jurassic. Permian strata are broadly exposed in the area and show remarkable lateral variations (Gregory, 1917, p. 19, 29; Darton, 1925, p. 207; Baker, 1936, p. 24–40).

NOMENCLATURE

The nomenclature for Permian strata here used follows to a considerable degree that proposed by Baker and Reeside (1929, p. 1441, 1445). Some modifications however, are suggested as a result of recent work. These are shown in table 1.

TABLE 1.—*Nomenclature of Permian strata in the Zuni uplift, Defiance uplift, and Monument Valley upwarp*

A. Zuni uplift, New Mexico

Baker and Reeside (1929, p. 1438)		This report		
Permian	Chupadera formation	Triassic		Lower part Shinarump member of the Chinle formation
		Permian		San Andres limestone
				Glorieta sandstone
			Yeso formation	San Ysidro member
				Meseta Blanca sandstone member
	Abo formation			Abo formation

B. Defiance uplift, Arizona and New Mexico

Baker and Reeside (1929, p. 1438)			This report		
Permian	Cutler formation	De Chelly sandstone member	Permian	De Chelly sandstone	Upper member
					Lower member
		Red beds [1]		Supai formation	

C. Monument Valley upwarp, Utah and Arizona

Baker (1936, p. 24–40) Baker and Reeside (1929, p. 1441)			This report		
Permian	Cutler formation	Hoskinnini tongue	Triassic(?)	Moenkopi formation	Hoskinnini member
		De Chelly sandstone member	Permian	Cutler formation	De Chelly sandstone member
		Organ Rock tongue			Organ Rock tongue
		Cedar Mesa sandstone member			Cedar Mesa sandstone member
		Halgaito tongue			Halgaito tongue
		Rico formation	Pennsylvanian and Permian (?)		Rico formation

[1] The name Supai was used in earlier reports but was not accepted by Baker and Reeside.

LOWER AND UPPER LIMITS OF THE PERMIAN SYSTEM

In the Zuni uplift the lower limit of the Permian system has been placed at the base of the Abo formation (see table 1*A*) although it is possible that the lowermost strata in this formation are locally Pennsylvanian in age. At some points in the Zuni uplift, a thin sequence of argillaceous limestone, shale, and sandstone beds underlies the Abo formation. These strata, although sparingly fossiliferous, have failed to yield material that will permit precise dating. Tentatively, they are assigned to the Pennsylvanian system.

The upper limit of the Permian system in the Zuni uplift has been a subject of some discussion. Darton (1928, p. 140–142) briefly described the sequence of rocks in the Zuni uplift and referred the Permian strata to the Manzano group, which consists of the Abo formation at the base and the Chupadera formation of former usage at the top. Above this group are strata that Darton (1928, p. 143) correlated with the Moenkopi formation. These are overlain by a conglomeratic sandstone that was identified as the Shinarump conglomerate, and this in turn is overlain by red beds assigned to the Chinle formation.

A year later, Baker and Reeside (1929, p. 1433) reviewed the sequence of rocks in the Zuni uplift and classified the strata that Darton had correlated with the Moenkopi formation as the upper part of the Chupadera formation of former usage. This assignment of the Moenkopi of Darton in the Zuni uplift to the Chupadera formation was based on the belief that inasmuch as the Moenkopi formation does not extend east of the vicinity of St. Johns, Ariz., it is unlikely that it is present in the Zuni area.

In 1941 the senior author reviewed the Zuni sequence and collected fossil plants from the unit called Moenkopi by Darton and referred to the Chupadera by Baker and Reeside. The species noted are identical with fossils collected from the Chinle formation at localities near Holbrook, Ariz., and described by Daugherty (1941). On the basis of this paleontologic data as well as on stratigraphic grounds that are outside the scope of this report, the rocks in question are here assigned to the Upper Triassic and are placed in the Chinle formation. The conglomerate identified as the Shinarump by Darton (1928, p. 143–144) and by Baker and Reeside (1929, p. 1433) is also assigned to the Chinle formation. A conglomeratic sandstone that is locally present but which was not earlier reported lies at the base of the Chinle formation and is now correlated with the Shinarump member of the Chinle in Arizona.

The upper limit of the Permian in the Zuni uplift is here placed at the top of the San Andres limestone. This accords with sequences farther east in New Mexico as well as those along the Mogollon Rim in Arizona (fig. 1) where the Kaibab limestone is the youngest formation of Permian age that is preserved (Darton, 1925, p. 96, 203).

There is general agreement regarding the upper and lower limits of Permian rocks in the Defiance uplift, Arizona and New Mexico. (See table 1*B*.) The lower part of the Supai formation is classified as Permian on stratigraphic grounds that are supported by meager paleontologic data. The upper limit of the Permian in this area is at the top of the De Chelly sandstone, as defined in this report, and below the Shinarump member of the Chinle formation. This accords with the opinion of Baker and Reeside (1929, p. 1427–1428). Strata referred to the Moenkopi by Darton (1925, p. 110) are now believed to occupy a part of the De Chelly sandstone interval, and therefore are Permian in age.

The writers believe that in the Monument Valley upwarp, Utah and Arizona, Baker's and Reeside's provisional lower limit of the Permian at the base of the Rico formation should be modified to the extent of classifying the Rico as Pennsylvanian and Permian(?). (See table 1*C*.) It must be stressed, however, that such an age assignation should be tentative inasmuch as the problem of the age range of the Rico formation and its lithologic correlatives does not appear to have been finally resolved in all areas.

The upper limit of the Permian according to Baker and Reeside (1929, p. 1422) and Baker (1936, p. 38–40) is at the top of the unit classified by them as the Hoskinnini tongue of the Cutler formation. They recognized an apparent disconformity between the Hoskinnini tongue and the Moenkopi formation. A result of the present investigation has been the identification of a disconformity at the base of the Hoskinnini. It is difficult to evaluate these two interruptions in sedimentation in terms of either a hiatus or a systemic boundary. The lithology of the Hoskinnini is generally similar to that of the Moenkopi, but the bedding structures are more similar, perhaps, to those in the Cutler formation. The authors believe that the Hoskinnini should be classified as a member of the Moenkopi formation but that the age assignment of the member should be questioned.

REGIONAL CORRELATIONS

The locations of the Permian sections that were examined are indicated on plate 1. The correlations are indicated by the line of sections on plate 2.

COTTONWOOD CREEK, NEW MEXICO, TO CANYON DEL MUERTO, ARIZONA

The sequence of Permian strata in the northern part of the Zuni Mountains, N. Mex., is illustrated on plate

2. These sections were measured at Cottonwood Creek (sec. 18) and in the vicinity of the settlement of McGaffey (sec. 17). At both points clastic strata that are assigned to the Abo formation at the base of the Permian sequence rest on metamorphic and plutonic rocks believed to be of Precambrian age. At Cottonwood Creek the contact is irregular, and the beds above it are coarse conglomerate. At McGaffey, similar conditions probably exist, although the strata at the contact are not well exposed. The Abo at the two localities ranges in thickness from 305 feet to approximately 790 feet but is similar in lithology. It consists of a monotonous sequence of alternating brown or brownish-orange fine-grained sandstone and arkose, several beds of limestone pellet conglomerate in one zone at Cottonwood Creek, and major intervals of siltstone. The basal contacts of sandstone on siltstone are commonly irregular, and bedding planes of the strata are marked by ripples, pits, mounds, and vague impressions of stems and leaves of terrestrial plants. The latter are characteristic of the Supai flora.

The basal strata of the Yeso formation rest evenly on the Abo formation in the Zuni Mountains and consist of a few feet of thinly bedded brownish-red siltstone that are overlain by 80 feet or more of intricately cross-laminated and lenticularly bedded sandstone. These strata, the few feet of siltstone and the overlying massive cross-laminated sandstone, constitute the basal member of the Yeso formation and are termed the Meseta Blanca sandstone member (Wood and Northrop, 1946). This member, coarse to medium grained at Cottonwood Creek (sec. 18) and fine grained to silty at McGaffey (sec. 17), is generally present in northern New Mexico. Analyses of directions of dip of foreset laminae indicate a preferred orientation toward the east or southeast, which is shown on figure 1. In the northern part of the Zuni Mountains the Meseta Blanca is overlain by 225 to 300 feet of evenly bedded fine-grained sandstone and siltstone of similar composition, interbedded with two or three thin layers of dense gray dolomitic limestone. At Cottonwood Creek the limestone beds have yielded poorly preserved specimens of *Dictyoclostus* sp. aff. *D. ivesi*. These evenly bedded brownish-orange clastic strata and the interbedded dolomitic limestone layers constitute the San Ysidro member of the Yeso formation (Wood and Northrop, 1946), which rests conformably and apparently gradationally on the underlying Meseta Blanca member.

Conformably overlying the San Ysidro member of the Yeso formation is a cliff-forming light-gray tangentially cross-laminated lenticularly bedded quartzose sandstone that has been correlated with the Glorieta sandstone, which is typically developed in north-central New Mexico at Glorieta Mesa (Read and others, 1945). Earlier reports (Read and others, 1945; Kelley and Wood, 1946; Wood and Northrop, 1946; Wilpolt and others, 1946; Wilpolt and Wanek, 1951) have classified the Glorieta sandstone as a member of the San Andres limestone in northern New Mexico. Although the Glorieta grades southward into beds of San Andres lithology the distinction between the two is so great that the authors consider the Glorieta sandstone a formation.

The Glorieta sandstone is 280 feet thick at Cottonwood Creek and is 300 feet thick at McGaffey. The foreset laminae generally dip to the southwest, as shown on plate 1. The Glorieta is, in turn, conformably overlain by gray medium- to thick-bedded porphyroblastic, dolomitic limestone beds that constitute the San Andres limestone. Like the Glorieta sandstone, this unit has been treated in the past as an unnamed member of the San Andres limestone (Read and others, 1945; Kelley and Wood, 1946; Wood and Northrop, 1946; Wilpolt and others, 1946; Wilpolt and Wanek, 1951), but is now recognized as formational in rank. These strata are as much as approximately 100 feet in thickness in the northern part of the Zuni Mountains, and are limited above by a very irregular erosional surface that is characterized by solution breccia, steep-walled buried depressions, collapsed blocks, and other features not unlike those observed in modern karst areas. The basal strata of the Upper Triassic rest upon this old and irregular surface with profound disconformity.

The sequence of strata at Black Creek (secs. 15 and 16) in the Defiance uplift, Arizona, is dominantly clastic and generally similar to that of the Zuni uplift. The pre-Permian core of the Defiance uplift is not exposed at Black Creek, and the oldest rocks are rather regularly bedded siltstone and sandstone that are chiefly brownish orange and are replete with so-called salt hoppers—sand casts and molds of halite crystals. Two thin beds of porphyroblastic, dolomitic limestone lie in the upper part of this sequence. Overlying these strata is a cliff-forming tangentially crossbedded gray to brownish-gray quartzose sandstone with foreset laminae inclined to the southwest in most places. The Permian sequence is truncated at this level by coarsely conglomeratic strata that are assigned to the Shinarump member of the Chinle formation of Late Triassic age.

The lower dominantly brownish-orange fine-grained clastic strata and interbedded dolomitic limestone of the Black Creek area are correlative with the San Ysidro member of the Yeso formation in the Zuni uplift. For geographic reasons, they are assigned, however, to the Supai formation (Hager, 1924, p. 167, 423; Darton, 1925, p. 85, 91, 207).

The overlying gray or brownish-gray quartzose sandstone in the Black Creek area is similarly correlated with the Glorieta sandstone in the Zuni Mountains and is classified as the upper member of the De Chelly sandstone, and the De Chelly is given formation rank. The names Glorieta and De Chelly are both firmly established in the literature, and the change from one to the other takes place in the subsurface. Therefore, no serious conflict arises from the use of the two names.

At Oak Springs (sec. 14), north of the Black Creek sections, the lower part of the Supai formation is overlain by approximately 95 feet of medium-grained highly crossbedded quartzose sandstone. This is the lower member or tongue of the De Chelly sandstone and is traceable northward throughout much of the uplift. The dips of foreset laminae in the lower member of the De Chelly are generally southeastward, in contrast with prevailing southwest dips in the upper member.

Overlying the lower member of the De Chelly sandstone are thickbedded and cross-laminated ledges of sandstone alternating with brownish-orange siltstone. This sequence, which is 235 feet thick, is regarded as an interfingering upper member of the Supai formation. Overlying it is a sandstone ledge that is directly traceable to the Black Creek sections where it is identified as all that remains of the De Chelly sandstone—the lower member having fingered out. It is thus apparent that northward along the Defiance uplift a lower tonguelike member of the De Chelly sandstone appears which fuses with the more persistent upper member farther northward, as will be indicated later.

At Hunters Point (sec. 13) the section is generally similar to that at Oak Springs. Geologic structure prevents measurement of the upper member of the De Chelly sandstone, but its presence was noted at the outcrop where it is similar in all respects to the sequence noted at Black Creek (secs. 15 and 16). As at Black Creek the Shinarump member of the Chinle formation rests directly on the irregularly eroded De Chelly sandstone.

North of Hunters Point, Permian strata are exposed at Bonito Canyon (sec. 12) in the vicinity of Fort Defiance. In that area quartzite classified as Precambrian crops out along Quartzite Creek and is overlain by the basal conglomerate of the Supai formation. Above this conglomerate are nearly 400 feet of fine-grained quartzose and feldspathic sandstone beds alternating with beds of siltstone. A limestone pellet conglomerate lens occurs locally in the sequence. The basal contacts of the sandstone on the siltstone beds are irregular, and laterally the strata show striking lenticularity. These strata are believed to be a part of the Supai formation and to be correlative with the lower parts of the sequences exposed at Hunters Point, Oak Springs, and Black Creek.

Above this sequence of irregularly bedded brownish-orange siltstone and sandstone are about 70 feet of evenly bedded brownish-orange siltstone beds containing salt hoppers or halite casts. These rocks are apparently correlative with the upper part of the lower member of the Supai at Hunters Point and Black Creek.

Beds of massive silty, fine-grained sandstone rest on the Supai formation with gradational contact. These strata are tangentially cross-laminated and grade upward into medium-grained quartzose sandstone that is also tangentially crossbedded. This sequence is approximately 270 feet thick and is believed to represent the lower member of the De Chelly sandstone. As indicated on plate 1, the inclined laminae generally dip southeast in sharp contract to the southwest dips of the laminae in the overlying sandstone. Above this massive sandstone is a thin but locally persistent layer of thin-bedded silty sandstone. An irregularly weathered cliff-forming sandstone that is tangentially cross laminated in very large lenticular beds overlies the thin silty sandstone. This cliff-forming sandstone is correlated with the upper member of the De Chelly sandstone in areas farther south. It is about 280 feet thick and is disconformably overlain by the irregularly channeling Shinarump member of the Chinle formation. The upper 80 feet of this sequence is medium bedded, and some silty layers are present. These strata have been interpreted by some geologists as possibly representing a remnant of the Moenkopi formation of Early Triassic age. There appears to be no field evidence that the strata are other than thinner bedded phases of the De Chelly sandstone.

At Buell Park (sec. 11) a few miles north of Bonito Canyon (sec. 12), the exposed sequence is similar to that just described. Irregularly bedded strata of the Supai formation are overlain by the De Chelly sandstone which is divided into a lower and an upper member.

Northwest of Buell Park, Permian strata are exposed at Canyon de Chelly where sections were measured in the walls of Monument Canyon (sec. 10) and Canyon del Muerto (sec. 9). At both places a thin interval of irregularly bedded conglomeratic strata that is assigned to the Supai formation is exposed in the floor of the canyons and is overlain by cross-laminated sandstone that was named the De Chelly sandstone by Gregory (1915, p. 102) from exposures in Canyon de Chelly. Both the lower and the upper members of the De Chelly can be recognized clearly at Monument

Canyon, and at Canyon del Muerto the identification is but slightly less certain. Contrasting dip directions of the cross laminae tend to confirm the identity of these two members.

CANYON DEL MUERTO, ARIZONA, TO NOKAI CANYON, UTAH

The Permian sequence in the Canyon de Chelly area is twofold. At the base of the exposed section in the walls of Canyon del Muerto as shown on plate 2, sec. 9, are irregularly bedded and highly variable clastic rocks of the Supai formation. These are overlain by the double-ledged De Chelly sandstone. The Shinarump member of the Chinle formation of Late Triassic age rests disconformably on this sandstone.

Northwest of Canyon de Chelly, Permian strata dip into the structurally depressed Black Mesa basin and reappear at the surface in the Monument Valley upwarp, approximately 64 miles distant. A partial section of the Permian is exposed at South Comb Ridge (sec. 8) in the southern part of the eastern side of Monument Valley. The oldest exposed strata are a few feet of the Cedar Mesa sandstone member of the Cutler formation. Resting on this is an alternating sequence of brownish-orange siltstone and thin sandstone beds about 590 feet thick that represents a part of the Organ Rock tongue of the Cutler formation. The remaining 110 feet of the Organ Rock interval are transitional strata consisting of an alternation of siltstone and silty sandstone. This Organ Rock sequence is overlain by a massive cross-laminated sandstone. In South Comb Ridge area the massive sandstone above the Organ Rock tongue is classified as the De Chelly sandstone member of the Cutler formation (Baker, 1936, p. 35–38), and is believed to correlate with the De Chelly sandstone in the Defiance uplift (Baker and Reeside, 1929, p. 1431; Baker, 1936, p. 35–38). Judging from the prevailing southwest dips of the inclined laminae, the correlation is with the upper member of the De Chelly in the Defiance uplift.

The De Chelly sandstone member is overlain by brown evenly bedded sandstone and siltstone beds containing scattered large and well-rounded grains. These strata are separated from the De Chelly sandstone member by a disconformity and are correlated with the Moenkopi formation.

Northwest of South Comb Ridge the De Chelly sandstone member thins rapidly, and a differentiation of minor units in the lower part of the Cutler formation is apparent. In Upper Gypsum Creek (sec. 7) the De Chelly sandstone member is about 200 feet thick and overlies 440 feet of brownish-orange siltstone and thin-bedded fine-grained sandstone. This, in turn, rests on a sequence of alternating gray sandstone, brownish-orange siltstone, and gypsiferous sandstone and siltstone. Lenses and platelike concretions of dolomitic limestone are present locally. In Upper Gypsum Creek the thickness of this lower unit cannot be measured. It is known, however, to overlie a brownish-red and brownish-orange unit which in turn rests on the marine Rico formation.

Baker has applied the term Organ Rock tongue to the dominantly brownish-orange silty unit that underlies the De Chelly sandstone member, and for the alternation of sandstone, siltstone, and gypsiferous strata underlying the Organ Rock tongue he has used the name Cedar Mesa sandstone member of the Cutler formation (Baker and Reeside, 1929, p. 1441; Baker, 1936, p. 33–35).

The upper part of the Permian sequence is well exposed in the buttes and mesas in the vicinity of Monument Pass in the central part of Monument Valley. At Wide Butte (sec. 6), where the sequence was measured, a few feet of brown irregularly bedded gritty sandstone that has been named the Hoskinnini tongue of the Cutler formation disconformably overlie the De Chelly sandstone member. The Hoskinnini tongue is, in turn, overlain with apparent disconformity according to Baker (1936, p. 38–40) by the evenly bedded brown clastic rocks of the Moenkopi formation. The Hoskinnini is now classified as a member of the Moenkopi but its age is Triassic(?).

The De Chelly sandstone member of the Cutler formation forms a vertical cliff in most of the buttes in this area and is 350 feet thick. It is a brownish-orange, tangentially cross-laminated, and medium-grained quartzose sandstone which rests with basal gradation on brownish-orange siltstone and sandstone beds of the Organ Rock tongue of the cutler formation. Inclination of the foreset laminae is generally toward the south. The Organ Rock grades basally into a sequence of alternating siltstone and gray or brown tangentially cross-laminated fine-grained sandstone beds of the Cedar Mesa sandstone member of the Cutler formation. The laminae show a preferred inclination to the southeast. A few thin beds of nodular and tabular limestone occur in this sequence which is 360 feet thick. The Cedar Mesa sandstone member, in turn, rests conformably and gradationally on the Halgaito tongue of the Cutler formation, which was not measured in detail at Wide Butte.

At the southeast point of Cedar Mesa, which lies north of the San Juan River in southern Utah, and in adjacent parts of Douglas Mesa (sec. 5) on the south side of the San Juan River, a section of the lower part of the Permian sequence was measured which supplements that observed at Monument Pass. The Cedar

Mesa sandstone member of the Cutler formation, which in the vicinity of Monument Pass as well as farther southeast is an alternation of gray sandstone and siltstone, grades laterally into a more massive facies and at Cedar Mesa is a virtually uninterrupted wall of gray cross-laminated fine-grained sandstone at least 420 feet thick. Inclination of the laminae is dominantly to the east. The Cedar Mesa sandstone member grades basally into 440 feet of brownish-orange siltstone, sandstone, and limestone beds that are assigned to the Halgaito tongue of the Cutler formation and that rest on the marine Rico formation. The Rico, in the great meanders or Goosenecks of the San Juan River, consists of about 335 feet of alternating calcareous sandstone, gray and red shale, and limestone that contain marine fossils that have reported affinities with Permian faunas (Baker, 1936).

The Rico formation rests conformably on alternating thick beds of limestone and thin beds of shale and sandstone which are believed to be the equivalent of the Hermosa formation. The Hermosa formation, both at the Goosenecks and to the east, contains marine fossils of Pennsylvanian age.

To the southwest of Douglas Mesa (sec. 5), Permian strata are broadly exposed. At Hoskinnini Mesa (sec. 4) near Oljeto Trading Post in the western part of Monument Valley, a section of the upper part of the sequence was measured.

At the top of the Cutler formation, as limited by Baker and Reeside (1929, p. 1422), are approximately 60 feet of sandy and gritty clastic beds that constitute the Hoskinnini tongue of the Cutler formation. According to Baker and Reeside (1929, p. 1422), these are separated from the overlying Moenkopi formation by a disconformity that marks a very considerable hiatus. The writers have noted a disconformity at the base of the Hoskinnini and accordingly question the classification of the Hoskinnini in the Permian. These strata are now regarded as the basal member of the Moenkopi formation and on the basis of available data are classified as Triassic(?).

The De Chelly sandstone member, which is 345 feet thick at Wide Butte, thins westward and at Hoskinnini Mesa is 250 feet thick. Inclination of the laminae is nearly due south. The De Chelly is locally disconformable on the Organ Rock tongue of the Cutler formation in this area but elsewhere the contact is gradational.

The Organ Rock tongue consists of characterstic red or brownish-orange siltstone and fine-grained sandstone beds that regularly alternate throughout an interval of about 440 feet. These strata overlie the upper beds of the Cedar Mesa member of the Cutler formation, which are alternating red siltstone and gray cross-laminated sandstone that contain calcareous nodules and tabular bodies.

The De Chelly sandstone member thins to the northwest at Monitor Butte (sec. 3) and is absent near the San Juan River at Piute Farms. Just south of the vanishing point of this member a section was measured. At the top of the sequence the Hoskinnini member of the Moenkopi is overlain by brown evenly bedded siltstone of the Moenkopi formation. The Hoskinnini rests sharply and with apparent disconformity either on the De Chelly sandstone member or directly on the Organ Rock tongue of the Cutler formation where the De Chelly is absent. The De Chelly sandstone member rests where present, on the Organ Rock tongue with a sharp contact. Sandstone dikes descend locally from the De Chelly and fill crevices in the Organ Rock tongue.

The Organ Rock tongue at Monitor Butte (sec. 3) is similar to the section exposed at Hoskinnini Mesa and at Wide Butte. It apparently grades basally into the alternating siltstone and gray sandstone beds that constitute the upper part of the Cedar Mesa sandstone member.

In the extreme western part of the Monument Valley upwarp, two sections provide information concerning the Permian strata as they dip westward under a broad, generally synclinal area. These sections are in the upper part of Copper Canyon (sec. 2) and at the mouth of Nokai Canyon (sec. 1) on the San Juan River.

In the upper part of Copper Canyon and at the mouth of Nokai Canyon, the Hoskinnini is overlain by the upper part of the Moenkopi formation. The contact relations are reported to be those of a disconformity (Baker and Reeside, 1929, p. 1422; Baker, 1936, p. 39–40).

The Hoskinnini member of the Moenkopi formation rests on the thin De Chelly sandstone member of the Cutler formation with a sharp and irregular contact and is locally disconformable on the Organ Rock tongue at both Copper Canyon and Nokai Canyon, as at Monitor Butte. The Organ Rock has a rather constant thickness (480 feet at Copper Canyon and 460 feet at Nokai Canyon) and a remarkably uniform lithology. At both localities it rests on alternating sandstone and siltstone beds that characterize the upper part of the Cedar Mesa.

GENERAL CORRELATIONS OF PERMIAN ROCKS IN PARTS OF ARIZONA, NEW MEXICO, AND SOUTHERN UTAH

It is, at present, impractical to establish general and reasonably final correlations of Permian strata in the Southwestern United States, but it is perhaps appro-

priate to make a limited and preliminary approach to the solution in a small area. Using the central and eastern part of the Navajo Reservation as a nucleus, the authors herein make general correlations over a somewhat larger area than those specifically studied in connection with this report.

CORRELATION OF THE SEQUENCE OF PERMIAN ROCKS IN THE ZUNI UPLIFT WITH THAT IN CENTRAL NEW MEXICO

The authors' opinions regarding correlations of the Zuni sequence with those exposed in the Lucero uplift and the Nacimiento Mountains (fig. 1) are shown in table 2. The suggestion that the San Andres limestone and the Glorieta sandstone in each of the three areas are generally equivalent sequences is based on comparison of the lithologic sequences and such limited paleontologic data as are available. Relations of the San Andres and the Glorieta indicate both vertical and lateral gradation. In general, the San Andres grades into the Glorieta sandstone in a northerly direction.

The Yeso formation in the Zuni uplift consists of the Meseta Blanca sandstone member and the San Ysidro member. These are substantially equivalent and similar in facies to the members of the Yeso formation in the Nacimiento Mountains to which these names were first applied. The Meseta Blanca sandstone member has also been recognized in the Lucero uplift where it is overlain by the Los Vallos member. The Los Vallos member, although lithologically dissimilar to the San Ysidro member, is tentatively correlated with it. No planes of disconformity or hiatus are believed to exist within the Yeso formation or between the Yeso and the Glorieta sandstone.

In the Zuni uplift, the Lucero uplift, and the southern part of the Nacimiento Mountains, the Yeso formation rests with a rather sharp contact on the Abo formation. This is a plane of possible disconformity and of regional angularity. However, it is not marked by a major hiatus, and despite the evidence for regional angularity, there is also some suggestion of regional lateral gradation. In fact, the entire Yeso, Glorieta, and San Andres sequence grades laterally into coarse clastic rocks of the Cutler formation in the northern part of the Nacimiento Mountains, and these cannot be readily separated from the generally similar rocks that constitute the Abo formation farther south.

CORRELATION OF THE SEQUENCE OF PERMIAN ROCKS IN THE ZUNI UPLIFT AND THE DEFIANCE UPLIFT WITH THAT EXPOSED ON THE MOGOLLON RIM, NAVAJO COUNTY, ARIZONA

Reconnaissance examination by the senior author, as well as a general acquaintance extending through several years, of the Mogollon Rim (fig. 1) sequence of Permian rocks has led to the conclusion that the Kaibab limestone of that area is correlative with the San Andres limestone of the Zuni uplift. The Coconino sandstone is equivalent to the Glorieta sandstone. The Yeso formation is generally correlative with the upper and middle members of the Supai formation, and the Abo formation is correlative with parts of the lower member of the Supai (Huddle and Dobrovolny, 1945).

Similarly, the upper member of the De Chelly sandstone of the Defiance uplift is equivalent to the Coconino sandstone and Kaibab limestone of the Mogollon Rim. The lower member of the De Chelly sandstone is equivalent to part of the upper member of the Supai formation. The Supai formation of the Defiance uplift is then correlative with the lower part of the upper member, the middle member, and the lower member of the Supai formation of the Mogollon Rim.

Problems of correlation of partly marine strata called the arkosic limestone member of the Madera formation (Read and others, 1945), the Red Tanks member of the Madera formation (Kelley and Wood, 1946), the lower part of the lower member of the Supai formation (Huddle and Dobrovolny, 1945), and the Rico formation of some areas (Baker, 1936) have not been satisfactorily resolved. All these strata represent transitions between marine and continental facies. Locally they may be Permian in part and elsewhere Pennsylvanian.

CORRELATION OF THE SEQUENCE OF PERMIAN ROCKS IN MONUMENT VALLEY, UTAH AND ARIZONA, WITH THAT IN GRAND CANYON, ARIZONA

The authors' general impressions are that the correlation of Permian rocks in Monument Valley with those of Grand Canyon (fig. 1) are not completely established. Baker and Reeside (1929) have suggested that the Cedar Mesa sandstone member, the Organ Rock tongue, the De Chelly sandstone member, and the Hoskinnini tongue of the Cutler formation coalesce into a single sandstone body. The upper part of this sandstone grades and tongues to limestone with the result that the Kaibab limestone and the Coconino sandstone can be differentiated. The lower part of the Supai formation is evidently correlative with the Halgaito tongue and perhaps a part of the Rico formation.

This correlation is quite reasonable, but it raises questions concerning the relations of the Kaibab limestone, the Coconino sandstone, and the Supai formation in the Grand Canyon with apparent equivalents on the Mogollon Rim. It appears more likely that the Coconino standstone and Kaibab limestone are equivalent to a part of or all the De Chelly sandstone member of the Cutler formation and that the Supai is equivalent to the Organ Rock tongue, the Cedar Mesa sandstone member, and the Halgaito tongue of the Cutler formation.

TABLE 2.—*Nomenclature and correlation of Permian sequences in parts of New Mexico, Arizona, and Utah*

[Equivalence is not necessarily implied in the Triassic and younger and Pennsylvanian and Permian(?) brackets when formations or members are placed opposite]

SYSTEM	Nacimiento Mountains New Mexico	Lucero uplift New Mexico	Zuni uplift New Mexico	Mogollon Rim Arizona	Defiance uplift, Arizona		Monument Valley, Utah and Arizona		Grand Canyon Arizona (east) (west)
					Southern part	Northern part	Eastern part	Western part	
TRIASSIC AND YOUNGER	Aqua Zarca sandstone member of Chinle formation	Shinarump member of Chinle formation	Shinarump member of Chinle formation	Various Mesozoic and Cenozoic formations	Shinarump member of Chinle formation	Shinarump member of Chinle formation	Moenkopi formation	Moenkopi formation	Moenkopi formation
TRIASSIC(?)							Hoskinnini member	Hoskinnini member	
PERMIAN	San Andres limestone / Glorieta sandstone	San Andres limestone: Limestone member / Evaporite member; Glorieta sandstone	San Andres limestone / Glorieta sandstone	Kaibab limestone / Coconino sandstone	De Chelly sandstone: Upper member	De Chelly sandstone: Upper member / Lower member	De Chelly sandstone member	De Chelly sandstone member	Kaibab limestone / Toroweap formation / Coconino sandstone
	Cutler formation: Yeso formation: San Ysidro member	Yeso formation: Los Vallos member	Yeso formation: San Ysidro member	Supai formation: Upper member	Supai formation	Supai formation	Cutler formation: Organ Rock tongue	Cutler formation: Organ Rock tongue	Hermit shale
	Meseta Blanca sandstone member	Meseta Blanca sandstone member	Meseta Blanca sandstone member	Middle member			Cedar Mesa sandstone member	Cedar Mesa sandstone member	Supai formation
	Abo formation	Abo formation	Abo formation	Lower member			Halgaito tongue	Halgaito tongue	
PENNSYLVANIAN AND PERMIAN(?)	Madera formation: Arkosic limestone member (May be Permian(?) in some areas)	Madera formation: Red Tanks member (May be Permian(?) in part) / Atrasado member	Madera formation: Red Tanks member	(Beds of Pennsylvanian age may be included in the Supai formation)			Rico formation (May contain beds of both Permian(?) and Pennsylvanian ages)	Rico formation (May contain beds of both Permian(?) and Pennsylvanian ages)	(Beds of Pennsylvanian age may be included in the Supai formation)
	Madera formation: Gray limestone member (Pennsylvanian)	Madera formation: Gray Mesa member (Pennsylvanian)	Madera formation	Naco limestone (Pennsylvanian)			Hermosa formation	Hermosa formation	

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