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TRIASSIC ROCKS IN THE SAN JUAN BASIN OF NEW MEXICO AND ADJACENT AREAS

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INTRODUCTION

Triassic rocks are present in the subsurface throughout the San Juan Basin and crop out in the uplifts that bound the basin (fig. 1). This report briefly describes the lithology of Triassic rocks in the areas of outcrop around the San Juan Basin and discusses their correlation and geologic history.

In the San Juan Basin area, Triassic rocks are as much as 520 m thick and are bounded everywhere at the base and probably everywhere at the top by regional unconformities. Over most of the area the unconformity at the base separates Permian rocks from Triassic rocks. Locally, in the eastern and northern parts of the San Juan Basin, the basal unconformity cuts across Pennsylvanian or Precambrian rocks. In most of the San Juan Basin area the unconformity at the top separates Triassic rocks from the Jurassic Entrada Sandstone.

Much, or all of the Glen Canyon Group, that overlies Triassic rocks in northeast Arizona has been thought to be of Triassic age. (See Galton, 1971, p. 793 and O'Sullivan and Green, 1973, p. 76.) Recent work (Peterson and others, 1977) now suggests that most of the Glen Canyon Group is Early Jurassic in age. Accordingly, the Glen Canyon Group is not discussed in this report.

In areas within or adjacent to the San Juan Basin, diverse mineral deposits are found in Triassic rocks. About 408,000 tonnes of oil have been produced from Triassic rocks at the Boundary Butte field near the Arizona-Utah state line. In northeast Arizona, helium is derived partly from Triassic rocks in gas fields east of Holbrook. In the Monument upwarp of Arizona and Utah south of the San Juan River, 3,360 tonnes of uranium metal and 6,300 tonnes of vanadium metal have been derived from rocks of Triassic age (Chenoweth and Malan, 1973, p. 140). Additional, small uranium and vanadium deposits are found in Triassic rocks in the De Chelly upwarp of Arizona. Near Cuba, New Mexico, copper has been mined at the Nacimiento pit from Triassic rocks with an average grade of 0.67 percent copper and with ore reserves in excess of 10,000,000 tonnes (Talbott, 1974, p. 302-303).

STRATIGRAPHY

Lower and Middle(?) Triassic Rocks

In the San Juan Basin area, Lower and Middle (?) Triassic rocks consist of the Moenkopi Formation in Arizona and the Moenkopi(?) Formation in New Mexico. This formation is described in detail by McKee (1954), Cooley (1959), Repenning, Cooley and Akers (1969), and Stewart, Poole and Wilson (1972b). The petrology of the Moenkopi Formation is discussed by Cadigan (1971).

Moenkopi Formation

The Moenkopi Formation in northeastern Arizona is composed mostly of reddish-brown siltstone with minor amounts of fine-grained sandstone. The Moenkopi is as much as 122 m thick and pinches out (fig. 2) west of the San Juan Basin along the De Chelly upwarp.

Moenkopi(?) Formation

In the Zuni Mountains and in areas to the east a red-bed unit, the Moenkopi(?) Formation, is present and is questionably correlated with the Moenkopi Formation in Arizona. The Moenkopi(?) Formation is made up of red siltstone and sandstone. Occasionally, conglomeratic sandstone or conglomerate is present with pebbles of chertz, quartz and quartzite as much as 90 mm across. The Moenkopi(?) Formation is locally absent in the Zuni Mountains; at Fort Wingate it is 11 m thick and thickens to 65 m at a locality north of Riley, New Mexico (fig. 2).

Upper Triassic Rocks

In the San Juan Basin area, Upper Triassic rocks comprise the Chinle Formation over most of the area and the partly equivalent Dolores Formation in southwest Colorado. The following lithologic descriptions of Upper Triassic rocks are derived largely from detailed regional reports by Stewart, Poole and Wilson (1972a) and Repenning, Cooley and Akers (1969).

Chinle Formation in western and southern San Juan Basin

The Chinle Formation was named for exposures along Chinle Wash in the vicinity of the settlement of Chinle in northeastern Arizona. The Chinle Formation includes, in ascending order, the Shinarump, Monitor Butte, Petrified Forest and Owl Rock members. Triassic strata overlying the Owl Rock Member are assigned at some localities to the Church Rock Member of the Chinle Formation and at other localities to the Rock Point Member of the Wingate Sandstone.

Shinarump Member

The Shinarump Member is very light gray, light tan and brown, and is composed of fluviatile coarse-grained sandstone, conglomerate and minor mudstone beds. The basal contact is marked by deep scours and channels as much as 23 m deep. The Shinarump is present over wide areas of Arizona and averages about 24 m in thickness, but locally is as much as 61 m thick. In New Mexico it has a very sporadic distribution and from Fort Wingate eastward toward Mount Taylor occurs as isolated lenses of small extent. At Fort Wingate it is 8 m thick (Cooley, 1959, p. 69).

Monitor Butte Member

The Monitor Butte Member is a sequence of red mudstones and siltstones intermixed with lighter colored sandstones and conglomerates. At many localities the Monitor Butte is characterized by numerous intraformational slumps, folds and faults undoubtedly formed before consolidation. The Monitor

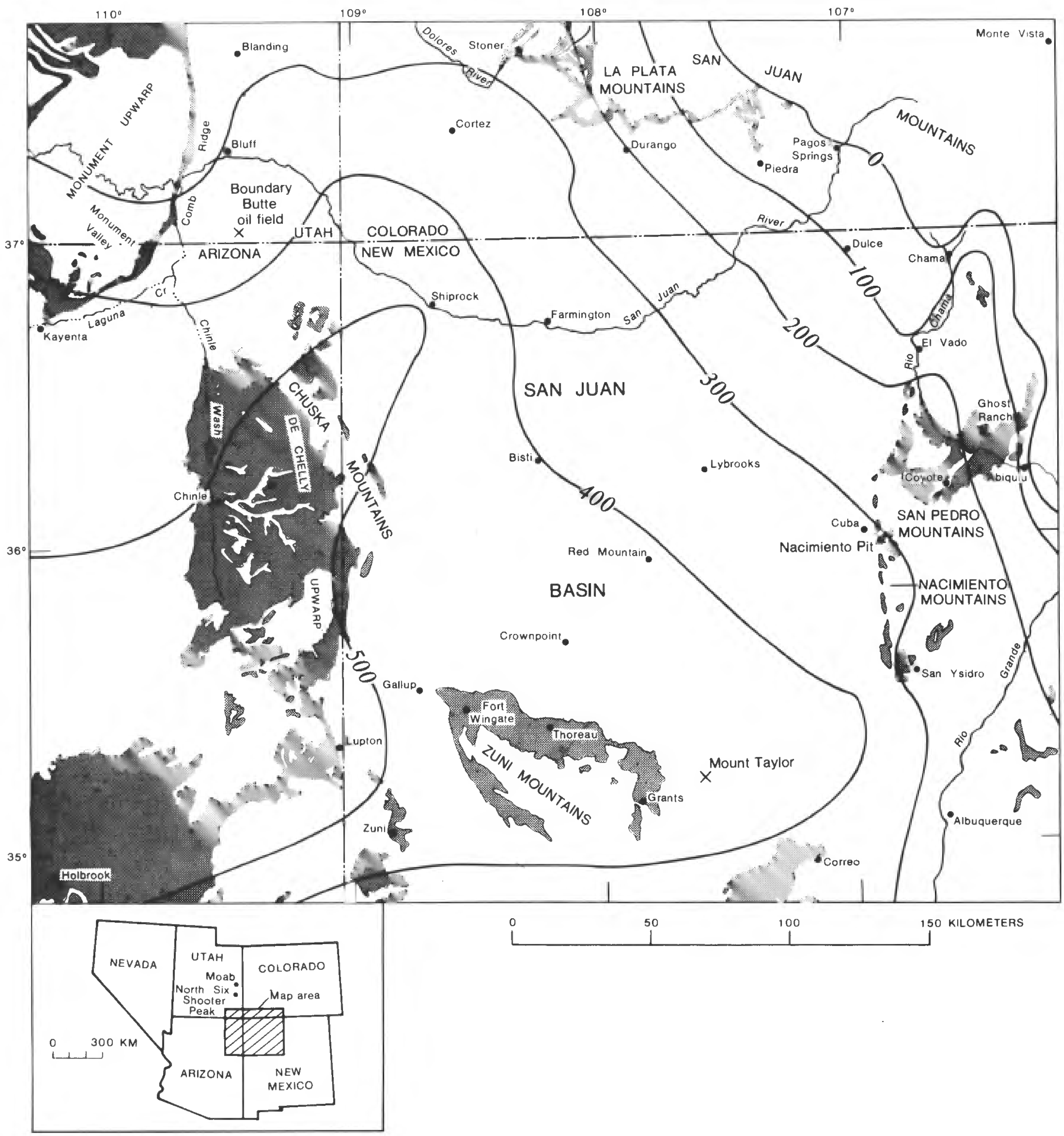

Figure 1. Map of San Juan Basin area showing thickness and approximate outcrop distribution of Triassic rocks (stippled). Isopach interval 100 m. Compiled in part from Andrews and Hunt (1948); Dane and Bachman (1965); McKee and others (1959); Stewart, Poole and Wilson (1972a, 1972b); U.S. Geol. Survey (1935); and Wilson, Moore and Cooper (1969).

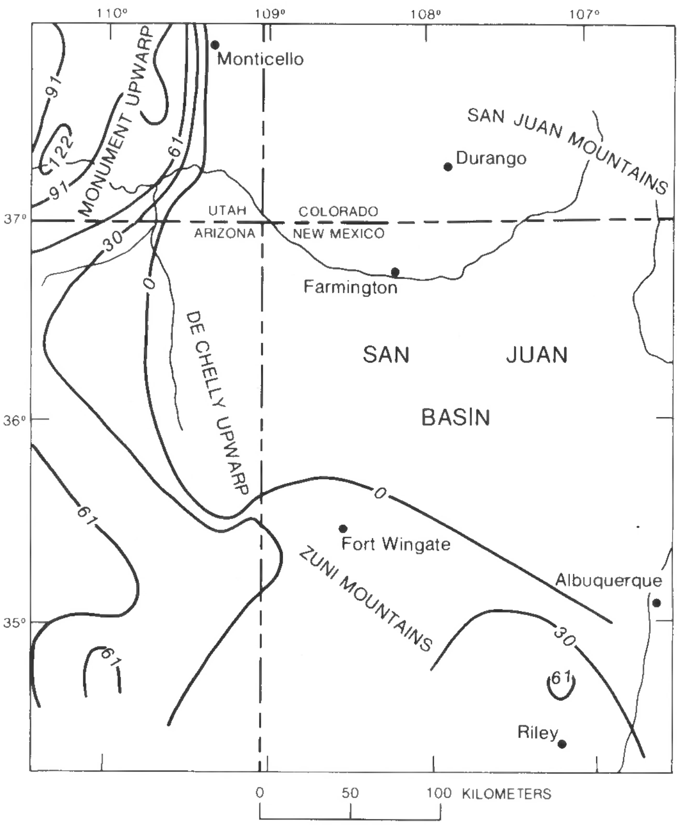

Figure 2. Thickness of the Moenkopi Formation in San Juan Basin area, Isopach interval approximately 30 m. Map from Stewart, Poole and Wilson (1972b, pl. 4A).

Butte Member is as much as 107 m thick in the De Chelly upwarp and thins eastward into New Mexico. The member is not recognized east of Mount Taylor.

Petrified Forest Member

The Petrified Forest Member is composed of variegated blue, gray, red, brown and purple fluviatile mudstone and siltstone. Much of the mudstone contains montmorillonite derived from the alteration of volcanic debris. The Petrified Forest Member is split into upper and lower parts by the Sonsela Sandstone Bed. The lower part is 61-91 m thick in the De Chelly upwarp area and thins to about 38 m in the eastern part of Zuni Mountains (Cooley, 1959, p. 70). The upper part of the Petrified Forest is 122-152 m thick in the northern part of De Chelly upwarp and thickens eastward to about 260 m (J. F. Robertson, oral commun., 1977) near Fort Wingate.

The Sonsela Sandstone Bed, widespread in northeast Arizona and northwest New Mexico, is a light-yellowish-gray crossbedded tuffaceous sandstone containing conglomerate lenses and interbedded siltstone and shale. The conglomerate is composed of quartz, quartzite and chert. The Sonsela is generally about 15 m thick; near Grants, New Mexico, it is as much as 95 m thick (R. E. Thaden, written commun., 1977).

In the southern San Juan Basin the upper part of the Petrified Forest Member is characterized by several sandstone beds as much as 12 m thick but of limited extent. Locally recognized units include the Taaiylone and Perea sandstone marker beds of local informal usage. The lenticular sandstones commonly are red and grayish purple and contain limestone pebble conglomerate.

Owl Rock Member

The Owl Rock Member consists mainly of pink and red shale mottled light greenish gray. The shale is generally silty and calcareous and forms slopes. Interspersed with the shale are several ledge-forming beds of cherty limestone, sandstone and siltstone. The member is about 91 m thick in the De Chelly upwarp. In the Zuni Mountains area of the southern San Juan Basin the Owl Rock and the overlying Rock Point Member were removed by erosion prior to deposition of the overlying Entrada Sandstone.

Church Rock Member of Chinle Formation and Rock Point Member of Wingate Sandstone

In northeast Arizona, a sequence of siltstone and sandstone overlying the Owl Rock Member is assigned to the Church Rock Member of the Chinle Formation north of Laguna Creek; south of Laguna Creek the same beds are assigned to the Rock Point Member of the Wingate Sandstone. The Church Rock and Rock Point members consist of reddish-orange and reddish-brown siltstone and very fine grained sandstone mottled light greenish gray. Beds in the two members are as much as 6 m thick and form a series of ledges and slopes. The Church Rock Member is 76 m thick near Kayenta. The Rock Point Member is about 107 m thick at the north end of the De Chelly upwarp.

The contact between the Church Rock and Rock Point and overlying parts of the Glen Canyon Group has various interpretations. The Church Rock and Rock Point members are overlain by the Lukachukai Member of the Wingate Sandstone. The Lukachukai Member is as much as 137 m thick and is mostly of eolian origin. In northeast Arizona, extensive intertonguing has been reported between the Rock Point and Lukachukai Members (Harshbarger and others, 1957, p. 7). According to Witkind and Thaden (1963, p. 34) such intertonguing was not detected anywhere between the Wingate Sandstone (north of Laguna Creek consisting solely of the Lukachukai Member) and the Church Rock Member in the Monument Valley area of Arizona. Moreover, at several places in the northern part of the De Chelly upwarp, an unconformity has been recognized at the base of the Lukachukai Member of the Wingate Sandstone. (See O'Sullivan and Green, 1973, p. 76.) This unconformity at the base of the Wingate Sandstone (Lukachukai Member) and equivalent rocks elsewhere is apparently widespread in Utah, Colorado and Wyoming. (See Stewart and others, 1959, p. 523; Pipiringos, 1968, p. D17.)

New information now suggests that most of the Glen Canyon Group is Early Jurassic in age. Early Jurassic palynomorphs (Peterson and others, 1977, p. 755) were found in the Moenave Formation, which is at the base of the Glen Canyon Group in south-central Utah and north-central Arizona. The Moenave is a lateral intertonguing equivalent of the Lukachukai Member of the Wingate Sandstone. Consequently, the Lukachukai Member may also be of Early Jurassic age. The Rock Point Member contains fossils indicating a Late Triassic age for it and the equivalent Church Rock Member. The probable unconformable contact between the Lukachukai and Rock Point members may represent the systemic boundary between Jurassic and Triassic rocks.

Chinle Formation in eastern San Juan Basin

Triassic rocks in the eastern San Juan Basin are represented solely by the Chinle Formation, which consists of, in ascending order, the Agua Zarca Sandstone Member, Salitral Shale Tongue, Poleo Sandstone lentil, Petrified Forest Member and the siltstone member.

Agua Zarca Sandstone Member

The Agua Zarca Sandstone Member is recognized at the base of the Chinle in parts of the eastern San Juan Basin (Wood and Northrop, 1946) in New Mexico. The member is as much as 50 m thick near San Ysidro, New Mexico, and consists of cross-bedded lenticular sandstone and lesser amounts of conglomerate, siltstone and shale. The sandstone is red, purple, and light gray, very fine to coarse grained; it contains variable amounts of granules to cobbles of quartz, quartzite and chert.

Throughout the Nacimiento Mountains, strata assigned to the Agua Zarca are different from strata to the north in the Coyote, New Mexico, area. The beds tend to be lighter colored and finer grained, and to contain smaller pebbles. In addition, paleo-stream directions, as indicated by crossbed studies, suggest an entirely different source area. Because of these differences, Stewart, Poole and Wilson (1972a, p. 23-24) assigned the basal strata of the Chinle Formation in the Nacimiento Mountains to an informal sandstone member.

Salitral Shale Tongue

The Salitral Shale Tongue is as much as 35 m thick in the northern part of the Nacimiento Mountains but thins and pinches out eastward in the direction of Abiquiu, New Mexico. It is composed of red, brown, purple and greenish-gray shale and siltstone with numerous limestone nodules (Northrop, 1950, p. 35). Locally, very fine to coarse-grained lenticular sandstone beds are present.

Poleo Sandstone Lentil

The ledge-forming Poleo Sandstone lentil consists of yellowish-gray fine- to medium-grained lenticular sandstone, conglomerate and some siltstone. The conglomerate is composed mainly of quartz, quartzite and red and orange chert granules and pebbles. The Poleo attains a maximum thickness of about 49 m near Abiquiu and pinches out about 12.9 km northwest of San Ysidro (Wood and Northrop, 1946).

Petrified Forest Member

The Petrified Forest Member is a sequence of silty shale and siltstone that is variegated reddish brown, red, greenish gray and purple. A few very fine to medium-grained red and light-gray, ledge-forming sandstone beds comprise a minor lithology in the Petrified Forest. The Petrified Forest Member is as much as 216 m thick near Coyote.

Siltstone Member

The siltstone member forms a steep slope and consists of light-brown and reddish-brown siltstone and shaly siltstone. Bedding is generally obscured but viewed from a distance a few horizontal bedding planes are apparent. The siltstone member is as much as 70 m thick near Ghost Ranch and all of it grades laterally to the southwest into the Petrified Forest Member near Coyote.

Chinle Formation in southeastern Utah

The Chinle Formation in southeastern Utah lies somewhat outside the perimeter of the San Juan Basin but is described here because of its relationship to the Chinle in the San Juan Basin area. In southeastern Utah the Chinle Formation consists, in approximate ascending order, of a lower part, Moss Back, Petrified Forest, Owl Rock, reddish-orange siltstone member and the Hite Bed.

Lower part

The lower part of the Chinle underlies the Moss Back Member at the surface and in the subsurface over large areas of southeastern Utah. The lower part is made up of blue, gray and red mudstone and interbedded lenticular light-colored sandstone and conglomerate. The Moss Back is absent along Comb Ridge south of the latitude of Blanding, Utah, and separation of a lower part at that location is arbitrary. The lower part is about 107 m thick in the subsurface east of Comb Ridge near the Boundary Butte oil field where the Moss Back is present. The lower part thins northward and pinches out at North Sixshooter Peak about 40 km northwest of Blanding.

Moss Back Member

The ledge-forming Moss Back Member consists of yellowish-gray, fine- to medium-grained sandstone, conglomerate and some siltstone and shale. The conglomerate is composed mainly of quartz, quartzite and chert. In places the conglomerate consists solely of siltstone and limestone pebbles. The Moss Back averages about 17 m in thickness but locally is as much as 46 m thick where it fills channels cut into underlying rocks.

Petrified Forest and Owl Rock Members

The typical lithologies of the Petrified Forest and Owl Rock members described earlier for exposures in Arizona, continue into the southern part of southeastern Utah. Traced northward toward Moab, Utah, the two members change character and grade laterally into the reddish-orange siltstone member. The Owl Rock and Petrified Forest members above the Moss Back are 168 to 183 m thick near the Boundary Butte oil field. East of Moab, equivalents of the Petrified Forest and Owl Rock are completely replaced by the reddish-orange siltstone member.

Reddish-orange siltstone member

The slope-forming reddish-orange siltstone member is reddish orange to reddish brown and much of it is spotted light greenish gray. The member is composed mainly of coarse silt-sized quartz grains but contains some grains the size of fine sand. At places, thin beds of medium- to coarse-grained sandstone containing pebbles of siltstone form a subordinate lithology. The reddish-orange siltstone member is as much as 107 m thick east of Moab; the member thins southward and grades into the upper part of the Owl Rock north of the Utah-Arizona state line. Between these two areas the reddish-orange siltstone member varies considerably in thickness.

Hite Bed of Church Rock Member

The Hite Bed is sporadically distributed, but where present it is a cliff-forming pale-red to reddish-brown sandstone. The sandstone is very fine to coarse grained and individual beds tend to be lenticular and commonly fill channels cut into underlying units. The Hite Bed locally includes conglomeratic lenses consisting of siltstone and limestone in sizes from granules to cobbles as much as 150 mm across. At places, thin beds of reddish-brown siltstone and shale are also present. The Hite Bed is as much as 19 m thick along Comb Ridge near the

Arizona-Utah state line; it thins northward and is absent near Moab.

Dolores Formation

The Dolores Formation crops out in the northern part of the San Juan Basin around the south and west flanks of the San Juan and La Plata mountains. The formation is named for exposures along the Dolores River north of Cortez, Colorado. The Dolores is equivalent to part of the Chinle Formation at the type locality in northeastern Arizona and consists of lower, middle and upper members (Stewart and others, 1972a, p. 48).

Lower Member

The lower member is made up of greenish-gray to yellowish-gray sandstone and conglomerate that tends to form a conspicuous ledge. Pebbles in the lower member are dominantly limestone with a few pebbles or granules of chert, feldspar and granite. The lower member is 27 m thick at Stoner, Colorado, and thins eastward to 8 m in the area north of Piedra, Colorado.

Middle member

The middle member consists of red, brownish-gray and greenish-gray siltstone and very fine grained sandstone. Thin lenticular beds of conglomerate, made up of angular to rounded pebbles of limestone set in a limy siltstone matrix, are a characteristic feature of the middle member. Similar conglomerate lenses are also found, but in much less abundance, in the upper member. The limestone conglomerate beds are carbonaceous and contain fragments of bone and teeth; the term "saurian conglomerate" has been applied to these beds (Eckel and others, 1949, p. 25-26). The thickness of the middle member is 82 m at Durango, Colorado, and 39 m near Piedra.

Upper member

The upper member is composed of reddish-brown siltstone and sandy siltstone. The member trends to form steep slopes, at places, interruped by one or more sandstone or silty sandstone ledges 3-15 m thick. The upper member is 165 m thick at Stoner, but is absent near Piedra because of erosion associated with the unconformity at the base of the overlying Entrada Sandstone.

CORRELATION

The correlation of Triassic rocks in the San Juan Basin area is shown in Figure 3. Facies changes and long distances between outcrops complicate the correlation of Triassic rocks.

The relationship of the Moenkopi Formation in Arizona to the Moenkopi(?) Formation in New Mexico is not clear. Cooley (1959, p. 69) reported that chert pebbles and petrified wood are present but limestone pebble conglomerate is absent in the Moenkopi(?) Formation, whereas limestone pebble conglomerate is present but petrified wood and chert pebbles are absent in the Moenkopi Formation. Later work by Stewart, Poole, and Wilson (1972b, p. 28) showed that petrified wood, limestone pebble conglomerate and chert pebbles are common to both the Moenkopi and Moenkopi(?) formations. They (Stewart and others, 1972b, p. 28) also thought that the stratigraphic position of the Moenkopi(?) above Permian rocks and below rocks undoubtedly assigned to the Chinle, together with the lithologic similarity, suggested a reasonable correlation with the Moenkopi Formation in Arizona. On the other hand, Read and Wanek (1961, p. H-3) believed that paleontologic data and stratigraphic relations indicate that the rocks termed Moenkopi(?) Formation should be assigned to the Chinle Formation. Triassic rocks are present in the subsurface in the Gallup-Zuni basin; this basin separates outcrops in Arizona from those in the Zuni Mountains. Correlations across this latter basin are as yet unresolved.

Upper Triassic strata are, in general, separated into upper and lower parts by a widespread fluviatile sequence. The fluviatile sequence consists of these equivalent units: Moss Back Member, Poleo Sandstone lentil, Sonsela Sandstone Bed of the Petrified Forest Member and the lower member of the Dolores Formation. Stewart, Poole, and Wilson (1972a, p. 35) tentatively correlated the lower member of the Dolores with the Poleo Sandstone lentil and Moss Back Member. Cooley (1959, p. 71) indicated the Poleo and Sonsela to be equivalent rocks (O'Sullivan, 1974, fig. 2). Subsurface studies by J. D. Strobell, Jr. (U.S. Geol. Survey, 1964, p. 100) showed that the Sonsela is physically continuous with the Poleo and Moss Back.

The lower part of the Chinle beneath the Moss Back and equivalent rocks has a more limited distribution than younger parts of the Chinle Formation. The lower part thins northward into southeastern Utah and pinches out near North Sixshooter Peak. It is also absent along the northern margin of the San Juan Basin where the lower member of the Dolores rests on Permian rocks. The Chinle Formation beneath the Sonsela Sandstone Bed thins eastward from Arizona toward the eastern San Juan Basin area. The Monitor Butte and Shinarump members cannot be recognized east of Mount Taylor.

In the eastern San Juan Basin two locally named members, the Salitral Shale Tongue and the Agua Zarca Sandstone Member, represent the lower part of the Chinle Formation. The lithology and stratigraphic position of the Salitral Shale Tongue (fig. 3) indicate that it is correlative with the lower part of the Petrified Forest Member in the west. The Salitral Shale Tongue and the Agua Zarca Sandstone Member are partly equivalent because they intertongue extensively. The Agua Zarca in New Mexico and the Shinarump in Arizona are considered by some geologists to be equivalent because both are at the base of the Chinle; this correlation, however, is tenuous for several reasons; the two members are not physically continuous across the southern San Juan Basin; the two members are somewhat different lithologically; and stream-direction vectors in the two units are different (Stewart and others, 1972a, p. 23). Furthermore, the Shinarump Member lies below the Monitor Butte Member, whereas the Agua Zarca underlies and is closely related to the Salitral Shale Tongue.

The Chinle Formation above the Moss Back and equivalent units is thicker and more extensive than the lower part. The upper part of the Petrified Forest Member is present above the Sonsela Sandstone Bed in northeastern Arizona and throughout much of the southern San Juan Basin. The Petrified Forest Member as recognized in southeastern Utah and in the eastern part of the San Juan Basin is equivalent only to the upper part of the Petrified Forest in northeast Arizona. The middle member of the Dolores Formation correlates with some of the upper part of the Petrified Forest because of its stratigraphic position immediately above the lower member, which is an equivalent of the Sonsela Sandstone Bed. In addition, this correlation is partly substantiated by lithology; the middle

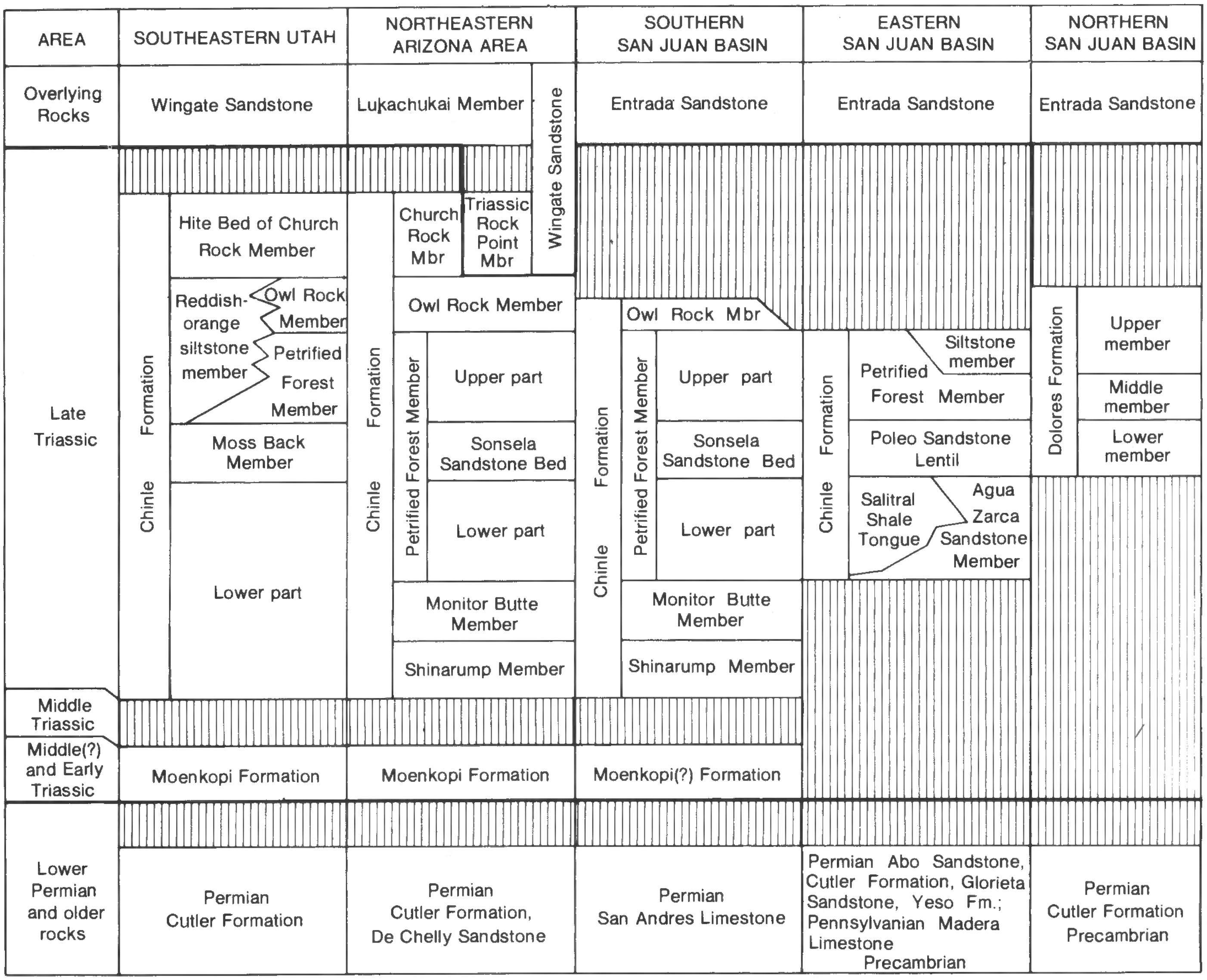

Figure 3. Chart showing correlation of Triassic formations and lesser subdivisions in the San Juan Basin area.

member of the Dolores is characterized by limestone pebble conglomerate lenses, which are also common in the upper part of Petrified Forest Member in the southern San Juan Basin.

The Owl Rock Member can be traced from northeast Arizona into southeast Utah and into the southern part of the San Juan Basin. Near Thoreau, New Mexico, the Owl Rock thins to a featheredge beneath an unconformity at the base of the Entrada Sandstone. During the period of erosion represented by this unconformity the Owl Rock was removed everywhere in the eastern and southern San Juan Basin. In the northern San Juan Basin, equivalents of the Owl Rock Member may be present in the upper member of the Dolores Formation.

The Church Rock Member can be followed from northeast Arizona into southeast Utah. Along Comb Ridge at a locality 14 km north of the Utah-Arizona state line, all of the Church Rock Member grades laterally into the Hite Bed. Strata of the Rock Point Member of the Wingate Sandstone, which are the same as the Church Rock Member except on the south side of Laguna Creek, thin southward from the north end of the De Chelly upwarp. The Rock Point Member is present in New Mexico along the south flank of the Zuni Mountains, but is absent at Fort Wingate, New Mexico. The record of the former extent of the Rock Point into the southern part of the San Juan Basin was removed by erosion prior to the deposition of the Entrada Sandstone. Similarly, erosion apparently removed the Rock Point Member in the northern San Juan Basin although the stratigraphic details are in the subsurface of extreme northwest New Mexico.

The equivalent reddish-orange siltstone member in southeast Utah and the siltstone member in the eastern San Juan Basin, both in the upper part of the Chinle Formation, and the upper member of the Dolores Formation, are similar lithologically and occupy about the same stratigraphic position. The reddish-orange siltstone member replaces the upper part of the Owl Rock Member near the Arizona-Utah state line. In the Comb Ridge-Moab area, over a distance of many kilometers, progressively older parts of the Owl Rock and Petrified Forest members gradually grade northward into the reddish-orange siltstone member. Superficially, the reddish-orange siltstone member resembles the Church Rock Member in Arizona. However, the reddish-orange siltstone member over wide areas of southeast Utah underlies the Hite Bed and is, therefore, stratigraphically older than the Church Rock Member. Furthermore the grain size distribution, fossil content, clay mineralogy, paleogeography and other regional relations (O'Sullivan, 1970) show that the reddish-orange siltstone member is unlike the Church Rock Member of the type locality. Stewart (1969) recognized these internal differences, but thought that the extension of the name Church Rock into Utah was a convenient method of showing the widespread distribution of similar though not identical strata.

The stratigraphic relationships of the siltstone member to the Owl Rock and Petrified Forest members are only partially revealed in the outcrops along the eastern and northern margins of the San Juan Basin. In the eastern San Juan Basin, the Owl Rock Member has been removed by erosion and the complete lateral gradation of the Petrified Forest Member into the siltstone member is concealed to the north; to the east the stratigraphic record has been destroyed by recent erosion.

The upper member of the Dolores Formation is lithologically like the siltstone member and occupies a similar stratigraphic position. The upper member is underlain by equivalents of the Petrified Forest Member and the upper member undoubtedly grades laterally into younger parts of the Petrified Forest in the subsurface to the south and southwest. Equivalents of the Owl Rock may be represented in the upper member of the Dolores Formation, however, the amount of truncation of the Owl Rock Member between northeast Arizona and southwest Colorado is not known.

GEOLOGIC HISTORY

Throughout Triassic time the San Juan Basin area was the site of either erosion or terrestrial deposition. At the same time, a thick sequence of related Triassic rocks accumulated to the west in a persistent geosyncline in Nevada.

In Middle(?) and Early Triassic time marine waters spread eastward into northeast Arizona. The Moenkopi Formation was laid down in a paralic environment on a broad shelf that sloped gently toward the geosyncline in Nevada. The eastern limit of the Moenkopi in Arizona represents dominantly continental or marginal marine depositions. In New Mexico, the Moenkopi(?) Formation was probably deposited at the same time by streams draining into the sea in Arizona.

Rocks of unquestioned Middle Triassic age are absent in the San Juan Basin area, but are as much as 3,050 m thick in Nevada (McKee and others, 1959, pl. 9, fig. 2). The top of Permian rocks throughout most of the San Juan Basin area is not marked by any pronounced erosional features indicating that the present day San Juan Basin was an area of low relief subjected to only slight erosion during the Middle Triassic.

A large irregularly shaped basin covering parts of Utah, Arizona, New Mexico and Colorado formed at the beginning of Late Triassic time. Sediments filled the deeper part of the basin first. Subsequently younger sediments progressively spread laterally over older deposits to eventually fill the Late Triassic basin. All the recovered flora and fauna are of freshwater origin and Upper Triassic rocks are therefore continental. The rocks were deposited in a temperate climate and display a variety of lithologies laid down in streams, in lakes and on flood plains.

The lower part of the Chinle Formation below the Moss Back and equivalent units was deposited in and restricted to a deeper part of the Late Triassic basin. The lower part was confined to an area south of a line running from North Sixshooter Peak roughly through the middle of the San Juan Basin to the Nacimiento Mountains area. The Shinarump and Monitor Butte members are restricted to areas well south of this line and are found no farther east than Mount Taylor. The lower part of the Petrified Forest extends over these older rocks to the eastern side of the San Juan Basin. The Agua Zarca Sandstone Member represents fluviatile deposition along the eastern margins of the Late Triassic basin perhaps in response to a new uplift in that area.

The separately recognized Poleo Sandstone lentil, lower member of the Dolores and the Sonsela Sandstone Bed were deposited by streams draining into a possible lake near the Four Corners where, according to Strobell (U.S. Geol. Survey, 1964, p. 100), equivalent beds are limy. Saline minerals have not been reported from these probable lacustrine beds. Consequently, the postulated lake undoubtedly represents a temporary base-level feature on a river system that drained westward. To the west, the Monument upwarp must have diverted the river system to the south, or more likely to the north, because the Moss Back and Sonsela are absent over a large part of the upwarp. The Moss Back is present on the northern part of the Monument upwarp and stream directions there, as determined by studies of crossbeds, are northwest (Stewart and others, 1972a, p. 77). The Moss Back in much of southeast Utah may represent fluviatile deposition downstream from the postulated lake near the Four Corners.

The river system that deposited the Moss Back and related rocks might ultimately have drained westward into the geosynclinal sea in Nevada. In Nevada, deltaic and marine Upper Triassic rocks probably are more than 7,600 m thick and have been termed "the mud pile" (Burke and Silberling, 1973, p. E13) by geologists because of their homogeneous lithologic character. Silberling and Wallace (1969, p. 40) speculated that the Colorado Plateau or the Rocky Mountain provinces were a source for this thick sequence of clastic rocks in Nevada. Some of the Upper Triassic sediments may have accumulated temporarily in the San Juan Basin area and were later distributed westward into Nevada, in part by the stream system that deposited the Moss Back and related units. The stream system probably reworked the sediments and deposited coarse grained rocks in the Four Corners area and carried finer grained components into Nevada.

The Chinle Formation above the Moss Back and equivalent units was then deposited. The Owl Rock Member and all the Petrified Forest Member, as well as older members of the Chinle, were derived for the most part from a volcanic terrane (Schultz, 1963, p. C37-C39), undoubtedly located in southern Arizona. According to R. A. Cadigan (oral commun., 1967), the poor internal sorting and lack of alteration of the contained tuffaceous material indicate rapid deposition of the Petrified Forest and older members in a sinking basin. Rates of deposition slowed and the Owl Rock Member filled the basin in Arizona and adjacent areas. At times extensive lakes formed; one lacustrine limestone has been traced for a distance of 64 km.

In the Moab area, beginning after the deposition of the Moss Back and equivalent units, red siltstone derived from a different source area spread laterally into the Late Triassic basin toward Arizona. The red siltstone, deposited contemporaneously with the Petrified Forest and Owl Rock members, is represented by the reddish-orange siltstone member along Comb Ridge, the siltstone member in the eastern San Juan

Basin and the upper member of the Dolores Formation in southwest Colorado. A source to the east is indicated by crossbed studies, regional thickness trends and the distribution of accessory kaolinite and chlorite (Schultz, 1963, p. C42).

Toward the end of Late Triassic time a new restricted basin, occupied by the postulated Rock Point lagoon (Harshbarger and others, 1957, fig. 18), formed in northeast Arizona. Strata of the Rock Point and Church Rock members were deposited in the Rock Point basin in a quiet-water environment. In the Lupton and Kayenta, Arizona, areas the configuration of the shoreline is marked by fluviatile deposits that were laid down by streams draining into the Rock Point lagoon (Harshbarger and others, 1957, fig. 3). Similar but more extensive fluviatile deposits in southeast Utah, around the northern periphery of the Rock Point basin, constitute the Hite Bed. The northeastern limits of the Rock Point basin are mostly concealed in the subsurface of extreme northeast New Mexico.

An unconformity in the east and a probable unconformity in the west mark the top of the Upper Triassic in the San Juan Basin area. The base of the Chinle Formation is apparently Carnian, and the top, based on scanty fossil evidence, may be latest Norian (see Ash, 1974, p. 42). Fossil footprints indicate that the top of the Chinle in northwest Colorado is no younger than Carnian (G. N. Pipiringos, oral commun., 1976). These age data, although far removed from the San Juan Basin area, suggest that the top of the Chinle in northeast Arizona might be older than previously thought. Most of the overlying rocks of the Glen Canyon Group are probably all of Early Jurassic age. Strata equal in age to the Rhaetian and possibly some or all of the Norian may be absent at the top of the Chinle; they were either never deposited or were eroded prior to the deposition of the Jurassic part of the Glen Canyon Group. Throughout most of the San Juan Basin the Jurassic Entrada Sandstone rests on Upper Triassic rocks and the contact is clearly an unconformity.

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