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TRIASSIC DEPOSITS OF THE ARIZONA-NEW MEXICO BORDER AREA

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The Triassic period is represented in the Colorado Plateau area by two principal groups of deposits: (1) the Moenkopi formation of Early Triassic and possibly also of Middle Triassic age, in part, and (2) the Shinarump conglomerate and Chinle formation of Late Triassic age. A widespread surface of erosion everywhere underlies the Moenkopi; another separates the Moenkopi formation from the Shinarump conglomerate. An unconformity above the Chinle formation is less conspicuous than those below, but probably also widespread and significant.

Strata of the Moenkopi formation contrast with those of the overlying Upper Triassic formations in numerous ways. First, they include extensive marine limestones and calcareous shales, whereas the Shinarump-Chinle deposits are entirely continental. Second, they decrease in thickness from many hundreds of feet in Nevada and western Utah to nothing near the Arizona-New Mexico line, whereas the Upper Triassic deposits extend as a blanket with fairly uniform thickness across most of northern New Mexico as well as Arizona. Third, they contain casts of salt crystals and extensive gypsum beds, suggesting semi-arid climate, whereas the Shinarump and Chinle contain none of the evaporites but an abundant and diversified flora suggestive of more humid conditions. Finally, they include only fine- or medium-grained detrital sediments, except for locally derived gravels at the base, even along margins of the basin, whereas the Upper Triassic deposits contain many beds of large, rounded gravels indicating the development of an uplifted source area to the south.

Pre-Moenkopi Unconformity

The pre-Moenkopi erosion surface marks one of the important breaks in the stratigraphic record of the Colorado Plateau. It is developed on rocks of Permian age, including the Kaibab limestone in western Arizona and Utah and on various members of the Cutler formation farther east. The time represented by hiatus involves the upper half of the Permian period (above Leonard time), plus the lower part (pre-Meekoceras zone) of the Triassic.

The physical record of the unconformity varies considerably in character from one part of the region to another. In southern Nevada and southwestern Utah are the profiles of many channels and valleys, carved several hundred feet into the Kaibab limestone surface and subsequently filled with boulders, pebbles and other debris of initial Moenkopi deposition (Longwell, 1925). In eastern Utah are recorded (McKnight, 1940) numerous illustrations of folding and bevelling of red Permian strata accomplished prior to Moenkopi development. In this area angular discordance between Permian and Triassic beds and the truncation of anticlines can be observed. In northeastern Arizona, on the other hand, erosion valleys are inconspicuous and structure bevelling is not known to exist; the unconformity is marked by a surface of slight relief with locally-derived gravels filling shallow depressions in the surface of Permian rock.

Different explanations have been used for the various types of pre-Moenkopi erosion surfaces. Hill-and-valley topography in the western part of the region has caused Longwell (1925) to suggest subaerial erosion as the process responsible for the surface of relief, whereas the smooth contact noted in eastern Utah is explained by Dane (1935) as the result of marine planation. In northeastern Arizona, where continental deposits of the Moenkopi rest on the erosion surface, marine processes cannot be considered responsible so the low relief probably is the result of long continued subaerial erosion to near base level.

The Moenkopi Formation

General Distribution: The Moenkopi formation is composed of sedimentary deposits of Triassic age that form a great wedge extending across northern Arizona and southern Utah. Along its western margin in southern Nevada and southwestern Utah, this wedge attains a thickness of 2000 feet. Farther east at the type locality near Cameron, Arizona it is 400 feet thick and in the vicinity of the Utah-Colorado border and the Arizona-New Mexico border, it thins to the vanishing point.

The eastern margin of the basin in which the Moenkopi was deposited forms a sinuous line from north to south as indicated by outcrop and well data. Isopach contours show that the basin included an eastward-extending embayment in the north and another in the south, separated by a westerly-extending ridge or peninsula in the area of northeastern Arizona.

The position of the southern embayment is indicated by thicknesses obtained at St. Johns, Arizona (81 feet), at Cheehilgeetho well, New Mexico (50 feet), northwest of McGaffey, New Mexico (73 feet) and near Fort Wingate, New Mexico (30 feet). These deposits show proximity to the margin of the basin not only by their thinness, but also by the large percentage of sandstone and other coarse detrital materials.

The westward projection of the Moenkopi boundary in northeastern Arizona is indicated by absence of the formation at Carrizo Mountains (J.D. Strobell, personal communication), Nazlini Canyon, Canyon de Chelly and Lukachukai. At all of these localities Upper Triassic deposits rest upon Permian strata. Influence of the westward projection also is noted along Echo Cliffs, midway across the state, for sections thicken considerably both north and south from the central part of these cliffs near The Gap.

A northern embayment of the Moenkopi basin occurs in southeastern Utah. Northeast of Moab the formation extends with moderate thickness into Colorado where it appears to end abruptly against the ancient landmass of Uncompahgre (Dane, 1935).

Lithologic Types: The Moenkopi formation is composed of both continental and marine deposits. It consists of six principal lithologic types: (1) massive, cross-laminated sandstone, (2) red shaly siltstone, (3) red brown structureless mudstone, (4) intraformational (mud pellet and limestone pebble) conglomerate, (5) gypsum and (6) limestone. Each of these represents a distinct environment and occurs in varying proportion across the region.

The marine limestones of the Moenkopi formation are restricted to the lower half and occur only in the western and central parts of the area. The massive sandstones are largely confined to the eastern borders of the region, but the red siltstones and structureless mudstones which occur at various levels throughout the region account for the characteristic red color.

Stratigraphic subdivisions: Three distinctive members are recognized in the Moenkopi formation throughout the Little Colorado River area of northeastern Arizona (fig. 1). These are from bottom to top, the (1) Wupatki, (2) Winslow and (3) Holbrook members. They do not correlate exactly with any of the six members of the formation that have been described by Gregory (1947) for the thick sections in southwestern Utah, but in general they correspond with the upper part of the formation there.

The Wupatki and Holbrook members are characterized by red beds--shaly siltstones and structureless mudstones--alternating with resistant, thick-bedded sandstones. The Winslow member between is composed largely of light-colored siltstones and mudstones with considerable bedded gypsum. It contrasts strongly with the members above and below both in color and in slope-forming tendencies.

Fauna and Flora: The invertebrate fauna from the marine deposits of the Moenkopi in northwestern Arizona and southwestern Utah and in east central Utah has been known in a general way for many years (Reeside and Bassler, 1922). It consists largely of mollusks, with pelecypods and gastropods abundant and some cephalopods. Locally brachiopods and crinoids are common. This fauna has not been studied in detail and many of the forms are undescribed.

In northeastern Arizona where Moenkopi deposits are entirely continental, a moderately large and varied vertebrate fauna occurs. It includes reptiles, amphibians and fish, with stegocephalians by far the most common type (Camp, et al., 1947). Skeletal remains have been found in many localities in both the Holbrook and Wupatki members. Trackways, mostly of reptiles, are also common and have proved to be of some value in correlation (Peabody, 1948).

The flora of the Moenkopi formation is very imperfectly known. Specimens are uncommon and poorly preserved. They include impressions of reeds and scouring rushes and a small amount of petrified wood.

Environment of deposition: A wide variety of environments is represented in deposits of the Moenkopi. The massive sandstones in the eastern part of the area clearly are the product of stream deposition and form thin sheets over wide areas, developed during times of regression. They contain abundant cusp-type ripple marks, both scour-and-fill and delta-front cross-lamination and the skeletons of amphibians.

Red shaly siltstones were developed on mud flats - either tidal or floodplain. They are covered nearly everywhere by parallel current ripple marks and locally

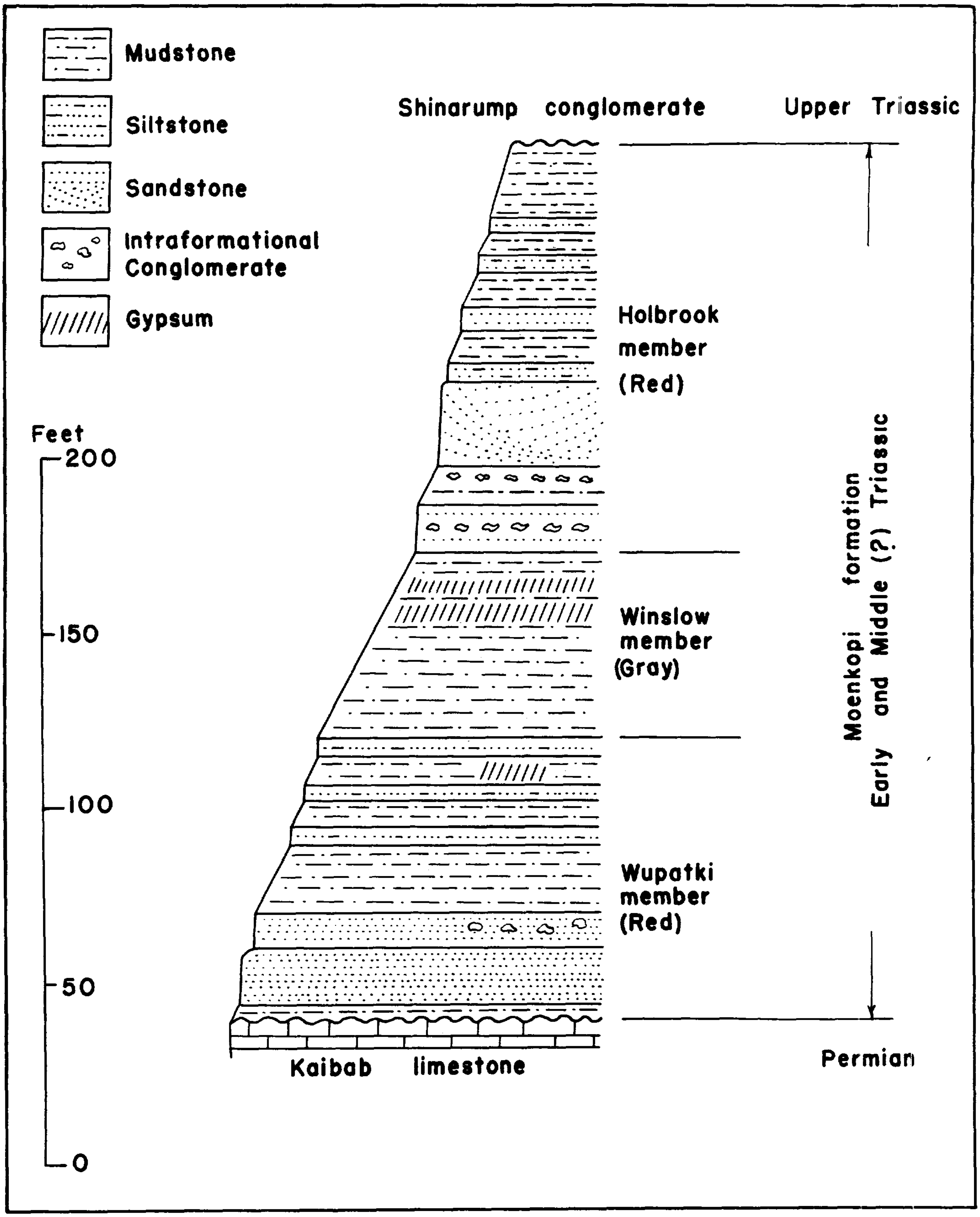

Fig. 1 - Generalized section of Moenkopi formation in Winslow-Holbrook area, Arizona

they contain rain pits, shrinkage cracks and casts of salt crystals. Red brown structureless mudstones probably are the result of clay and silt settling in ponds or lakes. Gypsum beds doubtless indicate lagoons or playas back from the margins of the sea and the limestones and calcareous shales with marine faunas clearly indicate shallow sea deposits.

In brief, the depositional environment of the Moenkopi consists of wide, flat plains extending from a topographically low source area on the east to a geosynclinal sea on the west. Streams introduced sand and silt from the eastern margins, shallow ponds and lagoons were widespread over the nearly flat surface and the sea alternately advanced and retreated from the west. Evaporation was of considerable magnitude indicating that the climate was semiarid or arid.

Age of formation: The lower part of the Moenkopi as represented by the Timpoweap member in southwestern Utah and the Sinbad limestone in San Rafael Swell, Utah, is dated by the presence of the ammonite Meekoceras. This marks the middle of the Lower Triassic according to the classification of zones by Smith (1932). The age of the younger fauna in the Virgin limestone has not yet been determined.

In the upper part of the Moenkopi most of the vertebrate remains indicate a Lower Triassic age according to Welles (1947), though one of the common forms (Cyclotosaurus) belongs in the Middle Triassic of Europe. Likewise, the reptilian tracks mostly are comparable to Lower Triassic forms in the Old World but some are similar to species from the Middle Triassic. Thus the Moenkopi formation definitely began in Early Triassic time but may have continued into Middle Triassic.

Moenkopi - Shinarump Unconformity

The contact between the Moenkopi formation and the Shinarump conglomerate is irregular and wavy even within short lateral distances. In some places, channels and pockets excavated in the upper Moenkopi surface extend downward many feet and are filled with sand and gravel of the Shinarump. Elsewhere the Moenkopi stood as hills or ridges, around and over which sediments of the Shinarump accumulated. In a few areas residual Moenkopi masses were sufficiently high to stand above the general surface of Shinarump accumulation and in such places Chinle deposits rest directly upon those of the Moenkopi. Such observations show plainly that the unconformity is the result of a long period of subaerial erosion and not a local feature.

The amount of time represented by the hiatus involved in the Moenkopi-Shinarump unconformity is difficult to determine. The age of the topmost beds in the Moenkopi formation is not known; they may belong late in the Lower Triassic as suggested by stratigraphic position high above the Meekoceras-bearing beds, or they may be of Middle Triassic age as suggested by some of the vertebrate fossils (Welles, 1947). Further-more, the time when Shinarump deposition began is open to question, as discussed under the age of that formation. In any event, the time of hiatus must have been considerable, even in a geologic sense, and during that time, apparently, regional uplift to the south took place (McKee, 1951) and renewed upwarping along anticlinal structures in the northeastern part of the basin occurred (McKnight, 1940).

Shinarump Conglomerate and Chinle Formation

General distribution: The Chinle formation consists of a series of deposits that extend with relatively uniform thickness across most of northern New Mexico and Arizona into southern Nevada, also northerly into central Utah and southwestern Colorado. It is considered a correlative of the Dolores formation of Colorado and the lower units may be equivalent to the Dockum of Texas, in part (Camp, 1950). In the Chinle Valley area, Arizona which is the type locality, it has a thickness of 900 to 1000 feet. Farther east near Fort Wingate, New Mexico it is about 1400 feet thick (Harshbarger, personal communication).

The Shinarump conglomerate which is considered by many geologists (Camp, et al., 1947) as a basal member of the Chinle formation occurs as a blanket deposit of sand and gravel across most of northern Arizona and southern Utah, eastward at least as far as Fort Wingate, New Mexico (Harshbarger, personal communication). Its thickness varies considerably from place to place, largely as a result of irregularities on the underlying Moenkopi surface, but its maximum thickness probably does not greatly exceed 160 feet as found on the north end of the Defiance Uplift. In numerous areas including that east of Holbrook, along Echo Cliffs and near Ganado, Arizona it is absent locally because of non-deposition where hills of Moenkopi stood above the general surface of accumulation.

Lithologic types: The Shinarump-Chinle deposits include five principal lithologic types. These are conglomerates, sandstones, mudstones, claystones and limestones. All are of continental origin, but they represent a variety of depositionaleenvironments. The conglomerates, sandstones and limestones are resistant and form ledges or cliffs; the mustones and claystones are exceptionally weak and weather to badland topography.

Conglomerate is abundant in the Shinarump, and also occurs as lenses and lenticular beds at various horizons within the overlying Chinle. Gravels in the conglomerate are mostly of durable rock types such as quartzite, jasper and chert and, in most places along the Little Colorado valley, range from 1/4 inch up to 2 1/2 inches in diameter. In the Shinarump conglomerate they average progressively smaller in successive northerly outcrops across Arizona; in the Chinle they do not extend far north of areas along the southern margin of the depositional basin (McKee, 1936).

Claystone and mudstone, which together make up a major part of the Chinle formation, commonly have been referred to as "marls", though many are non-calcareous. They are of various colors including grayish red, purple, greenish gray and variegated combinations of these. The claystones include bentonite beds. Brownish gray, thin-bedded limestones of lenticular character are numerous in the upper part of the formation north of Winslow, Arizona but are represented by only two beds eastward near Fort Wingate and are absent in the Black Rock area of New Mexico.

Stratigraphic subdivisions: At the type locality of the Chinle formation in Chinle Valley, Arizona the formation was divided by Gregory (1917) into four members which, in descending order, were designated as "A", "B", "C" and "D" (fig. 2). The underlying Shinarump conglomerate which grades upward into the "D" member may be considered an additional member of the Chinle formation. On the other hand, essentially all of Gregory's "A" member appears logically to belong to the Glen Canyon group rather than to the Chinle formation, on the basis of lithologic character and stratigraphic position above a wide-spread granule conglomerate. (Callahan, 1951).

The Shinarump conglomerate consists of conglomerate, sandstone, and minor amounts of mottled mudstone. The "D" member of the Chinle into which it grades is composed of alternating beds of sandstone, mudstone and claystone. Like the Shinarump, it is characterized by much channel-fill cross-stratification and it contains lenses of conglomerate so it is sometimes confused with the Shinarump. In some localities this member is not recognizable or identifiable. The "C" member or middle unit makes up more than one half of the total thickness of the Chinle. It is composed almost entirely of claystone and mudstone in the type area, although toward the south and southeast interbedded sandstones are progressively thicker and more numerous (Harshbarger, personal communication). In the Fort Wingate area a conglomeratic sandstone that has been called, erroneously, Shinarump, actually occurs near the middle of the member (Bates, 1933). The "B" member of Gregory, or top-most unit of the Chinle in this classification, consists of limestone and interbedded mudstone and claystone beds.

Fauna and Flora: The flora of the Upper Triassic of Arizona and New Mexico is famous because of the abundance of petrified trees that it includes. Most numerous of these are the conifers Araucarioxylon and Woodworthia, though others are present. Altogether 35 genera and 38 species of plants including many cycads and ferns have been recognized (Daugherty, 1941). Fossil plants occur in both the Shinarump conglomerate and the Chinle formation, but well preserved forms have been found only in the Chinle.

A considerable vertebrate fauna, including amphibians, fish and reptiles of several major groups, occurs in the Chinle formation. Most numerous in number and variety are the phytosaurs, described by Camp (1930), and stegocephalian amphibians. Small dinosaurs from the Chinle at Ghost Ranch, New Mexico, have recently been discovered by Colbert. In addition to the vertebrate remains, large concentrations of fresh water clams are found at numerous localities and fresh water gastropods have been described from the limestone beds.

Environment of Deposition: "The Upper Triassic of Arizona was characterized by subtropical to tropical temperatures, as indicated by the fern element" according to Daugherty (1941). He disagrees with many earlier writers who considered the climate to have been arid or semiarid and concludes on the basis of plant

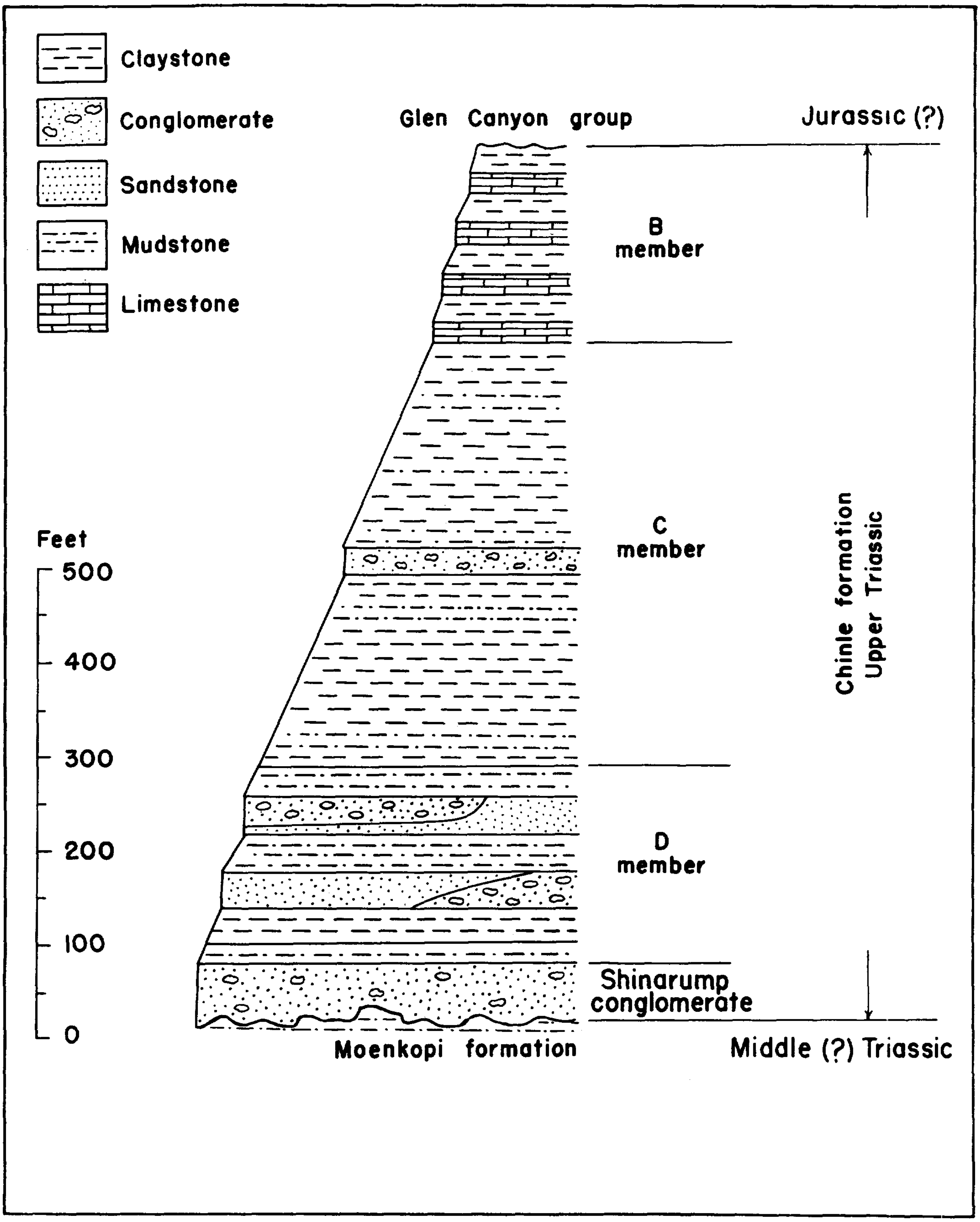

Fig. 2 - Generalized section of Shinarump-Chinle formations in Winslow-Holbrook area, Arizona.

life that the climate was like that of the savannas in the tropics of today. He envisions dense forests bordering permanent streams and swampy areas, with more open forests in the uplands.

There appears to be general agreement that the Shinarump and Chinle of the area discussed were deposited on the surface of a wide, low floodplain. In the early stages of sedimentation, streams transported abundant gravels and sands from a recently raised area to the south and gradually spread them northward as a thin blanket (Shinarump), the result of baselevel remaining nearly constant. At later stages in Shinarump-Chinle history, new but similar blankets of gravel also advanced northward across the flood plain for short distances. In general, the trend in sedimentation with the passing of time was toward deposition of finer and finer materials.

Sediments of the Chinle illustrate a transition from dominantly fluviatile conditions, shown by cross-stratification, channelling and conglomerate lenses in "D" member sandstones, to an environment of nearly continuous, quiet-water deposition represented by the muds and clays of the "C" member. Scattered lenticular beds of conglomerate and sandstone, similar to those found in "D" member and in the Shinarump, indicate intermittent fluviatile deposition. This was followed by limestone precipitation in bodies of fresh water("B"member) and finally by a complete cessation of sedimentation over much of the region.

Age of Formation: The Chinle has commonly been assigned to the Upper Triassic on the basis of similarities between its vertebrate fauna and that of the European Keuper. Although some paleontologists have suggested that the lower part of the Chinle may represent Middle Triassic time, considerable faunal evidence obtained by Camp (1930) has indicated that the entire formation belongs to the Upper Triassic and is younger than the Popo Agie of Wyoming and also probably, except for the lowest part, younger than the Dockum of Texas. Fossil plants likewise indicate a Late Triassic age for the Chinle according to Daugherty (1941).

The age of the Shinarump conglomerate has not been determined on the basis of vertebrate fossils, but petrified wood within it is considered Upper Triassic by Daugherty (1941). Furthermore, its stratigraphic position conformably below the Upper Triassic Chinle supports this contention. On the other hand, a middle Triassic age has been suggested by Stokes (1950) who concludes that it was formed in the manner of a pediment, attaining its distribution and growth during the general period of erosion represented by the Moenkopi-Chinle unconformity. The presence of comparable gravel deposits within the Chinle seems to the present writer to disprove this idea.

Post-Chinle Unconformity

What is believed to be an irregular erosion surface, overlain by a granule-pebble conglomerate occurs near the contact of Gregory's "A" and "B" members of the Chinle in many places. This unconformable surface is considered (Callahan, 1951) to represent the close of Chinle deposition and to mark the boundary between the Chinle and strata of the overlying Glen Canyon group. The marked lithologic similarity between the strata immediately above the unconformity and other units of the Glen Canyon group, especially the Kayenta formation, support this interpretation. Whether the break is also a boundary between Triassic and Jurassic deposits is not known and does not necessarily follow.

Some localities where evidence of the post-Chinle unconformity are well exposed are (1) Tuba City area, Arizona, where a maximum relief of 50 feet and a granule conglomerate occur (Callahan, 1951) (2) north of Winslow, Arizona, where a relief of 20 feet and a sharp lithologic break are present, (3) Black Rock area, New Mexico, where a one-to-two-foot thick pebble conglomerate occurs and limestone beds of the Chinle are absent, (4) near Fort Wingate, New Mexico, where cross-laminated, normal Wingate sandstone, rests upon the Chinle claystone surface and (5) north of Lupton, Arizona, where nearly 20 feet of pebble conglomerate containing numerous fragments of Chinle overlies the erosion surface. The above data, except that from Tuba City, were furnished by J. Harshbarger (personal communication) who states also that the unconformity is similarily exposed at various localities in the northern part of the Navajo reservation.

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