Correlation of Upper Triassic and Triassic(?) Formations Between Southwestern Utah and Southern Nevada

By RICHARD F. WILSON *and* JOHN H. STEWART

CONTRIBUTIONS TO STRATIGRAPHY

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CONTRIBUTIONS TO STRATIGRAPHY

CORRELATION OF UPPER TRIASSIC AND TRIASSIC(?) FORMATIONS BETWEEN SOUTHWESTERN UTAH AND SOUTHERN NEVADA

By Richard F. Wilson and John H. Stewart

ABSTRACT

Field studies in southwestern Utah and southern Nevada indicate that the Chinle Formation (Upper Triassic) as employed by previous workers in southern Nevada is the probable correlative of the Chinle Formation (Upper Triassic), the Moenave Formation (Triassic?), and the Kayenta Formation (Triassic?) of the Glen Canyon Group in southwestern Utah.

Three principal stratigraphic units make up the strata between the Moenkopi Formation (Lower and Middle? Triassic) and the Navajo Sandstone (Triassic? and Jurassic) in southwestern Utah and between the Moenkopi Formation and the equivalent of the Navajo Sandstone, the Aztec Sandstone, in southern Nevada. These units are a basal unit of sandstone and conglomerate; a conformably overlying middle unit of variegated purple, red, and gray sandstone and bentonitic claystone; and an unconformably overlying upper unit of reddish-brown nonbentonitic siltstone and sandstone that grades upward into the overlying Navajo Sandstone or Aztec Sandstone. Prior to recent work, the basal unit in southwestern Utah generally was termed the Shinarump Conglomerate, and the middle and upper units constituted the Chinle Formation. As now recognized in southwestern Utah, the lower and middle members are called, respectively, the Shinarump and Petrified Forest Members of the Chinle Formation. Probable equivalents of these members are recognized in southern Nevada. The upper unit in southwestern Utah comprises the Moenave and the Kayenta Formations of the Glen Canyon Group. Here these two formations are readily distinguished. In southern Nevada, no such division can be made; the strata of the upper unit as a whole are believed to be the probable undifferentiated equivalents of the Moenave and Kayenta Formations.

A unit that is lithologically similar to the Chinle Formation is present between the Shinarump(?) Member of the Chinle Formation and the subjacent unquestioned Moenkopi Formation in southern Nevada. This unit was included in the Moenkopi Formation by previous workers in Nevada. Until more is known about this unit, the authors tentatively retain it in the Moenkopi Formation and call it the upper unit of the Moenkopi(?) Formation.

INTRODUCTION

Correlation of rocks between the Moenkopi Formation (Lower and Middle? Triassic) and the Navajo Sandstone (Triassic? and Jurassic) from southwestern Utah to southern Nevada has suggested a reassignment of the boundaries of the Chinle Formation (Upper Triassic) in southern Nevada and the tentative correlation of the Moenave (Triassic?) and Kayenta (Triassic?) Formations of the Glen Canyon Group in southwestern Utah with the upper part of the Chinle Formation, as defined by previous authors, in southern Nevada.

The present study was undertaken by the U.S. Geological Survey on behalf of the Division of Raw Materials of the U.S. Atomic Energy Commission as part of a larger regional program concerned with the stratigraphy of rocks of Triassic age on the Colorado Plateau. The study involved the tracing of units in the St. George area in southwestern Utah into southern Nevada by means of stratigraphic sections measured at several localities (fig. 1). The distance between some of the sections is fairly large, but no well-exposed rocks of Late Triassic age are known to crop out between the sections. Outcrops in the Virgin Mountains in Arizona proved unsuitable for the measurement

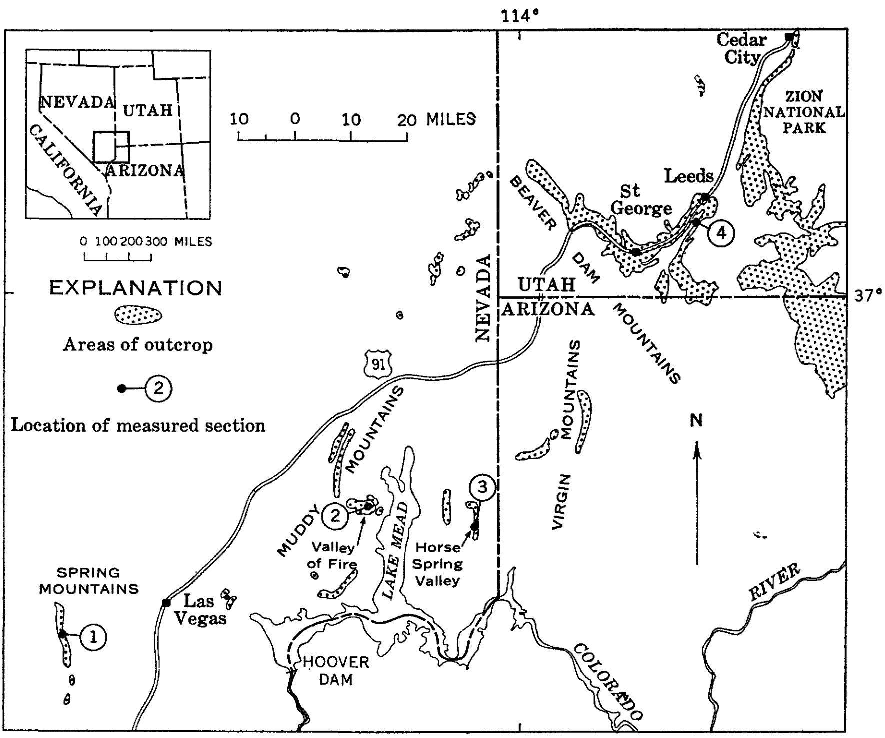


FIGURE 1.—Location of measured sections and the areas of outcrop of the combined Chinle, Moenave, and Kayenta Formations and equivalent rocks undivided in southwestern Utah, northwestern Arizona, and southern Nevada (compiled largely from Wells, 1952, general pl. 1; Bowyer and others, 1958; and Tschanz and Pampeyan, 1961).

of sections. Despite large gaps between some of the sections, most of the general stratigraphic units of Late Triassic age in southwestern Utah are identifiable in southern Nevada.

The area studied in Nevada is structurally complex; Triassic strata are exposed in complicated thrust-faulted and folded fault-block mountains. The major stratigraphic units are easily recognized, but thickness of units in some areas is difficult to determine accurately because of concealed faults and the problems in measuring the correct attitude of beds. Longwell (1928) measured stratigraphic sections near some of those described in this paper; his thicknesses for some units are markedly different from those of the authors. Some of these differences are probably the result of different interpretations of local faulting or attitude of beds.

STRATIGRAPHIC TERMINOLOGY

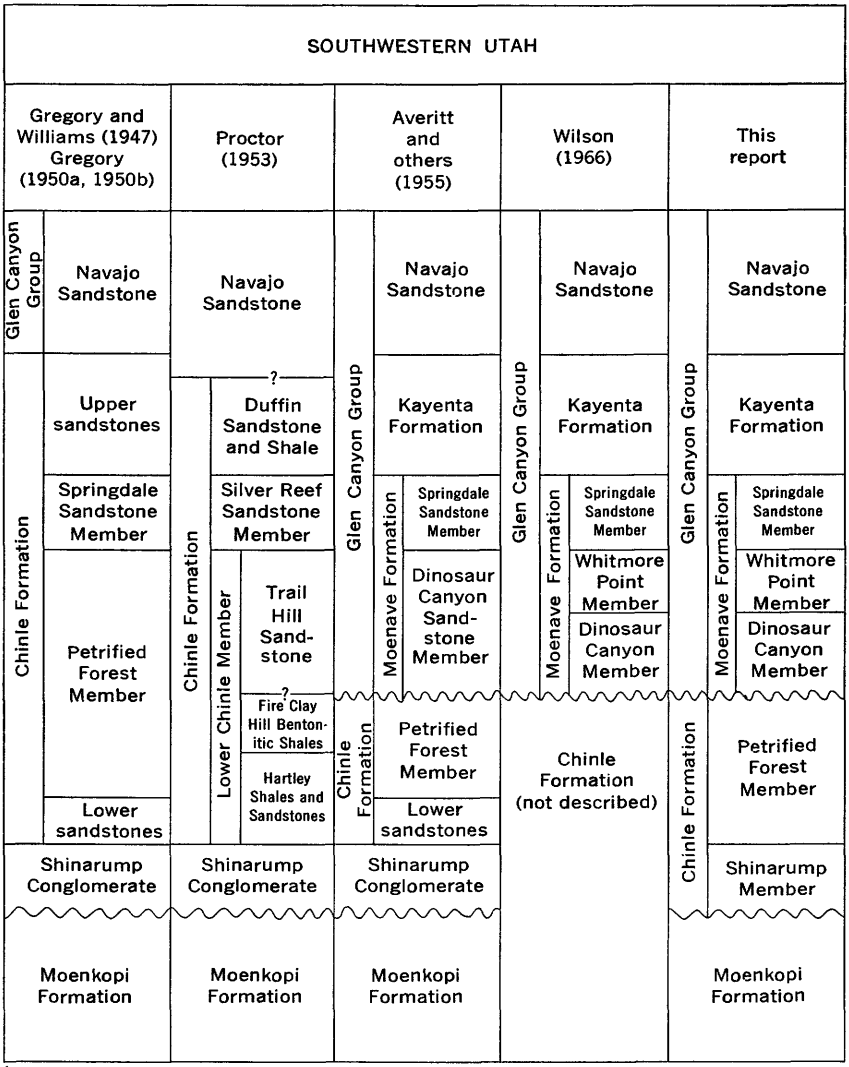
Until 1955, the rocks between the Moenkopi Formation and the Navajo Sandstone in most of southwestern Utah were divided into the Shinarump Conglomerate and the Chinle Formation (fig. 2). This division was made in the Zion National Monument, directly north of Zion National Park (Gregory and Williams, 1947), in part of the Zion Park region (Gregory, 1950b), the Cedar City area (Thomas and Taylor, 1946; Gregory, 1950a), the Leeds area (Proctor, 1953), the Beaver Dam Mountains (Reber, 1952), and the St. George area (Dobbin, 1939). Gregory (1950b) divided the Chinle Formation into four members, in ascending order: (1) the lower sandstones, (2) the Petrified Forest Member, (3) the Springdale Sandstone Member, and (4) the upper sandstones. Proctor (1953) divided the Chinle in the Leeds area into three principal members, in ascending order: (1) the lower Chinle member, which corresponds to Gregory's lower sandstones and Petrified Forest Member; (2) the Silver Reef Sandstone Member, which is identical with Gregory's Springdale Sandstone Member; and (3) the Duffin Sandstone and shale, which corresponds to most of Gregory's upper sandstones. Proctor divided his lower Chinle member into three local units, in ascending order: the Hartley Shales and Sandstones, the Fire Clay Hill Bentonitic Shales, and the Trail Hill Sandstone.

Stratigraphic studies by Averitt, Detterman, Harshbarger, Repenning, and Wilson (1955) and Wilson (1959) have shown that the upper part of the Chinle Formation as defined by earlier workers in northwestern Arizona and southwestern Utah lithologically correlates with the Moenave and Kayenta Formations of the Glen Canyon Group in northern Arizona. The top of their restricted Chinle Formation is placed at an erosion surface from 200 to 250 feet below the base of the Springdale Sandstone Member and within the Petrified Forest

<table>
<tr><th colspan="5">SOUTHERN NEVADA</th></tr>
<tr><th>Longwell (1928)</th><th>Glock (1929)</th><th>Hewett (1931) Longwell (1949)</th><th colspan="2">This report</th></tr>
<tr><td>Jurassic(?) sandstone</td><td>Crossbedded sandstone</td><td>Aztec Sandstone</td><td rowspan="2">Probable equivalent of Glen Canyon Group</td><td>Aztec Sandstone (Navajo Sandstone)</td></tr>
<tr><td rowspan="2">Chinle Formation</td><td rowspan="2">Chinle Formation</td><td rowspan="2">Chinle Formation</td><td>Probable equivalent of Moenave and Kayenta Formations</td></tr>
<tr><td rowspan="2">Chinle Formation (restricted)</td><td>Probable equivalent of Petrified Forest Member</td></tr>
<tr><td>Shinarump Conglomerate</td><td>Shinarump Conglomerate</td><td>Shinarump Conglomerate</td><td>Shinarump(?) Member</td></tr>
<tr><td rowspan="2">Moenkopi Formation</td><td rowspan="2">Moenkopi Formation</td><td rowspan="2">Moenkopi Formation</td><td colspan="2">? Upper unit of Moenkopi(?) Formation</td></tr>
<tr><td colspan="2">? Moenkopi Formation</td></tr>
</table>

FIGURE 2.—Recent and proposed terminology for Upper Triassic and

Member of the Chinle as used by Gregory (1950b). The Moenave Formation—named and defined by Harshbarger, Repenning, and Irwin (1957) in the western part of the Navajo Indian Reservation in northeastern Arizona—includes all strata between this erosion surface and the top of the Springdale Sandstone Member. The strata between the top of the Springdale and the base of the Navajo were assigned by Averitt, Detterman, Harshbarger, Repenning, and Wilson (1955) to the Kayenta Formation. Averitt, Detterman, Harshbarger, Repenning, and Wilson (1955) divided the Moenave Formation in south-



Lower Jurassic strata in southwestern Utah and southern Nevada.

western Utah into two members: a lower Dinosaur Canyon Sandstone Member and an upper Springdale Sandstone Member. The Dinosaur Canyon Sandstone Member—originally defined as a formation by Colbert and Mook (1951)—was placed in the Moenave Formation by Harshbarger, Repenning, and Irwin (1957). The Springdale is the same unit that Gregory (1950b) originally named Springdale Sandstone Member of the Chinle Formation.

In some parts of the Zion Park region, Gregory (1950b) recognized the Wingate Sandstone and Kayenta Formation above strata that he designated as Chinle Formation. The Wingate as recognized by Gregory was found by Wilson (1959) and by Averitt, Detterman, Harshbarger, Repenning, and Wilson (1955) to be a tongue of the Navajo Sandstone within the Kayenta Formation. Averitt, Detterman, Harshbarger, Repenning, and Wilson (1955) and Wilson (1959) discussed the terminology of these units.

Wilson (1959, 1966) used much of the terminology of Averitt, Detterman, Harshbarger, Repenning, and Wilson (1955) but dropped the word "sandstone" from the term Dinosaur Canyon Sandstone Member. The lithologic designation is not appropriate for southwestern Utah, where the Dinosaur Canyon Member is composed predominantly of siltstone. Wilson (1966) also proposed the name Whitmore Point Member of the Moenave Formation for a unit previously included in the Dinosaur Canyon Member by Averitt, Detterman, Harshbarger, Repenning, and Wilson (1955).

The present authors use the same terminology as Wilson for strata of the Glen Canyon Group in southwestern Utah. The term Shinarump Member of the Chinle Formation is substituted for the term Shinarump Conglomerate, following Stewart's redefinition (1957) of the Chinle Formation to include the Shinarump. The designation "lower sandstones of the Chinle Formation" is not used. This unit probably represents a transition zone between the Shinarump and Petrified Forest Members and is placed in the Petrified Forest Member of the Chinle as defined in this report.

In southern Nevada the rocks between the Moenkopi Formation and the Aztec Sandstone have been divided into the Shinarump Conglomerate and Chinle Formation; a division made by Glock (1929) and Hewett (1931) in the Spring Mountains to the southwest of Las Vegas and by Longwell (1928, 1949) in the Muddy Mountains area to the east of Las Vegas. Their usage corresponds to that of Gregory (1950b) for the Zion Park region.

As a result of new correlations, the present authors propose several new interpretations of the Upper Triassic and Triassic(?) stratigraphy in southern Nevada. A thin unit is recognized that corresponds to the uppermost part of what other geologists have called Moenkopi Formation but that is lithologically more similar to the Chinle Formation. For the present, the unit is questionably retained in the Moenkopi Formation as the upper unit of the Moenkopi(?) Formation. The name Shinarump(?) Member of the Chinle Formation is used by the authors in southern Nevada. The correlation of the Shinarump into southern Nevada from southwestern Utah is questionable because of large gaps between outcrops and because of some differences in lithology of the Shinarump in the two areas. The Shinarump was also recognized as a member of the Chinle Formation in southern Nevada by Longwell (1952, p. 34).

The Chinle Formation as defined by previous workers in southern Nevada is divided into two units by the present authors: a lower unit that is the probable equivalent of the Petrified Forest Member of the Chinle in southwestern Utah and an upper unit that is the probable equivalent of the Moenave and Kayenta Formations (fig. 2). In southwestern Utah, the Moenave and Kayenta Formations are distinctly separate units. In southern Nevada, corresponding separations cannot be made; the upper part of the Chinle Formation as defined by previous workers in Nevada is considered the probable undifferentiated equivalent of the Moenave and Kayenta Formations.

As pointed out by Baker, Dane, and Reeside (1936, p. 20 and table 1), a unit in southern Nevada termed Aztec Sandstone—proposed by Hewett (1931) for the Spring Mountains area and later extended by Longwell (1949) to the Muddy Mountains area—corresponds to the Navajo Sandstone in southwestern Utah. The present authors likewise believe that the Aztec and Navajo are equivalent and that they represent the same lithostratigraphic unit. Nevertheless, the term Aztec Sandstone is retained in this report for this unit in southern Nevada.

Although the correlations and stratigraphic interpretations presented in this paper are believed to be correct, an informal terminology is used for units in southern Nevada. More detailed work should permit formal terminology proposals.

MOENKOPI FORMATION

In southwestern Utah and southern Nevada, rocks unquestionably assigned to the Moenkopi Formation consist of interstratified limestone, gray siltstone and gypsum, and red siltstone and sandstone. Both marine and continental deposits are represented; the percentage of marine deposits increases to the west. Throughout southwestern Utah, the uppermost part of the Moenkopi consists of red beds—the upper red member (Gregory, 1950b). This member is believed to be present in southern Nevada also.

The upper red member is composed predominantly of very thick bedded siltstone and lesser amounts of ripple-laminated siltstone. Cross-laminated sandstone and minor amounts of gypsum are also present. The member forms a slope beneath cliffs formed by the Shinarump Member of the Chinle Formation. In sections examined in Nevada, the top several feet of the upper red member contains one or more beds 1–4 feet thick of sandstone composed of rounded grains of limestone or conglomerate composed of rounded grains to pebbles of limestone interbedded with red or gray siltstone. These sandstone or conglomerate beds are useful for determining the top of the upper red member in southern Nevada.

UPPER UNIT OF THE MOENKOPI(?) FORMATION

In southwestern Utah, the upper red member of the Moenkopi Formation unconformably underlies the Shinarump Member of the Chinle Formation. In the sections examined in southern Nevada, however, a peculiar unit is present between the Shinarump(?) Member of the Chinle and the undoubted Moenkopi Formation. This unit is lithologically similar to the Chinle Formation but is questionably retained in the Moenkopi Formation as the upper unit of the Moenkopi(?) Formation. The base of this unit directly overlies or is within a few feet of the uppermost of the calcarenite or conglomerate beds of the upper red member of the Moenkopi Formation. Thus, in southern Nevada, the position of the contact between the Moenkopi and the Chinle Formations—and therefore the position of the mid-Triassic unconformity—is in doubt and may be either at the top or at the base of this questionable Moenkopi unit.

The upper unit of the Moenkopi(?) Formation is probably represented in all the sections measured by the authors in southern Nevada. The thickness of this unit seems to decrease to the east (fig. 3)—at Spring Mountains, approximately 55 feet of strata are assigned to the unit; at Valley of Fire, 20 feet; and at Horse Spring Valley, 8 feet.

The upper unit of the Moenkopi(?) Formation is poorly exposed at many places and is quite variable in lithology. At Horse Spring Valley, it is composed of greenish-gray claystone to clayey sandstone; at the Spring Mountains the stratigraphic section is of grayish-red silty claystone. The claystone at both of these localities is composed of clays that expand in water and apparently belong, at least in part, to the montmorillonite group. These clays probably represent bentonitic material. At Valley of Fire, the Shinarump(?) Member of the Chinle Formation is underlain by a poorly exposed unit of grayish-red-purple siltstone that may represent the upper unit of the Moenkopi(?) Formation.

The swelling clay, clayey sandstone, and grayish and purplish colors of this unit at various localities are much more characteristic of the Chinle Formation than they are of the upper red member of the Moenkopi Formation, which contains nonswelling clay and is red to reddish-brown. Therefore, the transfer of this unit to the Chinle Formation would seem justified. In places, however, this unit might represent an altered zone, possibly a soil, at the top of the Moenkopi Formation. Further study of this unit seems necessary before its relationships to the overlying and underlying units are completely understood.

CHINLE FORMATION

The Chinle Formation in southwestern Utah is divided into two units: the Shinarump Member below and the Petrified Forest Mem-

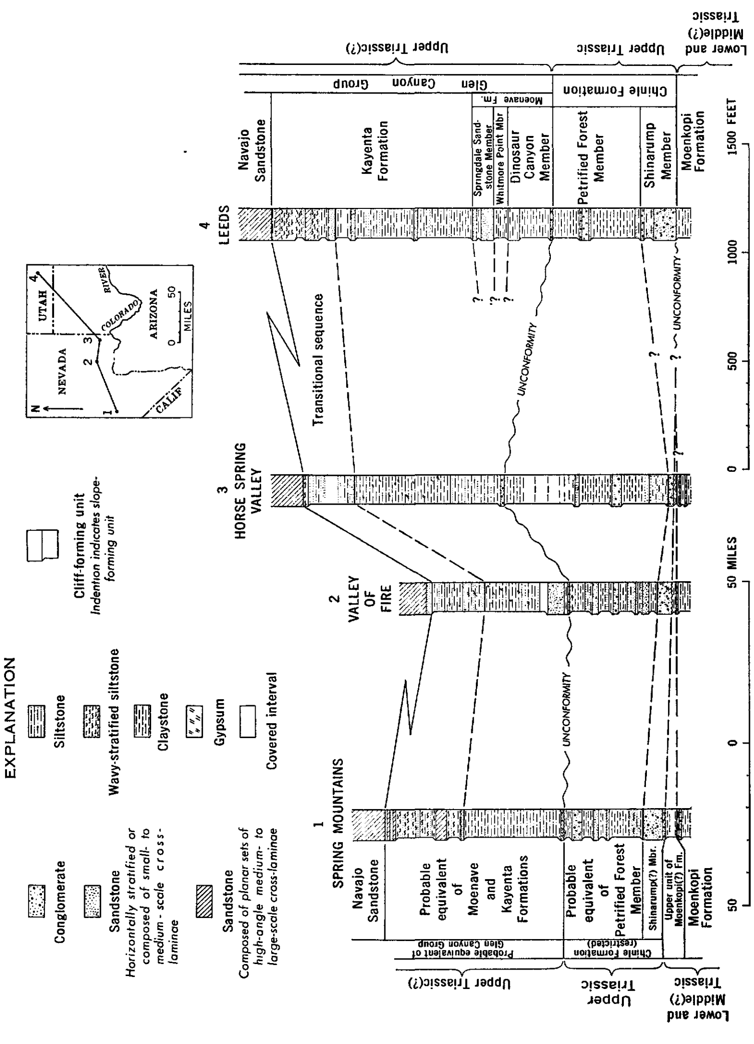


FIGURE 3.—Correlation of Upper Triassic and Upper Triassic(?) formations, southwestern Utah and southern Nevada.

ber above. That part of the section formerly considered the upper part of the Chinle is now assigned to the Moenave and Kayenta Formations of the Glen Canyon Group (Averitt and others, 1955). In southern Nevada, the Chinle Formation, as restricted in this paper, includes the Shinarump(?) Member and the probable equivalent of the Petrified Forest Member. The upper part of the Chinle Formation, as defined by previous workers in Nevada, is considered the probable equivalent of the Moenave and Kayenta Formations; it is discussed in the section on the Glen Canyon Group and its equivalents.

SHINARUMP MEMBER

Strata belonging to the Shinarump Member, or questionably assigned to the member, occur in all outcrops of Late Triassic age examined in southwestern Utah and southern Nevada. The thickness of these strata is variable and ranges from 29 feet at Horse Springs Valley, Nev., to 162 feet near Leeds, Utah (fig. 3).

Near Leeds, the lithology of the Shinarump Member is identical with the lithology of the member in its type area at the Shinarump Cliffs, about 50 miles east-southeast of Leeds. The Shinarump is composed predominantly of pale-orange to yellowish-gray fine- to coarse-grained horizontally laminated to cross-laminated sandstone and interstratified lenses of conglomeratic sandstone and conglomerate. Minor amounts of ripple-laminated siltstone are present in the member in some localities. The sandstone in the Shinarump contains trough sets of small to medium scale, low- to very low angle, cross-laminae [1] and probably represents stream-channel deposition. Pebbles in the conglomeratic parts of the member consist of quartz, quartzite, and chert. The member typically weathers to form prominent cliffs or hogbacks.

In southern Nevada, rocks questionably assigned to the Shinarump Member are composed predominantly of medium- to coarse-grained cross-laminated sandstone and lesser amounts of conglomeratic sandstone and conglomerate. These rocks differ from those of the Shinarump Member in southwestern Utah in that locally, as in Horse Spring Valley, they contain some clayey matrix. In addition, chert pebbles seem to be more abundant in the conglomerate beds of the Shinarump(?) Member in Nevada than they are in the type area of the Shinarump in southwestern Utah. At the Spring Mountains stratigraphic section (fig. 3), the lower 12 feet of the Shinarump(?) Member is composed entirely of chert-pebble conglomerate.

The contact of the Shinarump Member with the overlying Petrified Forest Member, or with strata in Nevada probably equivalent to the

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[1] Most of the stratification terminology used in this report is after McKee and Weir (1953).

Petrified Forest Member, is transitional in most localities; it is arbitrarily placed at the base of the lowest claystone, siltstone, or clayey sandstone unit above the ledge-forming sandstone of the Shinarump Member. Above this contact at many localities are sandstone units similar in lithology to the Shinarump. These sandstone units may represent tongues of the Shinarump Member in the Petrified Forest Member.

PETRIFIED FOREST MEMBER AND PROBABLE EQUIVALENT

The Petrified Forest Member, or its probable equivalent, forms most of the Chinle Formation in southwestern Utah and southern Nevada. A thickness of 350–450 feet for the unit is fairly constant throughout the area. A maximum thickness of 752 feet for the unit was measured in Horse Spring Valley, but this measured thickness may be too great, owing to difficulties in determining accurate dips and to the possible repetition of beds by concealed faults along the line of section.

In southwestern Utah and southern Nevada, the Petrified Forest Member, or its probable equivalent, exhibits the same lithology that characterizes the member in its outcrops in the Painted Desert and Petrified Forest in Arizona and elsewhere on the Colorado Plateau. Variegated hues of red, purple, yellow, and gray make it the most distinctive Triassic unit of this region. In general, the member is composed of lenses, lenticular beds, and interstratified masses of claystone, silty claystone to clayey siltstone, siltstone, clayey sandstone, sandstone, and minor conglomeratic sandstone to conglomerate. Most of the claystone and clayey constituents of the unit are composed of clay minerals that swell in water and presumably belong in part to the montmorillonite group of clays. Allen (1930), Waters and Granger (1953), and Schultz (1963, p. C37–C39) have shown that much of the clay of the Petrified Forest Member was probably formed by the devitrification of volcanic ash, pumice fragments, and tuffaceous material. This clay may be classed as bentonite. The claystone commonly weathers to form frothy surfaced slopes. A weathered zone extends several feet downward from the surface of the claystone and obscures the internal bedding structure. In general, however, the claystone seems to form horizontally bedded layers with bedding planes from 1 foot to many feet apart.

The sandstone in the Petrified Forest Member and its probable equivalent occurs in lenses a few inches to 50 feet thick interstratified with claystone and siltstone; this sandstone ranges from clayey and silty to coarse grained and is poorly to well sorted. Many of the clayey sandstone lenses are composed of fine to medium grains of quartz, chert, and sand-sized aggregates of clay in a clay matrix. The sand-sized clay grains were probably formed by the decomposition of water-deposited vitric particles of volcanic material that once were similar in size to the more stable grains of quartz and chert (Schultz, 1963, p. C33). The clayey sandstone in general is poorly indurated and weathers to form slopes, along with the claystone and siltstone of the member.

The better sorted, and less clayey, silty sandstone and sandstone in the Petrified Forest Member weathers to form ledges and cliffs and is better exposed than the clayey sandstone. This better-sorted sandstone is typically composed of thin to thick trough and minor planar sets of small- to medium-scale low-angle crosslaminae; the sandstone represents probable stream-channel deposits. Quartz and lesser amounts of chert and feldspar are the predominant minerals in the sandstone. Some of the sandstone units include lenses of conglomeratic sandstone and conglomerate composed of granules and pebbles of quartz, quartzite, chert, limestone, and siltstone.

The percentage of sandstone in the Petrified Forest Member and its probable equivalent increases toward the south or southwest. In southwestern Utah, the percentage of sandstone ranges from 16 to 19 percent. It increases to about 35 percent in southern Nevada and reaches a maximum of 42 percent in the Valley of Fire; this indicates that the source area lay toward the south. Additional evidence that the Chinle Formation in southern Nevada was deposited close to its source area is furnished by a bed of conglomeratic sandstone 190 feet above the base of the Petrified Forest Member equivalent in the Valley of Fire. Pebbles in this conglomeratic sandstone are largely composed of unstable volcanic rock, probably not transported far from source.

In the Leeds area, the Petrified Forest Member consists of two claystone units separated by a medial sandstone unit (fig. 3). The upper claystone unit is composed predominantly of grayish-red-purple claystone that contains several layers of limestone nodules. These nodules range from a fraction of an inch to more than 2 inches in diameter. The lower claystone unit is composed predominantly of grayish-red and gray claystone and lesser amounts of siltstone; limestone nodules are absent. At Horse Spring Valley, the medial sandstone unit cannot be differentiated, but the upper 100 feet of the Petrified Forest equivalent consists of purple claystone that contains limestone nodules. This purple claystone may be in part correlative with the upper claystone unit of the Petrified Forest Member at Leeds. Farther west, in the Valley of Fire, the upper 65 feet of the Petrified Forest equivalent is composed of purple claystone with limestone nodules concentrated in the top 30 feet; it may also be partly correlative with the upper claystone unit in the Leeds area. Still farther west, in the Spring Mountains, the purple claystone unit cannot be recognized; no limestone nodules are present in the Petrified Forest equivalent. The purple claystone is the only unit in the Petrified Forest Member that may be correlative from southwestern Utah to southern Nevada.

CHINLE FORMATION (RESTRICTED)–GLEN CANYON GROUP CONTACT

In southwestern Utah, the contact between the Petrified Forest Member of the Chinle Formation and the overlying beds of the Glen Canyon Group is a well-defined horizon that can be easily distinguished in the field. This same horizon is clearly recognizable in southern Nevada between the probable equivalent of the Petrified Forest Member of the Chinle and the probable equivalents of the Moenave and Kayenta Formations—the upper part of the Chinle as used by previous authors. The contact lies along an erosion surface that marks a stratigraphic hiatus that in regions to the east is occupied by the Owl Rock and Church Rock Members of the Chinle Formation, the youngest members of the Chinle (Stewart, 1957), and probably at least part of the Wingate Sandstone, which, where present, is the basal unit of the Glen Canyon Group. The erosion surface thus marks an important stratigraphic break in the Upper Triassic Series.

In southwestern Utah, the basal unit of the Glen Canyon Group, directly overlying the Chinle Formation, is the Dinosaur Canyon Member of the Moenave Formation. In southern Nevada, the Moenave equivalent, if present, could not be differentiated from the overlying Kayenta equivalent. Here the Chinle Formation (restricted) is overlain by beds collectively considered by the authors to be the probable equivalents of the Moenave and Kayenta Formations, undifferentiated. These beds comprise the upper part of the unrestricted Chinle Formation of previous reports.

East of the Leeds area, the basal bed of the Dinosaur Canyon Member is commonly a siltstone or very fine grained sandstone that contains laminae and scattered grains of coarse sand and fragments of reworked claystone and siltstone derived from the Chinle Formation. Lenses and layers of conglomeratic sandstone or conglomerate that contain pebbles of chert and minor quartzite are present in some localities but are not abundant. In most localities examined west of Zion National Park, however, the basal bed of the Glen Canyon Group or its probable equivalents consists of conglomeratic sandstone or of lenses of conglomeratic sandstone in a sandstone matrix. This bed ranges from 1 inch to 18 feet in thickness, and seems to be a persistent unit. The conglomeratic material contains granules to cobbles of chert and lesser amounts of quartzite and quartz. Siltstone and limestone pebbles are common. In the Spring Mountains, a considerable amount of the conglomeratic material in this bed consists of volcanic rock fragments.

Although the pebble assemblage of this bed at various localities is very similar to pebble assemblages in the Chinle Formation, there is one significant difference. Many of the siliceous pebbles in the basal bed of the Glen Canyon Group or its probable equivalent have pitted surfaces; some are faceted. These pebbles may be ventifacts. Within the Chinle Formation, pitted or faceted surfaces on pebbles in conglomerate units are rare. The pebbles in the basal bed of the Glen Canyon Group probably accumulated as lag gravel deposits on the erosion surface at the top of the Chinle Formation. No siliceous pebbles are in the Moenave or Kayenta Formations, or in their equivalents, above this basal bed; therefore, the pebbles probably were derived by reworking from the underlying Chinle Formation.

Topographic relief along the contact reaches a maximum of about 10 feet on the Vermilion Cliffs east of Zion National Park but is not particularly noticeable in the region west of the park. The contact surface is almost flat, and the average relief is not more than a few inches.

Several criteria, stated in terms of Utah nomemclature but also effective in southern Nevada, are useful for field recognition of the contact. First, the contact marks the uppermost occurrence of bentonitic clay in the Upper Triassic and Triassic(?) strata. No bentonitic claystone or clay is known to be present in the Moenave or the Kayenta Formations. Second, there is a definite color change at the contact from the grayish-red to grayish-red-purple strata of the uppermost part of the Chinle Formation to the pale-reddish-brown, grayish-brown, and light-brown strata characteristic of the Moenave and Kayenta Formations. Third, there is an increase in grain size at the contact from claystone and silty claystone of the uppermost beds of the Chinle Formation to sandstone and conglomeratic sandstone of the basal bed of the Glen Canyon Group. This basal bed of the Glen Canyon Group marks the highest occurrence of siliceous pebbles in rocks of Late Triassic and Triassic(?) age in this region, a fact that serves as an additional criterion for identifying the contact.

GLEN CANYON GROUP AND PROBABLE EQUIVALENTS

MOENAVE AND KAYENTA FORMATIONS AND PROBABLE EQUIVALENTS

In southwestern Utah, the Moenave and Kayenta Formations, which make up the lower part of the Glen Canyon Group in this area, form separate lithologic units that may be easily distinguished. In southern Nevada, the Moenave equivalent, if present, could not be separated from the Kayenta equivalent; the strata between the Chinle Formation (restricted) and the Aztec Sandstone form a relatively homogeneous unit. Owing to differences in the lithology of the Moenave and Kayenta Formations and their probable equivalents, the two areas are discussed separately.

SOUTHWESTERN UTAH

In most of southwestern Utah, the Moenave Formation is divided into three members, in ascending order: the Dinosaur Canyon, the Whitmore Point, and the Springdale Sandstone Members.

The Dinosaur Canyon Member in the Leeds area is approximately 200 feet thick. It is composed predominantly of horizontally thick-bedded to laminated pale-reddish-brown siltstone and weathers to form a slope. The upper 60 feet of the member forms a ledgy sequence that is composed largely of beds of coarse siltstone to sandy siltstone that are in part cross laminated on a small to medium scale. Some ripple-laminated beds composed of both parallel and cuspate ripple marks (McKee, 1954, p. 57–60) are present in the member.

In the Leeds area, the Whitmore Point Member is a distinctive unit approximately 60 feet thick composed of greenish-gray, dark-greenish-gray, and grayish-red horizontally stratified siltstone and claystone. It overlies the coarser siltstone of the Dinosaur Canyon Member with a sharp, even contact. The Whitmore Point Member intertongues with the overlying Springdale Sandstone Member; the contact between the two is transitional in some areas. Eastward from Zion National Park, the Whitmore Point Member tongues into and pinches out in the lower part of the Springdale Sandstone Member (Wilson, 1966).

The Springdale Sandstone Member is the uppermost and most distinctive member of the Moenave Formation. It typically forms a prominent irregular or vertical cliff that lies between slopes formed on the overlying Kayenta Formation and the underlying Whitmore Point Member. In Zion National Park and southward, the Springdale ranges from 150 to 200 feet in thickness. To the west, however, the Springdale thins and at Leeds is only 95 feet thick. The Springdale consists of a series of large overlapping or partly overlapping lenses and lenticular beds, from several feet to several hundred feet in length, composed of pale-red to light-brown fine-grained to very fine grained quartzose sandstone. The stratification of the sandstone lenses consists of thin to thick trough and planar sets of medium- to large-scale low-angle to very low angle cross-laminae and also of some sets of horizontal laminae or thin beds. Horizons of cuspate ripple-laminae are common in some areas. Most of the sandstone lenses are separated from each other by erosion surfaces; thin lenses of intraformational claystone and siltstone pellet conglomerate that fill or line channels cut into underlying sandstone lenses are characteristic. The Springdale represents deposition in stream channels in contrast to the predominant flood-plain or alluvial-plain environments that seem to have characterized the overlying and underlying units. The member is very similar in lithology to that in the type area, or "typical facies," of the Kayenta Formation.

Immediately to the east and the southeast of Leeds, the contact between the Springdale Sandstone Member of the Moenave Formation and the Kayenta Formation is a rather sharp, even surface. This surface marks a change in topography from a cliff below to a slope above, a change in color from hues of pale red below to a pale reddish brown above, a change in grain size from sand below to silt above, and a change in stratification from cross-lamination below to horizontal stratificaton above. Locally, a minor amount of intertonguing is present. The Springdale in the Leeds area, however, seems to intertongue to a considerable extent with the Kayenta Formation. At Leeds, the Springdale contains a unit of horizontally stratified claystone, siltstone, and sandstone 14 feet thick; this unit is similar in appearance to strata of the Kayenta Formation but is separated from the Kayenta by 18 feet of sandstone that exhibits typical Springdale lithology. This silty unit probably represents a tongue of the Kayenta Formation that extends into the Springdale Sandstone Member from the west; the westward thinning of the Springdale from Zion National Park to Leeds, therefore, is probably due to intertonguing with the Kayenta Formation.

In the Leeds–St. George area, the Kayenta Formation ranges in thickness from 930 to more than 1,000 feet and may be divided into two parts. The lower part consists of a slope-forming series, 550–650 feet thick, of interstratified grayish-red to pale-reddish-brown siltstone, sandy siltstone, and lesser amounts of silty claystone and very fine grained silty sandstone. The strata are predominantly horizontally laminated to very thick bedded, but sets of parallel ripple-laminae are common, and some of the sandstone and sandy siltstone units are cross laminated on a small to medium scale. Locally, the Kayenta contains lenses of pale-red cross-laminated fine-grained sandstone. At Leeds, the Kayenta contains a lens of sandstone 20 feet thick about 250 feet above the base of the formation that is similar in lithology to the Springdale Sandstone Member. A flood plain or alluvial plain was the probable environment of deposition of the lower part of the Kayenta, but the cross-stratified sandstone lenses, such as that at Leeds, represent stream-channel deposits.

The upper part of the Kayenta Formation, about 300–400 feet thick, contains a considerably higher percentage of sand than the lower part and represents a transition into the Navajo Sandstone. It weathers to form a series of cliffs and ledgy slopes below the massive Navajo Sandstone. The Kayenta is composed of interstratified pale-reddish-brown horizontally to wavy-stratified siltstone to sandy siltstone and light-brown, moderate-reddish-orange, and white horizontally stratified to cross-stratified sandstone. Most of the cross-stratification in the sandstone consists of thin to thick trough and planar sets of low-angle small- to medium-scale cross-laminae and is the result of stream-channel deposition. Some of the lighter colored sandstone units, however, are composed of thick wedge-planar sets of medium- to large-scale high- and low-angle cross-laminae. These units probably represent eolian deposited tongues of the Navajo Sandstone interstratified with water-laid deposits of the Kayenta Formation.

As indicated, the contact between the Kayenta Formation and the Navajo Sandstone is transitional, the result of intertonguing between the two formations. The upper contact of the Kayenta Formation is placed arbitrarily at the top of the uppermost unit of well-defined horizontally stratified to small-scale cross-stratified red siltstone or sandstone below the massive cliff of medium- to large-scale cross-stratified sandstone of the Navajo. Owing to intertonguing, the contact is not a continuous horizon from place to place. In southwestern Utah, the tongues of Navajo Sandstone in the Kayenta Formation merge with the Navajo to the northeast and pinch out into the Kayenta to the southwest. This relation indicates that the Kayenta-Navajo contact rises and becomes younger in age to the southwest (Wilson, 1959, p. 116).

SOUTHERN NEVADA

In southern Nevada, the strata between the Chinle Formation (restricted) and the Aztec Sandstone (Navajo Sandstone) are 920 feet thick at Horse Spring Valley and 820 feet thick in the Spring Mountains. These strata are here considered to be the probable equivalents of the Moenave and Kayenta Formations of southwestern Utah. A minimum thickness of 630 feet was measured in the Valley of Fire, but this measured thickness may be too small, owing to the cutting out of beds by possible concealed faults along the line of section.

The probable equivalents of the Moenave and Kayenta Formations in Nevada—the upper part of the Chinle Formation of previous reports—are very similar in lithology to the Kayenta Formation of the Leeds area and consist of a lower silty part and an upper sandy part that, in places, is transitional with the Aztec Sandstone (Navajo Sandstone). Units correlative with the various members of the Moenave Formation of southwestern Utah were not recognized.

The lower silty part of the probable equivalents of the Moenave and Kayenta Formations ranges from 450 to 650 feet in thickness. It is composed predominantly of pale-reddish-brown to grayish-red horizontally laminated to very thick bedded siltstone to sandy siltstone. Lesser amounts of silty sandstone are interstratified in thin to very thick sets with the siltstone. Much of the sandstone is cross laminated and ripple marked. Minor amounts of gypsum are also present. At Valley of Fire, a prominent ledge of pale-red sandstone, 75 feet thick, is present 22 feet above the base of the interval. The lithology of this sandstone is similar to that of the Springdale Sandstone Member of the Moenave Formation in southwestern Utah, and the two units may be correlative. This sandstone unit is absent, however, farther to the east at Horse Spring Valley. Thus, the correlation of the Springdale Sandstone Member into the Valley of Fire is questionable at best and probably should not be attempted.

The upper sandy part of the probable equivalents of the Moenave and Kayenta Formations is identical in lithology to the upper part of the Kayenta Formation in the Leeds area and also represents a transition into the overlying Navajo equivalent, the Aztec Standstone. The upper sandy part ranges in thickness from 230 feet at Horse Spring Valley to 360 feet at the Spring Mountains. Wavy-stratified coarse siltstone and horizontally stratified to cross-laminated sandstone are characteristic, but in some localities much of the siltstone is also horizontally stratified. In the Spring Mountains, a thick unit of white to pinkish-gray sandstone composed of wedge-planar sets of high- and low-angle small- to medium-scale cross-laminae is present 237 feet below the base of the Aztec Sandstone. This sandstone unit is probably of eolian origin and may represent a tongue of the Aztec Sandstone. Like the base of the Navajo Sandstone in southwestern Utah, the base of the Aztec Sandstone in southern Nevada is arbitrarily placed at the top of the highest horizontally stratified to wavy-stratified red sandstone or siltstone below the massive cliff of lighter colored Aztec Sandstone.

The percentage of sandstone in the lower part of the equivalents of the Moenave and Kayenta Formations in southern Nevada and in the Moenave Formation and the lower part of the Kayenta Formation in southwestern Utah increases northeastward from about 15 to 20 percent in southern Nevada to about 34 percent near Leeds, Utah; this increase suggests that the source area of these sediments lay to the east or northeast of southern Nevada.

NAVAJO SANDSTONE AND AZTEC SANDSTONE

The Navajo Sandstone and its equivalent in Nevada, the Aztec Sandstone, are believed to be a homogeneous unit throughout the region examined. In southwestern Utah, the Navajo has a maximum recorded thickness of 2,280 feet in Zion National Park (Gregory, 1950b,

p. 83). The top of the Aztec is missing everywhere in southern Nevada, either through faulting, as in the Spring Mountains, where the Aztec is overlain by Cambrian rocks in thrust contact (Hewett, 1931), or through erosion, as in the Muddy Mountains and Horse Spring Valley, where the Aztec is separated from overlying strata by an angular unconformity (Longwell, 1928, 1949). The formation has a maximum thickness of 2,500 feet, however, in the Valley of Fire (Longwell, 1949) and 2,100 feet in the Spring Mountains at the northern border of the Goodsprings quadrangle (Hewett, 1931).

The Navajo or Aztec consists of moderate-orange-pink, yellowish-gray and light-brown fine-grained to very fine grained well-sorted sandstone, typically composed of large wedge-planar sets of high-angle medium- to large-scale cross-laminae. It weathers to form a high cliff, or a hogback, above the ledges and slopes formed on the Kayenta Formation in southwestern Utah or on the probable equivalents of the Moenave and Kayenta Formations in southern Nevada.

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