Lucas, S.G. and Spielmann, J.A., eds. 2007, Triassic of the American West. New Mexico Museum of Natural History and Science Bulletin 40.

SECOND DAY: EARLY AND MIDDLE TRIASSIC STRATIGRAPHY, PALEONTOLOGY AND CORRELATION IN NORTHEASTERN ARIZONA

SPENCER G. LUCAS, ANDREW B. HECKERT, JUSTIN A. SPIELMANN, LAWRENCE H. TANNER AND ADRIAN P. HUNT

Assembly Point: Exit 20 (Muñoz Road) of I-40 in Gallup, New Mexico.
Departure Time: 8 AM
Distance: 177.3
Stops: 5

SUMMARY

Today's trip traverses a nearly east-west swath of the southern Colorado Plateau in northeatern Arizona (Fig. 2.1), where the low and barren topography is developed in Permian and Triassic sedimentary rocks. Here, our focus is on the Lower-Middle Triassic Moenkopi Formation. In northern Arizona, east of Flagstaff, the Moenkopi section (Fig. 2.2) is a relatively thin (< 150 m thick) and almost entirely nonmarine section of a normally much thicker and mixed marine-nonmarine lithosome that crops out from New Mexico-Arizona through Utah-Colorado into Wyoming-Montana. However, most of the nonmarine fossil record of the Moenkopi Formation (Group) comes from northeastern Arizona—megafossil plants, conchostracans, trace fossils (notably tetrapod tracks) and vertebrate body fossils (Table 2.1). These are fossils of Early Triassic (Nonesian/Spathian) and Middle Triassic (Perovkan/Anisian) age. Similarly, most of the published magnetostratigraphy of the Moenkopi is based on sampling in northeastern Arizona. Finally, the Moenkopi outcrops here provide us with an excellent opportunity to examine basinwide unconformities and regional lithostratigraphic correlation of the Moenkopi backed up by sequence stratigraphy, biostratigraphy and magnetostratigraphy.

Mileage	Comments
0.0	Exit 20 (Muñoz Road) of I-40, **enter I-40 Westbound. 20.0**
20.0	Enter Arizona; note cliffs of Jurassic Entrada Sandstone here. From here to near Holbrook (about 70 miles), we drive through a landscape developed in lower Chinle Group strata and localized exposures of part of the Moenkopi Formation. The Chinle stratigraphy (Fig. 2.3) will be explored in detail in tomorrow's trip (see third day roadlog). **1.9**
21.9	Exit 357 goes north to Window Rock; note Chinle outcrops here. **17.4**
39.3	Exit 339 is Highway 191 to St. Johns. **26.7**
66.0	Exit to north to Petrified Forest National Park. **7.2**
73.2	Exit 303 to Adamana Road. **0.7**
73.9	Cross Big Lithodendron Wash, which exposes strata of the lower part of the Petrified Forest Formation (Blue Mesa and Sonsela members). **2.4**

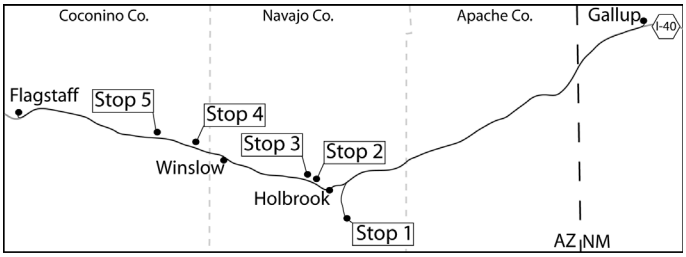


FIGURE 2.1. Map of route of second-day road log.

76.3	Cross Little Lithodendron Wash; note Sonsela Member of the Petrified Forest Formation well exposed here. **6.0**
82.3	Cross Twin Wash. **5.6**
87.9	Exit 292 to Keams Canyon (Highway 77 North). **3.4**
91.3	Exit 289 to Holbrook. **2.6**
93.9	Exit 286 Holbrook. **Take exit to enter Holbrook.** At the intersection of 180W/186E-77 South (Hopi Drive and Navajo Boulevard); **go south on 180/77. 0.1**
94.0	Cross railroad tracks. **0.3**
94.3	Crest of bridge over Little Colorado River. **0.4**

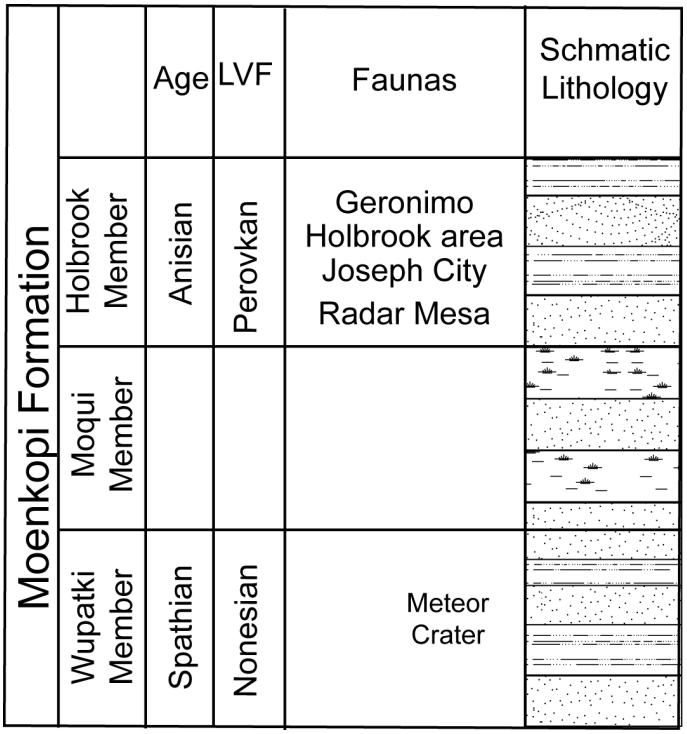


FIGURE 2.2. Generalized stratigraphic section of Moenkopi Formation in northeastern Arizona with vertebrate fossil assemblages and ages indicated (from Heckert et al., 2005).

94.7 Junction 180W/77S; continue south on 77. **0.4**

95.1 Note lower massive sandstone of Wupatki Member of the Triassic Moenkopi Formation (Fig. 2.2). **0.7**

95.8 Wupatki massive sandstone at road level. **0.5**

96.3 **Turn left to Navajo County complex. 0.1**

96.4 **Turn right on unpaved road. 0.1**

96.5 **Stop at curve.**

STOP 1. This is the type section of the Holbrook Member of the Moenkopi Formation and also exposes the upper part of the Moqui Member as well as the Shinarump Formation at the base of the Chinle Group above the Holbrook Member. The base of the Shinarump here is silica-pebble conglomerate with impressive scour-and-fill into an irregular surface (incised topography) developed on top of the Holbrook Member. This is the Tr-3 unconformity of Pipiringos and O'Sullivan (1978), which is present at the base of the Chinle Group tectonosequence throughout the western United States (Lucas, 1993; Lucas and Marzolf, 1993; Marzolf, 1993; Lucas et al., 1997b). We view deposition of the Shinarump as primarily resulting from a basinwide rise in base-level due to rising sea level during the Late Triassic.

When driving to this stop we traversed a stripped surface on the Lower Permian (Leonardian) Coconino Sandstone, an eolianite equivalent to the Glorieta Sandstone in New Mexico. The northeastern Arizona Moenkopi Formation section (Fig. 2.2), as much as 115 m thick, is a relatively thin wedge-edge of the Moenkopi Formation along the southern margin of the vast Moenkopi depositional basin that extended from Arizona-New Mexico to Wyoming-

TABLE 2.1. List of vertebrate fossil taxa and ichnotaxa from the Moenkopi Formation in northeastern Arizona.

Wupatki Member

Osteichthyes indet. (ganoid scales, possibly palaeoniscoid)
Dipnoi indet.
Wellesaurus peabodyi (Welles)
= *Stanocephalosaurus birdii* (Brown)
Cosgriffius campi Welles
Diapsida *incertae sedis*

Trace fossils:

Capitosauroides bernburganis Haubold
Chirotherium spp.
Isochirotherium spp.
Synaptichnium diabloense Peabody
Isochirotherium cotteri Peabody
Rotodactylus cursorius Peabody

Holbrook Member Fauna

Hybodontidae indet.
?*Boreosomus* sp.
Moenkopia wellesi
Dipnoi indet.
Taphrognathus bradyi Welles
Vigilius wellesi Warren and Marsicano
Haddrokkosaurus bradyi Welles and Estes
Cyclotosaurus randalli Welles
Rhadabognathus boweni Welles
Eocyclotosaurus wellesi Schoch
Quasicyclotosaurus campi Schoch
Cynodontia indet.
Prolacertiformes indet.
Archosauria indet. ("*Chatterjeea*-like taxon" of Nesbitt, 2005)
Ammorhynchus navajoi Nesbitt and Whatley
Anisodontosaurus greeri Welles
Arizonasaurus babbitti Welles

Trace fossils:

Synaptichnium cameronense Peabody
Synaptichnium sp.
Isochirotherium marshalli Peabody
Isochirotherium sp.
Rotodactylus mckeei Peabody
Rotodactylus brady Peabody
Therapsipus cumminsi Hunt et al.
coprolites

*Complete binomen including author = Type specimen

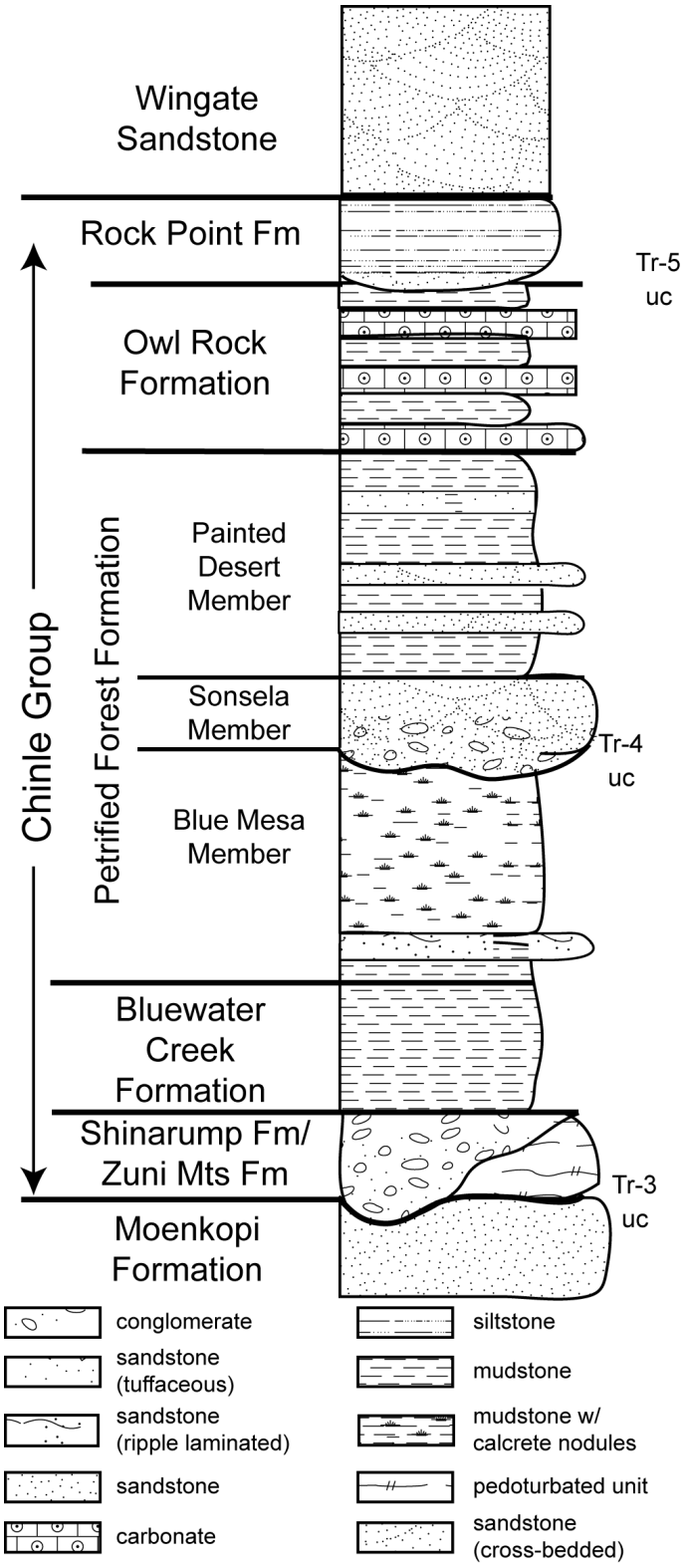


FIGURE 2.3. Generalized lithostratigraphy of the Chinle Group in northeastern Arizona; uc = unconformity. From Heckert et al. (2005).

Idaho (Stewart et al., 1972b). The basal Wupatki Member of the Moenkopi Formation unconformably overlies the Coconino Sandstone here. Conchostracans, fossil vertebrates (the capitosaurid *Wellesaurus peabodyi*, similar to *Stenotosaurus gracilis* from the Untere Rottone of the upper Buntsandstein and *S. semiclausus* from the Violet Horizon 5 of the upper Buntsandstein) and regional stratigraphic relationships indicate the Wupatki is of late Olenekian (Spathian) age (McKee, 1954; Morales, 1987; Kozur and Morales, 1993; Lucas and Schoch, 2002) (Fig. 2.4). Its upper portion, the "lower massive sandstone," can be traced into the Shnabkaib Member of the Moenkopi in southwestern Utah, which has produced an ammonoid of the *Columbites* Zone (McKee, 1954; Stewart et al., 1972b; Morales, 1987). This means the Tr-1 unconformity (of Pipiringos and O'Sullivan, 1978) at the base of the Wupatki Member represents a hiatus from Leonardian to Spathian time.

The Moqui Member has no fossils with which to determine its age. The overlying Holbrook Member, however, is extremely fossiliferous. Conchostracans from the unit suggest an Anisian age (Kozur and Morales, 1993). Tetrapods from the middle and upper parts of the Holbrook Member (especially the benthosuchid *Eocyclotosaurus*) suggest an early Anisian age (Lucas and Morales, 1985; Morales, 1987; Lucas, 1998; Lucas and Schoch, 2002).

Magnetostratigraphic studies of the Moenkopi Formation in northeastern Arizona (Steiner et al., 1993) reveal a reversed-normal-reversed pattern for the Holbrook Member. The overall magnetostratigraphy of the Moenkopi can be correlated with Early Triassic magnetostratigraphy from the Canadian Arctic and China to support assignment of a Spathian age to Moenkopi strata in Arizona older than the Holbrook Member.

	After stop turn around and return to highway. 0.1
96.6	**Turn left. 0.1**
96.7	**Turn right to north on highway. 1.4**
98.1	Holbrook, continue north on 77 to I-40. **1.7**
99.8	Go under I-40 bridge in far right lane. **0.2**
100.0	Go under I-40 onramp; highway is on Holbrook Member. **2.8**

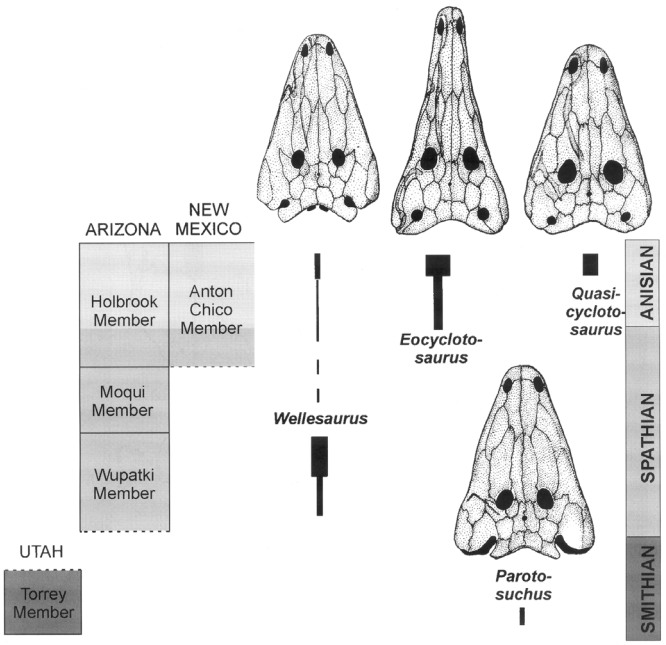


FIGURE 2.4. Stratigraphic ranges of temnospondyl taxa and correlation of the Moenkopi Formation of northeastern Arizona (from Lucas and Schoch, 2002).

102.8 LeRoux Wash. **1.7**

104.5 Moqui Member to right; base of Holbrook Member on hill to right. **1.6**

106.1 Geronimo Road/Hunt Road exit (280) to right; **exit here. 0.2**

106.3 Parking lot to right; stop here for Geronimo (Holbrook) fossil-vertebrate quarry.

STOP 2. Welles (1947) termed this the Holbrook quarry (Fig. 2.5), and it is by far the richest fossil-vertebrate site in the Holbrook Member, having produced much of the early Anisian vertebrates known from the unit, including the bizarre amphibian *Haddrokkosaurus bradyi*.

The quarry (UCMP V3922) is about 10 ft below the top of an isolated butte in the NE1/4 sec. 31, T18N, R20E, Coconino County. It is at the base of the ledge-forming sandstone Purucker et al. (1980) chose as the base of the Holbrook Member, but it is within the Holbrook Member of our usage. About 1 mile north of the quarry, the base of the Shinarump Formation of the Chinle Group can be seen above the Holbrook Member, well above the quarry. Magnetostratigraphy (Steiner et al., 1993) indicates that this quarry is in an interval of normal polarity and thus is older than some other Holbrook Member vertebrate sites. The vertebrate fauna includes

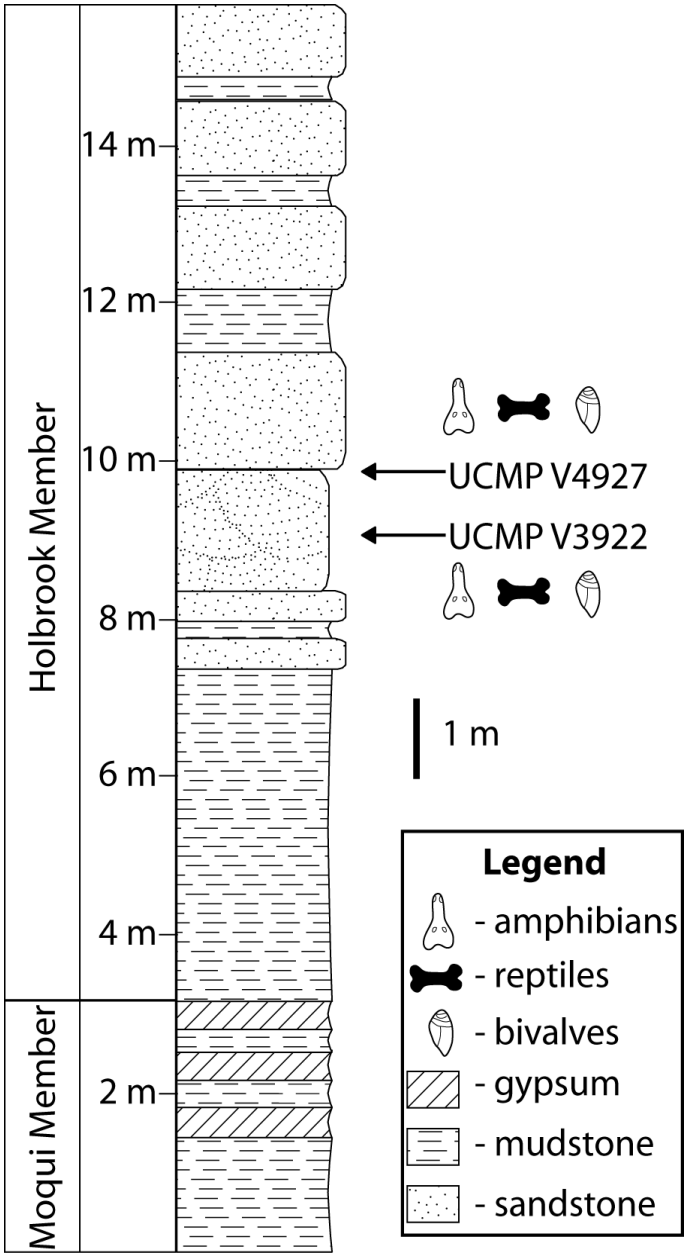


FIGURE 2.5. Measured stratigraphic section at the Holbrook quarry (after Nesbitt, 2005).

Haddrokkosaurus bradyi (Welles), *Eocycloto-saurus wellesi*, *Arizonasaurus babbitti* Welles, and *Anisodontosaurus greeri* Welles (Welles, 1947; Welles and Estes, 1969; Hunt et al., 1998; Schoch, 2000; Warren and Marsicano, 2000; Nesbitt, 2003, 2005; Heckert et al., 2005).

After stop continue west on frontage road to re-enter I-40 heading toward Flagstaff. 0.3

106.6 **Angle left, then right to I-40 onramp. 1.5**

108.1 **Stop at Moqui Member outcrop on right. Be extremely careful of the traffic at this**

highway stop!

STOP 3. Here, we examine spectacular exposures of channel fills, gypsum beds and calcareous horizons in the Moqui Member of the Moenkopi Formation. Blakey and Middleton (1986) described this outcrop but erroneously assigned it to the Holbrook Member; the Moqui-Holbrook contact is stratigraphically above this outcrop, up the hill from the roadcut.

Several channel fills near the base of this outcrop cross-cut and truncate mudstone and gypsum beds. These lateral-accretion beds, contrast with overlying thin, tabular sandstones that we interpret as un-channelized sheetflood deposits. Blakey and Middleton (1986) doubted a pedogenic origin for the calcareous beds. We hypothesize that deposition here was on a broad mudflat surface by cyclical processes that produced alternating beds of siliciclastic muds/silts, gypsum and carbonate. Incisions on this surface were conduits for river channels that cut into and laterally accreted over the cyclically-deposited surfaces. Climate cycles and local topography thus controlled sedimentation. This outcrop is particularly important because it underscores local depositional diversity on what was otherwise a rather featureless paleosurface that extended from northern Arizona to Utah and beyond at the end of the Early Triassic.

After stop continue west on I-40. 1.9

110.0 Power Plant exit (277). **7.2**

117.2 Jackrabbit Road exit (269). **3.7**

120.9 Holbrook Member outcrops to right are mostly sandstone. **8.7**

129.6 Second Mesa exit (257). **1.0**

130.6 Cross Little Colorado River. **0.9**

131.5 Winslow, Payson exit (255). **3.8**

135.3 Winslow west end exit (252); Moqui outcrops. **6.7**

142.0 Exit 245, to Leupp and Radar Mesa; **exit to right. 0.4**

142.4 Stop sign; **turn right. 0.2**

142.6 **STOP 4.** The Moenkopi section exposed here on the south flank at Radar Mesa (Fig. 2.6) reveals the upper part of the Wupatki Member, the Moqui Member and the Holbrook Member disconformably overlain by the Shinarump Formation of the Chinle Group. Benz (1980) provided an excellent, but unpublished description of this section, which we rely on here. However, note that most workers would place strata she identifies as Wupatki Member in the Moqui Member (e.g., Purucker et al., 1980). These "Wupatki Member" strata at Radar Mesa are 7 m of green to reddish brown trough-crossbedded sandstone and ripple laminated sandy mudstone. Overlying Moqui Member strata are 10 m of brown mudstone with thin interbeds of gypsum. The overlying Holbrook Member is 36.0 m of micaceous mudstone, siltstone and trough cross-bedded pebbly sandstone of mostly grayish red color. The Shinarump Formation is silica-pebble conglomerate and quartzarenite with fossil logs that disconformably overlies the Holbrook Mem-

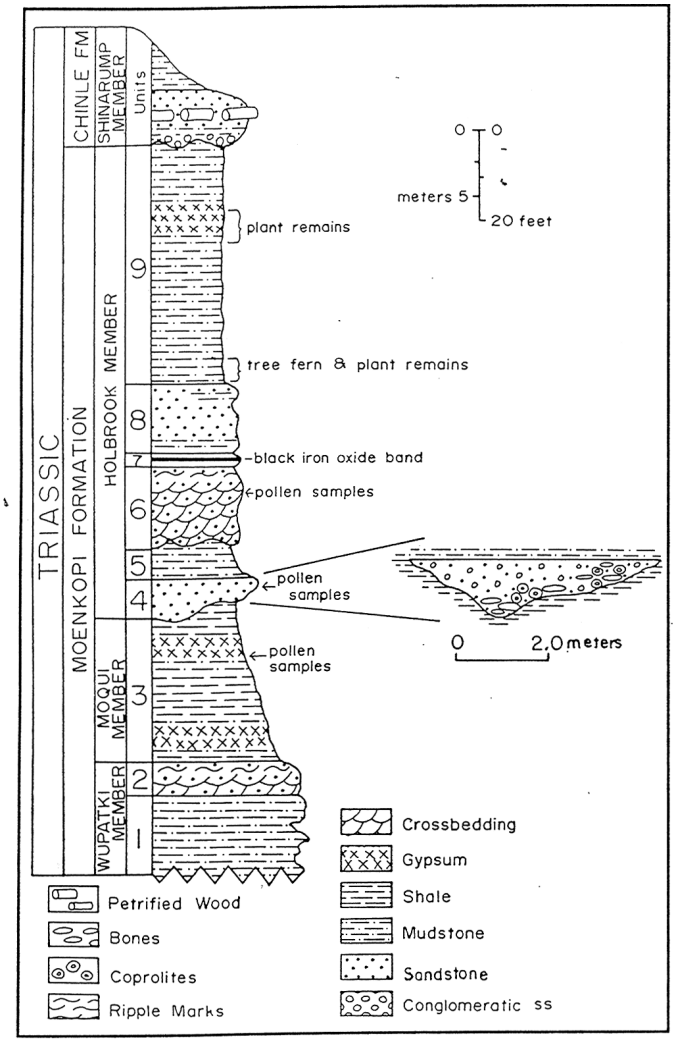


FIGURE 2.6. Measured stratigraphic section at Radar Mesa (from Benz, 1980).

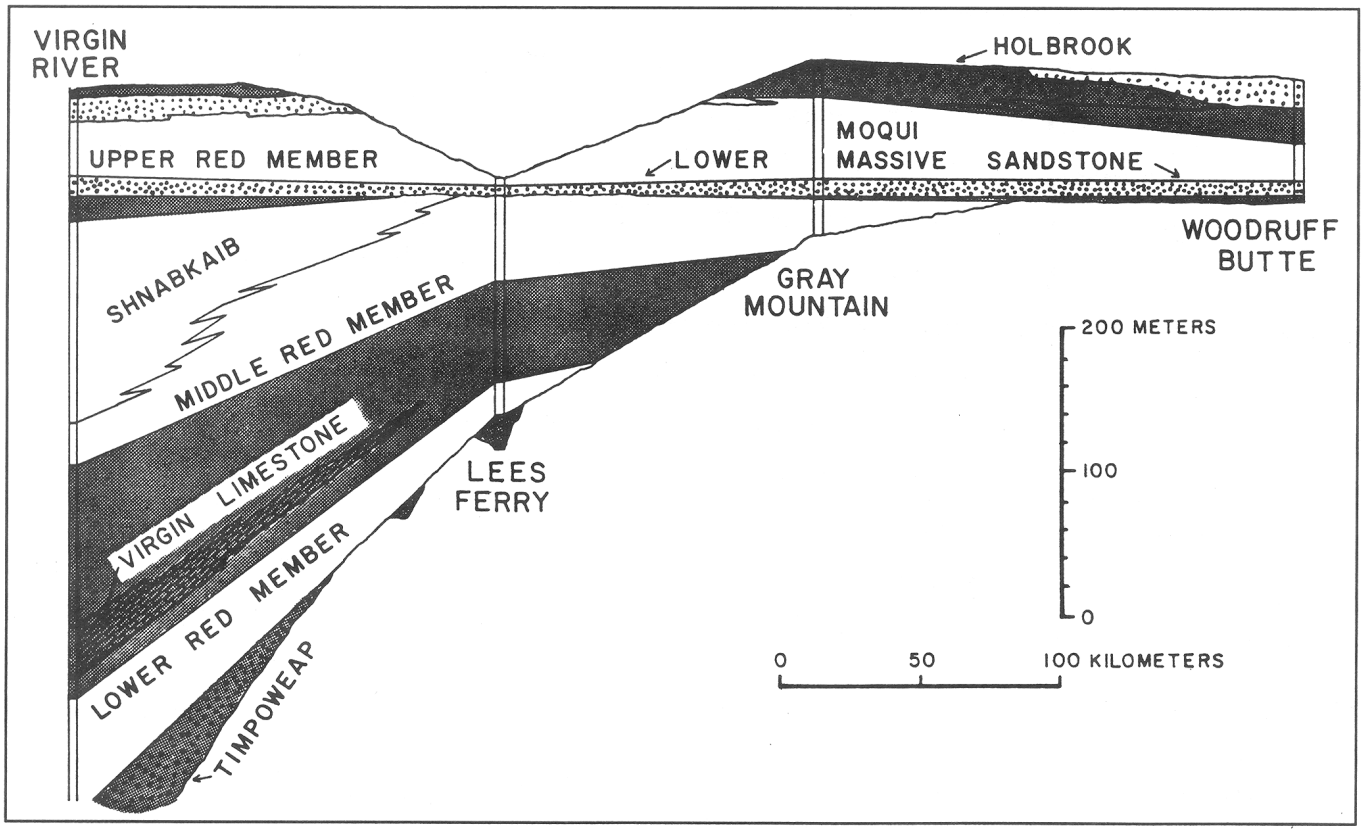


FIGURE 2.7. Stratigraphic correlation of the Moenkopi lithosome from northeastern Arizona to southwestern Utah (modified from Steiner et al., 1993).

ber (Tr-3 unconformity).

The basal sandstone of the Holbrook Member contains isolated teeth, bones and bone fragments. Benz (1980) identified the following taxa from this unit: *Taphrognathus bradyi*, *Cyclotosaurus randalli*, *Rhadalognathus boweni*, *Anisodontosaurus greeri* and coprolites. However, most of these identifications were based on fragmentary specimens that may not be diagnostic. More recent workers (Schoch, 2000; Nesbitt, 2005) recognized only *Eocyclotosaurus wellesi*, *Anisodontosaurus greeri*, and an indeterminate prolacertiform and an archosaur from this quarry.

Fossil plants are found here in the Holbrook Member at two stratigraphic levels, the main horizon being the upper one near the top of the member. These are the only well-preserved megafossil plants known from the Moenkopi Formation (Group) in Arizona and were described by Ash and Morales (1993). Significantly, the flora is essentially identical to that of the overlying upper Carnian lower Chinle Group. This may be explained in two ways: (1) many taxa found in the late Carnian actually have temporal ranges back to the Anisian; or (2) the Holbrook flora is Ladinian, given that Ladinian and Carnian floras are of similar composition (see Dobruskina, 1993).

Magnetostratigraphy of the Holbrook Member here suggests the fossil vertebrate occurrences low in the unit are correlative with the Geronimo (Holbrook) quarry at the last stop.

After stop turn around and return to I-40. **0.2**

142.8 I-40 onramp. **4.1**

146.9 Moqui Member crops out on right side of road. **3.8**

150.7 Lower massive sandstone of Wupatki Member in roadcuts and to right of road. **1.3**

153.0 Rest stop; get off to right; Permian Kaibab Limestone (a correlative of the San Andres Formation in New Mexico) in wash to right before exit. **0.6**

153.6 Stop in parking lot to look at lower massive sandstone of Wupatki Member.

STOP 5. The Wupatki Member rests

unconformably on the Kaibab Limestone in this area and is composed mostly of pale reddish-brown, horizontally laminated and ripple-laminated siltstones that weather to slopes. The widespread, ledge-forming sandstone at the top of the Wupatki Member is referred to as the "lower massive sandstone" of the Moenkopi Formation in this region (McKee, 1954). Baldwin (1971, 1973) distinguished four units within the lower massive sandstone on the basis of bedforms. Three of these units (Baldwin's units 2, 3 and 4) can be recognized here. Units 2 and 4 are cliff-forming, very fine-grained, laminated and crossbedded pale reddish-brown sandstone. Unit 3 is very fine-grained sandstone, silty sandstone and silty claystone. At most places, unit 3 is absent where unit 4 has scoured down into unit 2. The lower massive sandstone extends as an unbroken, 11-to-50-ft-thick blanket from Holbrook, Arizona across northern Arizona to St. George in southwestern Utah (Fig. 2.7). Baldwin (1971, 1973) regarded it as a transgression (unit 2)-regression (unit 4) equivalent to the transgression-regression recorded by the upper Shnabkaib Member (Spathian) in southwestern Utah.

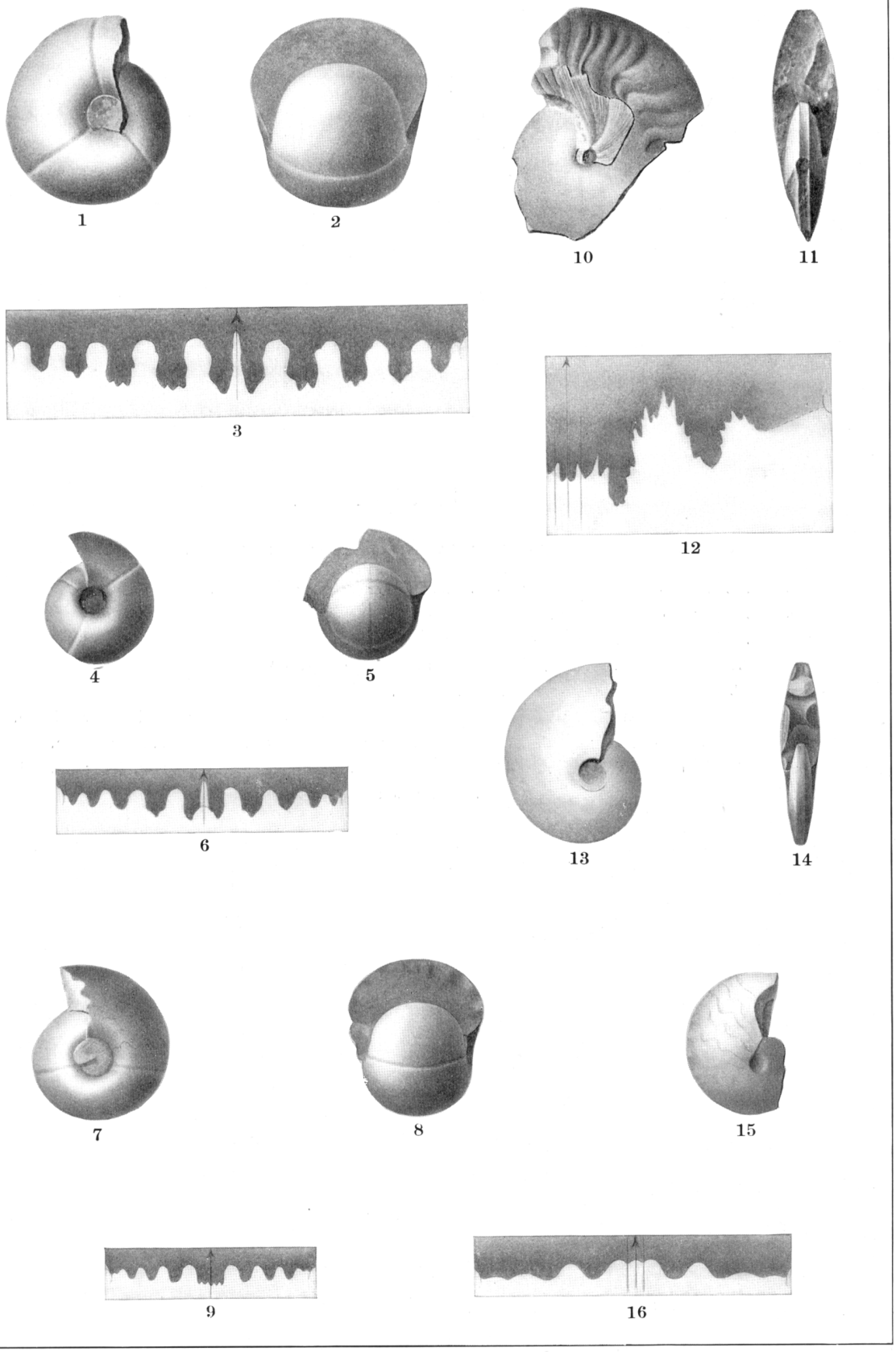
After stop re-enter I-40 heading west. 2.1

155.7 Exit 233, Meteor Crater Road (we visit the Meteor Crater on day 3). **27.7**

173.4 Flagstaff city limits. **3.9**

177.3 Exit 201, Flagstaff/Page.

End of second day road log.



ARCESTES (PROARCESTES) PACIFICUS, HAUERITES ASHLEYI, DIENERIA ARTHABERI.