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LOWER CHINLE GROUP (UPPER TRIASSIC:CARNIAN) STRATIGRAPHY IN THE ZUNI MOUNTAINS, WEST-CENTRAL NEW MEXICO

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Abstract—The lower Chinle Group in the Zuni Mountains consists of (ascending) the mottled strata, Shinarump Formation, Bluewater Creek Formation, and the Blue Mesa Member of the Petrified Forest Formation. A persistent, bench-forming sandstone that crops out extensively in the Bluewater Creek Formation is the McGaffey Member. This section rests disconformably on the Middle Triassic Moenkopi Formation, and is overlain disconformably by the Sonsela Member of the Petrified Forest Formation. The bounding surfaces are the Tr-3 and Tr-4 unconformities, respectively. Differential thinning of the Blue Mesa Member from 45 to 22 m from west to east across the Zuni Mountains probably represents erosional relief generated on the Tr-4 unconformity surface.

The Bluewater Creek Formation consists of three primary lithofacies assemblages, which we interpret as representing red-bed floodplain and overbank, low-sinuosity fluvial, and lacustrine deposits, respectively. Tetrapod biochronology indicates an Adamanian (latest Carnian) age for most lower Chinle Group strata in the Zuni Mountains, including both the Bluewater Creek Formation and the Blue Mesa Member of the Petrified Forest Formation.

Keywords: Upper Triassic, stratigraphy, Adamanian, Bluewater Creek Formation, New Mexico

INTRODUCTION

Lower Chinle Group strata in the Zuni Mountains in Cibola and McKinley counties, west-central New Mexico, crop out extensively along the northern edge of the uplift, with complete stratigraphic sections of this interval readily measured in a few transects. Most of these sections are along the southern margin of the northern limb of the Triassic outcrop belt in the Zuni Mountains, beneath the resistant bluffs of the Sonsela Member, which forms an elongate northwest-trending cuesta between Grants and Fort Wingate (Fig. 1). The stratigraphy and paleontology described here were derived primarily from numerous measured sections along this ridge line because, farther south, outcrops of Chinle strata are sparse, poorly exposed, and structurally complicated.

The history of stratigraphic study of the lower Chinle Group in the Zuni Mountains spans more than a century. One of the principal aims of this paper is to provide a comprehensive review of these previous studies. In addition, we record our observations of each stratigraphic unit and describe our interpretations of these units. Descriptions of the measured sections on which this study is based are in the Appendix.

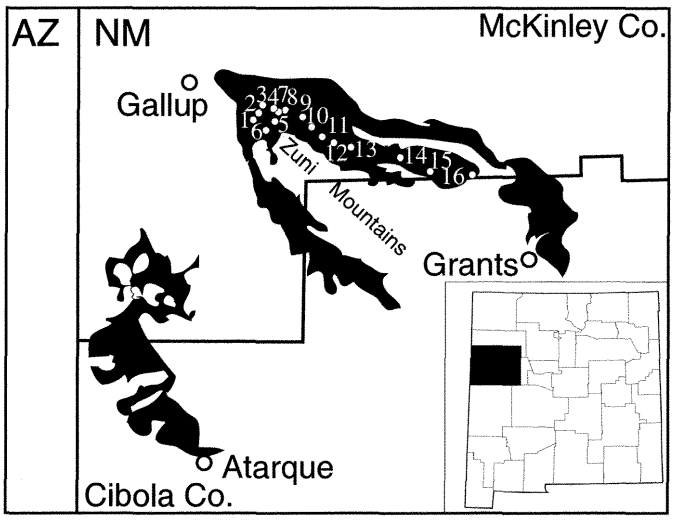


FIGURE 1. Distribution of Triassic outcrops and measured sections in the Zuni Mountains. Numbers correspond to those of measured sections in Figure 4 (Outcrop distribution after Stewart et al., 1972a).

HISTORY OF STUDY

Triassic outcrops in the Zuni Mountains were first studied by Dutton (1885), who noted their probable Triassic age, although he considered all rocks below the Sonsela Member of this paper to be of Permian age (Fig. 2). Darton (1910, 1928) modified this interpretation, and while he also equated the Sonsela Member with the Shinarump Formation (Shinarump Conglomerate of Dutton's usage), he considered lower Chinle beds to be part of the Moenkopi Formation. By 1928 he had adopted Gregory's (1917) term "Chinle" for all units above the Sonsela and below the Entrada. However, he still considered the lower Chinle to be Permian in age and therefore assigned the units investigated here to the Moenkopi Formation. Between Darton's studies, however, Mehl et al. (1916) had reported the first tetrapod fossils from the Fort Wingate area, including a pelvis of an aetosaur and the snout of a phytosaur, both from below the Sonsela Member and indicating a Late Triassic age for these strata. Mehl et al. (1916) thus were the first to establish a Late Triassic age for most of the well-exposed red-bed badlands of the lower Chinle Group that are the focus of this study.

This stratigraphy remained relatively unstudied and unchanged until the 1950s, when uranium exploration spurred additional research, principally that of Smith (1954, 1957, 1958a,b), Cooley (1957, 1959a,b), and much of the USGS work published by Stewart et al. (1972). Smith (1954) was the first to subdivide the Chinle of the Zuni Mountains into lower, middle, and upper members, with his informal "lower member" including all Triassic strata below the Sonsela Member, a lithostratigraphy he followed in a summary article on the Zuni Mountains (1957) and in later mapping projects (1958a,b). He was also the first to recognize the distinct stratigraphic positions of the Sonsela (higher) and the Shinarump (basal), designating the as-yet-unnamed former unit as an informal "middle" member of the Chinle Formation (Smith, 1954, 1957).

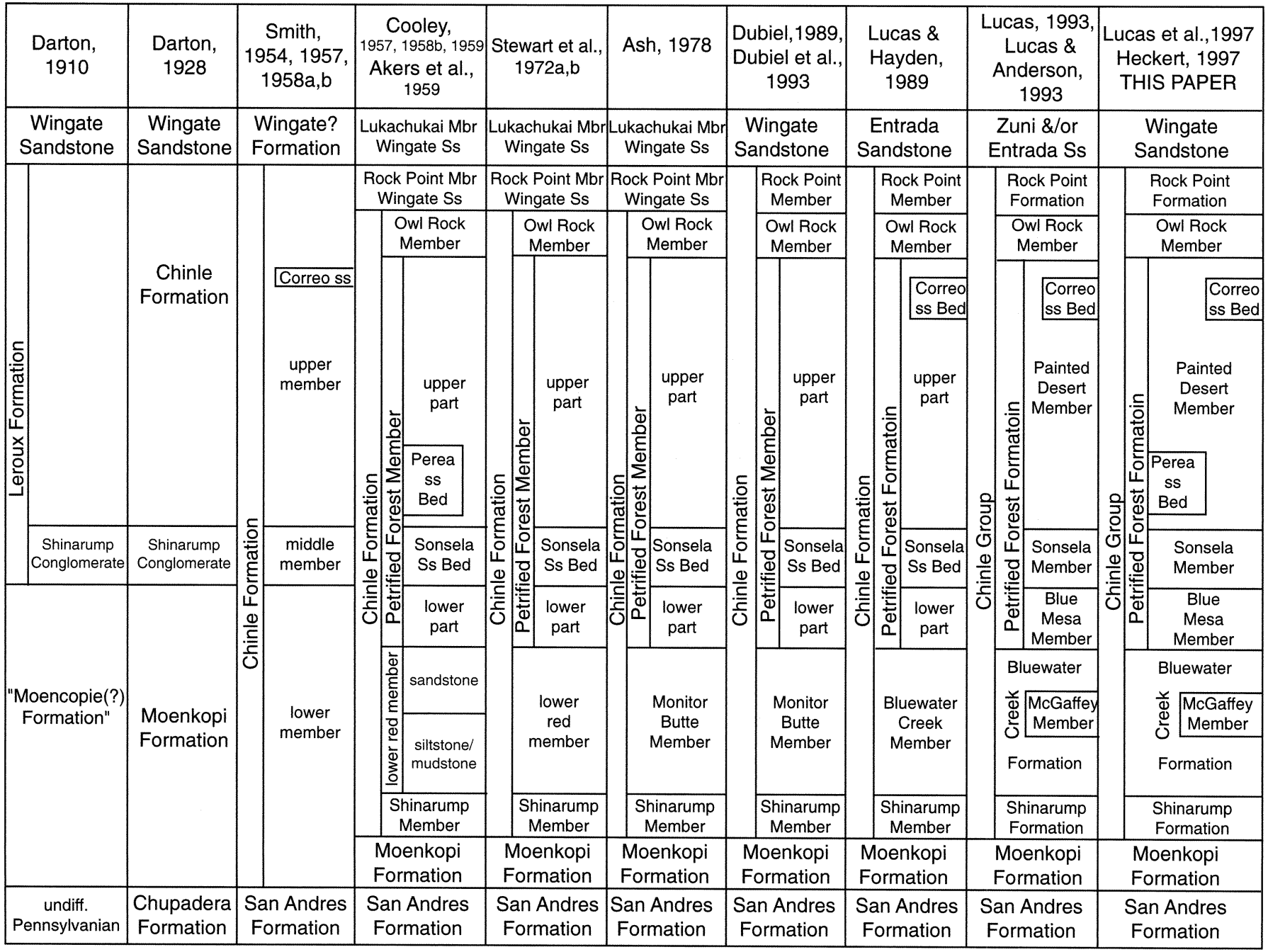


FIGURE 2. Chart showing the evolution of stratigraphic nomenclature for the Triassic System in the Zuni Mountains.

Cooley's (1957) master's thesis and subsequent publications (1959a,b) were the first to utilize an essentially modern stratigraphic nomenclature parallel to that used here (Fig. 2). Cooley followed the early insights of Darton (1910, 1928) in recognizing the Moenkopi Formation in western New Mexico, but improved upon Darton's work by restricting that terminology to the lowest sandstones and siltstones of the Triassic System. Above the Moenkopi, Cooley recognized scattered outcrops of the Shinarump and assigned overlying strata to the "lower red member" of the Chinle Formation, which were in turn overlain by the lower part of the Petrified Forest Member. Akers et al. (1958) named the Sonsela Sandstone Bed for outcrops of that unit in the Defiance uplift in northeastern Arizona, and Cooley (1959a) extended the term "Sonsela Sandstone Bed" to the Zuni Mountains.

Foster (1957) summarized stratigraphic work in west-central New Mexico and followed Smith's nomenclature for the Triassic System. Repenning et al. (1969) chose to lump together numerous informal Chinle units long recognized by the USGS and thus replaced the use of "lower red member" in the Zuni Mountains with "Monitor Butte Member," a term which had been used for correlative strata in the Four Corners region (Akers et al., 1958; Cooley, 1959a). However, in their summary of Chinle stratigraphy and sedimentology, Stewart et al. (1972) followed the conclusions of Cooley (1958, 1959a) and Akers et al. (1958) and identified the "lower red member" as a unit distinct from the Monitor Butte Member. Stewart et al. (1972) also introduced the informal term "mottled strata" to describe the thick, extensively pedoturbated paleosols at the base of the Chinle and formally included the Shinarump in the Chinle as a member.

Following these investigations, the work of Ash (1967, 1968, 1970a,b, 1978) focused on the lower Chinle in the vicinity of Fort Wingate. Ash (1978) followed Repenning et al. (1969) and applied the term Monitor Butte Member to strata identified by Cooley (1957, 1959a), Akers et al. (1958), and Stewart et al. (1972) as the "lower red member." Ash (1989) continued this usage, even though lower Chinle Group strata near Fort Wingate are quite distinct from the type Monitor Butte Member in southeastern Utah (Stewart et al., 1972a; Blakey and Gubitosa, 1983; Dubiel, 1989a,b). Ash (1978) also recognized 2.1 m of gray and green shales low in the Chinle as the Ciniza Lake Beds of the Monitor Butte Member. Dubiel (1989a,b), Hasiotis and Dubiel (1993), and Hasiotis et al. (1994) followed Ash in identifying the unit above the mottled strata in the Zuni Mountains as the Monitor Butte Member. None of these workers modified the existing stratigraphic nomenclature above this interval.

Lucas and Hayden (1989) introduced the basic stratigraphic nomenclature advocated here, and essentially followed Cooley (1957, 1959a) in recognizing the Moenkopi Formation at the base of the Triassic System in the Zuni Mountains (Fig. 2). They also named the "lower red member" (as used by Cooley [1957, 1959a], Akers et al. [1958], and Stewart et al. [1972]) the Bluewater Creek Member of the Chinle Formation, designating a type section at the eastern edge of the Chinle outcrop belt in the Zuni Mountains (Lucas and Hayden, 1989). Later Lucas (1993) elevated the Chinle to group status, likewise promoting member-rank units of previous authors to formation rank. Lucas (1993) also introduced names for the old "lower" and "upper" members of the Petrified Forest Formation as the Blue Mesa and Painted Desert Members, respectively (Fig. 2). Mapping projects undertaken by Orin Anderson of the NMBMMR in the Upper Nutria (Anderson, 1997) and Fort Wingate (Anderson et al., 2002) 7 1/2 minute quadrangles resulted in further refinements in the stratigraphic column. As a result of observations made during these projects, Anderson and Lucas (1993) identified the McGaffey Member of the Bluewater Creek Formation as a distinct lithostratigraphic unit in the upper half of the formation. Lucas et al. (1997a) described the Triassic stratigraphy of the Fort Wingate quadrangle near the western edge of the Zuni Mountains, drawing upon some of the data we present here, which is based largely on a master's thesis by the senior author (Heckert, 1997a).

STRATIGRAPHY

The lower Chinle Group succession in the Zuni Mountains consists of (ascending) "mottled strata," Shinarump Formation, Bluewater Creek Formation, and Blue Mesa Member of the Petrified Forest Formation (Fig. 3). Most recent workers recognize the

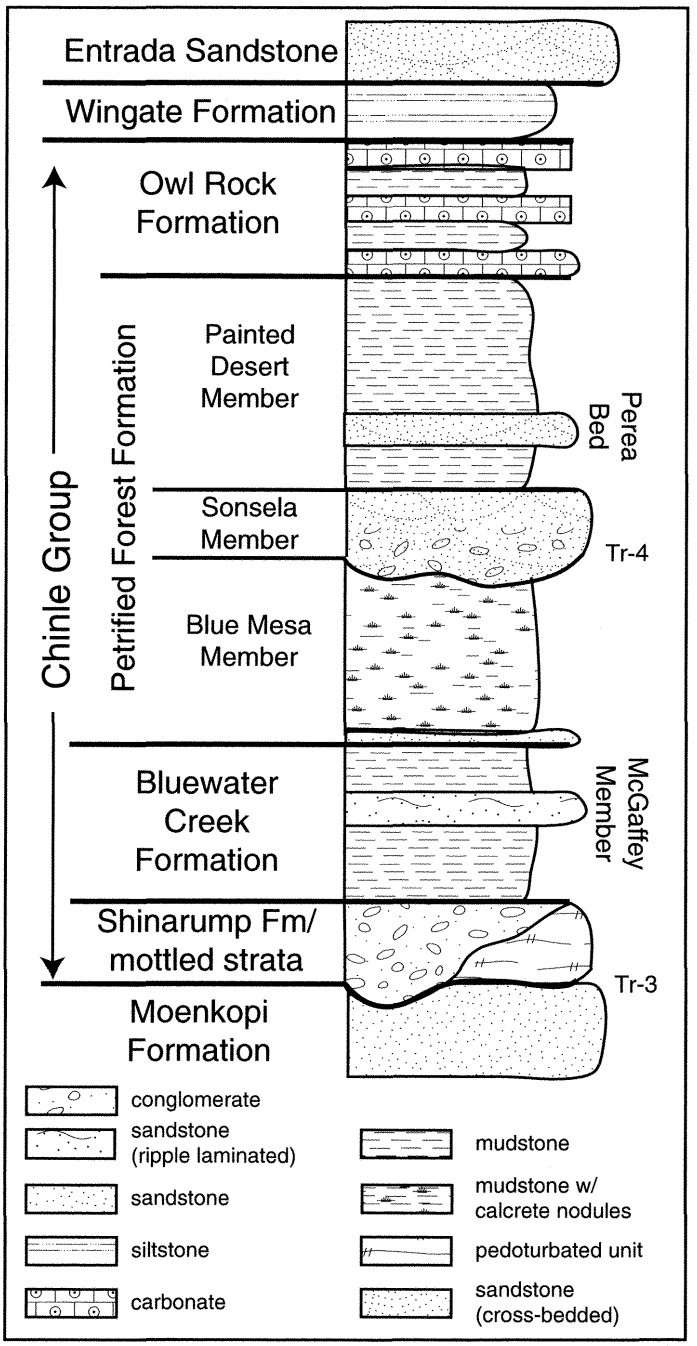


FIGURE 3. Generalized stratigraphic column of the Chinle Group in the Zuni Mountains. Stratigraphic units not necessarily to scale. Total Chinle Group thickness in the Zuni Mountains is approxmately 600 m (Stewart et al., 1972a).

base of the Chinle as the first deposits above the Lower-Middle Triassic Moenkopi Formation, the top of which is the surface representing the Tr-3 unconformity of Pipiringos and O'Sullivan (1978). In the Zuni Mountains, the base of the Chinle Group generally consists of pedogenically modified siliciclastic deposits assigned to the mottled strata, although channel-fill conglomerates of the Shinarump Formation locally overlie either the mottled strata or the Moenkopi Formation. Red beds of the Bluewater Creek Formation conformably overlie these units throughout the Zuni Mountains.

Within the Bluewater Creek Formation, the McGaffey Member crops out as a regionally persistent, bench-forming ripple-laminated sandstone, 4-20 m thick in the upper half of the formation. The Bluewater Creek Formation is conformably overlain by muddy sandstones and highly bentonitic mudstones of the Blue Mesa Member of the Petrified Forest Formation. The Tr-4 unconformity of Lucas (1993) is expressed as an erosional surface between the Sonsela Member and the underlying Blue Mesa Member, which thins eastward from 45 to 22 m as a result of erosion during that hiatus.

mottled strata

As an informal stratigraphic unit, the mottled strata do not appear on Figure 2. Stewart et al. (1972) coined the term "mottled strata" to describe a variety of pedogenically altered sediments that appear at the base of the Chinle regionally. Since that time, workers have used this unit to denote paleosols overlying Moenkopi or older strata on the Colorado Plateau that are in turn overlain by younger Chinle Group units. In the Zuni Mountains, the mottled strata are usually overlain by the Bluewater Creek Formation, although the Shinarump Formation overlies or is sharply incised into the mottled strata locally. These deposits vary widely in composition and color from outcrop to outcrop and are seldom mappable, yet are consistent enough and persistent enough to recognize informally. Mottled strata in the Zuni Mountains include some of the thickest known sections, up to 25 m near Fort Wingate, although they may be locally absent, as in the NM-400 section (Fig. 4). Notably, mottled strata are so prevalent relative to the Moenkopi Formation in the Fort Wingate 7.5 minute quadrangle that Anderson et al. (2002) were unable to map the two units separately at the 1:24000 scale. Robeck (1957) named lithologically similar strata in south-central Utah the "Temple Mountain Member" but we refrain from using that term for the strata in the Zuni Mountains at this time.

In general, mottled strata in the Zuni Mountains are extensively pedoturbated siliciclastics that are color mottled shades of purple, red, yellow, white, blue, and gray and crop out in beds 1-25 m thick (Stewart et al., 1972; Lucas and Hayden, 1989; Heckert, 1997a, Fig. 5A). All mottled strata lithologies indicate some degree of pedogenesis, sometimes to the extent that accurately describing mottled strata lithologies in the field is challenging. This pedogenesis and, in places, arthropod (crustacean?) bioturbation (Hasiotis and Dubiel, 1993), has obliterated most original bedding features of these deposits. Thus, throughout the Zuni Mountains, most mottled strata conglomerates and sandstones lack distinct primary bedforms, or else contain abundant rhizoliths and/or arthropod burrows (Lucas and Hayden, 1989). Locally, arcuate stringers of chert and jasper pebbles mark the remnants of trough crossbeds. Many sandstones are heavily calcified, and some mottled strata are so highly silicified that they are best classified as silcretes and porcellanites. Mudrocks are considerably less common but still exhibit color mottling and bio- or pedoturbation similar to that of the coarser-grained rocks. Locally, the mudstones of the mottled strata may include numerous nodules and veins of secondary gypsum, some as large as 20 cm diameter. Flaggy sandstones and mudstones that exhibit similar color mottling and occur at or near the base of the mottled strata are probably pedogenically altered Moenkopi Formation sediments and should be considered part of that unit.

Shinarump Formation

The Zuni Mountains lie near the southern terminus of Shinarump Formation deposition (Evensen, 1958; Stewart et al., 1972), and outcrops of the unit are relatively sparse throughout the region (Lucas and Hayden, 1989; Heckert, 1997a). The thickest unambiguous measured Shinarump Formation deposits are 7 m of trough-crossbedded extrabasinal conglomerate and conglomeratic sandstone near the entrance to the Cibola National Forest on NM-400 (Lucas et al., 1997a) (Fig. 4).

Where present the Shinarump Formation consists of well-indurated conglomerates, conglomeratic sandstones, and sandstones that are dominantly quartzose. Conglomerate clasts are principally large (up to cobble-sized) extrabasinal chert and quartzite clasts, with some additional Paleozoic limestone cobbles but few, if any, intrabasinal clasts. Typically, conglomerates grade upward to finer, quartzose sandstones in large troughs that may be truncated by additional conglomerate-sandstone sets. Petrified wood is rare and occurs primarily as shattered log fragments generally less than 0.5 m long, unlike the complete logs found higher in the Chinle. Shinarump Formation sediments were deposited in response to an initial base-level rise at the onset of Chinle deposition after development of the Tr-3 unconformity, and thus represent channel-fill in an incised topography. The primary Chinle drainage was to the northwest, roughly parallel to the Zuni Mountain outcrop belt (Stewart et al., 1972). Therefore, most Shinarump outcrops in the Zuni Mountains probably represent subsidiary drainages to the main river, which is probably represented by the Agua Zarca Formation in northern New Mexico (Lucas and Hunt, 1992; Marzolf, 1993; Lucas et al., 1999). Therefore, tracing the outcrop and subsurface distribution of the Shinarump Formation should delineate paleovalleys that were first incised during the interval represented by the Tr-3 unconformity and then filled by channel-drowning associated with post-incision base-level rise.

Bluewater Creek Formation

The Zuni Mountains contain extensive outcrops of the Bluewater Creek Formation, with a nearly continuous outcrop belt from the type section near the community of Bluewater in the east to Fort Wingate in the west (Figs. 1, 4, 5B). To the south, outcrop is considerably more sparse. Throughout this region the Bluewater Creek Formation is consistently 50-60 m thick and consists of up to three distinct siliciclastic lithofacies assemblages (Heckert, 1997a). These assemblages are, in order of frequency of occurrence, (1) interbedded mudstone and siltstone with scattered calcrete nodule horizons, (2) ripple laminated to plane-bedded sandstone with minor intraformational conglomerate, and (3) greenish bentonitic mudstone and black shale. Also present in the Bluewater Creek Formation in the Zuni Mountains is at least one limestone that, when present, occurs coincident with the third lithofacies assemblage. Figure 6 documents correlations of these lithofacies assemblages in a schematic fashion across the Zuni Mountains.

First lithofacies assemblage

The dominant feature of the Bluewater Creek Formation throughout the Zuni Mountains is a succession of reddish-brown, bluish gray, and grayish purple mudstones with minor siltstones that crop out as brilliantly colored badlands: the first lithofacies

TABLE 1. Clay mineral analysis of mudstone samples from the Chinle Group in the Zuni Mountains.

#	NMBMMR #	Kaolinite	Illite	Chlorite	Smectite	Mixed layer (illite/smectite)	others	Stratigraphic unit	Measured section
1	GA95080	TR	-	-	10	TR	qtz, fel	Blue Mesa Member	Smith Canyon
2	GA95079	1	2	2	1	4	qtz, cal	Blue Mesa Member	Fourmile Canyon
3	GA95075	TR	-	TR	7	3	-	Blue Mesa Member	Fourmile Canyon
4	GA95076	TR	2	TR	TR	7	qtz, cal, ?	Bluewater Creek Formation	Fourmile Canyon
5	GA95081	2	2	1	TR	5	qtz	Bluewater Creek Formation	Las Tuces
6	GA95082	1	2	1	1	5	qtz	Bluewater Creek Formation	White Water

All clay fractions expressed as parts in ten of the clay fraction.
Key terms: qtz=quartz; cal=calcite; fel=feldspar; ? =unknown; underline=major component, TR = trace. Descriptions of measured sections in Appendix.

assemblage. Most mudstones are silty to sandy and only slightly bentonitic, as expressed by a low percentage of smectite and mixed layer smectite-illite (Table 1, samples 4-6). Stringers of reddish-brown siltstone 0.1-0.5 m thick are common in these mudstones. Grayish-brown and yellowish-brown calcrete and siderite nodules occur sporadically in thin, widely separated horizons throughout the section, representing limited soil development in an otherwise aggradational fluvial complex dominated by crevasse splay and overbank deposits. Deposits of this lithofacies assemblage are the single thickest package of sediments in the formation, and occur throughout the section (Fig. 6). Sediments of this type are only occasionally present at the base of the unit, but ubiquitous throughout the rest of the unit up to the base of the McGaffey Member. Above the McGaffey Member, this is the only lithofacies assemblage present in the Bluewater Creek Formation.

Second lithofacies assemblage

Ripple-laminated to laminated and plane-bedded sandstones in the Bluewater Creek Formation occur primarily at two stratigraphic levels: (1) in discontinuous lenses at or near the base of the unit and (2) within the McGaffey Member, in the upper half of the formation. The sandstone bodies of this lithofacies assemblage are usually thin, typically 4-6 m thick, but locally reach 20 m in thickness. Individual sets are generally 1 to 1.5 m thick. These sandstones are predominantly fine-to-medium-grained, well-rounded, well-sorted, micaceous sublitharenites and lithic arenites. Quartz is considerably more common than feldspar in these sandstones. In the eastern Zuni Mountains one prominent horizon of this lithofacies assemblage several meters thick marks the base of the Bluewater Creek Formation. There, gray, yellowish gray, and yellowish brown ripple-laminated sandstones are as much as 8 m thick and occur above the mottled strata at the base of the type section and farther east near Mitchell Draw (Fig. 4). These micaceous sandstones, with abundant lithic fragments and no significant conglomerate clasts, are too immature and fine-grained to assign to the Shinarump Formation, which commonly occurs at a similar stratigraphic position in the Chinle. Instead we assign these strata to the Bluewater Creek Formation, based on their conformable relationship with overlying red-beds and high degree of lithologic similarity to other Bluewater Creek Formation sandstone bodies, such as the McGaffey Member.

The most prevalent occurrence of the sandy lithofacies assemblage is in the McGaffey Member of the Bluewater Creek Formation (Figs. 4,6). Thin, intraformational conglomerates of cannibalized calcrete pebbles are locally present at the base of the McGaffey Member, but the rest of the unit is dominated by ripple-laminated sandstones that are more typical of the second lithofacies assemblage. These can be seen both at the type section (Anderson and Lucas, 1993) and in the numerous McGaffey sections described here (Fig. 4). The McGaffey Member represents the most widespread and highest occurrence of the second lithofacies assemblage of the Bluewater Creek Formation. McGaffey Member strata are present throughout much of the Zuni Mountains.

Third lithofacies assemblage

Isolated outcrops of the third lithofacies assemblage occur low in the Bluewater Creek Formation, primarily in the western Zuni Mountains. These deposits are typically only 5-10 m thick. The third lithofacies assemblage of the Bluewater Creek Formation consists of interbedded bentonitic mudstones and dark shales. Mudstones are shades of greenish gray with locally abundant lignitic plant debris and numerous slickensides from shrinking and swelling of bentonitic clays. Shales are both rarer and thinner than mudstones and are very dark gray to black with abundant plant debris and microfossils (Ash, 1978, 1989). This lithofacies assemblage is only locally present at the base of the Bluewater Creek Formation and appears to represent various lowland and pond deposits in the poorly drained paleotopography that was present at the onset of Bluewater Creek Formation deposition. These deposits give way upward to the red-beds facies as base-level continued to rise and true fluvial depositional systems established themselves.

Ash (1978) termed 2.1 m of dark shales from the third lithofacies assemblage the "Ciniza Lake Beds," with his type section of that unit measured through a particularly fossiliferous plant- and microfossil horizon near Fort Wingate. He also diverged from the stratigraphy of Stewart et al. (1972) and assigned the strata of the Bluewater Creek Formation to the Monitor Butte Member because of the similarity of the third lithofacies assemblage to that unit. Although sediments of the third lithofacies assemblage can be as much as 10 m thick they consist of discontinuous lenses, both across the Zuni Mountains (Fig. 6) and in other outcrop belts. Lucas and Hayden (1989), Anderson and Lucas (1993), Heckert and Lucas (1996a), Anderson et al. (1997), and Lucas et al. (1997a) all considered the term "Ciniza Lake Beds" superfluous. Certainly, the unit is not mappable at the 1:24000 scale, even on the Fort Wingate quadrangle, where outcrops of greenish-gray bentonitic mudstones and dark gray to green shales are most prevalent (Anderson et al., 1997a). Therefore, the utility of the name "Ciniza Lake Beds" is debatable, and appears at best to be a way of applying a formal name to the discontinuous third lithofacies assemblage.

The nature of the third lithofacies assemblage has been used both by Ash (1978, 1989) and by some later workers (Dubiel, 1989a,b; Dubiel et al., 1993; Hasiotis and Dubiel 1993) as justification for referring to the entire Bluewater Creek Formation as the "Monitor Butte Member" of the Chinle Formation. While the third lithofacies assemblage of the Bluewater Creek Formation is grossly similar to the Monitor Butte Formation in lithology, these greenish-gray bentonitic mudstones and dark shales have neither the lateral extent nor the stratigraphic thickness to merit identification as a formation-rank unit. Indeed, mapping on the Fort

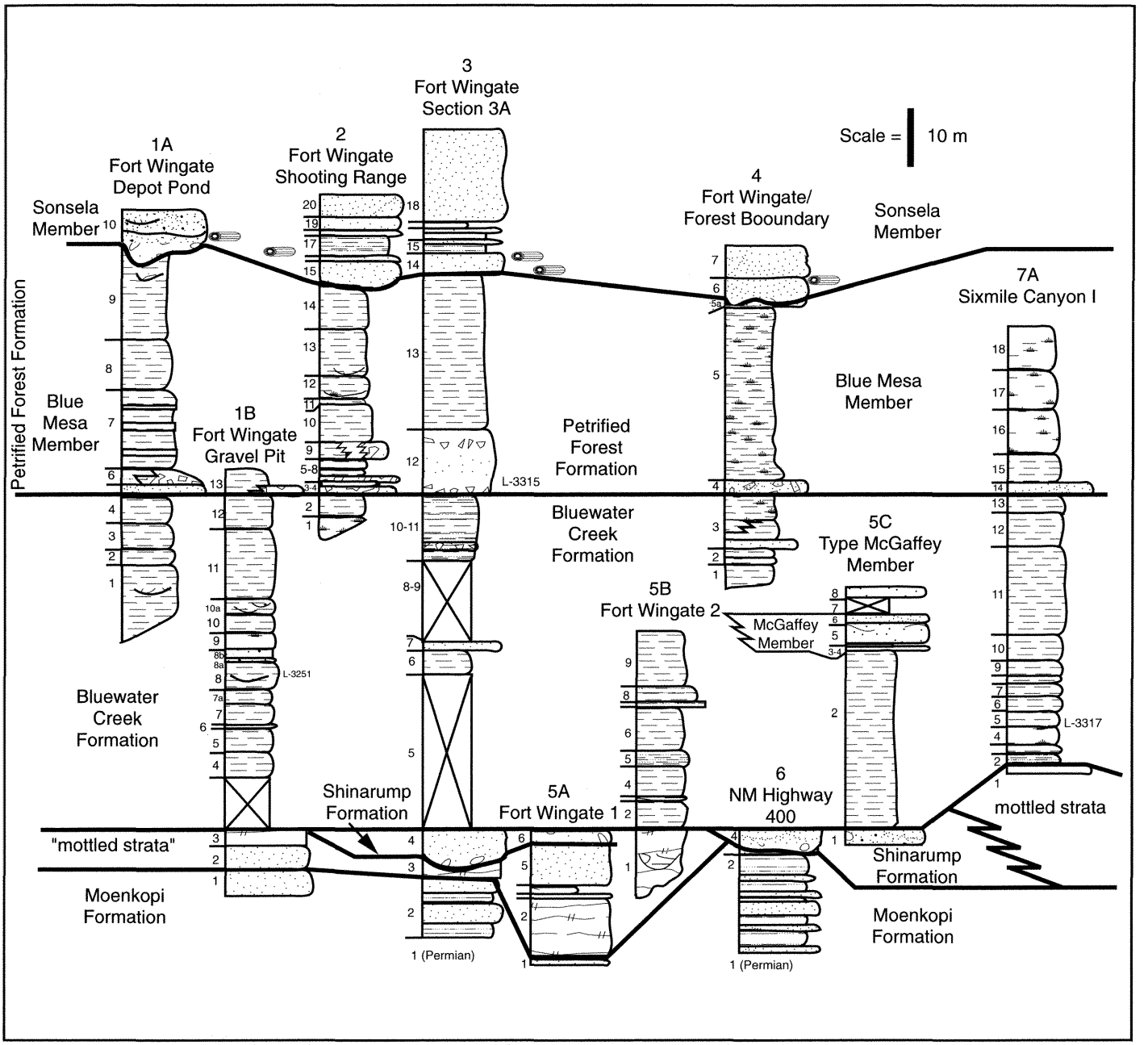


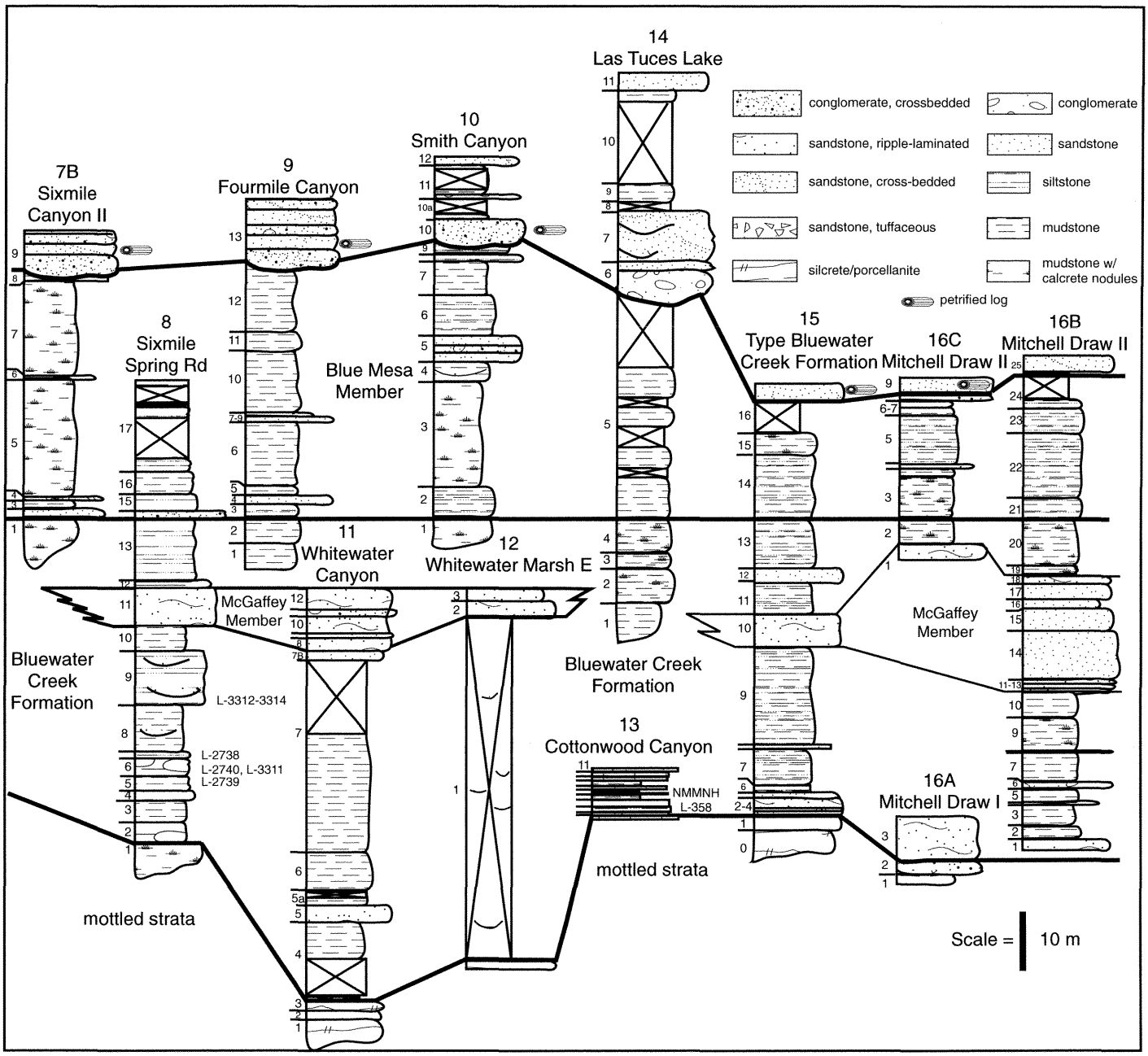
FIGURE 4. (This and facing page) Correlated measured sections of the lower Chinle Group in the Zuni Mountains.

Wingate quadrangle, where extensive outcrops of this lithofacies assemblage occur east of NM-400 south of the village of Fort Wingate, reveals that this unit is too inconsistent to merit recognition as even a member-rank unit (Anderson and Lucas, 1993; Anderson et al., 2002). Rather, this lithofacies assemblage is seldom, if ever, more than 10 m thick, and never represents more than 15-20% of the total thickness of the Bluewater Creek Formation. Further, it is not ubiquitous at the base of the Bluewater Creek Formation, and is instead absent locally, as in the Sixmile Canyon I section (Fig. 4) and where flaggy, ripple-laminated sandstones of the second lithofacies assemblage mark the base of the formation (e.g., the type and Mitchell Draw sections—Figs. 4,6).

Because of these lithologic differences in the first two lithofacies and the spotty outcrop pattern of the third lithofacies, parsimony dictates its inclusion in the Bluewater Creek Formation as local facies in that unit rather than trying to recognize its scattered occurrences as outliers of the Monitor Butte Formation. Certainly, to identify the entire Bluewater Creek Formation as the Monitor Butte, as done by Repenning et al. (1969), Ash (1978, 1989) or Dubiel (1989a,b), contradicts long-standing observations regarding lithologies, bedforms, and depositional environments such as those made by Cooley (1957, 1959a), Akers et al. (1958), and Stewart et al. (1972) as well as those made later by Lucas and Hayden (1989), Anderson and Lucas (1993), Heckert and Lucas (1996a), Lucas et al. (1997a,b), and Anderson et al. (2002).

Bluewater Creek Formation limestones

A thin bed of limestone that crops out very low in the Bluewater Creek Formation in the vicinity of Cottonwood Canyon has been problematic for years. The best outcrops of this limestone occur in the W1/2 NW1/4 SW1/4 SW1/4, sec. 19, T13N, R13W, although the unit as a whole is considerably more extensive, occurring as a mostly covered, very-low-angle dipslope in sections 19 and 20, and farther down the valley in sec. 13, T13N R14W.



Cooley (1959b) proposed that this limestone was a cave developed in the Permian San Andres Formation and subsequently infilled by Triassic sediments. Lucas and Hayden (1989) revisited the area, measured a section, and concluded that the siliciclastics involved were a terrestrial facies of the San Andres Formation, to which they assigned the limestone. Since that time we have returned to Cottonwood Canyon and concluded that almost all of the exposed strata belong to the Bluewater Creek Formation.

The lowest exposures in Lucas and Hayden's (1989) Cottonwood Creek section (Fig. 4) are massive, highly bioturbated sandstones that only crop out in the floor of the wash. Above these are 6.2 m of lignitic shales, mudstones and siltstones that contain numerous plant fossils and coprolites in addition to the single tetrapod fossil fragment reported by Lucas and Hayden (1989). Here, we assign these strata to the third lithofacies assemblage of the Bluewater Creek Formation. Above these deposits is a single bench of micritic limestone that is typically less than 1 m thick. This limestone lacks the extensive nodular textures and pedogenic alteration found in Chinle Group limestone deposits, which typically represent paleosols, such as those of the Owl Rock Member (Lucas and Anderson, 1993). Instead, this limestone is micritic and lacks silica replacement. There does appear to be minor gypsum replacement, and the limestone is overlain by (mostly covered) bentonitic mudstones. Some bioturbation in the form of thin (< 5 mm diameter) burrows is present, but rare. This unit lacks even fragmentary Paleozoic fossils, unlike many San Andres Formation limestone deposits in the area (e.g., Kues and Lucas, 1989). All of these features indicate that this limestone bed is one of the rare Chinle lacustrine limestones, and probably formed in a poorly drained lowland area as is typical of third lithofacies assemblage deposits in the Bluewater Creek Formation.

McGaffey Member

Anderson and Lucas (1993) named the McGaffey Member

of the Bluewater Creek Formation for a 4-12-m-thick sequence of ripple laminated sandstones with minor intraformational conglomerates in the Bluewater Creek Formation near Fort Wingate, New Mexico. With the exception of some local pinch-outs, this unit crops out extensively throughout the entire outcrop belt of the Bluewater Creek Formation (Fig. 4). Its upper and lower contacts are conformable. McGaffey Member sediments are primarily subangular, moderately- to well-sorted, micaceous sublitharenites and quartzarenites. Locally, it is conglomeratic with most clasts consisting of cannibalized calcrete-pebble or, rarely, mudstone rip-up clasts. These strata are typically shades of pale red and gray and crop out as persistent bench-formers. This unit forms numerous cuestas near NM-400, such as at the type section, the low sandstone knobs south of the shooting range section on Fort Wingate, and a persistent ledge well below the Sonsela throughout much of the Zuni Mountains, including at the Mitchell Draw and type Bluewater Creek Formation sections (Fig. 4).

The thickness of the McGaffey Member is highly variable. Where present, its thickness varies from as little as 4 m to as much as 20 m. Locally, such as just south of the Sixmile Canyon I section (Fig. 4), it pinches out entirely. The McGaffey Member is well-indurated in most places, and forms a persistent bench throughout much of the northern Zuni Mountains, with particularly prominent ridges present throughout Los Tuces Valley and overlooking the village of Bluewater. Although it appears to represent a period of increased lateral migration of Bluewater Creek Formation fluvial sands that might be interpreted as a time of low subsidence versus sediment supply (Blakey and Gubitosa, 1983), it is not immediately clear how to characterize the McGaffey Member in terms of regional base level. It may represent an interval of temporarily lowered, then recovering base-level coincident with a lower-order sequence than those responsible for the Tr-3 and Tr-4 unconformities. Little, if any, paleotopography is evident at the base of the McGaffey Member at the outcrop scale. However, its thickness variations (Fig. 6) may be at least partially explained by McGaffey Member sediments filling regional paleotopography that was generated during a base-level fall.

Petrified Forest Formation

The Petrified Forest Formation in the Zuni Mountains consists of all three members, the Blue Mesa, Sonsela, and Painted Desert members, in ascending order. Only the Blue Mesa and Sonsela members are directly relevant to discussion here, with the Blue Mesa Member conformably overlying the Bluewater Creek Formation throughout the study area and the Sonsela disconformably overlying the Blue Mesa Member at the top of the succession of rocks described here. The Painted Desert Member conformably overlies the Sonsela Member.

Blue Mesa Member

Throughout much of the Zuni Mountains the contact of the Petrified Forest Formation and the Bluewater Creek Formation is marked by a white, tuffaceous sandstone of the Blue Mesa Member that rests on uppermost red-beds of the Bluewater Creek Formation (Figs. 4, 5C,D). In the easternmost Zuni Mountains the contact is more difficult to distinguish, but the fact that the Blue Mesa Member is dominated by purplish and greenish, highly bentonitic mudstones with abundant calcrete pebble horizons allows the careful observer to separate the two units (Fig. 4). This unit varies from 45 m thick in the western Zuni Mountains to as little as 21 m above the type Bluewater Creek Formation section. This change in thickness can be attributed to erosion during development of the Tr-4 unconformity before the onset of deposition of the overlying Sonsela Member (Heckert and Lucas, 1996).

Above the basal tuffaceous sandstone, the Blue Mesa Member consists primarily of stacked, highly bentonitic, paleosols. On a fresh vertical surface, significant pedogenesis is apparent, and numerous reduction spots and calcrete pebble horizons indicate soil formation. Clastic input was principally mud- and clay-sized particles, presumably from flood events. Mudrocks in the Blue Mesa Member are generally higher in smectite and mixed-layer smectite-illite than their Bluewater Creek Formation counterparts at the expense of quartz and other coarser materials (Table 1). Red-beds are rare in the Blue Mesa Member and generally less than 4 m thick (e.g., unit 11, Fourmile Canyon section). These probably represent occasional unchannelized flow. Clay sample 3 was taken from such a deposit, and its mineralogy is similar to that of the Bluewater Creek Formation mudstones (Table 1). In general, the Blue Mesa Member represents a very stable depositional environment, with distal floodplain and paleosol deposits accumulating during flood (floodplain) and normal (paleosol) conditions as basin accommodation permitted.

The Blue Mesa Member thins markedly across the outcrop belt from approximately 45 m in the western Zuni Mountains to a mere 21 m at the eastern terminus of Chinle Group outcrops. This marked change in thickness appears to be more closely related to base level fall and subsequent erosion as a result of the Tr-4 unconformity than it is to original basin parameters (Heckert and Lucas, 1996). For example, the Bluewater Creek Formation maintains a relatively constant thickness underneath the Blue Mesa Member both in the Zuni Mountains and along the southern edge of the Colorado Plateau (Fig. 4). The presence of abundant, thicker Blue Mesa deposits in Arizona, the generally inconsistent nature of this thinning (as seen in Figure 4), and the absence of the Blue Mesa Member in the Lucero uplift to the east all point to erosion and incision of Sonsela channels in the Blue Mesa Member as the most likely explanation for thickness variations of the Blue Mesa Member in the Zuni Mountains.

Sonsela Member

The Sonsela Member crops out most prominently in the Zuni Mountains as the heavily vegetated, bench-forming unit holding up the dipslope south of I-40 in the strike valley between Gallup and Grants. Throughout the Zuni Mountains the Sonsela Member rests disconformably on the Blue Mesa Member and is conformably overlain by the Painted Desert Member. The Sonsela Member generally crops out as two distinct benches, each 8-12 m thick, with an intervening mudstone interval up to 10 m thick between them. The Sonsela Member is dominated by conglomeratic sandstones with lenses of true conglomerates and thin, scattered mudstone intervals. Locally, the conglomerates consist of trough-crossbedded channel lags of cobble-sized extraformational clasts. The cobbles are primarily chert and quartzite, with higher beds having a greater proportion of intraformational mudstone and calcrete pebble clasts (Fig. 5F). Above the Sixmile Canyon I section, the Sonsela includes banks of unionid bivalves in a coquina or packstone (Fig. 5E). Petrified wood is abundant, and usually consists of large silicified logs several meters in length and up to 1 m in diameter. Sandstones are generally trough-crossbedded, yellow to gray sublitharenites and subarkoses. The basal surface is commonly covered but, where exposed, is sharp and highly irregular. Although the Sonsela is a cliff-former, it is not a massive unit, displaying instead fine-grained breaks between depositional units. Sandstone beds typically occur in sets 1.5 to 3 m thick. Generally, two to four such beds are present in the basal Sonsela below a mudstone interval that closely resembles the Blue Mesa Member in color but appears less bentonitic and is generally covered. Upper Sonsela Member deposits are very similar to the lower sandstones and conglomerate, although extrabasinal clasts are much less common.

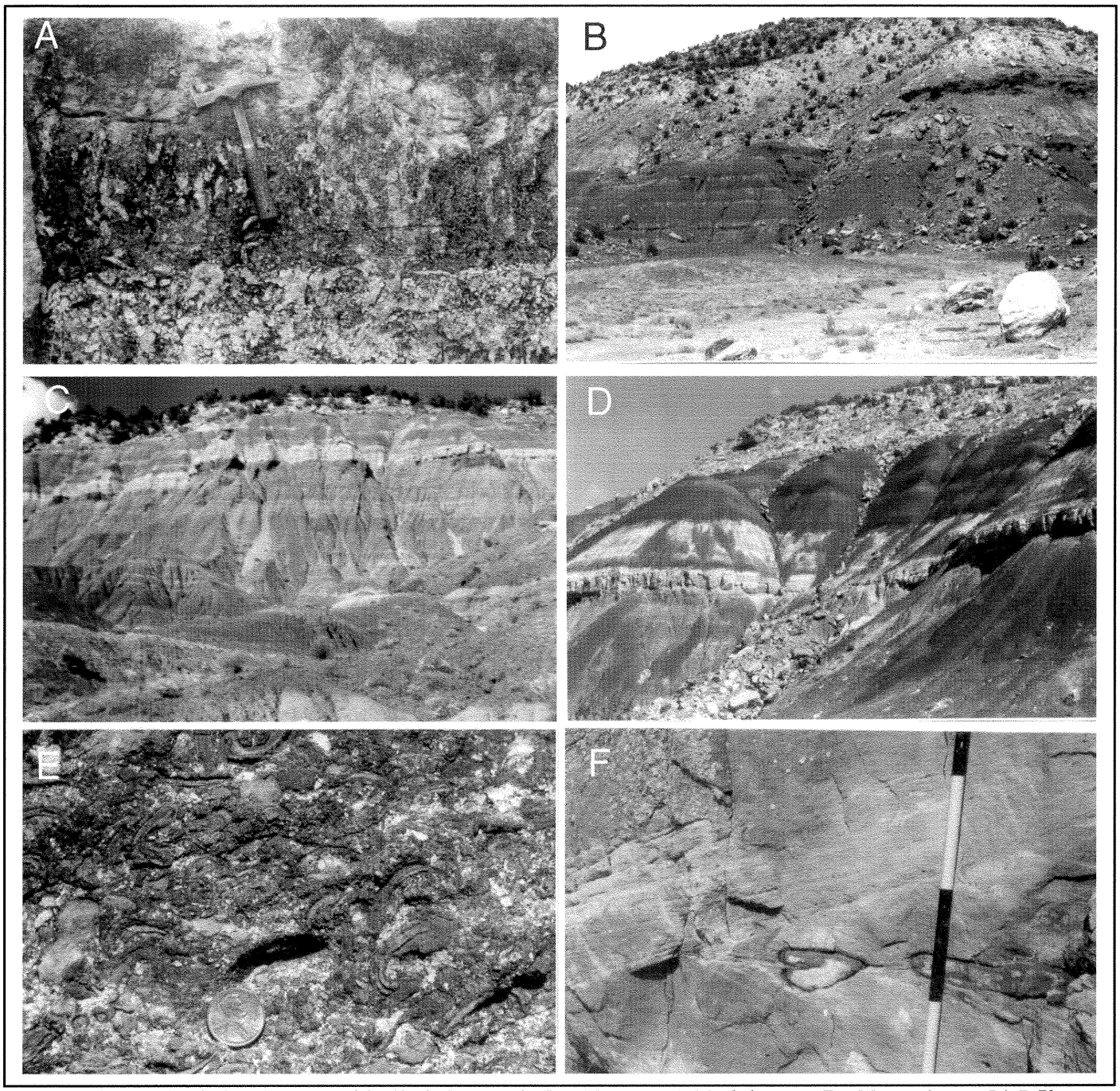


FIGURE 5. Photographs of selected outcrops of the Chinle Group in the Zuni Mountains. **A**, Mottled strata at Fort Wingate (section 5a); **B**, Bluewater Creek Formation type section; **C**, Sixmile Canyon 1; **D**, Fort Wingate shooting range; **E**, Crossbedded intraformational conglomerate and unionid packstone of the Sonsela Member at Sixmile Canyon (float from above Sixmile Canyon 1); **F**, Crossbedded sandstone and intraformational calcrete conglomerate of the Sonsela Member at Fort Wingate Shooting Range. Coin is approximately 19 mm in diameter. Divisions on staff are 250 mm.

Painted Desert Member

Painted Desert Member outcrops in the Zuni Mountains are relatively rare, with much of the unit covered in the broad strike valley running from northwest to southeast between Gallup and Grants. The Painted Desert Member conformably overlies the Sonsela Member, although the contact is commonly concealed by colluvium, whereas the Sonsela typically crops out as a heavily vegetated dipslope. Painted Desert Member deposits are typically brownish-red bentonitic mudstones and brownish red and reddish purple micaceous sandstones, both of which superficially resemble the Bluewater Creek Formation. Lucas et al. (1997a) described the Painted Desert Member on the Fort Wingate quadrangle in some detail, and Lucas et al. (1999) discussed its regional correlation.

LITHOSTRATIGRAPHIC CORRELATION

The lower Chinle Group stratigraphy of the Zuni Mountains is relatively straightforward and can be readily correlated both across the outcrop belt and to other outcrop belts to the east and west. The mottled strata are nearly ubiquitous, and commonly underlie the Shinarump Formation when the latter is present. Shinarump Formation deposits are, as discussed previously, very

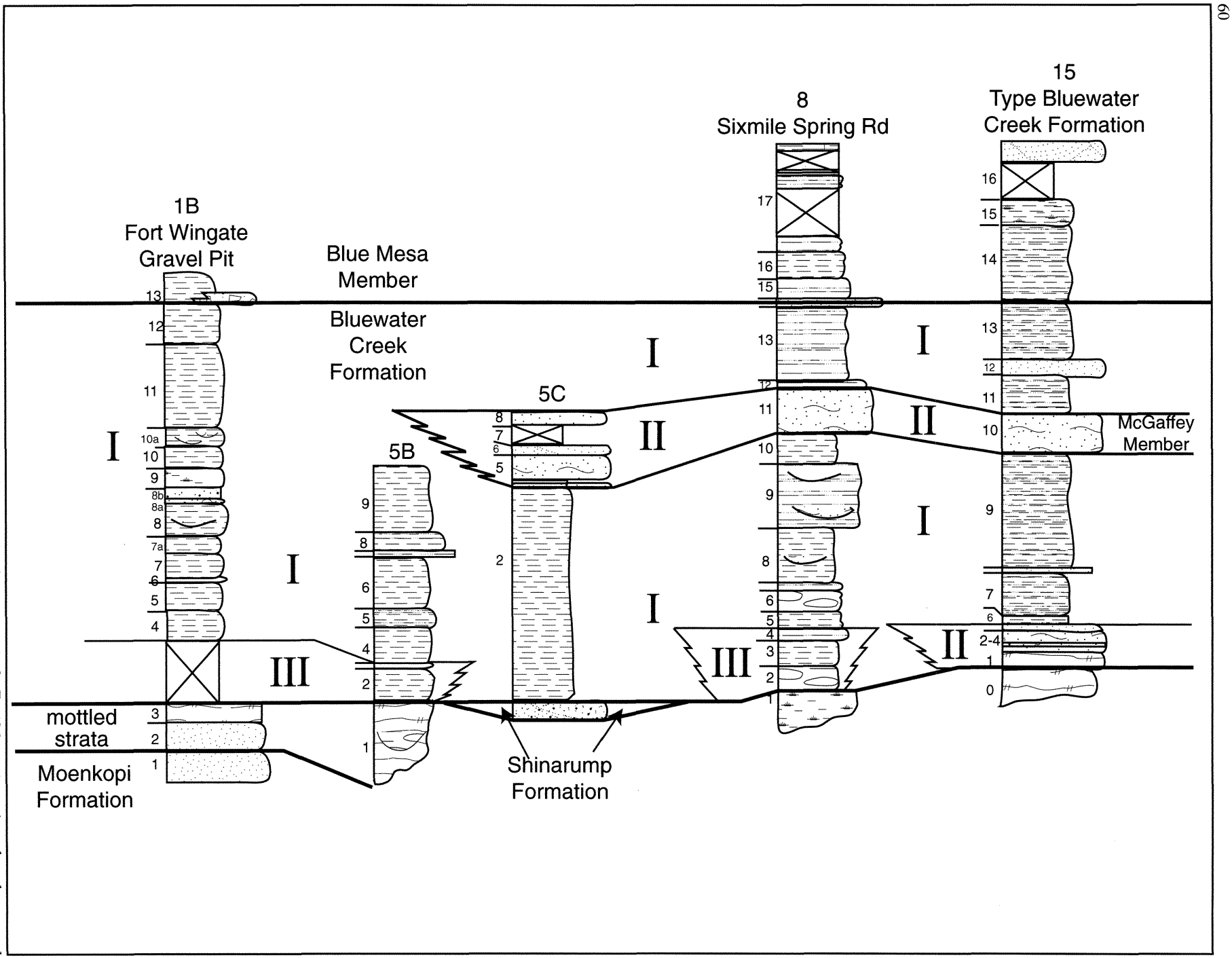


FIGURE 6. Correlation of the three primary lithofacies assemblages of the Bluewater Creek Formation in the Zuni Mountains, using selected measured sections from Figure 4.

patchy and scarcely mappable at the 1:24000 scale, although they are of some importance in determining the paleotopography generated during the Tr-3 unconformity. Both the mottled strata and the Shinarump Formation are readily correlated to lithologically similar units in outcrop belts to the east and west. Northward, Shinarump Formation deposits appear to correlate with the Agua Zarca Formation in northern New Mexico (Lucas and Hunt, 1992; Lucas et al., 1999).

Correlation of the Bluewater Creek Formation across the Zuni Mountains is easily achieved upon recognition of the three primary siliciclastic lithofacies assemblages. Numerous problems of local and regional correlation succumb to a basic understanding of the interrelationships of these lithofacies assemblages. For example, the third lithofacies assemblage of the Bluewater Creek Formation only occurs at the base of the formation, where there was significant ponding in the incised paleotopography. Ripple-laminated micaceous litharenites of the second lithofacies assemblage usually correlate either to outcrops of the McGaffey Member high in the Bluewater Creek Formation or, in the eastern Zuni Mountains, may persist near the base of the unit. The Bluewater Creek Formation is also readily recognized to the west in the vicinity of St. Johns (Lucas et al., 1997b) and to the east in the Lucero uplift (Lucas and Heckert, 1994; Heckert, 1997a).

The purplish- and greenish-gray highly bentonitic mudstones of the Blue Mesa Member are readily correlated across the Zuni Mountains, particularly west of Bluewater Lake, where an ashy sandstone marks the base of the Petrified Forest Formation. The Blue Mesa Member does thin substantially across the Zuni Mountains, however, and varies from as much as 45 m in the western Zuni Mountains to a mere 20-24 m at the eastern terminus of Chinle outcrops. These mudstones are readily correlated to lithologically identical strata in the vicinity of St. Johns to the west, but the Blue Mesa Member is absent to the east in the Lucero uplift. This is a result of erosion associated with the Tr-4 unconformity (Lucas and Heckert, 1994; Heckert and Lucas, 1996; Heckert, 1997a). The Sonsela Member can be quite thick, as much as 20 m or more, in the Zuni Mountains and is readily correlated across the regional hogback south of Interstate 40. The Sonsela is typically thicker than it is to the west in Arizona, but this thickening does not appear to come at the expense of the Blue Mesa Member, as the later thins dramatically across the Zuni Mountains while the thickåness of the Sonsela Member remains relatively constant.

PALEONTOLOGY

Mehl et al. (1916) were the first to report significant tetrapod fossils from the Chinle in the Zuni Mountains, although Darton (1910, p. 46) earlier mentioned indeterminate bone fragments from this region. The material described by Mehl et al. (1916) was derived entirely from the Bluewater Creek Formation and, in addition to a generically undiagnostic phytosaur snout, they described a new aetosaur *Acompsosaurus wingatensis* from a well-preserved pelvis. This holotype specimen is now lost, which is unfortunate as it has repeatedly been referred to either *Desmatosuchus* (Long and Ballew, 1985; Hunt and Lucas, 1993a) or *Stagonolepis* (Lucas and Hayden, 1989; Hunt and Lucas, 1989; Long and Murry, 1995; Heckert, 1997). Camp visited the area briefly in the 1920s, was disappointed in the apparent barrenness of the area, and struck west for more prosperous locales, although he (Camp, 1930) briefly mentioned indeterminate postcrania of metoposaurids and phytosaurs from the Fort Wingate area.

Ash (1967, 1970a,b, 1978, 1989) reported numerous megafossil plants, primarily from the Bluewater Creek Formation in the Fort Wingate area, and noted briefly the presence of an amphibian and a phytosaur in the lower units of the Chinle. Numerous conchostracans were named *Cyzicus* (*Lioestheria*) *wingatella* by Tasch (in Ash, 1978). Isolated fish scales were attributed to the coelacanth *Chinlea* by Ash (1978), who also illustrated abundant vertebrate coprolites. Ash (1989) also published a summary article of the Chinle flora in the Zuni Mountains.

TABLE 2. Vertebrate faunal list of the lower Chinle Group in the Zuni Mountains (after Heckert, 1997, 2001).

Chondrichthyes:
"*Xenacanthus*" sp.
Hybodontoidea indet.
Osteichthyes:
Chinlea sp.
Redfieldiidae indet
Palaeoniscidae indet. aff. *Turseodus*
Coelacanthidae indet.
Actinopterygii indet
Amphibia:
Buettneria perfecta
Apachesaurus cf. *A. gregorii*
microvertebrate taxa
Primitive Reptiles:
several microvertebrate taxa
Procolophonidae:
aff. *Chinleogomphius*
Synapsida:
Indeterminate ?dicynodont
Phytosauria:
aff. *Angistorhinus* sp.
aff. *Rutiodon* sp.
Aetosauria:
Desmatosuchus haplocerus
Stagonolepis wellesi
Paratypothorax andressorum
Dinosauria:
aff. *Tecovasaurus murryi*
Ornithischian n. sp.
two theropods of unknown affinities
Trace fossils (vertebrate):
cf. *Grallator*
abundant coprolites

Plant fossils identified by Ash (1978, p. 21) include "leaves, leafy shoots, stems, spores, [and] pollen." He (1978) distinguished 27 plant taxa, the most common of which are the gymnosperm *Dinophyton*, pith casts assigned to *Neocalamites*, and the palynomorphs *Pityosporites* and *Klausipollenites*. By 1989, Ash recognized at least 40 taxa of plants, including representatives of the horsetails, ferns, cycads, gingkoes, and conifers from the megaflora and ferns, seed ferns, cycads or ginkgoes, and conifers from palynological specimens (Ash, 1989, p. 226). Almost all plant fossils recovered from the Chinle Group on the Fort Wingate quadrangle are from Ash's "Ciniza Lake Beds" low in the third lithofacies assemblage of the Bluewater Creek Formation. Ash assigned this paleoflora to his "*Dinophyton* floral zone" of late Carnian age (Ash, 1980, 1989). All non-woody Upper Triassic plant fossils in the Zuni Mountains are from low in the Bluewater Creek Formation and occur in strata assigned to the third lithofacies assemblage. The only other plant fossils known from the quadrangle are the abundant petrified logs, probably of the genus *Araucarioxylon*, that weather out of the Sonsela Member throughout the region.

Except for the abundant coprolites described by Ash (1978), the only Upper Triassic tetrapod trace fossils thus far reported from the Zuni Mountains area are the footprints of a small dinosaur from the vicinity of Fort Wingate (Hasiotis et al., 1994) (see also Lucas and Heckert, this volume). This specimen was recovered from sandstones of the second lithofacies assemblage very

low in the Bluewater Creek Formation near Ash's plant localities.

Hunt and Lucas (1989, 1993a) reviewed the vertebrate paleontology of the Fort Wingate area, noting (1989) the presence of another coelacanth in addition to *Chinlea* after reviewing the material published by Ash (1978). Heckert (1997b) recently summarized the tetrapod fauna of the lower Chinle Group in the Zuni Mountains, reporting numerous new records as well (Table 2).

BIOCHRONOLOGY

No biochronologically significant fossils are known from the mottled strata, either in the Zuni Mountains or elsewhere in the region. For this reason, the age of the mottled strata continues to rely entirely on that unit's stratigraphic position between better constrained units. Unfortunately, the Shinarump Formation in the Zuni Mountains is not one of these well-constrained units, as it too lacks age-diagnostic fossils. Palynological and tetrapod evidence from Arizona implies that the Shinarump Formation is of Otischalkian (late Carnian) age (Litwin et al., 1991; Lucas, 1997).

Fossil plants from the lower part of the Bluewater Creek Formation on the Fort Wingate quadrangle belong to Ash's (1980) *Dinophyton* floral zone of late Carnian age. Fossil tetrapods from the Bluewater Creek Formation, especially the aetosaur *Stagonolepis*, indicate an Adamanian age, which is latest Carnian (Lucas and Hunt, 1993a; Heckert, 1997). Although the Blue Mesa Member is essentially barren in the Zuni Mountains, the type Adamanian fauna was collected from the Blue Mesa Member in the PFNP in western Arizona, and there is no reason to think that the Blue Mesa Member in the Zuni Mountains is of different age. West of the Zuni Mountains the Bluewater Creek Formation yields an Adamanian fauna from the *Placerias* quarry in Arizona (Lucas et al., 1997b). Similarly, the occurrence of *Stagonolepis* in the Lucero uplift indicates an Adamanian age for that unit to the east (Lucas and Heckert, 1994; Heckert, 1997), so the Bluewater Creek Formation appears to be well-constrained to the Adamanian. No age-diagnostic fossils are known from the Sonsela Member in the Zuni Mountains, but palynological (Litwin et al., 1991) evidence from elsewhere indicates a Norian age for that unit.

CONCLUSIONS

Lower Chinle Group strata along the north flank of the Zuni Mountains can be readily correlated both within the Zuni Mountains and across the Colorado Plateau to the east and west. The mottled strata in the Zuni Mountains, as elsewhere, are of indeterminate age and appear to represent both pedogenesis of uppermost Moenkopi sediments and fluvial sediments that postdate the Moenkopi Formation. We recognize the base of the mottled strata as the first pedogenically modified sediments that are lithologically distinct from the Moenkopi Formation. We recognize that, under this definition, at least some of the mottled strata may represent extremely pedogenically modified Moenkopi Formation strata. However, our approach is consistent with that followed by most previous workers. The Tr-3 unconformity is identified at the base of the mottled strata or, where the mottled strata are not evident, at the base of the Shinarump Formation. The Shinarump Formation is the first definitively Late Triassic deposition in the Zuni Mountains, and appears to represent a series of isolated fluvial systems in paleovalleys that were filled in by aggradation during a late Carnian rise in base level.

The Bluewater Creek Formation is a moderately complex unit exhibiting three siliciclastic lithofacies assemblages and a lacustrine limestone of localized extent. As such, the Bluewater Creek Formation represents a diverse suite of depositional environments, from fluvial channels to floodplain paleosols and localized lakes. Basal Bluewater Creek Formation strata typically consist of the third lithofacies assemblage and localized, rare, lacustrine limestones. These strata appear to represent deposition in at least seasonally wet, poorly drained lowlands that occupied the existing paleotopography prior to base level rise. Locally, the lowermost Bluewater Creek Formation consists of drowned, slowly aggrading channel deposits of ripple-laminated sandstone pertaining to the second lithofacies assemblage. Above these deposits the bulk of the Bluewater Creek Formation consists of channel, overbank, and crevasse splay deposits that manifest themselves as red beds of mudstone and silty mudstone plus sandstone units such as the McGaffey Member, indicating a temporary return to fluvial deposition. Paleosol development in the Bluewater Creek Formation was restricted, and calcrete and siderite nodules are known only from a limited subset of the total stratigraphic thickness of the Bluewater Creek Formation.

The Bluewater Creek Formation is the primary fossil-producing unit in the Zuni Mountains, and it is the most biochronologically constrained unit in the lower Chinle Group studied here (Heckert, 1997). Fossil plants found in the Bluewater Creek Formation belong to Ash's (1980) late Carnian *Dinophyton* floral zone, and tetrapod vertebrates from numerous localities in the Zuni Mountains indicate an Adamanian (latest Carnian) age for the Bluewater Creek Formation.

Above the Bluewater Creek Formation the Blue Mesa Member of the Petrified Forest Formation represents an interval of high base level, when floodplain deposition and pedogenesis dominated aggradational processes, and calcrete and siderite nodule formation was especially prevalent. A thin layer of plane-bedded to low-angle trough- and planar-crossbedded, poorly sorted sandstone at the base of the Petrified Forest Formation west of Bluewater Lake may represent a reworked ash fall deposit, and can be traced westward at least as far as the PFNP. To the east, the thin (20-25 m) Blue Mesa Member can be differentiated from underlying Bluewater Creek Formation strata at the outcrop scale by color, apparent content of bentonitic clays, and degree of paleosol development, with the Blue Mesa Member consisting of mudstones that are darker shades of purple and blue than the Bluewater Creek Formation, and demonstrating a higher degree of popcorn weathering and calcrete nodule development.

Thinning of the Blue Mesa Member eastward across the outcrop belt from 45 to 20 m appears to represent erosion during lowered base level associated with the development of the Tr-4 unconformity of Lucas (1991a, 1993) described in detail by Heckert and Lucas (1996a). Neither the underlying Bluewater Creek Formation nor the overlying Sonsela Member thicken appreciably across the outcrop belt, so Blue Mesa Member thinning appears to have occurred independent of thickness changes in those units. Localized scours and channel incision of the Sonsela into the Blue Mesa Member confirms the presence of an unconformity at the top of the lower Chinle Group as defined here.

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APPENDIX—DESCRIPTION OF MEASURED SECTIONS

The following are detailed lithologic descriptions of the stratigraphic sections referred to here in this report. This includes some sections already published by Lucas and Hayden (1989), included here with stratigraphic revision and additional detail. Where possible, sections are named for local geographic features found on USGS 1:24000 maps. Colors used to describe rocks follow Goddard et al. (1984). The order of measured sections in this appendix is from west to east, north to south, across the study area, as illustrated in Figures 1 and 4.

Fort Wingate Depot Gravel Pit

Section is in SE1/4 NW1/4 sec. 13 (unsurveyed) T14N R17W. Attitudes from mottled strata in the stream cut on the base road are N30°W to N18°W, dipping 16-19° WSW; strata above this clearly dip less; approximately 8.5°. Section measured up to the Blue Mesa Member on 11 August, 1994 and completed on 6 July, 1995, by A.B. Heckert.

unit	lithology	thickness (m)
Chinle Group:		
Petrified Forest Formation:		
Blue Mesa Member:		
13	Sandstone and mudstone; basal sandstone is light greenish gray (5GY8/1) with black (N1) flecks/clasts and some pale red purple (5RP6/2) staining; silty; ashy; fine- to medium-grained; subangular to subrounded; moderately poorly sorted sublitharenite; laminar; very porous; not calcareous; mudstone is grayish blue (5PB5/2) to grayish red purple (5RP4/2); slightly silty; bentonitic; not calcareous; this unit is visibly continuous with unit 5 of Fort Wingate Pond section.	2.0
Bluewater Creek Formation:		
12	Mudstone; pale reddish brown (10R5/4); silty; bentonitic; calcareous; contact with unit 11 gradational.	6.3
11	Mudstone; same color and lithology as unit 9; an 0.8 m-thick intraformational conglomerate channel is present just south of measured section 1.5 m above base; conglomerate is grayish red (10R4/2) to pale red (10R6/2); clasts are primarily intraformational calcrete nodules with minor mudstone chips; very calcareous; lenticular; very well-indurated.	13.3
10A	Mudstone and occasional siltstone; same color and lithology as unit 5.	3.3
10	Mudstone; grayish red purple (5RP4/2) with light greenish gray (5G8/1) flecks; bentonitic; calcareous.	3.4
9	Mudstone; pale red purple (5RP6/2) to grayish red purple (5RP4/2) with brownish gray (5YR4/1) calcrete nodules; slightly silty; very calcareous.	3.5

8B Mudstone; same color and lithology as unit 5. 1.8
8A Mudstone; same color and lithology as unit 6. 0.6
8 Silty mudstone; pale red purple (5RP6/2) to pale red (5R6/2); ripple laminated; calcareous; unit contains an intra-formational conglomerate that is mostly greens and grays with light olive gray (5Y6/1) and olive gray (5Y4/1) predominating; massive; forms a minor hogback between eastbound drainages; extremely fossiliferous; clasts are calcrete nodules and bones; 0.2-0.3 m thick. 4.9
7A Mudstone; same color and lithology as unit 5. 2.7
7 Mudstone and siltstone; mudstone is pale red (10R6/2); slightly bentonitic; calcareous; siltstone is grayish yellow green (5GY7/2) to greenish gray (5GY6/1); ripple laminated; calcareous. 3.9
6 Basal 0.2 m is mudstone; grayish yellow green (5GY7/2) with pale reddish brown (10R5/4) stains; bentonitic; very calcareous; rest of unit is same color and lithology as unit 5 .0.8
5 Mudstone; dark reddish brown (10R3/4) with some whitish (N9) flecks; bentonitic; very calcareous. 4.5
4 Mudstone; grayish purple (5P4/2); bentonitic; not calcareous. 4.5
There is approximately 10 m of cover between units 3 and 4. Regional stratigraphy and outcrop pattern suggests that this interval is not faulted, and probably contains dark, carbonaceous shales and bentonitic mudstones of "Lake Ciniza"-like lithologies. Unit 3A (below) was 9 m into the covered interval.
3A Mudstone; greenish gray (5GY6/1) and dark greenish gray (5GY4/1); overlain by pale reddish brown (10R5/4); bentonitic; includes barite chips that are very pale orange (10YR7/2) and darker shades. not measured

Thickness of Bluewater Creek Formation: 53.5 m

mottled strata:
3 Porcellanite/silicified sandstone; grayish blue (5PB5/2) with streaks and mottles of yellowish gray (5Y7/2) and white (N9); only some mottles calcareous; forms stream-cut notch in road. 3.0
2 Sandstone; pale red purple (5RP6/2), pale blue (5PB7/2), dark yellowish orange (10YR6/6), and other shades; medium-grained, subangular to subrounded litharenite; not calcareous. 4.5

Thickness of mottled strata: 7.5 m

unconformity (Tr-3 unconformity of Pipiringos and O'Sullivan, 1978)

Moenkopi Formation:
1 Sandstone; pale reddish brown (10R5/4) with spots of grayish red purple (5RP4/2); very fine- to fine-grained, subrounded, moderately well-sorted litharenite; not calcareous; laminar. not measured

Fort Wingate Depot Pond

Section measured in the SE1/4 SW1/4 SW1/4 sec. 13 (unsurveyed) T14N R17W, one drainage north of a large pond/feed tank that postdates the 1:24000 Fort Wingate map. Strata strike to NE (N38-46°E) and dip 8.5° to the NW. Section measured 7 July 1995 by A.B. Heckert.

unit **lithology** **thickness (m)**

Chinle Group:
Petrified Forest Formation:
Sonsela Member:
10 Sandstone and conglomerate; basal conglomerate is light olive gray (5Y6/1) with many olive gray (5Y4/1) calcrete nodule clasts; matrix is coarse- to very coarse-grained, subangular, poorly sorted sublitharenite; matrix is only slightly calcareous; clasts often up to 60 mm in diameter; sandstones are predominantly yellowish gray (5Y8/1) and bluish white (5B8/1); may weather to darker yellowish grays (5Y7/2) or even pale red (10R6/2); medium- to coarse-grained, subangular to angular, poorly sorted sublitharenite; often conglomeratic with reworked calcrete nodules up to 25 mm in diameter; not calcareous; trough crossbedded with conglomeratic stringers/lag deposits; unit scours and fills up to 3-4 m into underlying Blue Mesa Member; sandstone is in sets 1.2-2.0 m thick with 0.2-0.8 m interbeds of mudstone; unit forms a cliff; top is stripped surface. 6.2+

unconformity (Tr-4 unconformity of Lucas, 1993)

Blue Mesa Member:
9A Bentonitic mudstone; bleach-out below Sonsela is yellowish gray (5Y8/1) and light greenish gray (5GY8/1) with some pale brown (5Y5/2) nodules; only locally exposed directly beneath the Sonsela; calcareous. not measured
9 Mostly covered colluvial slope; some lenses of micaceous sandstone; grayish yellow green (5GY7/2); very fine- to fine-grained, muddy/ashy, moderately poorly sorted sublitharenite; not calcareous; also, 2 m below cliff unit is sandstone; yellowish gray (5Y8/1); fine- to medium-grained, subangular, moderately poorly sorted, micaceous sandstone; slightly calcareous; only locally exposed. 15.5
8 Bentonitic mudstone; predominantly grayish red purple (5RP4/2) with light greenish gray (5GY8/1) mottles and spots; base especially demonstrates popcorn weathering; less dramatic higher up; weakly calcareous; unit becomes lighter (light greenish gray dominant) higher up; prominent purple band 0.7 m thick 4.0 m above base. 9.0
7 Bentonitic mudstone; pale red purple (5RP6/2) with spots/flecks of light greenish gray (5GY8/1); forms a deep purple band; portions calcareous; popcorn weathering; forms a steep slope; at least partially a paleosol. 15.0
6 Bentonitic mudstone and muddy/ashy sandstone; variegated pale red purple (5RP6/2), pale greenish yellow (10Y6/2); sandstone is very ashy; very fine- to medium-grained, subangular, poorly sorted micaceous litharenite; not calcareous; same bedforms as unit 5; mudstone is weakly calcareous; essentially a mudstone-dominated variation of unit 5. 3.2
5 Heterolithic; silty/muddy/ashy sandstone interbedded with silty/sandy mudstone and muddy siltstone; light greenish gray (5GY8/1) fresh, weathers to moderate orange pink (10R7/4) and pale red (10R6/2); very fine- to coarse-grained, angular to subangular, poorly sorted micaceous sublitharenite; many low-angle planar crossbeds; sand is in 3-8 cm ledges, dominating lower half of section; appears white with some stains above in outcrop. At top of this unit offset 100 m south-southwest. 1.8

Thickness of Blue Mesa Member: 44.5 m

Bluewater Creek Formation:
4 Mudstone; same color and lithology as unit 2; grading upward into unit 3 lithologies. 5. 1
3 Bentonitic mudstone; same color and lithology as unit 1; no conglomerate present. 4.4
2 Mudstone; moderate reddish orange (10R6/6) to pale reddish brown (10R5/4) with a few flecks of light greenish gray (5GY 8/1); somewhat bentonitic; calcareous. 3.4
1 Mudstone; pale red (10R6/2) to grayish red (10R4/2); some mottles and flecks of light greenish gray (5GY8/1); some stringers of siltstone that are also light greenish gray; unit contains an 0.2-m-thick well-indurated calcrete nodule lens that is variegated light olive gray (5Y6/1) and pale red purple (5RP6/2); clast-supported; very coarse sandstone to pebble conglomerate; crops out only locally in valley; unit 1 floors valley north of pond. 8.9+

Thickness of incomplete Bluewater Creek Formation: 21.8 m

Fort Wingate Shooting Range

Section measured in NE1/4 SW1/4 sec. 32 (unsurveyed) T15N R16W. Strata dip approximately 5° to the north. Section measured once in 1990 by S.G. Lucas and O.J. Anderson and again in August, 1994, by A.B. Heckert. These descriptions are a composite of both parties' observations.

unit **lithology** **thickness (m)**

Chinle Group:

Petrified Forest Formation:
Sonsela Member:

20 Conglomerate; same colors and lithologies as base of unit; top is sandstone; light greenish gray (5GY8/1), weathering to medium light gray (N6) salt and pepper coloration; medium-grained, subrounded, well-sorted quartzarenite; not calcareous. 4.0

19 Sandstone; yellowish gray (5Y8/1); medium-grained, sub angular, moderately well-sorted quartzarenite; trough crossbedded; not calcareous. 2.7

18 Conglomeratic sandstone; light greenish gray (5GY8/1) with spots/flecks of dark yellowish orange (10YR6/6) and some darker grays; medium-grained to conglomeratic, subrounded to subangular, extraordinarily poorly sorted sublitharenite; conglomerate clasts are mainly mudstones; very friable; calcareous. 0.8

17 Silty sandstone; light greenish gray (5GY8/1); fine- to medium-grained, subangular, moderately poorly sorted quartzarenite; not calcareous; friable. 4.0

16 Sandstone; light greenish gray (5G8/1); medium-grained, subangular, moderately well-sorted quartzarenite; trough crossbedded; friable; not calcareous. 0.9

15 Sandstone; bluish white (5B9/1); medium- to coarse-grained, subangular, poorly sorted quartzarenite; occasional chert-dominated conglomerate clasts up to 4 mm in diameter; very friable; not calcareous. 3.9

Thickness of Sonsela Member: 16.3 m

unconformity (Tr-4 unconformity of Lucas, 1993)

Blue Mesa Member:

14 Much covered; same color and lithologies as unit 10 with lenses of muddy siltstone with thin lenses of very muddy slightly conglomeratic sandstone; siltstone is pale greenish yellow (10Y 8/2); slightly sandy; not calcareous; sandstones are medium to coarse grained muddy litharenites; poorly sorted; very friable; not calcareous; slightly ashy or kaolinitic; this interval is mostly covered. 8.5

13 Bentonitic mudstone; mottled yellowish gray (5Y7/2) to medium gray (N5); upper portion is much covered by Sonsela float blocks; not calcareous. 8.8

12 Bentonitic mudstone; pale red purple (5RP6/2); not calcareous; 1.5 m above base is a prominent band of calcrete nodules that are light olive gray (5Y6/1) and vary from 1 mm to 5 cm in diameter. 4.5

11 Bentonitic mudstone; yellowish gray (5Y7/2); forms a slope much covered by calcrete nodules. 1.0

10 Bentonitic mudstone; variegated, with pale red purple (5RP6/2) and pale red (5R6/2) colors dominating minor yellowish gray (5Y7/2) mottles; not calcareous; slope is purple and weathers to a popcorn texture. 7.2

9 Interbedded sandstone, siltstone, and silty mudstone; lithologies similar to units 5 (sandstone and siltstone) & 6 (mudstone); sandstones are yellowish gray (5Y8/1); medium-fine grained; very slightly micaceous; moderately well-sorted litharenites; mudstones are pale red purple (5RP6/2); bentonitic; slightly silty; siltstones are also yellowish gray (5Y8/1); bentonitic; and muddier than the sandstones; none of these lithologies are calcareous. 3.0

8 Bentonitic mudstone; grayish red purple (5RP4/2) to grayish purple (5P4/2); some minor grayish red (10R4/2) to white oxidation spots; weathers to a popcorn texture; forms a prominent dark band. 1.4

7 Same color and lithology as unit 5. .5-1.0

6 Bentonitic mudstone; dominantly pale red purple (5RP6/2) with mottles of yellowish gray (5Y7/2); slightly silty; not calcareous; grades vertically into both units 5 (below) and 7 (above). 1.0

5 Siltstone and very fine-grained sandstone; both units are primarily pale red purple (5RP6/2) with some yellowish gray (5Y7/2) mottles; (sandstones are very fine-grained, silty, well-sorted litharenites; siltstones are slightly sandy; bentonitic; not calcareous; unit forms a thin ledge with some low angle crossbeds. 1.0

4 Muddy siltstone and silty mudstone; bentonitic; pale red (5R6/2) with light greenish gray (5GY8/1) spots; not calcareous. 1.3

3 Sandy siltstone and silty sandstone; pale greenish yellow (10Y-8/2) with minor pale red purple (5RP6/2)mottles; low-angle crossbeds; some minor pinching and swelling of unit along contact; not calcareous. 0.5-1.5

Thickness of Blue Mesa Member: 39 m

Bluewater Creek Formation:

2 Mudstone; moderate reddish orange (10R6/6); not calcareous. 4.0

1 Mudstone, pale reddish brown (10R5/4); slightly micaceous; some very large (5-6 cm diameter) calcrete nodules are stained pale red (10R6/2); fresh nodule interiors are variegated dark reddish brown (10R3/4), pale olive (10Y6/2), olive gray (5Y4/1), and medium gray (N5). not measured

Fort Wingate/Cibola National Forest Boundary

Strata dip gently (less than 5°) to the north and were treated as flat-lying for purposes of measuring this section. Measured in the SW1/4 NW1/4 of sec. 3 T14N R16W, McKinley County, New Mexico. Section measured 28 July 1995 by A.B. Heckert.

unit	lithology	thickness (m)

Chinle Group:
Petrified Forest Formation:
Sonsela Member:

7 Sandstone; yellowish gray (5Y8/1) and bluish white (5B9/1) fresh, weathering to moderate yellowish brown (10YR5/4), fine-medium grained, subangular, moderately poorly sorted quartzarenite; laminar and ripple-laminar with some low-angle trough crossbeds; not calcareous; forms a series of ledges retreating/sloping up to a stripped surface. 6.0+

6 Sandstone and conglomerate; yellowish gray (Y8/1) to pinkish gray (5YR8/1) fresh; weathers to dark yellowish orange (10YR 6/6) due to much limonite staining; conglomerate clasts include many calcrete nodules, chert pebbles, and mudstone rip-ups that weather to voids; up to 4-5 cm in diameter; sandstone is medium grained, subangular, moderately well-sorted quartzarenite; much iron (limonite?) staining accounts for brownish weathering colors; trough and planar crossbeds; base of unit often covered by colluvium; middle third contains dramatic crossbeds and many conglomerate clasts; much wood on slopes below; unit forms a cliff. 4.0

Thickness of incomplete Sonsela Member: 10.0 m+

unconformity (Tr-4 unconformity of Lucas, 1993)

Blue Mesa Member:

5A Sandstone; yellowish gray (5Y8/1) with bands of light gray (N7) fresh, weathers to grayish orange (10YR7/4); very fine-to fine-grained, subangular, moderately well-sorted muddy/ashy quartzarenite; laminar with micro cross-laminations; present at break in much-covered slope; not calcareous; lenticular. 0.5-1.5

5 Bentonitic mudstone; mottled grayish purple (5P4/2) and white (N9) to yellowish gray (5Y8/1); very slightly silty; contains siderite and calcrete nodules that are light olive gray (5Y6/1) commonly and rarely moderate reddish orange (10YR6/6); some nodules appear to be root casts/replacement features; unit forms a steep, brilliant, popcorn-weathering slope; nodules are common above 7.5 m; 19.5 m above base is a fine-medium grained sandstone (5A), above which unit is almost entirely covered by colluvium. 32.5

4 Ashy sandstone; mottled pale blue (5PB7/2) and white (N9); appears predominantly white in outcrop; very fine- medium-grained, subangular to subrounded, poorly sorted, muddy/ashy sublitharenite; some low angle crossbeds; up to 1.5 m of scouring into underlying purple mudstones; not calcareous; forms a short, ribbed cliff. 2.8

Thickness of Blue Mesa Member: 36.3 m

Bluewater Creek Formation:

3 Red beds; basal 3 m is conglomerates and sandstones described

below, rest of unit is mudstone of unit 2 lithologies; unit 4 has scoured into the top of this unit locally; conglomerates and sandstones are pale- to moderate reddish brown (10R5/4-10R4/6); conglomerate is intraformational, clast-supported with mudstone and calcrete pebbles up to 6-7 mm in diameter; very calcareous; occasionally bone-bearing; occurs at base of unit as 4-5 sets of 0.2-0.3 m thick layers; sandstone is very fine- to fine-grained, subrounded, moderately poorly sorted litharenite; ripple laminar to low angle crossbeds; grades into unit 2 lithologies approximately 4-5 m above base. 9.9

2 Slightly bentonitic mudstone; pale red purple (5RP6/2) and pale reddish brown ; abundant calcrete nodules in lower third; nodules are both light olive gray (5Y5/2) and (5Y6/1); some very thin ripple laminar sandstones are light greenish gray (5GY8/1) fresh; nodule-rich portions of unit are calcareous. 6.0

1 Red mudstone with green mottles; not sampled; floors valley; some calcrete horizons; essentially a facies of unit 2. not measured

Thickness of incomplete Bluewater Creek Formation: 15.9 m+

New Mexico Highway 400

Section measured from east side of NM-400 at UTM 12722126E, 3923499N to top of bluff west of highway in the SE1/4 sec. 20, T14N R16W (unsurveyed). Strata considered flat-lying. Section measured 8 October 1994 by S.G. Lucas and A.B. Heckert

unit **lithology** **thickness (m)**

Quaternary:

5 Soil and colluvium; caps exposures. not measured

unconformity

Chinle Group:

Shinarump Formation:

4 Sandstone; same colors and lithologies as unit 3 but with less conglomerate. 3.3

3 Conglomerate and conglomeratic sandstone; very light gray (N9) to light gray (N8) fresh; weathers pale reddish brown (10R5/4); sandstone is fine- to medium-grained, subrounded, moderately well-sorted, quartzarenite; conglomerate clasts are primarily chert pebbles up to 15 cm long axis but usually smaller; trough crossbedded; not calcareous. 0.6

Thickness of possibly incomplete Shinarump Formation: 3.9 m

unconformity (Tr-3 unconformity of Pipiringos and O'Sullivan, 1978)

Moenkopi Formation:

2 Sandstone; pale red (5R6/2) to moderate red (5R5/4); very fine- to medium-grained, subrounded, moderately well-sorted litharenite; some cover, some low angle trough crossbeds; forms a red slope. 19.2

Thickness of Moenkopi Formation: 19.2 m

unconformity (Tr-0 unconformity of Pipiringos and O'Sullivan, 1978)

Glorieta Sandstone:

1 Sandstone; moderate orange pink (10R7/4); medium-coarse grained, subrounded, well-sorted quartzarenite, well-indurated, forms a series of small cliffs in the drainage. not measured

Sixmile Canyon II

Section is west of Sixmile Canyon Road in the NW1/4 NW1/4 sec. 13 (unsurveyed) T14N R16W in McKinley County, New Mexico. GPS position: UTM 729011E, 3925721N, UTM zone 12. Strata dip very gently to the north to northwest, treated as flat-lying. Section measured by A.B. Heckert on August 21, 1994.

unit **lithology** **thickness (m)**

Chinle Group:

Petrified Forest Formation:

Sonsela Member:

9 Conglomerate fining upward into a conglomeratic sandstone; pale greenish yellow (10Y8/2) and yellowish gray (5Y8/1); much agatized wood, clasts are primarily mudstone rip-ups with minor chert and calcrete nodules; sandstone matrix is yellowish gray (5Y6/1) to very pale orange (10R8/2), medium-grained, subrounded, well-sorted quartzarenite; not calcareous; sandstone and conglomerate; sandstone is medium- to coarse-grained litharenite; conglomerate clasts include dusky blue (5PB3/2); grayish blue (5PB3/2) and very pale orange (10YR8/2) chert clasts, much moderate yellowish brown (10YR5/4) to dark yellowish orange (10YR6/6) petrified wood; beds are wedge-planar to planar crossbeds, some modest scouring into the underlying strata (unit 8). Above this unit is mostly covered to a second sandstone and conglomerate bench approximately 5 m higher. 2.8+

unconformity (Tr-4 unconformity of Lucas, 1993)

Blue Mesa Member:

8 Bentonitic mudstone; pale olive (10Y6/2); calcareous; this is a thin bleach-out zone below the Sonsela. 1.6

7 Mudstone; same colors and lithology as unit 5; calcrete nodules are greenish gray (5GY6/1) to bluish white (5B9/1). 17.4

6 Prominent calcrete horizon; nodules are light olive gray (5Y6/1) to greenish gray (5GY6/1); up to 35 mm in diameter; other horizons of this lithology exist throughout units 5 (below) and 7 (above), but are not as laterally persistent. 15-.2

5 Bentonitic mudstone; variegated, with colors both horizontally and vertically inconsistent; primary colors include grayish blue (5PB5/2), greenish gray (5GY6/1), medium gray (N5) and pale red purple (5RP6/2); occasional olive gray (5Y6/1) calcrete nodules; base is a light greenish gray (5G8/1) bleach out 0.3 m thick; unit weathers primarily to the gray and purple colors and a popcorn texture. 22.0

4 Sandstone and siltstone interbedded; upper sandstone is mottled very light gray (N8) and yellowish gray (5Y8/1); micaceous lith-arenite; middle siltstone is primarily pale red purple (5RP 6/2) with very light gray (N8) mottles; basal sandstone is pale red purple (5RP6/2); very slightly micaceous; silty litharenite; only top and bottom units are calcareous; individual thicknesses, from bottom up, are 0.15, 0.5, and .2 m respectively. 0.85

3 Mudstone; slightly silty; not bentonitic; not calcareous; with lenses of unit 2 lithology. 1.4

2 Silty sandstone; very light gray (N8) with mottles of greenish gray (5GY6/1) and pale red (5R6/2); laminar to ripple laminated; some mudstone partings; often covered by slope debris. 0.5-.8

Thickness of Blue Mesa Member: 44. 1 m

Bluewater Creek Formation:

1 Mudstone; grayish red purple (5RP4/2); some calcrete nodules that are medium gray (N5), stained grayish red purple (5RP4/2), and up to 60 mm in diameter. not measured

Sixmile Canyon I

Section measured in SW1/4 SE1/4 sec. 13 (unsurveyed), T14N, R16W, McKinley County, New Mexico. Section started at GPS position 728679E, 3924707N, UTM zone 13 at localized mottled strata outcrop in valley floor and continues due west toward Sonsela crest. Strata dip slightly to the north-northwest, treated as flat-lying. Section measured August 20, 1994 by A.B. Heckert and M.J. Grubensky.

unit **lithology** **thickness (m)**

Chinle Group:

Petrified Forest Formation:

Blue Mesa Member:

18 Slope covered with much colluvium; probably same lithologies as unit 17 (below) and approximately 10 m below the Sonsela Member. not measured

17 Bentonitic mudstone; mottled pale red purple (5RP6/2) and light greenish gray (5GY8/1) with abundant siderite nodules of same colors; very weakly calcareous; forms a light green slope. 7.5

16 Bentonitic mudstone with calcrete/siderite nodule conglomer-

ate at base; mudstones are pale purple (5P6/2) to grayish blue (5PB5/2) with white (N9) mottles; calcrete conglomerate is mottled pale red purple (5RP6/2), white (N9) and light olive gray (5Y6/1); forms a thin (. 15 m) knobby crust at base of unit; calcareous. 8.5

15 Bentonitic mudstone; pale red purple (5RP6/2) with yellowish gray (5Y8/1) and white (N9) mottles; not calcareous; forms a prominent purple band. 5.5

14 Muddy sandstone and sandy mudstone; pale red purple (5RP 6/2) and light greenish gray (5GY8/1); very fine-grained, subangular, muddy; poorly sorted litharenite; slightly micaceous; some very low angle trough crossbeds; interbeds approximately 10-20 cm thick; not calcareous. 1.5

13 Sandstone; pale red purple (5RP6/2) with pinkish gray (5YR8/1) mottles; some dark greenish gray (5GY4/1) fine- to medium-grained, rounded, moderately well-sorted muddy litharenite; laminar; blocky to massive; not calcareous. 0.5

Thickness of incomplete Blue Mesa Member: 23.5 m

Bluewater Creek Formation:

12 Interbedded mudstone and siltstone; mudstones are pale reddish brown (10R5/4); siltstones are pale green (5G7/2) with pale reddish brown (10R5/4) mottling and stains; siltstones are pale green (5G7/2) fresh; weathering to form a prominent white band; calcareous. 9.5

11 Mudstone; pale red purple (5RP6/2) and pale reddish brown (10R5/4) interbedded in 1-3-m-thick bands; both with light greenish gray (5G8/1) mottles; slightly bentonitic; some greenish gray (5G6/1) calcrete nodules up to 5 cm diameter; not- to very calcareous. 16.8

10 Mudstone; pale reddish brown (10R5/4) with minor spots/mottles of light greenish gray (5GY8/1); some thin (0.2-0.3-m-thick) white bands; calcareous. 4.9

9 Mudstone; pale reddish brown (10R5/4) to pale red (10R6/2); some siltstone like unit 5 at top in places; calcareous. 2.9

8 Mudstone; moderate reddish brown (10R4/6) to grayish red purple (5RP4/2); a grayish red purple (5RP4/2) to white (N9) and greenish gray (5G6/1) calcrete pebble conglomerate 0.3-m-thick is present at the base of unit; calcareous. 1.5

7 Mudstone; moderate reddish brown (10R4/6) to grayish purple (5RP4/2); forms a purple band; very weakly calcareous; the base of this unit is the top occurrence of bones in this section. 2.6

6 Mudstone; shades of moderate reddish brown (10R4/6); calcareous. 2.9

5 Mudstone; moderate reddish brown (10R4/6) to grayish red (10R4/2) with some light greenish gray (5GY8/1) siltstones in upper half; siltstones are laminar with some very low angle crossbeds; calcareous. 2.3

4 Mudstone; grayish blue (5PB5/2) with olive gray (5Y4/1), light brownish gray (5YR6/1) and light greenish gray (5GY8/1) calcrete nodules; not calcareous; abundant bones locally at the base of this unit. 3.7

3 Mudstone; grayish red purple (5RP4/2); some grayish red (5R 4/2) calcrete nodules; very calcareous; much bone at the top of this unit. 1.5

2 Mudstone; pale red (10R6/2) to grayish red (10R4/2); very slightly silty; calcareous. 2. 1

Thickness of the Bluewater Creek Formation: 50.7 m

Mottled strata:

1 Sandy siltstone and silty sandstone; mottled very light gray (N8), grayish blue (5PB5/2) and light greenish gray (5G8/1); forms an irregular surface that only locally floors wash; very well-indurated; very fine-grained, subrounded, sublitharenite. not measured

Sixmile Spring Road

Section measured above a tributary to Sixmile Canyon, in W1/2 SE1/4 sec. 25, T14N R16W and E1/2 NW1/4 sec. 30, T14N R15W (unsurveyed), McKinley County, NM. Section measured by S.G. Lucas and A.P. Hunt in 1992.

unit	lithology	thickness (m)
Chinle Group:		
Petrified Forest Formation:		
Blue Mesa Member:		
17	Bentonitic mudstone; same color and lithology as unit 15; mostly covered by slump blocks of overlying Sonsela Member.	18.0
16	Mudstone; light greenish gray (5GY8/1) with bands/mottles of grayish purple (5P4/2); bentonitic; slightly calcareous.	4.5
15	Silty bentonitic mudstone; grayish purple (5P4/2); not calcareous.	3.0
14	Ashy sandstone; dark greenish gray (5G4/1); weathers to light greenish gray (5G8/1); poorly sorted; fine- to medium grained; litharenite; angular; laminar to trough and planar crossbedded; not calcareous.	0.5
	Thickness of incomplete Blue Mesa Member: 26.0 m	
Bluewater Creek Formation:		
13	Silty mudstone and muddy siltstone; same color and lithology as unit 9; much calcrete.	11.8
12	Siltstone; pale red (5R6/2) to light olive gray (5Y6/1) and light greenish gray (5G8/1); ripple laminated; calcareous; some thin lenses of sandstone.	1.5
	Thickness of upper Bluewater Creek Formation: 13.3 m	
McGaffey Member:		
11	Sandstone and silty sandstone; pale red (5R6/2); very finely micaceous; fine- to medium-grained; sublitharenite; siliceous cement; calcareous; ripple laminated; forms a prominent; persistent ledge.	6.0
	Thickness of McGaffey Member: 6.0 m	
Bluewater Creek Formation:		
10	Mudstone; grayish red purple (5RP4/2) with bluish white (5B 9/1) and greenish gray (5GY6/1) flecks; bentonitic; calcareous; forms a slope.	4.5
9	Siltstone; light brownish gray (5YR6/1) with moderate red (5R 5/4) calcrete nodules; calcareous; some soft sediment deformation and lenticular ripple laminated sandstones.	10.5
8	Mudstone; grayish red purple (5RP4/2) with light olive gray (5Y5/2) calcrete nodules; bentonitic; calcareous; 4 m above base is a conglomeratic sandstone (8a) which is very light gray (N8), weathering to a grayish brown (5YR3/2); fine-grained; poorly sorted; sublitharenite; subangular; calcareous.	8.5
7	Very slightly silty mudstone; pale red purple (5RP6/2); bentonitic; calcareous; locality BWC-3 in this unit.	1.0
6	Mudstone; pale yellowish brown (10YR6/2); nodular; calcareous; some gypsum plates.	3.2
5	Mudstone; grayish red purple (5P4/2) to grayish blue (5PB4/2); extensive veins of barite which is dominantly light olive gray (5Y6/1); bentonitic; not calcareous. BWC-1 (NMMNH-2739) and BWC-2 localities.	2.5
4	Silty mudstone; same color and lithology as unit 2; some gypsum platelets.	1.7
3	Mudstone and lignitic mudstone; grayish brown (5YR3/2); not calcareous.	4.0
2	Silty mudstone; light bluish gray (5B7/1) to grayish blue (5PB 5/2); bentonitic; not calcareous; much grayish orange pink (5YR 7/2) gypsum plate rosettes.	3.8
	Thickness of lower Bluewater Creek Formation: 39.7 m	
	Thickness of Bluewater Creek Formation: 59.0 m	
mottled strata:		
1	Siltstone; grayish brown (5YR3/2) to grayish purple (5P4/2) to light greenish gray (5G8/1); very slightly to very calcareous.	1.5+

Fourmile Canyon

Section measured in the NW1/4 SW1/4 SE1/4 sec. 21, T14N R15W. Strata dip as much as 4° to due north, but were treated as flat-lying for purposes of this section, which was measured on strike from west to east. Section measured 19 July, 1995 by A.B. Heckert and K. Cockerill.

unit **lithology** **thickness (m)**

Chinle Group:

Petrified Forest Formation:

Sonsela Member:

13 Sandstone and conglomerate; very pale orange (10YR8/2); conglomerate clasts are pale red (10R4/2) and light olive gray (5Y 6/1) chert and quartzite with minor light gray (N7) siltstones; clasts up to 75 mm in diameter; also mudstone and white calcrete pebbles; matrix is medium- to coarse-grained, subrounded to rounded, moderately poorly sorted quartzarenite; much cross-bedding; upper 1.5 m more flaggy; top is a stripped surface. 12.0+

Thickness of incomplete Sonsela Member: 12.0 m+

unconformity (Tr-4 unconformity of Lucas, 1993)

Blue Mesa Member:

12 Bentonitic mudstone; grayish blue (5PB5/2) to grayish purple (5P4/2); some white (N9) spots; silty; slightly calcareous; only basal 2.0 m well-exposed. 12.0

11 Bentonitic mudstone; dark reddish brown (10R3/4) to pale reddish brown (10R5/4); some light green flecks and minor siltstones that are also reddish brown; not calcareous. 3.8

10 Bentonitic mudstone; mottled grayish purple (5P4/2) with minor yellowish gray (5Y8/1) and pinkish gray (5YR8/1); very similar to unit 5; not calcareous. 11. 1

9 Bentonitic mudstone; same color and lithology as unit 6; forms a prominent purple band. 0.25

8 Bentonitic mudstone; slightly darker than light greenish gray (5GY8/1); silty; micaceous; not calcareous. 0.75

7 Sandstone; very light gray (N8) fresh, weathers pinkish gray (5YR8/1); very fine-grained, well-sorted, slightly clayey quartzarenite; laminar, with each 1-2 mm-thick laminae well-indurated; micaceous; not calcareous. 1.5

6 Bentonitic mudstone; grayish red purple (5RP4/2); not calcareous; popcorn weathering; thin lens of unit 4 lithology 4-5 m above base. 11.8

5 Bentonitic mudstone; mottled pale red purple (5RP6/2) and yellowish gray (5Y8/1); very slightly silty; not calcareous; some lenses of unit 4 lithology approximately 5 cm thick. 1.8

4 Sandstone; medium light gray (N7) to light gray (N6) with specks and mottles of white (N9); very fine- to fine-grained, subangular to subrounded, moderately poorly sorted clayey/ashy micaceous sublitharenite; thinly laminar to 9 cm-thick ledges; forms only prominent ledge in Blue Mesa slope; not calcareous. 1.5

3 Bentonitic mudstone; medium gray (N5) to light gray (N7); some remnant crossbeds large-scale, low-angle trough crossbeds; some scour-and-fill on unit 2, below, up to 0.5 m of relief apparent; not calcareous. 2.4

Thickness of Blue Mesa Member: 46.9 m

Bluewater Creek Formation:

2 Bentonitic mudstone; grayish red purple (5RP4/2); not calcareous. 3.75-4.25

1 Bentonitic mudstone; dark reddish brown (10R3/4) fresh, weathers lighter; light gray (N7) and light greenish gray (5GY 8/1) flecks; slightly silty; not calcareous; ABH 95-8, nodule-encrusted bone, at base. 4.5+

Thickness of incomplete Bluewater Creek Formation: 8.75 m+

Smith Canyon

This is the best exposure of upper Blue Mesa Member sediments in western New Mexico. Section measured in the N1/2 NW1/4 SE1/4 sec. 22 T14N R15W in McKinley County, New Mexico. Strata are flat-lying. Section measured 21 July 1995 by A.B. Heckert and K. Cockerill.

unit **lithology** **thickness (m)**

Chinle Group:

Petrified Forest Formation:

Sonsela Member:

12 Sandstone; very light gray (N8) to light gray (N7) fresh, weathers to pale blue (5PB7/2) and/or pale red (10R6/2); fine-grained, subangular, moderately well-sorted sublitharenite; dirty; blocky to massive; some remnant trough cross beds; calcareous; top ridge on hill. 1.4+

11A Same lithology and colors as unit 10A; much covered. 5.7

11 Sandstone; white (N9) and bluish white (5B9/1) fresh; weathers to greens and dark greenish gray (5G6/1); fine- to medium-grained, subangular, moderately poorly sorted quartzarenite; calcareous; forms a thin ledge. 0.5-0.6

10A Much covered interval; grayish purple (5P4/2) bentonitic mudstone with some white (N9) mottles; calcareous. 3.7

10 Intraformational conglomerate; white (N9) fresh, weathering to light brown (5YR6/4); abundant calcrete nodule clasts, rarer mudstone rip-ups and chert pebbles; clasts up to 30 mm in diameter; sandstone matrix is medium grained, subrounded, moderately poorly sorted quartzarenite; occurs in two primary sets, 2.0 and 2.2 m thick, respectively; crossbedded; weakly calcareous except for calcrete clasts (very calcareous); forms a cliff at top of slope as seen from valley. 4.2

Thickness of Sonsela Member: **15.5 m**

unconformity (Tr-4 unconformity of Lucas, 1993)

Blue Mesa Member:

9 Sandstone and intraformational conglomerate; whitish (N9), weathering to light olive gray (5Y6/1); dirty-ashy, medium-grained, subangular, moderately well-sorted sublitharenite; calcareous; some sand and many conglomerate clasts are mudstone rip-ups; conglomerate clasts up to 20 mm in diameter; matrix-supported; poorly sorted; not calcareous; both are poorly indurated and form a slope much covered by colluvium. 2.6

8 Muddy sandstone; white (N9) with pale purple (5P6/2) and yellowish gray (5Y8/1) mottles/spots on weathering surfaces; very fine-grained, subrounded, moderately well-sorted ashy sublitharenite; low angle trough crossbeds; occasional mudstone laminae/interbeds; very calcareous. 1.3

7 Bentonitic mudstone; pale red purple (5RP6/2), light greenish gray (5GY8/1) and pale yellowish gray (5Y7/2); calcareous; basal contact gradational. 6.0

6 Bentonitic mudstone; light greenish gray (5GY8/1) and grayish yellow green (5GY7/2); slightly silty/sandy; slightly calcareous. 7.5

5 Sandstone and intraformational conglomerate; sandstone is very pale orange (10YR8/2) and yellowish gray (5Y8/1) fresh, weathering to grayish orange (10YR7/4)); fine- to medium-grained, subangular to angular, moderately well-sorted, very ashy/muddy quartzarenite; micaceous; low angle crossbeds; bottom third forms a low ledge; middle third is conglomerate described below; upper third is a slope; conglomerate is similar colors but with grayish yellow (5Y8/4) mudstone chips up to 4 mm indiameter in a matrix of muddy, poorly sorted, subangular quartzarenite; not calcareous. 4.5

4 Bentonitic mudstone; light greenish gray (5GY8/1); calcareous; contains an 0.2-0.3 m thick sandstone that is pale green (10G6/2) to greenish gray (5G6/1); very fine- to fine-grained, subangular, moderately poorly sorted quartzarenite; ripple laminated; not calcareous; forms a small ledge within the mudstone slope. 3.6

3 Bentonitic mudstone; pale purple (5P6/2) to grayish purple (5P4/2) with white (N9) spots; light olive gray (5Y8/1) calcrete nodules; calcareous; forms a prominent purple popcorn weathering slope. 19.75

2 Bentonitic mudstone; grayish red purple (5RP4/2) mottled with light greenish gray (5GY8/1); slightly silty; not calcareous; ABH 95-10 approximately 4.5 m above base—purplish bone with some black concretions. 5.75

Thickness of Blue Mesa Member: 51 m

Bluewater Creek Formation:

1 Mudstone; pale red purple (5RP6/2); some sand-sized light olive gray (5Y6/1) calcrete nodules; slightly bentonitic; calcareous; floors valley. not measured

Whitewater Canyon

Section measured in the E1/2 SW1/4 SE1/4 sec. 36, T14N R15W. Strata treated as flat-lying. Section measured 20 July 1995 by A.B. Heckert and K. Cockerill.

unit **lithology** **thickness (m)**

Chinle Group:
Bluewater Creek Formation:
McGaffey Member:

12 Sandstone; pale pink (5RP8/2) and yellowish gray (5Y8/1); fine-grained, subangular to subrounded, well-sorted quartzarenite; micaceous, ripple-laminated; ledgy to flaggy; stripped surface; not calcareous; approximately 120-140 feet (35-45m) below Sonsela topographically. 4.0

11 Intraformational conglomerate; same colors and lithologies as unit 9. 1.5

10 Sandstone; same color and lithology as unit 8.3.0

9 Intraformational conglomerate; conglomerate is grayish red (5R4/2), mud-pellet/rip-up supported; clasts up to 20 mm on long axis; silty to sandy, micaceous matrix. 0.6

8 Sandstone yellowish gray (5Y8/1) fresh, weathering to crusts of grayish red (10R4/2); fine-grained, subangular to subrounded, well-sorted micaceous quartzarenite; not calcareous. 2.9

Thickness of McGaffey Member: 12.0 m

7B Bleach-out sandstone; light olive gray (5Y6/1) fresh, weathers to moderate yellow (5Y7/6); well-indurated, fine-grained, well-sorted micaceous sublitharenite; underlying contact indefinite. not measured

7 Bentonitic mudstone; pale reddish brown (10R5/4) with grayish yellow green (5GY7/2) specks/spots; upper portions more bentonitic/popcorn weathering; some faint purples; calcareous; some minor siltstones and thin white bands; upper 1/3 much covered by colluvial blocks of units 8-12; thickness includes 7B at top. 36.8

6 Bentonitic mudstone; grayish purple (5P4/2) with brownish gray (5YR4/1) calcrete/siderite nodules; slightly calcareous; much covered by colluvium. 7. 1

5A Mostly covered interval; probably reddish brown bentonitic mudstone like unit 7. 3.0

5 Sandstone; very pale orange (10YR8/2) to grayish orange pink (5YR7/2) fresh; weathers to pale red (10R6/2); very fine- to fine-grained, subangular to subrounded, moderately well-sorted micaceous sublitharenite; ripple-laminated; flaggy; slightly calcareous. 2.7

4 Bentonitic mudstone; light brownish gray (5YR6/1); powdery to popcorn-weathering; some moderate orange pink (10R8/2) to light brown (5YR6/4) barite platelets; not calcareous; bottom 3-7.5 m much covered. 14.5

Total exposed Bluewater Creek Formation: 64. 1 m

mottled strata:

3 "Porcellanite"; grayish blue (5PB5/2); flaggy and heavily fractured; forms a much-covered hackly slope and is somewhat gradational with unit 2; not calcareous. 1.4

2 ?Pedogenic limestone?; mottled grays and yellowish greens; calcareous; forms ledge in south-draining arroyo. 1.6

1 ?Pedogenic limestone?/"porcellanite"; mottled grays and reddish- to yellow-browns; calcareous; porcellanite ledge is 0.4 m thick; rest of unit is slope-forming. 2.9+

Thickness of exposed mottled strata: 5.9+

Whitewater Marsh East

Grab samples from a much-covered section in the NE1/4 NE1/4 NE1/4 sec. 7 T13N R14W. Strata treated as flat-lying. Section measured 20 July 1995 by A.B. Heckert and K. Cockerill.

unit **lithology** **thickness (m)**

Chinle Group:
Bluewater Creek Formation:
McGaffey Member:

3 Sandstone; nearly white, i.e. pinkish gray (5YR8/1) or very pale orange (10YR8/2) fresh, weathers to pale red (10R6/2); very fine-grained, subangular, well-sorted, micaceous quartzarenite; ripple-laminated to hummock; forms a rocky ledge/small cliff (basal 4.5 m) and ribbed slope (upper 3.0 m); top is a stripped surface. 7.5

2 Much covered slope, some bentonitic mudstone and siltstone, grayish red (10R4/2); slightly silty; not calcareous. 63

unconformity(?)

1 Moenkopi Formation or mottled strata sandstones; very light gray (N8) and medium dark gray (N4) banded fresh; weathers to medium dark gray (N4) and pale brown (5YR5/2); very fine-grained, moderate well-sorted micaceous litharenite; ripple laminated; crops out in springs in valley floor; 1.0+ m thick in springs. not measured

Las Tuces Lake

Section measured in the SE1/4 NE 1/4, sec. 25, T13N, R13W. Strata dip 8-12° to the north. Section measured by A.B. Heckert, 5 July, 1995.

unit **lithology** **thickness (m)**

Chinle Group:
Petrified Forest Formation:
Sonsela Member:

10 Sandstone; very pale orange (10YR8/2) and grayish orange (10YR7/4) fresh, weathers grayish orange pink (5YR7/2) and pale yellowish brown (10YR6/2); medium-grained, subrounded, moderately well-sorted quartzarenite; sugary; forms a thin ledge with additional very thin ledges of this lithology on a stripped surface; very slightly calcareous. 3.0+

9 Mostly covered slope; some bentonitic mudstone is grayish blue (5PB3/2); calcareous; much sandstone debris, some of which may be in place but most of which is from unit 10. 21.4*

*This Sonsela Member thicknesses may be high due to overestimated dip.

8 Sandstone; white (N9) fresh; weathers pinkish gray (5YR8/1); fine-grained, subangular to subrounded, moderately well-sorted muddy quartzarenite; planar crossbeds; laminar and ledgy; some red mudstone interbeds; not calcareous. 9.0

7 Conglomerate and sandstone; conglomerate is dark gray (N3) to greenish black (5GY2/1) matrix; clasts are quartzite and chert up to 80 mm in diameter; and much more lightly colored; matrix is medium- to very coarse-grained, moderately poorly sorted sublitharenite; much euhedral quartz; unit fines upward to sandstones; much crossbedding; some calcite cement is calcareous, rest not; bottom half more slope-forming and covered by colluvium; upper half cliff-forming. 4.9

Thickness of Sonsela Member: 38.3 m+*

*This Sonsela Member thicknesses may be high due to overestimated dip.

unconformity (Tr-4 unconformity of Lucas, 1993)

Blue Mesa Member:

5 Bentonitic mudstone; mottled pale purple (5P6/2), pale blue (5PB7/2) and bluish white (5B9/1); some light green siltstones approximately 6 m above base; some remnant low-angle trough crossbeds; not calcareous; approximately 9 m above base unit is mostly covered by colluvium, completely so at 33 m above base. 41

Thickness of Blue Mesa Member: 41 m

Above portion of section begins northeast of a drainage with a driveway on west bank. Offset is at top of unit 4

Bluewater Creek Formation:

4 Bentonitic mudstone; same colors and lithology as unit 2 but not fossiliferous; grades upward into unit 1 lithologies with minor siltstones as well. 6.0

3 Bentonitic mudstone; same colors and lithologies as unit 1. 7.5

2 Bentonitic mudstone; pale reddish brown (10R5/4) with grayish red (10R4/2) to grayish brown (5YR3/2) calcrete nodules; nodules often contain, or are attached to, bone; nod-ules up to 30 mm in diameter; nodules very calcareous; rest of unit slightly calcareous; some remnant low-angle trough crossbeds; appears more purple in outcrop. 6.0

1 Bentonitic mudstone; pale reddish brown (10R5/4); some nodules in upper half; very slightly calcareous. 3.0+

Thickness of incomplete Bluewater Creek Formation: 22.5 m+

Bluewater Creek Formation of Lucas and Hayden (1989) Type Section

This is section BW-1 of Lucas and Hayden, 1989. Section measured in the "NE1/4 NW1/4 SE1/4 and the W1/2 NE1/4 section 36 T13N, R12 W; Prewitt quadrangle, Cibola County, New Mexico; measured 23 June 1988, by S.G. Lucas and T.E. Williamson." (Lucas and Hayden, 1989, p. 208). Lithologic descriptions are taken verbatim from the same source. Stratigraphy follows that used by Lucas and Heckert (1994) and this paper. Only the basal Moenkopi-Chinle contact and overlying units are described here. For a complete description, including the entire Moenkopi Formation, see Lucas and Hayden (1989).

unit **lithology** **thickness (m)**

Chinle Group:

Petrified Forest Formation:

Sonsela Member:

13 Sandstone (quartzarenite); pale yellowish orange (10YR8/6); lower 3 m has planar crossbedding; this is overlain by conglomeratic bases, trough crossbedded sandstone in erosional contact; contains abundant fossilized wood; conglomerate clasts are mostly siliceous-chert and quartzite-pebbles; shows graded bedding toward the top of the section; sand is coarse grained to 1 mm, and the sandstone is super mature. not measured

unconformity (Tr-4 unconformity of Lucas, 1993)

Blue Mesa Member:

12 Mudstone; grayish purple (5P4/2); slightly calcareous; upper third contains nodular calcrete; upper 5.5 m is rubble covered. 21.0

Thickness of Blue Mesa Member: 21.0 m

Bluewater Creek Formation (type section):

11 Silty mudstone; same lithology and colors as unit 5, but with laminar-sandstone interbeds. 9.5

10 Sandstone; grayish red (5R4/2), with pale orange (10YR8/2) mottling which may be flaser bedding; lenticular body pinches out laterally; contains lateral accretion deposits; has 0.3 m of laminar sand at base and at least 2 more internal scour surfaces; micaceous; calcareous cementation; very fine grained to 100 microns. 2.4

9 Silty mudstone; dark reddish brown (10R3/4) with dark yellowish orange (10YR6/6) mottling; contains iron concretions which are dark yellowish orange (10YR6/6) and moderate yellowish brown (10YR6/4). 5.6

Thickness of upper Bluewater Creek Formation: 17.5 m

McGaffey Member:

8 Sandstone (sublithic, subarkosic arenite); pale yellowish brown (10YR6/2); limestone-pebble conglomerate at base; thinly bedded lenticular sandstone bodies composing wide, sheet-sandstone body, somewhat like unit 12 in fining-upwards packages with mud drapes. 5.8

Thickness of McGaffey Member: 5.8 m

Bluewater Creek Formation:

7 Silty mudstone; same lithology and colors as unit 15. 17.5

6 Sandy siltstone; grayish red (10R4/2), weathers to pale reddish brown (5R5/4). 0.4

5 Silty mudstone; moderate reddish brown (10R4/6); contains thin, greenish-gray sandy layers; calcareous. 6.4

4 Sandstone; same lithology and colors as unit 2 in lower 1.5 m of lenticular sandstone bodies; grades upward into siltstone and silty mudstone; mud is medium gray (N5), medium light gray (N6) and brownish gray (5YR4/1); calcareous; in places there are thin (up to 2 mm), platy gypsum layers and nodular, muddy calcrete, both of which are grayish red (10R4/2); contains concretions. 4.1

3 Sandstone/conglomerate; intraformational conglomerate containing mudstone-siltstone and limestone-pebble clasts in a matrix of, and interbedded with, sandstone with same lithology and colors as unit 12; contains calcrete nodules. 0.2

2 Sandstone (quartzarenite), yellowish gray (5Y8/1) and pinkish gray (5YR8/1), weathers brownish gray (5YR4/1) and olive gray (5Y4/1); ripple laminated; calcite cement; fine grained to 250 microns. 0.2-1.0

Thickness of lower Bluewater Creek Formation: 30.2 m

Thickness of Bluewater Creek Formation: 53 m

mottled strata:

1 Limestone; same lithology as unit 0, but lighter colored; mostly light olive gray (5Y6/1) and yellowish gray (5Y8/1). 1.5

0 Silty, sandy limestone (micrite to sparite); light brownish gray (5YR6/1), brownish gray (5YR4/1) and medium gray (N5); clastic content is mostly clay and silt with calcite cement. 6. 1

Thickness of mottled strata; 7.6 m

Mitchell Draw

Mitchell Draw sections were measured in various portions of sec. 4, T12N, R11W, Valencia County, New Mexico. These stratigraphic sections mark the easternmost terminus of Chinle Group outcrops in the Zuni Mountains

Segment III

Section is in the SE1/4 SE1/4 NW1/4 sec. 4, T12N, R11W. Strata strike N42°E, dip 3.5 degrees to the NW. Section measured 5 July, 1995, by A.B. Heckert.

unit **lithology** **thickness (m)**

Chinle Group:

Petrified Forest Formation:

Sonsela Member:

9 Sandstone and conglomeratic sandstone; white (N9) fresh; weathered surfaces are grayish orange pink (10R8/2); fine-grained, subangular; moderately poorly sorted quartzarenite; trough crossbedded; channels into underlying units; conglomeratic stringers composed principally of reworked mud pellets and calcrete nodules; weakly calcareous. not measured

unconformity (Tr-4 unconformity of Lucas, 1993)

Blue Mesa Member:

8 Sandstone and intraformational conglomerate; yellowish gray (5Y8/1); fine- to medium-grained, subangular, poorly sorted conglomeratic quartzarenite; some low angle crossbeds; not calcareous; conglomerate clasts are mudstone rip-ups; much covered beneath unit 9. 1. 1

7 Bentonitic mudstone; mottle pale purple (5P6/2) and light olive gray (5Y6/1); very slightly calcareous; slope-former. 1.25

6 Bentonitic mudstone; grayish red (10R4/2) to pale red purple (5RP6/2); slightly silty; micaceous; calcareous; forms a steeper slope. 1.0

5 Bentonitic mudstone; mottled grayish purple (5P4/2) and white (N9); calcareous; forms a slope much covered by col-luvium. 9.0

4 Welded calcrete nodule horizon; principally shades of olive gray (5Y4/1) bleached white (N9) and stained pale purple (5P6/2); forms an irregular ledge; massive; extremely cal-careous. 0.8

3 Bentonitic mudstone; grayish purple (5P4/2) and pale purple (5P6/2); not calcareous; some barite chips. 8.7

Thickness of Blue Mesa Member: 21.8 m

Bluewater Creek Formation:

2 Bentonitic mudstone; pale red purple (5RP6/2) and light gray (N7); many nodules; calcareous. 5.0

McGaffey Member:

1 Sandstone; pinkish gray (5YR8/1) with stains of moderate pink (5R7/4) and pale purple (5P6/2); very fine-grained, subrounded to subangular, moderately well-sorted sub-litharenite; ripple-laminated; very calcareous; floors upper valley/gully and is observably continuous with unit 18 in Mitchell Draw II (below). not measured

Segment II

Section measured in NE1/4 SE1/4 NW1/4 sec. 4, T12N, R11W. Strata dip 9° to the NW. Section measured in August, 1994, by A.B. Heckert and H.D. Rowe.

unit **lithology** **thickness (m)**

Chinle Group:

Petrified Forest Formation:

Sonsela Member:

25 Sandstone; yellowish gray (5Y8/1) fresh, weathers pale red (5R 6/2) to pale yellowish brown (10YR6/2); fine-grained, rounded, well-sorted super clean quartzarenite; planar crossbeds; not calcareous. not measured

unconformity (Tr-4 unconformity of Lucas, 1993)

24 Green mudstone; much covered by colluvium to Sonsela, but probably no more than 5 m from base of unit to first Sonsela troughs. 1.5+

23 Red mudstone; not as bentonitic as underlying units. 4.5

22 Purple mudstone; very bentonitic; some blotches/blebs of lighter colors. 12.0

21 Light blue to light green mudstone; some calcrete horizons; remnant crossbeds expressed in color variations. 3.0

Above unit 20 samples were not taken, but the above observations and measurements facilitate correlation to Mitchell Draw III

Thickness of Blue Mesa Member: 21 m

Bluewater Creek Formation:

20 Mudstone; grayish red purple (5RP4/2) to moderate reddish brown (10R4/6); bentonitic; calcareous; popcorn weathering; many calcrete nodules on low angle slope; nodular horizons are mottled medium gray (N5), pale red purple (5RP6/2) and light greenish gray (5Y8/1) with intermediate shades; nodules up to 10 cm in diameter; very calcareous, and may fuse up to 0.2 m thick. 8.9

19 Silty mudstone; dark reddish brown (10R3/4) to moderate reddish brown (10R4/6); numerous small (2.5 cm or smaller) calcrete nodules of similar color; bentonitic; not calcareous. 1.5

Thickness of upper Bluewater Creek Formation: 10.4 m

McGaffey Member:

18 Sandstone; white (N9) to yellowish gray (5Y8/1) fresh, stained moderate reddish orange 910R6/6) to grayish red (10R4/2); very fine-grained, rounded, well-sorted silty quartzarenite; micaceous; not calcareous; ripple laminated to hummocky bedded; honeycombed weathering; top is ripple laminated surface. 1.3

17 Sandstone; interbedded sets of units 12 and 15 lithologies. 3.0

16 Sandstone; same color and lithology as unit 12; mostly covered. 1.3

15 Sandstone; pale red purple (5RP6/2) to pale pink (5RP8/2) fresh, stained pale reddish brown (10R5/4); very fine-grained,subrounded, well-sorted quartzarenite; micaceous; calcareous. 3.5

14 Sandstone; pale red purple (5RP6/2) fresh, stained and weathered to pale reddish brown (10R5/4); very fine-grained,subrounded, sublitharenite; micaceous; slightly calcareous; massive; forms a cliff. 9.0

13 Sandstone; grayish orange pink (10R8/2) with grayish red purple (5RP4/2) and grayish red (10R4/2) spots/mottles; very fine- to fine-grained, subrounded, moderately well-sorted litharenite; coarsely micaceous; slightly calcareous; ripple laminated to hummocky bedded. 0.5

12 Sandstone; thin laminae of grayish red (10R4/2) and pale red purple (5RP6/2); fine-grained, subangular, moderately well-sorted litharenite; coarsely micaceous; not calcareous; muddy; flaser bedded. 0.9

11 Sandstone; grayish blue (5PB5/2) fresh, grayish red purple (5RP4/2) weathered; very fine- to medium-grained, subangular; poorly sorted silty litharenite; blocky; calcareous; ripple laminated; scours slightly into underlying unit. 0.4

Thickness of McGaffey Member: 19.9 m

Bluewater Creek Formation:

10 Mudstone with siltstone interbeds; mudstone is pale red purple (5RP6/2) to pale reddish brown (10R5/4); bentonitic; calcareous; siltstone is light greenish gray (10GY8/1), stained and mottled pale reddish brown (10R5/4); calcareous. 4.5

9 Mudstone; grayish red purple (5RP4/2); bentonitic; calcareous; popcorn weathering; many calcrete nodules. 5.8

8 Calcrete nodule conglomerate; greenish gray (5GY6/1) and grayish red purple (5RP4/2) calcrete nodules; calcareous. 0. 1

7 Mudstone; pale red purple (5RP6/2) with some mottles of yellowish gray (5Y8/1); bentonitic; calcareous. 5.75

6 Nodule conglomerate; brownish gray (5YR4/1) to grayish red purple (5RP4/2); clasts are nodules and mudstone rip-ups; extremely calcareous. 1.0

5 Mudstone; pale reddish brown (10R5/4); bentonitic; calcareous. 2.75

4 Siltstone; yellowish gray (5Y7/2); ripple laminated; very calcareous. 0.2

3 Mudstone; pale reddish brown (10R5/4) with light greenish gray (5GY8/1) mottles; blocky; bentonitic; calcareous. 3.8

2 Mudstone; pale red (10R6/2) to grayish red (10R4/2); bentonitic; not calcareous. 2.75

1 Sandstone; medium gray (N5); very fine-grained, well-sorted quartzarenite; well -cemented; ripple laminated; calcareous. This unit = unit 2 of Bluewater section, above and unit 3, Mitchell Draw Segment A, below. not measured

Thickness of incomplete lower Bluewater Creek Fm: 22.6 m

Thickness of incomplete Bluewater Creek Formation: 52.9 m+

Segment I

Strata strike N 77-79°E, dipping 8-10° to SE. Section measured in the SE1/4 SE1/4, sec. 4, T12N, R11W. Clearly, there is some structure, most likely several faults, between this section and the other Mitchell Draw sections. However, unit 3 of this section clearly corresponds to unit 1 of Mitchell Draw Segment B and thus can be used to figure a maximum thickness of the Bluewater Creek Formation in this area. Section measured 5 July 1995, by A.B. Heckert.

unit **lithology** **thickness (m)**

Chinle Group:

Bluewater Creek Formation:

3 Sandstone; yellowish gray (5Y7/2) to pale yellowish brown (10YR6/2); very fine- to fine-grained, subangular to subrounded, moderately well-sorted, micaceous litharenite; ripple laminated; some what lenticular; much color variation and interbeds of silt- and mudstone; calcareous; top is a stripped surface. 8.0+

mottled strata:

2 Conglomerate and sandstone; heavily mottled, including grayish red (10R4/2), grayish orange (10YR7/4) and light olive gray (10Y6/1); clasts are Paleozoic limestones with minor chert; up to 30 mm in diameter but commonly 4-6 mm; some Moenkopi rip-ups; top of unit is grayish purple (5P4/2) mudstone with pale yellowish orange (10YR8/6) flecks; unit is very calcareous. 2.4

1 Mudstone to porcellanite; grayish purple (5P4/2) and yellowish orange (10YR8/6); calcareous. not measured