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STRATIGRAPHY, AGE AND CORRELATION OF THE UPPER CRETACEOUS TOHATCHI FORMATION, WESTERN NEW MEXICO

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Abstract. —The Upper Cretaceous Tohatchi Formation is at least 160 m of nonmarine siliciclastic strata exposed in extreme western New Mexico along the southeastern and eastern flank of the Chuska Mountains. The Tohatchi Formation conformably overlies the Menefee Formation, is unconformably overlain by the Deza Member of the Chuska Formation and consists of two members named here, a lower, sandstone-dominated Separate Hill Member and an upper, mudstone-dominated Red Willow Wash Member. A significant change in sandstone lithology and bedform at the base of the Tohtachi Formation is a mappable contact and justifies continued recognition of the unit as a distinct formation.

Dinosaur fossils found throughout the Tohatchi Formation indicate it is of Late Cretaceous age, and we report extensive palynomorph assemblages that refine this age assignment to early Campanian. The Tohatchi Formation is not, as has been thought for 50 years, a correlative of part of the upper Campanian Pictured Cliffs-Fruitland-Kirtland formations succession to the west. Instead, the Tohatchi Formation is the uppermost part of the Mesaverde Group in western New Mexico, younger than the underlying Allison Member of the Menfee Formation locally, and older than the late Campanian turnaround of the Cliff House-Pictured Cliffs shoreline to the east.

INTRODUCTION

One of the least studied and little understood Upper Cretaceous stratigraphic units in west-central New Mexico is the Tohatchi Formation. Originally termed the "Tohachi shale" and assigned a Cenozoic age by Gregory (1917), the formation is exposed in extreme western New Mexico along the Chuska Mountain front from about Chuska Peak to Narbona Pass (Fig. 1). Current understanding of the Tohatchi Formation is based primarily on work published by Allen (1953) and Allen and Balk (1954); little has been done since then. Here, we present a revised understanding of the lithostratigraphy, age, and correlation of the Tohatchi Formation. NMMNH = New Mexico Museum of Natural History, Albuquerque.

PREVIOUS STUDIES

The Tohatchi Formation, first termed the "Tohachi shale," was initially described by Gregory (1917, p. 80) as "poorly consolidated clays and sands with a few strata of impure lignite," 61 to 335 m thick. Gregory noted the presence of unionid bivalves and fossil bone fragments in the "Tohachi," but stated they are not age diagnostic. He assigned the "Tohachi" a Tertiary age, based on perceived similarities in lithology and depositional environments between it and the "Nacimiento Group" (now Nacimiento Formation), strata of Paleocene age in the San Juan Basin to the east.

Allen (1953) first referred to the unit as the Tohatchi Formation, indicating that it is of Late Cretaceous age, conformably overlies the Menefee Formation and is unconformably overlain by the Chuska Sandstone. He divided it into a "lower carboniferous member" (259 m thick) and an upper, bentonitic member (at least 152 m thick).

Silver (1954) wrote a comment on Allen (1953), claiming that Allen misapplied the name Tohatchi to rocks that Gregory would have called Mesaverde, so the original Tohatchi according to Silver is a post-Mesaverde unit of probable Cenozoic age. Allen's (1954) reply to Silver, as well as the comments of Repenning (1954) and Wright (1954), indicate that Allen did correctly identify the Tohatchi Formation of Gregory; Silver's comment was thus of little merit.

Allen and Balk (1954) mapped and described the Tohatchi Formation as consisting of a lower member that is "400 to 850 feet [122 to 259 m] of sandstones," and an upper member, which is "highly bentonitic shales which are carbonaceous near the base," with a thickness of 500 feet (152 m). They characterized lower member sandstones as thin to medium bedded and containing about 50% shale interbeds. Allen and Balk assigned the age of the Tohatchi Formation to the Late Cretaceous. This evaluation was based on vertebrate fossils collected in part in the Tohatchi Formation, including ornithischian dinosaur (hadrosaur) fossils. Based on these fossils, and on stratigraphic position (Tohatchi overlies the Menefee Formation), Allen and Balk (1954) suggested that the lower sandstone member of the Tohatchi correlates to the merged Cliff House and Pictured Cliffs Sandstone and suggested that the upper bentonitic unit of the Tohatchi may be equivalent to the Fruitland and part of the Kirtland Formation to the east.

Repenning (1954) also critiqued Silver (1954) and supported Allen's (1953) conclusions. He reported that molluscs and fossil plants from the lower member of the Tohatchi Formation are of Late Cretaceous age, and that R. T. Brown considered fossil plants from the upper member to be comparable in age to those of the Kirtland Formation in the San Juan Basin and the Vermejo Formation in the Raton Basin.

Wright (1954) also agreed with Allen as to the inclusion of the "shales" beneath the Cretaceous-Tertiary unconformity in what he described as the 411 m thick Tohatchi Formation. Wright (1954) coined the name Deza Formation for the strata immediately above the Tohatchi Formation (also see Wright, 1956).

Beaumont et al. (1956) revised Mesaverde Group stratigraphy in the San Juan Basin. They accepted the Tohatchi Formation as redefined by Allen and Balk (1954) as the upper formation of the Mesaverde Group, but preferred to spell the name as "Tohachi." Beaumont et al. (1956) also expressed skepticism over correlation of the Tohatchi Formation to the Pictured Cliffs-Fruitland-Kirtland succession to the east.

Despite Beaumont et al.'s (1956) willingness to retain the Tohatchi Formation as a separate unit in the Mesaverde Group, by the mid-1950s several U. S. Geological Survey geologists had abandoned the name Tohatchi and mapped the unit as the "Kirtland and Fruitland Formations undivided" (Zieglar, 1955; O'Sullivan and Beikman, 1963; O'Sullivan et al., 1972; Hackman and Olson, 1977). Others simply mapped the Tohatchi with the Menefee Formation (Dane and Bachman, 1957, 1965; Cooley et al., 1969).

O'Sullivan et al. (1972, p. 47-48) detailed the reasoning behind abandoning the name Tohatchi and simply extending distribution of the Kirtland and Fruitland formations westward, into the Chuska Mountains. They presented a detailed listing of the invertebrate and plant fossils from the Tohatchi Formation briefly mentioned by Repenning (1954), and considered these fossils definitive evidence that the Tohatchi is the same age as the Fruitland-Kirtland formations.

LITHOSTRATIGRAPHY

Type Section

Gregory (1917, p. 80) named the "Tohachi shale" for strata exposed "2 miles north and 3 miles west of Tohachi Indian School." This must be considered the type area (section) of the Tohatchi Formation, and it is the escarpment just southeast of Chuska Peak between Red Willow Wash and Muddy Wash (Fig. 1) (Allen and Balk, 1954). Repenning's (1954) statement that only the lower member of the Tohtatchi Formation is present at the type locality is not correct (also see Allen and Balk, 1954). We measured a lectostratotype section of the Tohatchi Formation here (Figs. 2-3, Appendix 1) and divide the Tohatchi Formation into two members, named here.

Separate Hill Member

Allen and Balk (1954, p. 97, pl. 11, sec. 11) termed the lower, sandstone-dominated interval of the Tohatchi Formation the "lower member." We name this unit the Separate Hill Member, after the geographic feature near the type section.

At its type section (Figs. 1-3, Appendix 1), the Separate Hill Member is approximately 78 m thick. More than half of the unit is ledge- and cliff-forming sandstone (54% of the measured section). Slope forming units are siltstone (18% of the section), mudstone (16% of the section), or lignite/lignitic mudstone (10% of the section). Ironstone ledges and crusts are a minor (<2%) but conspicuous part of the section. Sandstones are typically fine-grained and very fine-grained subarkoses that are yellowish brown to very pale orange. The siltstones and mudstones are of similar color. Sandstone bedforms are almost exclusively trough-crossbeds in thin, multistoried sets. Rip-ups are intraformational, and lignite beds are persistent, yellowish brown to black bands.

Allen and Balk (1954) determined a thickness of 122-259 m for their lower member of the Tohatchi Formation, two to three times the thickness of our Separate Hill Member. This difference reflects the fact that we place the Tohatchi Formation base much higher stratigraphically than did Allen and Balk (1954). Thus, we consider at least half of their lower member strata to belong to the Menefee Formation. We do so because the base we choose corresponds to a significant change in sandstone lithology and bedform that we believe is a mappable formation-rank contact.

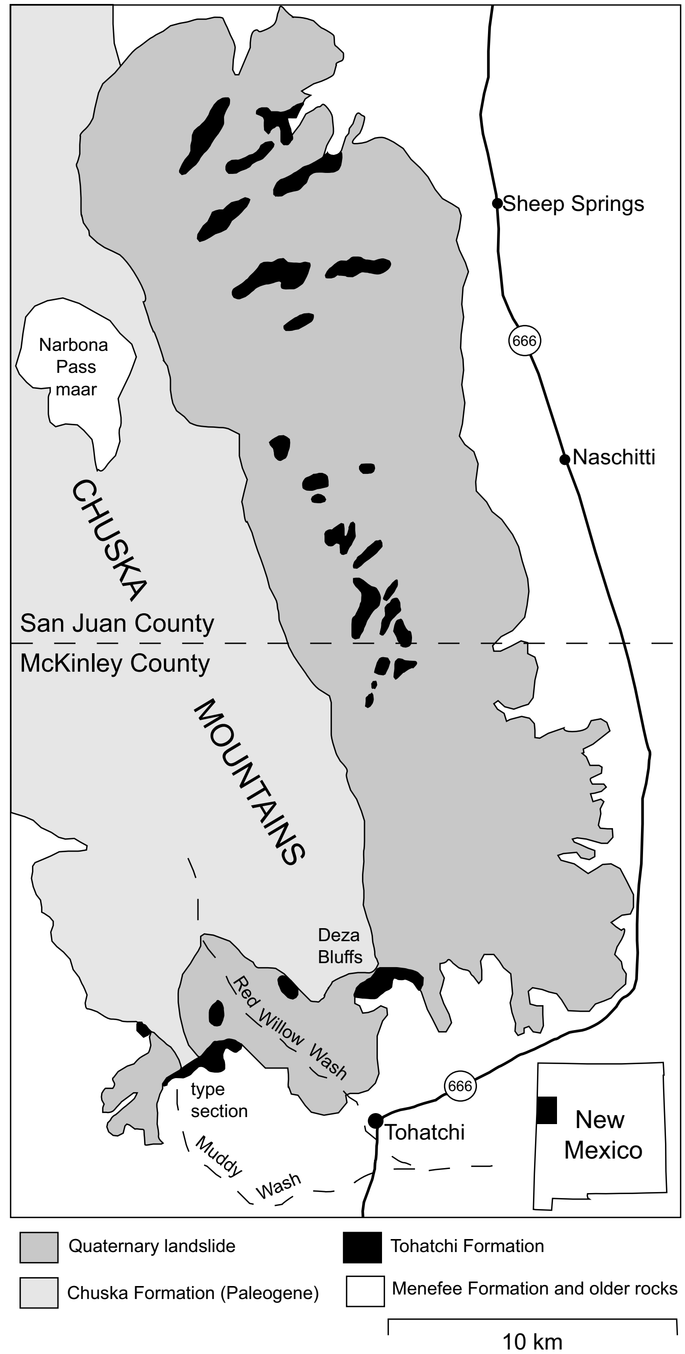

FIGURE 1. Simplified geologic map of southern part of Chuska Mountains showing distribution of outcrops of Upper Cretaceous Tohatchi Formation. Geology after O'Sullivan and Beikman (1963) and Hackman and Olson (1977).

Thus, Menefee sandstones below our Tohatchi Formation base are very friable, thick bedded, yellowish orange, very fine-grained subarkoses. They are exposed as thick benches or soft shoulders and slopes on hillsides. In contrast, sandstones of the

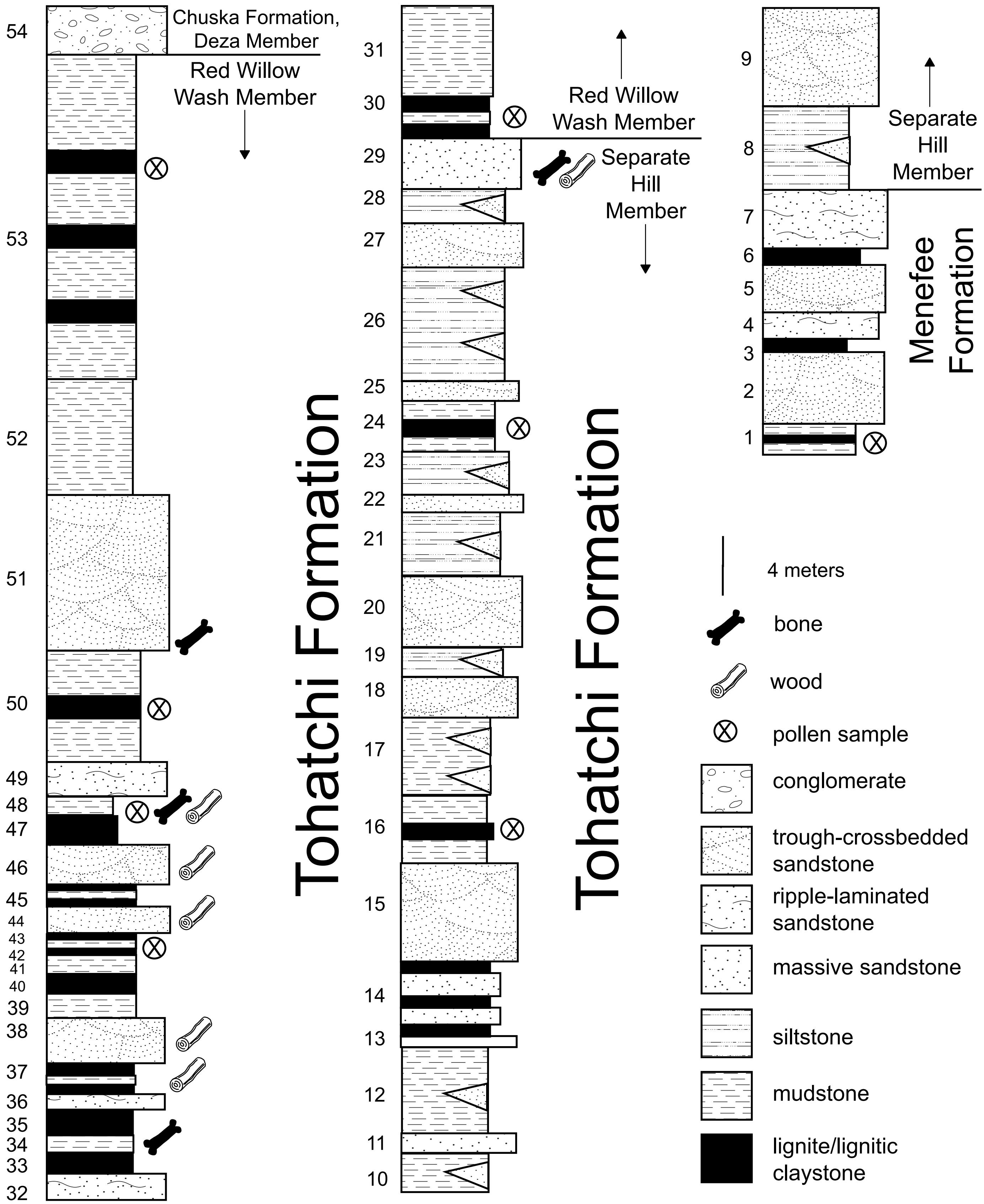

FIGURE 2. Type section of the Tohatchi Formation and of its two members, named here. See Appendix 1 for exact location and descriptions of numbered lithologic units.

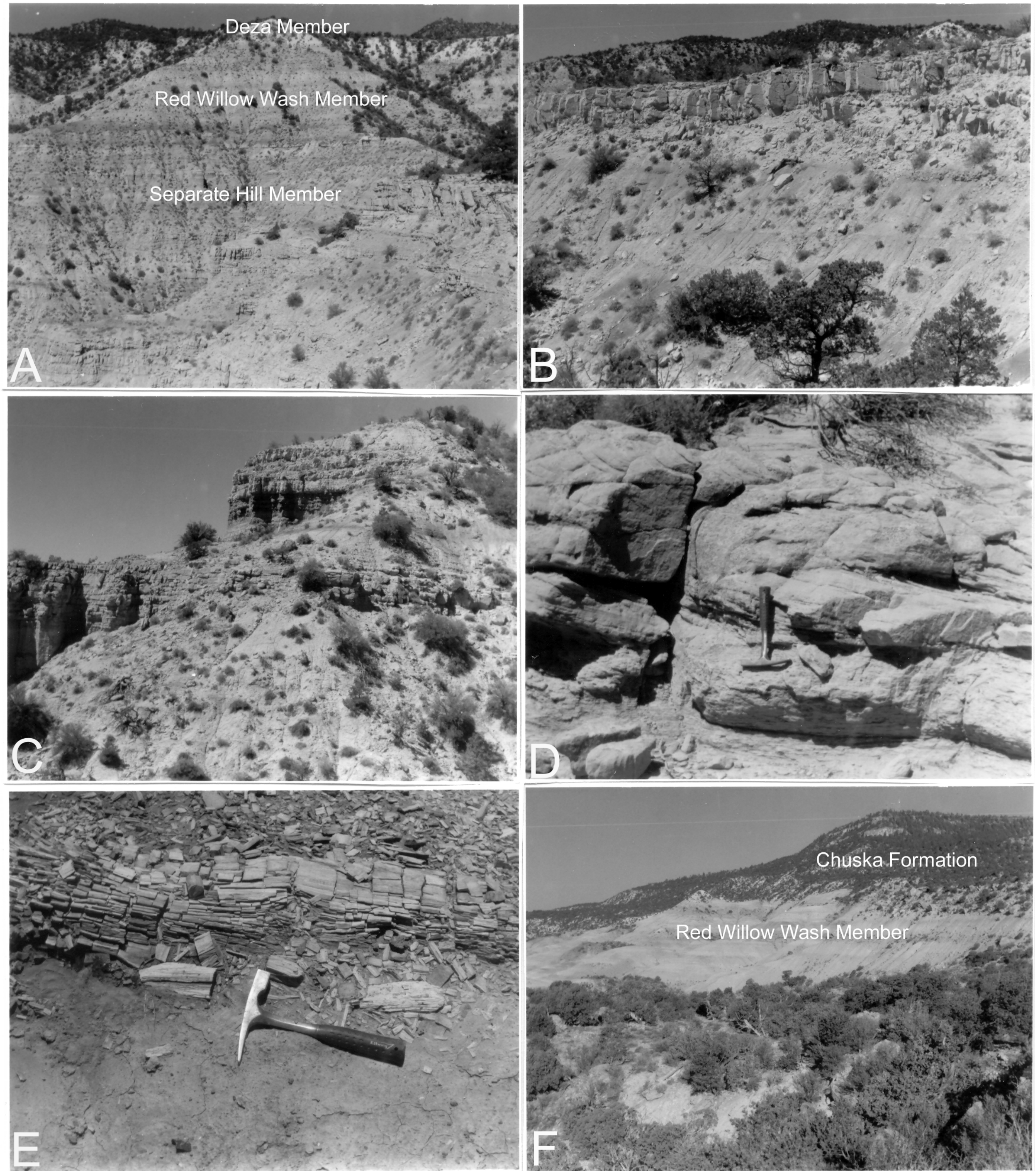

FIGURE 3. Photographs of selected outcrops of Tohatchi Formation. A. Overview of upper part of Tohatchi Formation type section, showing contacts of Separate Hill and Red Willow Wash members, and of Deza Member of Chuska Formation. B. Type section of Tohatchi Formation, upper bench of Separate Hill Member (Fig. 2: units 27-29). C. Type section of Tohatchi Formation, typical multistoried sandstone beds of Separate Hill Member (Fig. 2: units 13-15). D. Type section of Tohatchi Formation, closeup of unit 29 sandstone of the Separate Hill Member (Fig. 2: unit 29) showing east-north-east-dipping crossbeds. E. Type section of Tohatchi Formation, closeup of unit 38 fossil log in the Red Willow Wash Member. F. View of Deza Bluffs showing Red Willow Wash Member of Tohatchi Formation overlain by Chuska Formation.

Separate Hill Member of the Tohatchi Formation are indurated, thin bedded, and yellowish brown. They are exposed as prominent, well-bedded ledges, cliffs and benches.

Gregory (1917) claimed that there is an angular unconformity between the Tohatchi Formation and underlying Menefee Formation, but we, and all subsequent workers (see especially Allen and Balk, 1954 and Repenning, 1954) have seen no evidence of such an unconformity.

Other than the type section, the only other extensive outcrop of the Separate Hill Member of the Tohatchi Formation is southeast of the Deza Bluffs, northeast of Tohatchi. Here, the unit is 70 to 90 m thick and is of similar lithology to the type section.

Red Willow Wash Member

We introduce the term Red Willow Wash Member of Tohatchi Formation for the unit Allen and Balk (1954) termed the upper member. At its type section (Figs. 1-3), the Red Willow Wash Member is 83 m thick and mostly mudstone (43% of the measured section) and lignite/lignitic mudstone (24% of the section). About one third of the section is sandstone.

Mudstones of the Red Willow Wash Member are bentonitic and typically yellowish green and olive gray. The sandstones are grayish orange and yellowish gray, fine-grained subarkoses. The entire member is exposed as a greenish mudstone-dominated slope between the ledge- and cliff-forming Separate Hill Member below and Paleogene Desza Member of the Chuska Formation above. The contact of the Red Willow Wash and Separate Hill members is a sharp break from sandstone (below) to mudstone or siltstone (above) but appears to be conformable.

The contact of the Deza Member of the Chuska Formation on the Tohatchi Formation is an angular unconformity (Wright, 1954, fig. 3). Southeast of the Deza Bluffs, northeast of Tohatchi, the Red Willow Wash Member of the Tohatchi Formation is thicker, as much as 150 m thick. In the extensive Chuska Mountain landslide, from the McKinley County-San Juan County line to west of Sheep Springs (Fig.1), most of the outcrops of the Tohatchi Formation are the Red Willow Wash Member.

AGE

Previous Ideas

Although Gregory (1917) assigned the Tohatchi Formation a Cenozoic age, he had no data to support the assignment other than overall stratigraphic position and purported lithology similarity to Cenozoic strata to the east (Nacimiento Formation of the west- and south-central San Juan Basin). Allen and Balk (1954) reported dinosaur fossils from the Tohatchi Formation and thus assigned it a Late Cretaceous age. Repenning (1954) mentioned nonmarine invertebrate and megafossil plants, listed in detail by O'Sullivan et al. (1972), found near Sheep Springs, that they concluded suggested correlation with the Fruitland and Kirtland formations of the San Juan Basin.

Our field reconnaissance indeed confirms that fragmentary turtle and dinosaur bones are common at several horizons in the Tohatchi Formation. At the type section, fragmentary dinosaur fossils are present in both the Separate Hill and Red Willow Wash members (Fig. 2). No serious effort has been made to collect and study vertebrate fossils from the Tohatchi Formation, so none of the vertebrate taxa noted to date yield a more restricted age determination than Late Cretaceous.

Palynology

We collected 10 samples for pollen analysis, one from the Menefee Formation and nine from the Tohatchi Formation (Table 1). Eight of these samples are from the Tohatchi Formation lectostratotype section (units 1, 16, 24, 30, 43, 48, 50 and 53: Fig. 2), and two are from localities west of Sheep Springs (NMMNH localities 5252 and 5253: Fig. 2). The samples were processed for palynomorphs using standard preparation procedures. The prepared slides yielded good results and allow a more precise dating of the sequence than has previously been possible. Table 1 provides a list of taxa recognized in the 10 samples by horizon and locality. One interesting aspect of the samples is the presence of dinoflagellates in several of the Tohatchi Formation samples (Table 1), indicating some marine influence on deposition throughout the formation.

The pollen samples all appear to be early Campanian in age, although not earliest Campanian. The assemblages of the uppermost Menefee and Tohatchi formations have elements that appear younger than those seen in the Milk River Formation of southern Alberta and lower Eagle Formation of Montana. They appear older than those seen in the Pakowki Formation and Judith River Group of southern Alberta and the Claggett and Judith River formations of Montana. The closest assemblages to those seen in the Tohatchi Formation appear in the upper unnamed member of the Eagle Formation. In southern Alberta, this time interval is represented by an unconformity between the Milk River and Pakowki formations. A surprising observation is the similarities with the Milk River assemblages in Alberta, which represent latest Santonian time, and the general lack of similarities to the South Hospah coal-bearing early Campanian assemblages in New Mexico described by Jameossanaie (1987).

No previous palynological studies are known from the Tohatchi Formation. R. H. Tschudy (1973) described palynological assemblages from the Gassbuggy core taken in the San Juan Basin, which spanned a time interval of Paleocene to late Campanian. There is the possibility that a portion of this core is equivalent to the Tohatchi Formation, though this is difficult to evaluate as only a species list is provided and it is not entirely clear how the taxonomic nomenclature was being applied. Jameossanaie (1987) completed a large palynological study of the Cleary Coal Member of the Menefee Formation in the South Hospah coalfield, McKinley County, New Mexico, and he concluded that the age of the sediments is earliest Campanian. Although some similarities exist with the current material, it is apparent that the Menefee assemblages are older than those seen in the Tohatchi Formation. Other published palynological studies from New Mexico have dealt with assemblages from considerably younger units.

Nichols et al. (1982) and Nichols (1994) have constructed a biostratigraphic zonation that spans the interval of the Tohatchi

TABLE 1. Palynomorph taxa recovered from 10 samples from the Menefee and Tohatchi formations (Fig. 2). The taxa of palynomorphs are listed by locality/horizon. The sample number in parentheses is the number assigned to the sample by the Royal Tyrrell Museum of Palaeontology.

	NMMNH Locality 5252 (RTMP # 02-15-1)	NMMNH Locality 5253 (RTMP # 02-15-2)	Type Section, Unit 1 (RTMP # 02-15-3)	Type Section, Unit 16 (RTMP # 02-15-4)	Type Section, Unit 24 (RTMP # 02-15-5)	Type Section, Unit 30 (RTMP # 02-15-6)	Type Section, Unit 43 (RTMP # 02-15-7)	Type Section, Unit 48 (RTMP # 02-15-8)	Type Section, Unit 50 (RTMP # 02-15-9)	Type Section, Unit 53 (RTMP # 02-15-10)
*Accuratipollis lactiflumis*Braman 2002			X							X
Aequitriradites spinulosus (Cookson & Dettmann) Cookson & Dettmann 1961					X		X	X	X	
Aequitriradites verrucosus (Cookson & Dettmann) Cookson & Dettmann 1961									X	
Alisporites bilateralis Rouse 1959	X							X		X
Aquilapollenites attenuatus Funkhouser 1961									X	
Aquilapollenites dolium (Samoilovitch) Srivastava 1968	X									
Aquilapollenites trialatus Rouse 1957			X							
Aquilapollenites turbidus Tschudy & Leopold 1971					X	X		X	X	X
Aquilapollenites spp.	X		X		X			X	X	
Arecipites tenuiexinous Leffingwell 1970								X		
Asterisporites chlonovae (Doring) Venkatachala & Rawat 1971				X						
Baculatisporites comaumensis (Cookson) Potonié 1956			X							
Baculatisporites sp.								X		
Biretisporites deltoidus (Rouse) Dettmann 1963			X				X	X	X	
Brevimonosulcites corrugatus Yu & Zhang 1987	X		X				X	X		X
Callialasporites dampieri (Balme) Dev 1961	X		X	X	X		X	X	X	X
Camarozonosporites ambigens (Fradkina) Playford 1971			X		X				X	
Cicatricosisporites intersectus Rouse 1962			X							
Cicatricosisporites spp.								X		X
Circulina parva Brenner 1963			X				X		X	
Circumflexipollis tilioides Chlonova 1961			X		X				X	
Concavissimisporites punctatus (Delcourt & Sprumont) Brenner 1963					X		X	X	X	X
Cupanieidites sp.										X
Cupuliferoidaepollenites levitas (Tschudy) Jameossanaie 1987					X					
Cupuliferoidaepollenites sp.	X		X		X					X
Cyathidites australis Couper 1953				X			X		X	
Cyathidites minor Couper 1953			X	X	X		X	X	X	X
Cycadopites fragilis Singh 1964	X		X		X					
Deltoidospora diaphana Wilson & Webster 1946			X	X						X
Deltoidospora sp.			X							
Echinatisporis spp.			X	X						X
Enzonalasporites bojatus Braman 2002			X	X						
Enzonalasporites sp.					X					
Equisetosporites rousei Pocock 1964			X							
Eucommiidites couperi Anderson 1960										X
Eucommiidites minor Groot & Penny 1960	X		X					X		X
Foraminisporis semiscalaris (Paden Phillips & Felix) Braman 2002				X	X		X	X	X	X

Table 1. Continued.

Foraminisporis undulatus Leffingwell 1971			X	X			X	X	X	X
Foveogleicheniidites confossus (Hedlund) Burger *in* Norvick & Burger 1976				X						X
Foveosporites sp.					X					
Ghoshispora sp.									X	X
Gleicheniidites delicatus (Bolkhovitina) Pocock 1970				X						
Gleicheniidites senonicus Ross 1949				X	X			X	X	X
Gleicheniidites sp.					X					
Hazaria sp.								X		
Heliosporites kemensis (Chlonova) Srivastava 1972									X	X
Inaperturotetradites scabratus Tschudy 1973	X									X
Interulobites sp.								X		
Klukisporites foveolatus Pocock 1964			X						X	
Kuprianipollis sp.			X							
Laevigatosporites haardtii (Potonié & Venitz) Thomson & Pflug 1953			X	X	X	X	X	X	X	X
Laevigatosporites undulatiformis Beilstein 1994			X					X		
Leptolepidites sp.								X		
Liliacidites variegatus Couper 1953								X		
Liliacidites sp.									X	
Marcellopites sp.									X	
Microfoveolatosporis pseudoreticulatus (Hedlund) Singh 1983									X	
Monosulcites riparius Braman 2002	X					X				X
Monosulcites sp.									X	
Ovoidites ligneolus(Potonié) Thomson & Pflug 1953				X						
Ovoidites sp.								X		
Penetetrapites inconspicuus Sweet 1986					X				X	X
Periretisyncolporites chinookensis Braman 2002				X					X	
Peromonolites subengelmanni (Elsik) Jameossanaie 1987									X	
Pityosporites constrictus Singh 1964	X			X	X		X			X
Polycingulatisporites reduncus (Bolkhovitina) Playford & Dettmann 1965								X		X
Polyporina sp.				X						
Polyporites sp.			X							
Pristinuspollenites microsaccus (Couper) Tschudy 1973	X					X	X	X	X	X
Proteacidites retusus Anderson 1960			X		X				X	X
Proteacidites thalmanni Anderson 1960	X		X	X	X	X	X	X	X	X
Proteacidites sp.								X		
Pseudoplicapollis newmanii Nichols & Jacobson 1982										X
Pulcheripollenites krempii Srivastava 1969										X
Quadripollis krempii Drugg 1967							X	X	X	
Rousea sp.							X			
Rugubivesiculites reductus Pierce 1961			X	X			X	X		
Schizosporis parvus Cookson & Dettman 1959	X						X		X	X
Stenozonotriletes dedaleorimosus Fradkina 1967			X							
Stereisporites antiquasporites (Wilson & Webster) Dettmann 1963									X	
Subtriporopollenites alpinus (Wolf) Tschudy 1973	X							X		
Taxodiaceaepollenites hiatus (Potonié) Kremp 1949	X						X		X	X
Taxodiaceaepollenites vacuipites (Wodehouse) Wingate 1980					X				X	X
Tetrangulidinium sp.				X						X
Tetraporina sp.	X									
Todisporites sp.								X		

Table 1. Continued.

Tricolpites hians Stanley 1965				X						
Tricolpites reticulatus Cookson 1947	X				X			X	X	
Tricolpites spp.	X		X				X	X	X	X
Tricolporites spp.	X		X		X					
Trilites bettianus Srivastava 1972								X		
Trilobapollis laudabilis Braman 2002				X						
Triporites spp.							X	X	X	X
Triporoletes involucratus (Chlonova) Playford 1971				X						
Triporoletes stellatus Srivastava 1972				X					X	X
Triporopollenites sp.	X									
Varirugosisporites tolmanensis Srivastava 1972										X
Verrucosisporites sp.				X	X					
Verrutricolporites sp.			X							
Weylandipollis sp.							X			
Wulongspora sp.	X									
Zlivisporis sp.							X			
Dinoflagellates	X	X		X				X	X	

Formation from areas of northern New Mexico, Colorado, Utah, Wyoming, Montana and North Dakota. The assemblages seen in the Tohatchi Formation fall within the *Aquilapollenites senonicus* Interval Zone, but neither of the defining species of the zone boundaries (*Aquilapollenites senonicus* and *Aquilapollenites quadrilobus*) were seen in the present study. Inclusion within the zone is indicated based on comparisons of the total assemblage with those of Nichols et al. (1982) and Nichols (1994).

B. D. Tschudy (1973) has provided one of the best published accounts of assemblages from the upper Campanian Judith River Formation in Montana. Her assemblages appear younger than those seen in the Tohatchi Formation. Braman (2002) and Payenberg et al. (2002) have described assemblages from the Milk River and Eagle formations of Alberta and Montana, and these have a number of similarities with the assemblages seen in the Tohatchi Formation.

The presence in the Tohatchi Formation of such species as *Accuratipollis lactiflumis*, *Brevimonosulcites corrugatus*, *Callialasporites dampieri*, *Microfoveolatosporis pseudoreticulatus*, *Periretisynolporites chinookensis*, and *Rugubivesiculites reductus* suggests links to the upper Santonian assemblages seen in the Milk River and lower Eagle formations of Alberta and Montana. These species are absent or very rare in units of the upper lower Campanian to the north. On the other hand, species such as *Aquilapollenites attenuatus*, *A. trialatus*, *A. turbidus*, *Pulcheripollenites krempii* and *Tricolpites reticulatus* are more closely related to assemblages described from the Pakowki Formation and Judith River Group of Alberta and the Claggett and Judith River formations of Montana. They are absent from the upper Santonian assemblages, and their lowest occurrence seems to be in the lower Campanian (Nichols, 1994). The conclusion is that the palynological assemblages recovered from the Tohatchi Formation are lower Campanian, but not lowest Campanian.

CORRELATION

Based on observations of Payenberg et al. (in press), the Tohatchi assemblages show a mixture of palynomorphs that have only been briefly described to date. The closest comparable assemblages appear to occur in the upper unnamed member of the Eagle Formation of central Montana. This interval of time is represented by an unconformity between the Milk River and Pakowki formations in southern Alberta. The Ardmore Bentonite zone within the basal Pakowki and Claggett has been radioisotopically dated at 80.7 Ma (Hicks et al., 1995; Payenberg et al., in press). The Tohatchi palynomorphs appear to be an older assemblage than those seen in the basal Pakowki and Claggett, therefore, it must be older than 81 Ma, the age suggested for the base of these units. Obradovich (1993) has indicated that the Santonian-Campanian boundary is about 83.5 Ma, and this date would also approximate the top of the Milk River and lower Eagle formations. The Tohatchi assemblages seem to be somewhat younger than the upper Santonian assemblages and therefore their oldest age must be younger than the 83.5 Ma Santonian-Campanian date. Thus, the Tohatchi Formation palynomorph assemblages indicate an age between about 81 Ma and 83.5 Ma.

Two lines of evidence were used to correlate the Tohatchi Formation to the Pictured Cliffs-Fruitland-Kirtland succession in the eastern San Juan Basin: (1) simply projecting the turnaround point of the late Campanian shoreline (point at which Cliff House and Pictured Cliffs sandstones merge) westward to correlate by stratigraphic position; (2) dinosaur bones and nonmarine mollusks from the Tohatchi Formation indicative of a Late Cretaceous age. This correlation became the consensus by the 1960s, but the new palynological data presented here indicate it is incorrect.

The palynological data indicate the Tohatchi Formation is of early Campanian age. This means it is older than the Pictured Cliffs-Cliff House turnaround (Fig. 4), which is approximately

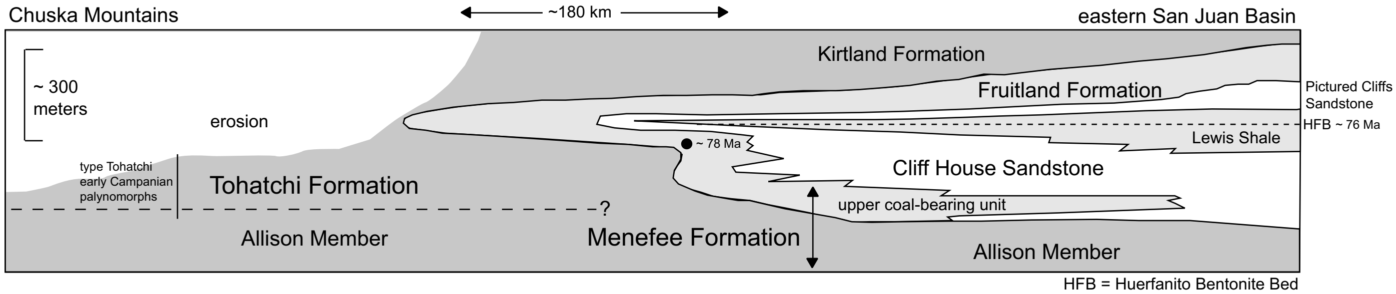

FIGURE 4. Restored cross section (based in part on O'Sullivan et al., 1972, fig. 8) showing correlation of Tohatchi Formation in Chuska Mountains to units in the eastern San Juan Basin. Ar/Ar age of upper Menefee Formation from Amarante et al. (2002) and of Huerfanito Bentonite Bed from Fassett et al. (1997).

the same age (it approximates the *Baculites scotti* and *B. gregoyensis* zones: Molenaar, 1983) to slightly older than the Huerfanito Bentonite Bed in the Lewis Shale, which is in the uppermost *Baculites scotti* ammonite zone and has been radioisotopically dated at 75.76 $\pm$ 0.34 Ma (Fassett and Hinds, 1971; Fassett et al., 1997). This places a minimum age on the Tohatchi based on regional stratigraphic relationships of ~ 76 Ma.

Amarante et al. (2002) recently reported an Ar/Ar age of 78 $\pm$ 0.26 Ma for a bentonite at the top of the Menefee Formation near Regina in the east-central San Juan Basin. Unfortunately, available stratigraphic data do not allow a precise correlation of the dated horizon in the eastern San Juan Basin to the Tohatchi Formation, though the Tohatchi Formation apparently is older (Fig. 4). Thus, the Tohatchi Formation of early Campanian age is older than the youngest Menefee Formation strata in the eastern San Juan Basin. Regional correlation of the Tohatchi Formation indicates it is part of the overall regressive cycle of deposition (R-4 regression of Molenaar, 1983) that produced the Menefee Formation, not part of the overlying regressive cycle (R-5 regression) that produced the Fruitland and Kirtland formations.

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APPENDIX — DESCRIPTION OF MEASURED SECTION

Base of section is at UTM zone 12, 697845 3972699, NAD 27 and top at UTM zone 12, 696827 3972884. Strata are flat-lying, weather to form slope; base of Tohatchi Formation is a prominent, cliff-forming sandstone that is relatively thin bedded and indurated to form cliffs, and thus is a mappable break.

unit	lithology	thickness (m)
Chuska Formation:		
Deza Member:		
54	Conglomerate and sandy mudstone; mudstone is moderate red (5R5/4), not calcareous; conglomerate has clasts of red, gray, yellow, and white chert, jasper and siliceous volcanics up to 30 cm in diameter.	**not measured**
angular unconformity		
Tohatchi Formation:		
Red Willow Wash Member:		
53	Mudstone; dark yellowish brown (10YR4/2) and dusky yellowish green (5GY5/2); bentonitic (weathers to a "popcorn" slope); some lignitic seams and thin sandy mudstone lenses that are pale yellowish brown (10 YR 6/2), not calcareous; forms a slope.	**22.5**
52	Sandy mudstone, light olive gray (5Y6/1), not calcareous; forms a prominent "pale blue" band locally.	**8.5**
51	Sandstone, grayish orange (10YR7/4); very calcareous; fine-grained; subarkose; ironstone concretions and hematitic crusts are moderate brown (5YR3/4); trough crossbedded; some dinosaur bone in lower part of unit.	**10.5**
50	Sandy mudstone; and lignite; mudstone is light olive gray (5YR5/2); lignite is pale yellowish brown (10YR6/2); slope.	**7.7**
49	Silty sandstone; yellowish gray (5Y7/2); slightly calcareous; very fine grained; subarkose; ripple laminated to massive; forms a "shoulder" on the slope.	**1.6**
48	Sandy mudstone, moderate olive brown (5Y4/4), not calcareous, some plant debris; wood and trionychid turtle shell fragments.	**1.5**
47	Lignite; green clay interbeds; same lithology as unit 30.	**2.0**
46	Silty sandstone, grayish orange (10YR7/4), not calcareous; fine grained; trough crossbedded; much wood and ironstone concretions.	**2.6**
45	Lignite; green clay interbeds; same lithology as unit 30.	**1.4**
44	Sandstone; same lithology as unit 38.	**1.0**
43	Lignite and lignitic clay, brownish gray (5YR4/1), not calcareous	**1.2**
42	Lignite; green clay interbeds; same lithology as unit 30.	**0.2**
41	Mudstone; same lithology as unit 39.	**1.0**
40	Lignite; green clay interbeds; same lithology as unit 30.	**0.9**
39	Mudstone; same lithology as unit 34.	**1.1**
38	Fine sandstone, grayish orange (10YR7/4) with dark yellowish brown (10YR4/2 hematitic crusts, calcareous; trough cross-bedded; some lignitic lenses; wood.	**3. 5**
37	Lignite with green clay beds, abundant wood.	**2.2**
36	Very fine lignitic sandstone, grayish orange (10YR7/4) and moderate yellowish brown (10YR5/4), subarkose; ripple laminated.	**0.5**
35	Lignite; same lithology as unit 33.	**1.5**
34	Mudstone, very pale orange (10YR8/2), not calcareous; trionychid shell fragments.	**1.2**
33	Lignite; green clay interbeds; same lithology as unit 30.	**1.1**
32	Very fine-grained silty sandstone, very pale orange (10YR8/2), very calcareous, subarkose; ripple laminated; ironstone concretions	**1.1**
31	Sandy mudstone, pale yellowish brown (10YR6/2); not calcareous, sandstone is very fine-grained, subarkose.	**5.7**
30	Lignite; moderate brown (5YR3/4), not calcareous; some clay interbeds like unit 31.	**2.4**
Total member thickness		**82.9**
Tohatchi Formation:		
Separate Hill Member:		
29	Sandstone, pale yellowish brown (5YR6/2), not calcareous, fine subarkose; multistoried; trough crossbedded; units 27-29 form an extensive bench; turtle shell and dinosaur bone fragments; fossil logs.	**3.5**
28	Sandy siltstone; same lithology as unit 26.	**1.8**
27	Sandstone, very pale orange (10YR8/2), not calcareous, fine-grained subarkose; trough crossbedded; multistoried.	**2.8**
26	Very fine-grained sandy siltstone, moderate orange pink (5YR8/4) and moderate brown (5YR3/4), not calcareous.	**6.7**
25	Sandstone; same lithology as unit 18.	**1.2**
24	Lignite and mudstone, pale yellowish brown (10YR6/2), not calcareous.	**3.7**
23	Siltstone; same lithology as unit 19.	**2.5**
22	Sandstone, same lithology as unit 18.	**0.8**
21	Siltstone; same lithology as unit 19.	**4.4**
20	Sandstone; same lithology as unit 18; multistoried; prominent bench.	**4.8**
19	Siltstone, pale yellowish brown (10YR6/2), not calcareous.	**1.4**
18	Sandstone, pale yellowish orange (10YR8/6); not calcareous; fine grained; subarkose; trough crossbedded; some intra-formational rip-ups.	**2.2**
17	Mudstone, pale yellowish brown (10YR6/2), not calcareous, thin (0.2 m) lenses of sandstone of same lithology as unit 18.	**5.3**
16	Sandy mudstone and lignite, pale yellowish brown (10YR6/2) and dark yellowish orange (10YR6/6); some ironstone.	**4.5**
15	Sandstone, very pale orange (10YR8/2); not calcareous;very fine grained; subarkose; trough crossbedded; some lignite lenses; tall cliff.	**6.3**
14	Silty mudstone; same lithology as unit 10.	**5.5**
13	Sandstone; ironstone, black (N1) and pale yellowish brown (10YR6/2), not calcareous; ledge.	**0.2**
12	Silty mudstone; same lithology as unit 10.	**5.3**
11	Lignite and lignitic sandstone; light brown (5YR6/4), not calcareous, silty, very fine-grained, subarkose.	**0.3**
10	Silty mudstone; pale yellowish brown (10YR6/2), not calcareous; thin sandy lenses.	**2.2**
9	Sandstone, very pale orange (10YR8/2), not calcareous, very fine, subarkose; trough crossbedded; climbing ripples; multistoried; cliff forming	**6.4**
8	Siltstone, pale yellowish brown (10YR6/2), not calcareous; thin sandy lenses.	**6.1**
Total member thickness		**77.9**
Total formation thickness		**160.8**
Menefee Formation:		
7	Sandstone, very pale orange (10YR8/2), not calcareous, very fine, silty, quartzose; ripple laminated.	**1.8**
6	Lignite, same lithology as unit 3.	**0.8**
5	Sandstone, same lithology as unit 2.	**3.1**
4	Sandstone, same lithology as unit 7, but fine, silty, subarkose.	**0.7**
3	Lignite and lignitic sandstone; grayish orange (10YR7/4) and moderate yellowish brown (10YR5/4), not calcareous.	**0.4**
2	Sandstone, pale yellowish orange (10YR8/6), not calcareous, very fine silty subarkose; trough crossbedded; some lignitic lenses.	**3.7**
1	Silty mudstone and lignite; very pale orange (10YR8/2), pale brown (5YR5/2), and light brown (5YR5/6), not calcareous.	**not measured**