1. Magnetic Stratigraphy and Biostratigraphy of the Middle Eocene Uinta Formation, Uinta Basin, Utah

DONALD R. PROTHERO

ABSTRACT

The Uinta Formation in northeastern Utah was the original basis of the Uintan land mammal "age." Magnetostratigraphic studies were conducted in four sections in the northeastern, north-central, and northwestern Uinta Basin. The uppermost Evacuation Creek Member of the Green River Shale, and all of unfossiliferous Uinta Formation unit "A," was of normal polarity. This normal interval probably correlates with Chron C21n (46.3-47.8 Ma), as originally suggested by Prothero and Swisher (1992). Most of Uinta "B" was reversed (= Chron C20r, 43.8-46.3 Ma). A short normal zone spanning upper Uinta "B" and lower Uinta "C" probably correlates with Chron C20n (42.5-43.8 Ma). The upper part of the Uinta "C" and the lowermost portion of the Duchesne River Formation were also reversed (= C19r, 41.4-42.5 Ma), with normal (= C19n, 41.1-41.4 Ma) and reversed (= C18r, 40.0-41.1 Ma) magnetozones in the higher part of the Brennan Basin Member.

Although the original biostratigraphic data for most Uinta Basin collections are very poor, distinctions between the faunas of Uinta "B1," "B2," and "C" are possible. Uinta "B1" (the "*Metarhinus* zone" of Osborn, 1929) spans the interval 45-46 Ma, and is characterized by overlapping ranges of the brontotheres *Sthenodectes* and *Metarhinus*, the rhinocerotoids *Hyrachyus eximius*, *Forstercooperia grandis* and *Triplopus obliquidens*, and the agriochoerid oreodont *Protoreodon parvus*. Uinta "B2" (the "*Eobasileus-Dolichorhinus* zone" of Osborn, 1929), including White River Pocket, spans the interval 43-45 Ma, and is characterized by the overlapping ranges of the brontotheres *Sphenocoelus*, *Metarhinus*, *Eotitanotherium*, the chalicothere *Eomoropus*, the horse *Epihippus gracilis*, the creodont *Oxyaenodon*, and the artiodactyls *Diplobunops*, *Oromeryx*, and *Leptotragulus*. The taeniodonts (*Stylinodon*), uintatheres (*Uintatherium* and *Eobasileus*), achaenodont artiodactyls, and protoptychid and sciuravid rodents last appear in Uinta B2.

Uinta "C" (the "*Diplacodon-Protitanotherium* zone" of Osborn, 1929), including Myton Pocket, Kennedy Hole, and Leota Quarry, spans the interval from 42.5-43 Ma, and is characterized by the first occurrences of the brontotheres *Protitanotherium*, *Metatelmatherium*, the lagomorph *Mytonolagus*, the primate *Mytonius*, the rodent *Janimus*, and the last appearance of numerous taxa, including the rodents *Thisbemys*, *Ischyrotomus*, and *Reithroparamys*, the creodont *Oxyaenodon*, the carnivorans *Procynodictis* and *Uintacyon*, the artiodactyls *Poebrodon*, *Oromeryx*, *Auxontodon*, *Bunomeryx*, and *Mytonomeryx*, and the rhinocerotoids *Amynodon* and *Triplopus*. The upper part of Uinta "C" (spanning the interval 42.0-42.5 Ma) is unfossiliferous. Sparse but distinctive fossils characterize the latest Uintan Brennan Basin Member and the Duchesnean Lapoint Member of the Duchesne River Formation.

INTRODUCTION AND GEOLOGIC SETTING

The Uinta Basin in northeastern Utah (Dane, 1954; Untermann and Untermann, 1964; Cashion, 1967) is an asymmetric synclinal structure about 7000 square miles in area (Fig. 1). Its axis trends roughly east-west, and the north limb is inclined more steeply than the shallow-dipping south limb. The Uinta Basin is about 135 miles wide along its east-west axis and 100 miles across in the north-south direction. It is bounded by the Uinta Mountains to the north, the Douglas Creek arch to the east (which separates it from the similar Piceance Basin of Colorado), the Wasatch Range on the west, and the Roan Cliffs to the south.

Thick sequences of Paleozoic and Mesozoic rocks are found along the edges of the basin and plunge into the subsurface. These were deformed during the latest Cretaceous-middle Eocene Laramide Orogeny, which created the basin in its present configuration. During Laramide orogenesis, over 15,000 feet of Eocene sediments accumulated in this rapidly subsiding structure. The bulk of the sedimentary package consists of the fluvial lower Eocene Wasatch Formation (up to 4100 feet thick) and the lacustrine lower middle Eocene Green River Formation (up to 7000 feet thick). The latter is part of an extensive system of middle Eocene lakes that once covered much of northeastern Utah, southwestern Wyoming, and western Colorado. Because of its importance as source rock for oil and oil shale, the Green River Formation has been studied in great detail (see Bradley, 1929, 1931, 1964; Dane, 1954; Cashion, 1967; Ryder et al., 1976; Surdam and Stanley, 1979, 1980; Johnson, 1985; and Roehler, 1992b, for some of the key features of the Green River lake system).

Toward the end of the early middle Eocene

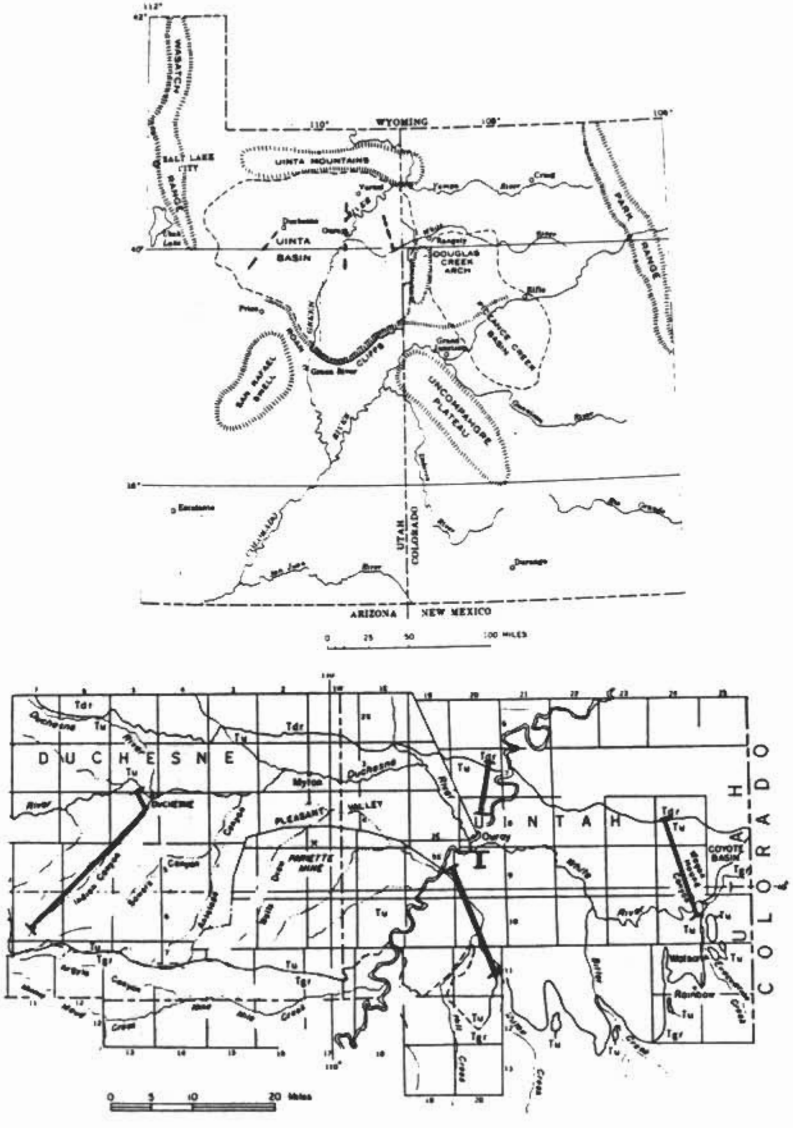


Figure 1. Index map of the Uinta Basin, showing the location of the stratigraphic sections and key localities. Tdr = Duchesne River Formation; Tgr = Green River Formation; Tu = Uinta Formation. (Top map after Cashion, 1967; bottom map modified after Dane, 1954).

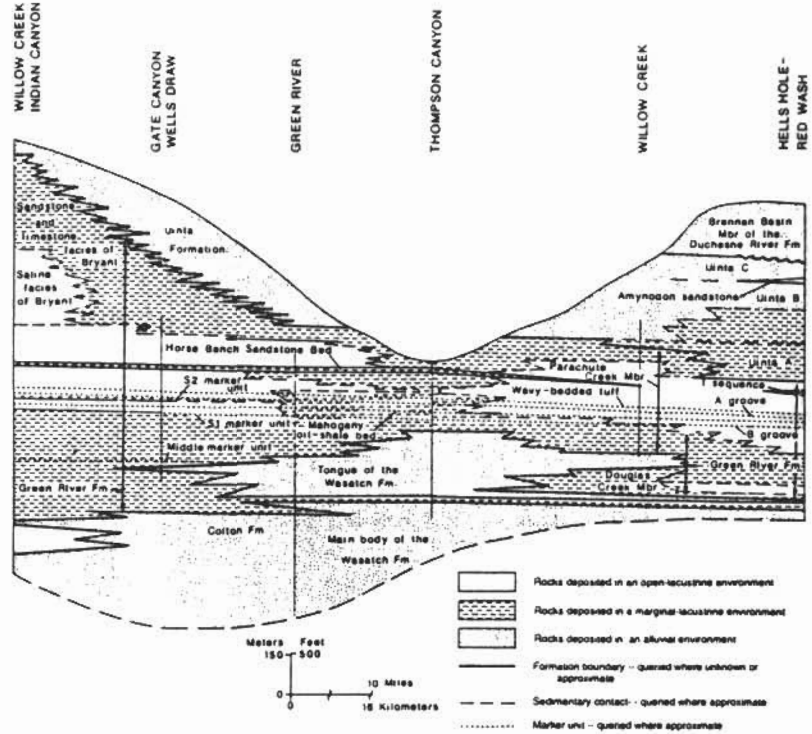


Figure 2. Stratigraphic cross-section of the Uinta Basin, showing the interfingering relationships between the Green River, Uinta, and Duchesne River formations (after Franczyk et al., 1989, fig. 14).

(Bridgerian, about 47-49 Ma), the Green River lake system began to recede. Lacustrine shales were replaced by fluvial-deltaic mudstones and sandstones which entombed many terrestrial fossil vertebrates. The Bridger Basin (Bridger Formation) and Washakie Basin (Kinney Rim Member of the Washakie Formation–Roehler, 1973, 1992a) began to dry up first, with Bridgerian-aged fluvial sediments capping and interfingering with the Green River shales. Much of this fluvial sediment was supplied by a large influx of volcaniclastic debris from the Absaroka volcanic field of northwestern Wyoming and the Challis volcanics of Idaho, forming the "volcanic lithic sandstone petrofacies" of Surdam and Stanley (1979, 1980; see also Johnson, 1985). The Piceance Basin began to dry up slightly later as volcanic debris spilled south from the Washakie-Sand Wash Basins (Surdam and Stanley, 1979, 1980; Dickinson et al., 1988; see Stucky et al., this volume, Chapter 3).

In the Uinta Basin, the Green River lake system was gradually replaced by the fluvial Uinta Formation prograding westward from the east end of the basin (Fig. 2). Thus, the lower fluvial sandstones of the eastern Uinta Formation are laterally equivalent to lacustrine evaporites, and sandstones and limestones in the western Uinta Basin, with complex interfingering between the two units (Dane, 1954, 1955; Ray et al., 1956; Cashion, 1967; Ryder et al., 1976). Most lower Uinta Formation sandstones have west-trending channels and paleocurrents (Stagner, 1941; Cashion, 1967), and apparently had arkosic source areas to the southeast in the Laramide uplifts, especially the Uncompahgre uplift in west-central Colorado, and the Park Ranges of central Colorado (Stagner, 1941; Bruhn et al., 1983; summarized by Dickinson et al., 1986). By the Duchesnean, these sources were swamped by quartzite debris and recycled Paleozoic sedimentary clasts from the Uinta Mountains to the north as these ranges experienced renewed late Laramide uplift (Andersen and Picard, 1972, 1974; Picard and Andersen, 1975; Dickinson et al., 1986).

Compared to the Green River Formation, the Uinta Formation has been much less studied. The unit was first named by Comstock (1875), and fossils from the upper part of the formation were first reported by Marsh (1870) and Scott and Osborn (1887). The history of collecting in the Uinta Basin is reviewed by Black and Dawson (1966, pp. 326-328). Peterson (in Osborn, 1895) first used the terms "Uinta A" and "Uinta B" for the lower fossiliferous sequence, and "Uinta C" for the upper fossiliferous beds. Most of the early collections follow this terminology. However, Osborn (1929) confused matters by reshuffling the names "Uinta A" and "B." The unfossiliferous sandstones at the base of the sequence (the lower half of Peterson's "Uinta A") became the totality of Osborn's "Uinta A," and the upper half of Peterson's "Uinta A" was renamed "Uinta B1." Peterson's "Uinta B" was renamed "Uinta B2." This unfortunate recycling of similar terminology led to much confusion, and every museum specimen label has to be read carefully to determine when and where the stratigraphic data were determined. Paleontologists who understood these changes (e.g., Krishtalka et al., 1987, p. 83) were fooled by older museum labels, and erroneously attributed collections from Uinta "B1" to Osborn's Uinta "A" (e.g., Krishtalka et al., 1987, p. 89; see Prothero and Swisher, 1992, p. 54, for discussion). Wood (1934) renamed Uinta "A" and "B" the Wagonhound Member and Uinta "C" the Myton Member. Wood et al. (1941) based their Uintan land mammal "age" on the faunas from the Uinta Formation, and considered it late Eocene in age.

Osborn (1929) also introduced another change in terminology which can cause confusion. Peterson (in Osborn, 1895) originally drew the boundary between his Uinta "B" and "C" at the color change from greenish-gray mudstones in the Devil's Playground area of Kennedy's Hole and the reddish beds overlying them. But Osborn and Matthew (1909, fig. 8) and Osborn (1929, fig. 63 and p. 92) redefined the Uinta B-C boundary as the *Amynodon* sandstone, placing the overlying greenish-gray mudstones of Peterson's Uinta B in their Uinta C. This confusion means that some specimens which are called "Uinta B, Kennedy's Hole" (such as the type of *Protoptychus hatcheri*) are actually from Uinta C as currently understood. For this reason, it is important to go back to the original locality data on every specimen, and not trust assignments such as Uinta A, B, or C.

Overlying and interfingering with the Uinta Formation is the Duchesne River Formation. It was originally named Duchesne Formation by Scott (1932), and then renamed Duchesne River Formation by Kay (1934) when the original name was found to be preoccupied. Cropping out along the northern flank of the Uinta Basin, it locally consists of more than 3,000 feet of fluvial sandstones and conglomerates with lesser floodplain mudstones (Andersen and Picard, 1972, 1974). Although the distinction is subtle, the reddish color of the Duchesne River Formation is typically used to distinguish it from the greenish-gray-tan Uinta Formation. The Wood Committee (1941) used the Duchesne River Formation as the basis for their Duchesnean land mammal "age," and considered it late Eocene.

The age of the Duchesne River Formation, and of the Duchesnean land mammal "age," has been the subject of considerable dispute ever since the Wood Committee report. The fossils of the lower two members, Andersen and Picard's (1972) Brennan Basin and Dry Gulch Creek Members (source of the Randlett and Halfway faunas of Peterson, 1934) are now considered latest Uintan in age (Clark et al., 1967, p. 59; Tedford, 1970, pp. 690-692; Emry, 1981; Krishtalka et al., 1987, p. 84). Only the fauna of the third member, or Lapoint Member of Andersen and Picard (1972), is presently used as the basis for the Duchesnean. The fourth, or uppermost member, the Starr Flat Member of Andersen and Picard (1972) is unfossiliferous (Krishtalka et al., 1987). Because of the limited nature of the Lapoint fauna, some authors have suggested making the Duchesnean a subage of the Chadronian (Wilson, 1978, 1984; Emry, 1981), but more recently the value of retaining the Duchesnean as a distinct land mammal "age" has been reaffirmed (Krishtalka et al., 1987; Kelly, 1990; Lucas, 1992).

In addition to this confusion between rocks, faunas, and time terms, the Lyellian epoch assignment of the Duchesnean has also been controversial. Scott (1945) and Clark et al. (1967) regarded it as early Oligocene, whereas Simpson (1946), Black and Dawson (1966), and Krishtalka et al. (1987) considered it late Eocene. Clearly, a better chronostratigraphic framework for the Uinta and Duchesne River formations is critical to understanding the middle-late Eocene transition.

MAGNETIC ANALYSIS

In the summers of 1986, 1987, and 1988, we sampled the Uinta Formation, parts of the underlying Evacuation Creek Member of the Green River Formation, and the overlying Brennan Basin Member of the Duchesne River Formation. The final laboratory work on these samples was completed and presented in 1990 (Prothero, 1990; Prothero and Swisher, 1990). A summary of this research was published (Prothero and Swisher, 1992).

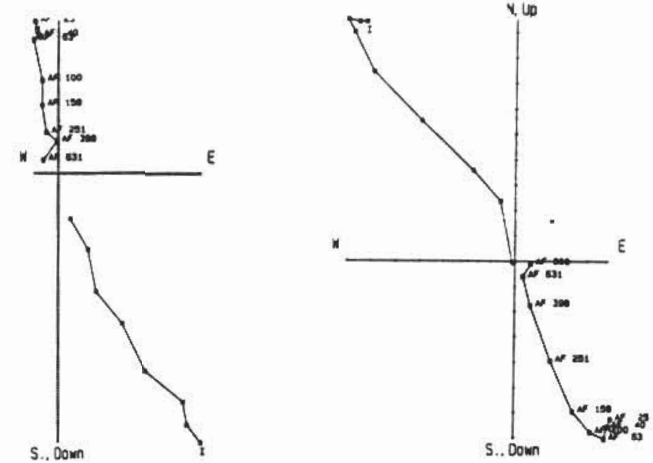


Figure 3. Vector demagnetization ("Zijderveld") plots of AF demagnetization of representative samples from the Uinta Formation. AF intensity in Gauss shown at each step. Horizontal component indicated by circles, vertical component by asterisks. I = NRM direction of vertical component. Note that both samples declined rapidly in intensity, indicating that a low-coercivity mineral such as magnetite is a significant component of the remanence.

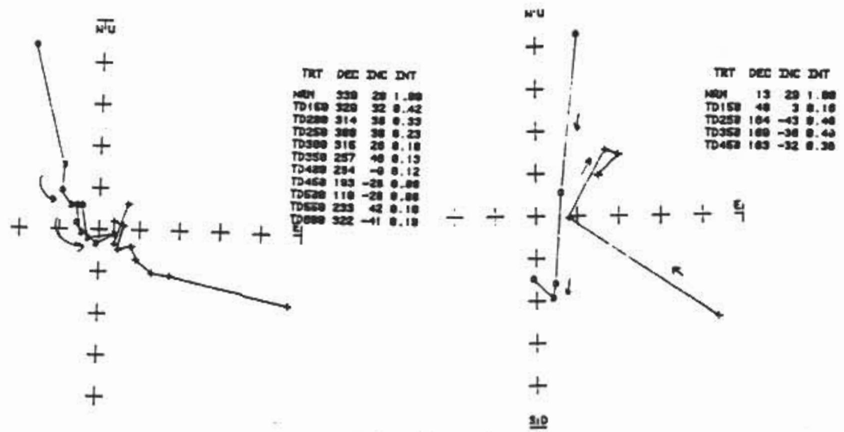


Figure 4. Vector demagnetization plots of selected thermal demagnetization results from the Uinta Formation. Circles indicate horizontal component, + symbol is the vertical component. Sample on left had a normal overprint that was removed by 400°C. Sample on right had a normal overprint removed by 250°C.

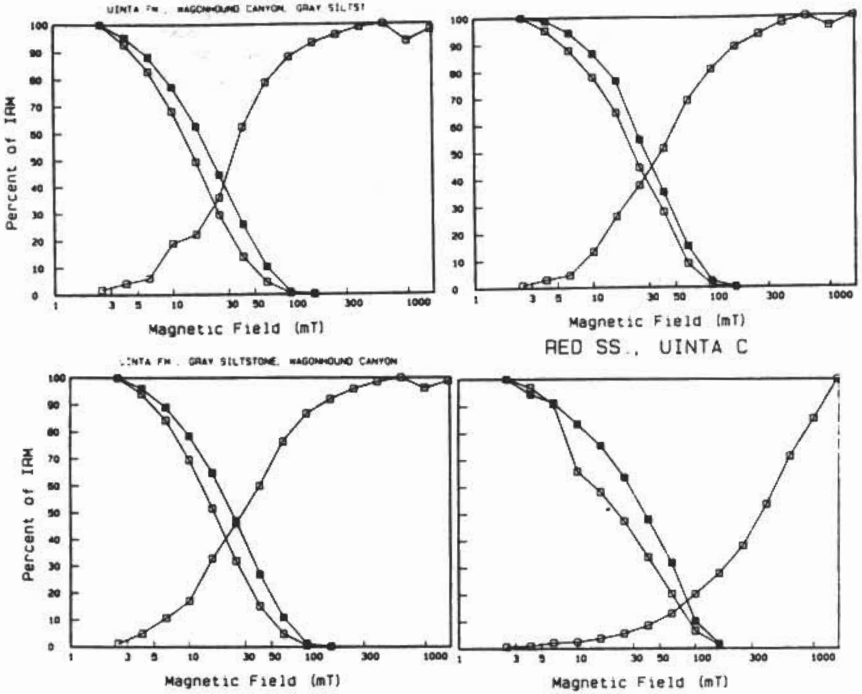


Figure 5. IRM acquisition and Lowrie-Fuller tests of selected samples from the Uinta Formation (see text and Pluhar et al., 1991, for further details). Solid boxes are ARM intensities at each AF demagnetization step, open boxes are IRM intensities. Note that during IRM acquisition (ascending curve on right), most samples reached saturation at about 300 mT, indicating the presence of magnetite; only the red sandstone from Uinta C (lower right) failed to saturate, showing that hematite is a primary component of the remanence in that sample. In the modified Lowrie-Fuller tests (descending curves on left), the ARM is more resistant to AF demagnetization than the IRM, showing that the remanence is carried by single-domain or pseudo-single domain grains.

Over 350 sites (each containing a minimum of three samples) were collected using simple hand tools, resulting in over 1200 individual samples. Four sections, representing the northeastern, north-central, and northwestern parts of the basin, were taken to see if the magnetic pattern could be correlated across the basin, and to tie in as many fossil localities as possible (Fig. 1). The routes of each section are described in the Appendix. Given the time-transgressive nature of the formational boundaries, and the lateral facies changes, such parallel sampling was critical (Fig. 2).

After measurement of NRM (natural remanent magnetization), a suite of pilot samples was demagnetized using alternating field (AF) and thermal demagnetization. Under AF demagnetization (Fig. 3), nearly all samples decreased rapidly in intensity with increasing applied fields, suggesting that the carrier of the remanence is a low-coercivity mineral such as magnetite. Thermal demagnetization (Fig. 4) typically showed a normal overprint which was removed by 250-350°C; this overprint was probably due to an iron hydroxide such as goethite. A stable reversed component was typically obtained between 350-500°C, and that component was used for further analysis in all samples. Above the Curie point of magnetite (580°C), less than 10% of the magnetization remained, suggesting that very little of the remanence is carried by hematite.

This interpretation was corroborated by IRM (isothermal remanent magnetization) acquisition studies (Fig. 5). Most samples (Fig. 5A-C) from the Uinta Formation reached saturation IRM values at 100-300 mT (millitesla); the remanence in these rocks is carried mostly by magnetite. However, some red sandstones from Uinta "C" and the Duchesne River Formation

(Fig. 5D) showed no evidence of IRM saturation, even at fields of 1300 mT; these samples clearly contained hematite. A modified Lowrie-Fuller ARM (anhysteretic remanent magnetization) test (e.g., Johnson et al., 1975) was also conducted along with the IRM analysis (see Pluhar et al., 1991, for details). This test compares the resistance of AF demagnetization of both an IRM acquired in a 100 mT peak field, and an ARM gained in a 100 mT oscillating field. In almost all samples, the ARM (black squares) demagnetizes at higher peak fields than does the IRM (open squares), indicating that the remanence is carried by single-domain or pseudo-single domain grains.

The stable sample directions were then clustered by site, and statistically analyzed by the methods of Fisher (1953; see Butler, 1992). Class I sites of Opdyke et al. (1977) showed a clustering that differed significantly from random at the 95% confidence level. In Class II sites, one sample was lost or crumbled, but the remaining samples gave a clear polarity indication. In Class III sites of Opdyke et al. (1977), two samples showed a clear polarity preference, but the third sample was divergent because of insufficient removal of overprinting. A few samples were considered indeterminate if their magnetic signature was unstable, or their direction uninterpretable.

The beds of the Uinta Basin ranged in dip from 45° to horizontal, so it was possible to conduct a modified fold test for stability. Before the dip correction, the cleaned mean inclination (I) for normal sites was 340.7°, and declination (D) was 56.3°; the precision parameter (k) was 2.4 and the ellipse of confidence (α_{95}) was 40.8°. After dip correction, the directions were much less scattered [D = 2.9, I = 51.7, k = 14.6, α_{95} = 5.6] and much closer to the Eocene pole position for the region, showing that the remanence was acquired before tilting. The cleaned but uncorrected mean for reversed sites [D = 155.2, I = -35.6, k = 1.5, α_{95} = 44.1] is much more scattered than the corrected mean of reversed sites [D = 176.9, I = -57.8, k = 8.9, α_{95} = 13.1], also suggesting that the magnetization was acquired prior to tilting.

These statistics also provide a reversal test. The mean direction of all cleaned and corrected normal sites shown above was antipodal to the mean direction of all cleaned and corrected reversed samples, indicating that the magnetization was probably acquired during deposition of the beds.

MAGNETIC CORRELATIONS

The magnetic pattern for all the Uinta Basin sections is shown in Fig. 6. In the northeastern Uinta Basin (Wagonhound Canyon, Bonanza area, Coyote Basin, plus Kennedy Wash of the topographic maps, or Kennedy Hole of Peterson and Kay), the uppermost Evacuation Creek Member of the Green River Shale, and all of Uinta "A" were of normal polarity. Most of Uinta "B" was reversed, except for the top 100 feet, which was of normal polarity; this normal polarity persisted through the lower half of Uinta "C." The rest of Uinta "C" was of reversed polarity, as was nearly all of the lower part of the Duchesne River Formation in Kennedy Hole (except for the last two sites at the top, which were of normal polarity).

In the central Uinta Basin, the Willow Creek-Ouray-Brennan Basin section showed a similar pattern. The Green River section below the base of the Uinta Formation was of normal polarity, but most of what was called "Uinta A" and "Uinta B" in Willow Creek by Kay (1934; Peterson and Kay, 1931) was reversed. This is not really surprising, since there are rapid facies changes across the basin, and the migrating fluvial Uinta "A" channel complex would be expected to be time-transgressive. This reversed magnetozone ended low in Uinta "C," just above White River Pocket, and most of the rest of Uinta "C" in the Leota Bottom area was of normal polarity. After a reversed magnetozone in upper Uinta "C," the base of the type Brennan Basin Member of the Duchesne River Formation was of normal polarity, and the top three sites in that section were reversed. As discussed in the Appendix, the rest of the Duchesne River Formation type section of Andersen and Picard (1972) was not sampled due to difficulties with chemical overprinting by iron oxides and hydroxides.

The other section in the central Uinta Basin, Myton Pocket, was entirely of normal polarity. This is not surprising, since the fauna of Myton Pocket is usually correlated with Uinta "C" faunas, such as those of Leota and Skull Pass quarries (Hamblin, 1987).

In the western Uinta Basin section at Indian Canyon, comparable results were obtained. If the Horse Bench Sandstone correlates with the rocks just below Uinta "A" of the eastern part of the basin (Dane, 1954; Franczyk et al., 1989), then the normal magnetozone in the upper Evacuation Creek Member probably correlates with the Uinta "A" normal zone in Wagonhound Canyon. Assuming no discontinuities, the second normal magnetozone in the middle of the saline facies probably correlates with the lower Uinta "C" magnetozone. Finally, the zone of normal polarity in the sandstone and limestone facies at the top probably correlates with the normal magnetozone near the base of the Duchesne River Formation to the east.

Geochronological calibration of this magnetic pattern has been problematic. Mauger (1977) reported a number of K-Ar dates from the Indian Canyon section, including a date of 43.1 ± 1.3 Ma from an ash about 70 m above the Horse Bench Sandstone (in the middle of the lowest normal magnetozone), and 42.8 ± 1.0 Ma for a tuff 19 m below the contact between the saline facies and the limestone and sandstone facies (in the middle of the higher reversed magnetozone). On the current magnetic polarity time scale (Cande and Kent, 1993; Berggren et

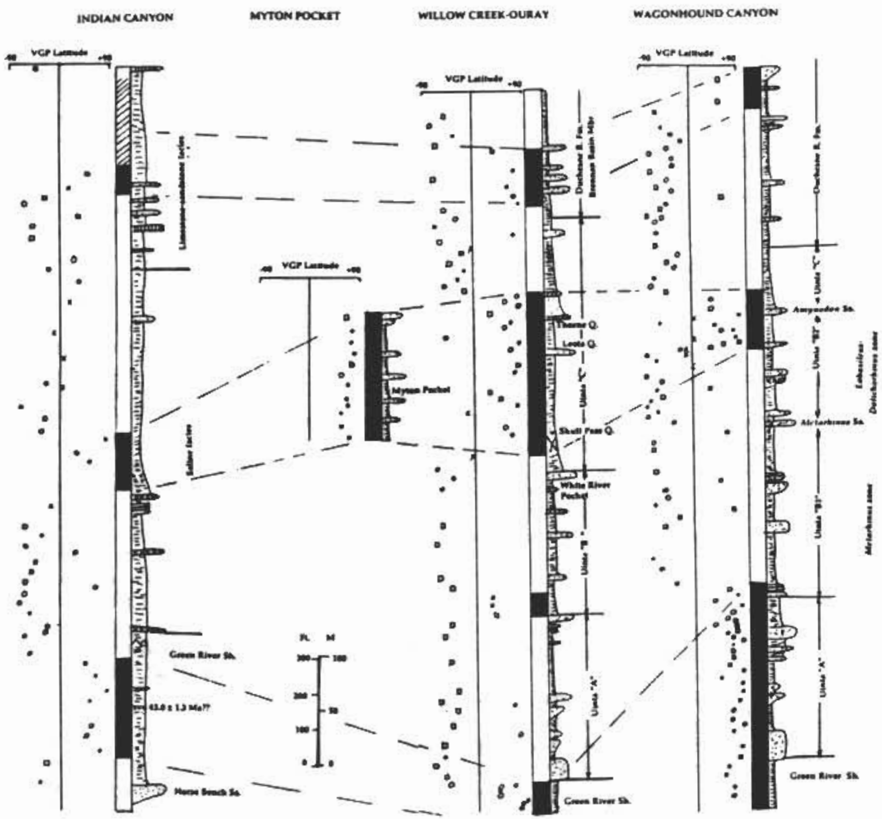


Figure 6. Magnetic stratigraphy of four sections in the Uinta Basin, Utah (see Fig. 1). Positive virtual geomagnetic pole (VGP) latitudes indicate normal polarity; negative VGP latitudes indicate reversed polarity. Solid circles are Class I sites of Opdyke et al. (1977); open squares, Class II sites; open circles, Class III sites; X = indeterminate sites. Stratigraphy of Wagonhound Canyon after Osborn (1929); Willow Creek-Ouray area after Kay (1934); Indian Canyon after Dane (1954) and Dyni and Cashion (unpublished). See Appendix for location of sections.

al., 1995), the lower date would place the lowest Uinta normal magnetozone in Chron C20n (42.5-43.7 Ma), but the upper date is also within the age span of Chron C20n—yet it occurs in reversed rocks that should correlate with Chron C18r if the lowest normal magnetozone is truly C20n. Either one date or the other (or both) must be wrong. Because a number of authors (e.g., Krishtalka et al., 1987; Prothero and Swisher, 1992) have questioned the quality of Mauger's (1977) dates, I will not rely on them too heavily here.

Ideally, $^{40}Ar/^{39}Ar$ dating would provide much better chronostratigraphic tie points for the magnetostratigraphy, but the date of 47.4 ± 0.24 Ma in upper Uinta "B2" in Coyote Basin reported by Prothero and Swisher (1990) appears to be in error, since the date probably came from detrital contaminants. Swisher (personal communication) has tried dating other volcanic materials from the same Indian Canyon ashes dated by Mauger (1977), but so far without success. Hence, other correlation tie points must be sought.

Prothero and Swisher (1992, pp. 54-55) attempted to calibrate the Uinta Basin section based on similiarities of the faunas in other magnetically calibrated areas (Fig. 7). Two correlations were possible, and discussed in that paper. In one interpretation, the Uinta "A" normal magnetozone was correlated with Chron C21n, and the Uinta Basin sequence continues through C20n (lower Uinta "C") and C19n (lower Duchesne River Formation). We thought this interpretation was the most reasonable, because early Uintan faunas do not occur until Uinta "B1" in the Uinta Basin (which was reversed, and thought to be C20r), and early Uintan faunas are associated with upper Chron C20r in the Washakie Basin (Flynn, 1986), and also in Trans-Pecos Texas (Walton, 1992).

The other alternative was that the Uinta "A" normal magnetozone corresponds to Chron C20n, the lower Uinta "C" normal magnetozone correlates with C19n, and the lower Duchesne River Formation records C18n. Prothero and Swisher (1992, p. 55) rejected that interpretation because it conflicts with the K-Ar date of 42.7 ± 1.6 Ma just above the late Uintan Serendipity l.f. (Walton, 1992). It also conflicts with the $^{40}Ar/^{39}Ar$ date of 39.74 ± 0.07 Ma on the Lapoint tuff, which marks the contact between the Dry Gulch Creek and Lapoint members (Prothero and Swisher, 1992, p. 49, tables 2.1-2.2). This date would fall in Chron C18n of the Berggren et al. (1995) time scale. If the upper Dry Gulch Creek and lower Lapoint members of the Duchesne River Formation are correlative with Chron C18n, then our reversed-normal-reversed magnetozones in the Brennan Basin Member cannot also be C18n, but must correlate with C19r-C18r.

Prothero and Swisher (1992, p. 55) also suggested that the alternative correlation would conflict with the supposed occurrence of late Uintan faunas in the upper

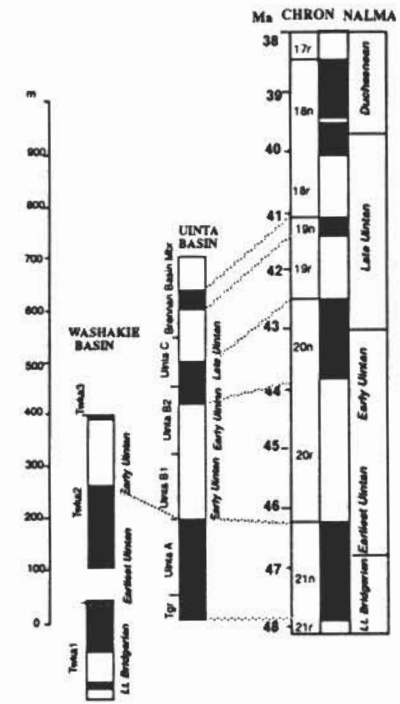


Figure 7. Magnetostratigraphic correlation of Uinta Basin sections with those of the Washakie Basin (after Flynn, 1986, and McCarroll et al., this volume, Chapter 2) and the magnetic polarity time scale (after Berggren et al., 1995). Abbreviations: Tgr = Green River Formation; Twkk = Kinney Rim Member; Twka1-3 = Adobe Town Member, levels 1-3.

part of the Washakie Basin section. Flynn (1986, p. 347 and fig. 9) briefly mentions upper Washakie faunal level "D," which he correlated (Flynn, 1986, fig. 9) with late Chrons C20n and early C19r. Although Flynn does not specifically describe this fauna as late Uintan, we followed earlier workers (Roehler, 1973; Turnbull, 1978), who speculated that the upper levels of the Washakie Formation might be late Uintan based on lithologic changes. As McCarroll et al. (1993; this volume, Chapter 2) point out, however, recent detailed study shows that there are no late Uintan (Uinta "C") fossils in the Washakie Basin; the sequence spans only the late Bridgerian, earliest Uintan (Shoshonian), and early Uintan (= Uinta "B"). However, this is a minor point. The preponderance of the evidence still favors the original interpretation of Prothero and Swisher that the Uinta Basin sequence spans Chrons C21n-C18r (see Walsh, this volume, Chapter 4, and the summary chapter to this volume).

BIOSTRATIGRAPHY

Judging from these calibrations, the Uintan is one of the longest of the North American land mammal "ages." It spans late Chron C21n (46.5 Ma) to early C18n (40 Ma), with a duration of about 6.5 million years. Unfortunately, it has never been finely divided into biostratigraphic zones, but instead the lithostratigraphically based "zones" of Uinta "B1," "B2," and "C" have been used. Osborn (1929, pp. 92-95) gave biostratigraphic names to these lithostratigraphic units. "B1" was called the *Metarhinus* zone, "B2" the *Eobasileus-Dolichorhinus* zone, and "C" the *Diplacodon* zone. Except for the detailed position of a few brontothere fossils (Osborn, 1929, figs. 65, 66) and some other specimens, however, no detailed range information was provided to facilitate biostratigraphic subdivision of these units.

Osborn's biostratigraphic zonal terminology was not adopted by later workers, including Kay and Peterson of the Carnegie Museum, who used lithostratigraphic terms, or Wood, who named the Wagonhound and Myton members. In spite of the fact that Osborn's zonal names were established long before, Gunnell (1989) named two "zones" (Ui1, the *Epihippus* assemblage "zone," and Ui2, the camelid-canid appearance "zone") for the early and late Uintan. However, these are not based on recent biostratigraphic work, but simply rename the distinction between the faunas of Uinta "B" and "C." In addition, both names are now inappropriate, as discussed below.

It would be expected that the 6.5 million years of the Uintan should be divisible by biostratigraphy into more than three zones. However, in most cases the original collections do not have adequate stratigraphic data, since the collectors (mostly Peterson, Kay, Clark, Riggs, and other early twentieth-century parties) rarely recorded the position of their fossils beyond Uinta "B" or "C." I have made an extensive survey of the collections and field notes (primarily in the Carnegie Museum and American Museum) and it is clear that more detailed information cannot be obtained from most of these old collections. Unfortunately, the best specimens that had weathered out over the centuries from the Uinta Formation were removed by these early collectors, and numerous parties since then have not obtained significant new collections that would help refine the biostratigraphy. Only Myton Pocket (Hamblin, 1987), and occasionally some of the other classic localities, such as White River Pocket (e.g., Dawson, 1966), are still producing. Tab Rasmussen (personal communication) has recently collected in the Coyote Basin/Bonanza area.

Given these limitations, I re-examined the museum collections and their original labels to tie down as many specimens as possible to the new magnetic sections. Fortunately, many of the specimens come from named quarries and localities whose position in the section is known. I kept the biostratigraphy of the eastern (Wagonhound Canyon-Bonanza-Coyote Basin-Kennedy Hole) and central (Willow Creek-Ouray-Leota Bottom-Brennan Basin, plus Myton Pocket) areas separate, since the "Uinta A" rocks of Willow Creek are temporally equivalent to Uinta "B" in the Wagonhound-Bonanza area (Fig. 6).

The results are shown in Table 1. As is clear from the table, most specimens come from a single local level in only one area, so the ranges are not very long or overlapping. In addition, these are only partial range zones, or teilzones, for a single basin. Many of these ranges would surely be extended if other regions were taken into account (e.g., Black and Dawson, 1966; Stucky, 1992). This is particularly true of the small mammals. Most of the insectivores, primates, rabbits, and rodents are known from only two localities: White River Pocket and Myton Pocket. Very little collecting for small mammals has occurred in higher or lower beds in the Uinta Basin, so many of these smaller mammals would have longer ranges if there were not such a size bias in the collections.

Nevertheless, some overlapping ranges of biostratigraphic utility can be detected from the existing collections. These ranges can also be combined with stratigraphic data from the adjacent Washakie-Sand Wash Basins of Colorado and Wyoming (McCarroll et al., this volume, Chapter 2; Stucky et al., this volume, Chapter 3), to produce a composite biostratigraphy for the Uintan in the greater Green River Basin (Fig. 8). Of course, the teilzones for this basin would be extended if the biostratigraphic data from other regions (especially Texas, San Diego, the Sespe Formation, the Badwater area, and others) were added to them (see Krishtalka et al., 1987).

Uinta A

As discussed above, approximately 500 feet of fluvial sandstones at the base of Wagonhound Canyon were part of Peterson's Uinta A (in Osborn, 1895), but Osborn (1929) split off the upper fossiliferous part of Peterson's Uinta A and renamed it Uinta B1. Hence, most of the pre-1929 museum labels that say "Uinta A" should be read "Uinta B1," and very few specimens can be traced positively to Uinta A *sensu* Osborn (1929). I have double-checked the specimen labels and the museum records, and the specimens of *Amynodon*, *Triplopus*, *Metarhinus*, *Dolichorhinus*, and

Table 1. Stratigraphic distribution of mammals from the Uinta Basin. Most ranges after Osborn (1929), Peterson (1931, 1934) Peterson and Kay (1931), Kay (1934), Black and Dawson (1966), Hamblin (1987), Emry (1981), and Stucky (1992). Abbreviations: WRP, White River Pocket, R/H/L, Randlett, Halfway, Lapoint faunas.

TAXON	WAGONHOUND MBR.		MYTON MBR.		DUCHESNE R.
Eastern area	**"B1"**	**"B2"**	**"C" (Kennedy Hole)**		
Ma	46.0		44.0	43.0	40.0
Central area	**Willow Creek**	**WRP**	**Myton Pocket**	**Leota Q.**	**R/H/L**
INSECTIVORES					
Talpavus duplus			MP		
Nyctitherium sp.			MP		
Micropternodus sp.			MP		
Simidectes magnus			MP		
Simidectes medius		WRP			
Apatemys uintensis		B2			
Protictops alticuspidens					L
PRIMATES					
Ourayia uintensis		B2, WRP	KH, MP		
Mytonius hopsoni			MP		
Macrotarsius jepseni		WRP			
RODENTS					
"Paramyids"					
Thisbemys uintensis		B2			
Thisbemys medius			MP, KH		
Leptotomus mytonensis			MP		
Leptotomus leptodus			KH		
Leptotomus sciuroides			KH		
Leptotomus kayi					R
Janimus rhinophilus			MP		
Microparamys dubius		WRP			
Ischyrotomus petersoni		B2	KH		
Ischyrotomus compressidens		WRP	MP		
Ischyrotomus eugenei			MP		
Reithroparamys gidleyi			KH (base)		
Prosciurines					
Mytonomys robustus		WRP	MP		R
Sciuravids					
Sciuravus altidens		WRP			
Sciuravus popi		WRP			
Protoptychids					
Protoptychus hatcheri			KH		
Cylindrodonts					
Pareumys troxelli		WRP			
Pareumys grangeri		WRP			
Pareumys milleri		WRP			
Pareumys guensbergi					L
Eomyids					
Protadjidaumo typus				R, L	
LAGOMORPHS					
Mytonolagus petersoni			MP		
Mytonolagus robustus					R
CREODONTS					
Oxyaenodon dysclerus		WRP	KH		
Oxyaenodon wortmani		B2			
Limnocyon douglassi		B2	MP		
Apataelurus kayi		B2			
Hyaenodon vetus					L

TAXON	WAGONHOUND MBR.		MYTON MBR.		DUCHESNE R.
Eastern area	"B1"	"B2"	"C" (Kennedy Hole)		
Ma	46.0		44.0	43.0	40.0
Central area	Willow Creek	WRP	Myton Pocket	Leota Q.	R/H/L
CARNIVORES					
Miacis gracilis		B2	MP		
Miacis uintensis		B2			
Uintacyon robustus			MP		
Procynodictis vulpiceps			MP, KH (base)		
Mimocyon longipes			MP		
Miocyon scotti		B2	MP		
Eosictis avinoffi					H
ARTIODACTYLS (Gazin, 1955)					
"Dichobunids"					
Auxontodon pattersoni			MP		
Bunomeryx montanus			KH		
Bunomeryx elegans			MP, KH		
Hylomeryx annectens		WRP			
Hylomeryx quadricuspis			MP, KH		
Mesomeryx grangeri		B2			
Pentacemylus leotensis				LQ	
Pentacemylus progressus			MP		R
Mytonomeryx scotti			MP		
Simimeryx minutus					L
Achaenodonts					
Achaenodon uintensis	WC	B2			
Entelodonts					
Brachyhyops wyomingensis				L	
Agriochoeres					
Protoreodon petersoni			MP, KH		
Protoreodon pumilus			MP, KH		R
Protoreodon parvus	B1	B2			
Protoreodon paradoxicus		WRP			
Protoreodon medius		B2, WRP			
Protoreodon primus				LQ	R
Protoreodon minor			KH		
Diplobunops matthewi			MP	LQ	
Diplobunops vanhouteni		WRP			
Diplobunops crassus					R
Agriochoerus maximus					L
Oromerycids					
Oromeryx plicatus	B1?	B2	MP		
Protylopus petersoni		B2	KH		
Protylopus annectens			MP		
Camelids					
Poebrodon kayi			MP		
Protoceratids					
Leptotragulus proavus		B2	MP, KH		
Leptotragulus clarki			MP		
Leptotragulus medius			MP		
Leptoreodon marshi		B2	MP, KH		
Poabromylus kayi					L
MESONYCHIDS					
Harpagolestes uintensis	B1				
Harpagolestes leotensis			MP	LQ	
Mesonyx obtusidens	B1	B2			
Hessolestes ultimus					L

TAXON	WAGONHOUND MBR.		MYTON MBR.		DUCHESNE R.
Eastern area	"B1"	"B2"	"C" (Kennedy Hole)		
Ma	46.0		44.0	43.0	40.0
Central area	Willow	Creek WRP	Myton Pocket	Leota Q.	R/H/L
PERISSODACTYLS					
Equids					
Epihippus gracilis		B2, WRP			
Epihippus parvus			MP, KH		
Epihippus (Duchesnehippus) intermedius				H	
"Tapiroids"					
Isectolophus annectens		B2, WRP	MP		
Dilophodon leotanus				LQ	R
Chalicotheres					
Eomoropus amarorum	B1	B2			
Rhinocerotoids					
Hyrachyus eximius	B1				
Amynodon reedi		B2			
Amynodon advenus		B2, WRP	MP, KH		
Megalamynodon regalis					R
Triplopus implicatus	B1,WC	B2	KH (base)		
Triplopus obliquidens	B1	B2, WRP	MP, KH	LQ	
Triplopus rhinocerinus			?MP		
Forstercooperia grandis	B1				
Epitriplopus uintensis		B2	MP		
Epitriplopus medius					R, L
Hyracodon primus					L
Brontotheres					
Sthenodectes priscus	WC (just above Green River Fm.)				
Sthenodectes incisivum	B1				
Dolichorhinus	B1, WC	B2			
Eotitanotherium osborni		WC (just below WRP)			
Diplacodon			MP, KH	LQ	
Metatelmatherium ultimum		KH			
Rhadinorhinus	B1, WC	B2			
Metarhinus	B1				
Protitanotherium			KH	LQ	R
Duchesneodus uintensis					L
UINTATHERES					
Eobasileus cornutus	B1, WC	B2			
Uintatherium anceps	B1	B2			
TAENIODONTS					
Stylinodon mirus		B2			

Forstercooperia reported by Krishtalka et al. (1987, p. 89) from Uinta "A" are actually from Uinta "B1" in Osborn's (1929) terminology (see Prothero and Swisher, 1992, p. 54).

Peterson (in Osborn, 1895), Riggs (1912), and Osborn (1929) all found the lower 500 feet of the Uinta Formation (all of Uinta "A" in modern parlance) in Wagonhound Canyon to be unfossiliferous. Kay (1934, plate XLVI) indicates that *Sthenodectes priscus* comes from a horizon about 30 feet above the base of the Green River Formation in Willow Creek, which he correlated with Uinta A. However, this sequence is reversed in polarity and apparently correlates with Uinta B1 in the Bonanza area, not with the Uinta A sandstones. Hence, there are no well documented mammal fossils from Uinta A as it is now understood.

Uinta B1

The lower part of Uinta B is not particularly fossiliferous, either, so most of the stratigraphic data must be inferred from Riggs (1912, fig. 1) and Osborn (1929, fig. 65) in the Wagonhound Canyon-Bonanza area, and from Kay (1934, plate XLVI) for the Willow Creek-Ouray area. In addition, there are important localities like "Well no. 2" (Peterson and Kay, 1931, plate IX) just north of Bonanza that can be placed high in Uinta B1, allowing the determination of the exact level of a number of specimens.

Most of the specimens positively known from Uinta B1 are brontotheres, but among them *Metarhinus fluviatalis* last appears in Uinta B1, and *Sthenodectes* (both *priscus* and *incisivum*, if they are both valid) appears to be restricted to this level. Mader (1989) indicates that

"*Sthenodectes*" *australis* from the Pruett Formation of Texas (Wilson, 1978) is not referable to that genus. A few taxa (*Protoreodon parvus, Triplopus obliquidens*) first appear at the B1 level, and a few more (*Pareumys grangeri, Harpagolestes uintensis, Hyrachyus eximius, Forstercooperia grandis*) last occur at this level. Osborn (1929) called this interval the "*Metarhinus* zone," and that name could still be used, since *Metarhinus* is one of the commonest mammals in the interval. However, *Metarhinus* is no longer restricted to Uinta B1, but first occurs in the middle Adobe Town Member in the Washakie Basin (McCarroll et al., this volume, Chapter 2), which correlates with Chron C21n. Mader (1989) has also synonymized *Rhadinorhinus* with *Metarhinus*, extending the range of *Metarhinus* into Uinta B2. Hence, the Uinta B1 interval could be redefined by the overlapping ranges of *Protoreodon parvus* and *Triplopus obliquidens* (first occurrence), and *Hyrachyus eximius, Forstercooperia grandis, Pareumys grangeri*, and *Harpagolestes uintensis* (last occurrence). *Sthenodectes* is the only taxon restricted to this interval.

Uinta B2

By contrast with Uinta B1, the upper part of the Wagonhound Member is very fossiliferous due to the extensive collections of small mammals from White River Pocket. Osborn (1929) called this the "*Eobasileus-Dolichorhinus* zone," and both of those taxa are still characteristic, and last occur in the interval (although both have earlier occurrences). A long list of taxa (mostly small mammals from White River Pocket) is restricted to the upper Wagonhound Member (Fig. 8), including *Simidectes medius, Apatemys uintensis, Ourayia uintensis, Thisbemys uintensis, Microparamys dubius, Pareumys troxelli, Pareumys milleri, Oxyaenodon wortmani, Apataelurus kayi, "Miacis" uintensis, Hylomeryx annectens, Mesomeryx grangeri, Protoreodon paradoxicus, Protoreodon medius, Diplobunops vanhouteni*, and *Amynodon reedi*. Numerous other taxa (*Ischyrotomus petersoni, Oxyaenodon dysclerus, Limnocyon douglassi, Miocyon scotti, Oromeryx plicatus, Leptotragulus proavus, Leptoreodon marshi, Isectolophus annectens*) first occur in Uinta B2 and continue into Uinta C. There is a major faunal break between the Wagonhound and Myton members, with taxa which persisted from the Bridgerian and earliest Uintan (*Sciuravus, Eobasileus, Uintatherium, Stylinodon, Eomoropus, Protoptychus hatcheri, Achaenodon, Sphenocoelus, Epihippus gracilis, Pareumys grangeri*, and *Metarhinus*) disappearing at the top of Uinta B.

Uinta C

Again, there is a long list of small mammals from the lower part of the Myton Member because of the extraordinarily diverse collections from Myton Pocket. However, most of the other quarries and levels in the Myton Member are much less rich, so the local ranges of Uinta C mammals are often restricted to this single locality. Nearly all the fossil localities appear to be located in the lower part of the member (except for Leota Quarry), and the upper part of the Myton Member above Leota Quarry is virtually unfossiliferous.

Taxa restricted to the lower Myton Member (mostly small mammals from Myton Pocket) include *Talpavus duplus, Simidectes magnus, Mytonius hopsoni, Thisbemys medius, Leptotomus mytonensis, Leptotomus sciuroides, Janimus rhinophilus, Ischyrotomus eugenei, Reithroparamys gidleyi, Uintacyon robustus, Procynodictis vulpiceps, Mimocyon longipes, Auxontodon pattersoni, Bunomeryx montanus, Bunomeryx elegans, Hylomeryx quadricuspis, Pentacemylus progressus, Mytonomeryx scotti, Protoreodon petersoni, Protoreodon pumilis, Protoreodon minor, Leptotragulus clarki, Leptotragulus medius, Epihippus parvus*, and *Metatelmatherium ultimum*. In addition, *Diplacodon, Protitanotherium, Harpagolestes leotensis*, and *Diplobunops matthewi* are restricted to the interval spanning Myton Pocket to Leota Quarry. *Pentacemylus leotensis, Protoreodon primus, Dilophodon leotanus*, and *Pentacemylus progressus* first occur at the Leota Quarry level; the first two taxa are also restricted to that locality.

In addition to this uniquely Uinta C fauna, a number of taxa from the early Uintan (*Amynodon advenus, Poebrodon, Leptotomus leptodus, Protylopus petersoni, Triplopus implicatus, Triplopus obliquidens, Ischyrotomus petersoni, Ischyrotomus compressidens, Protoreodon parvus, Oxyaenodon dysclerus, Limnocyon douglassi, Miocyon scotti, Oromeryx plicatus, Leptotragulus proavus, Leptoreodon marshi, Isectolophus annectens*) last occur at the Myton Pocket level. Only one taxon (*Mytonolagus*) that first appears in Uinta C continues into the Duchesnean. Thus, there is a big drop in diversity and change in the fauna in the middle of the late Uintan (between Leota Quarry and the Randlett horizon, around 42 Ma), as numerous authors (Black and Dawson, 1966; Krishtalka et al., 1987; Stucky, 1990, 1992) have noted.

Osborn (1929) called Uinta C the "*Diplacodon-Protitanotherium* zone," and that name is still appropriate, since both of these brontotheres are restricted to Uinta C. However, the names coined by Gunnell (1989) are no longer useful for the Uintan. His "*Epihippus* assemblage zone" (Ui1) for Uinta A-B is not very descriptive, since *Epihippus parvus* occurs in Uinta C, and *Epihippus (Duchesnehippus) intermedius* is found in the Halfway fauna. With the discovery of the camelid *Poebrodon* in the early Uintan middle Adobe Town Member of the Washakie Basin (McCarroll et al., this volume, Chapter 2), the "camelid-canid appearance zone" (Ui2) is no longer appropriate for Uinta C. Nor does Wang (1994) regard any Uintan "miacids" as canids. The earliest true canid is from the Duchesnean.

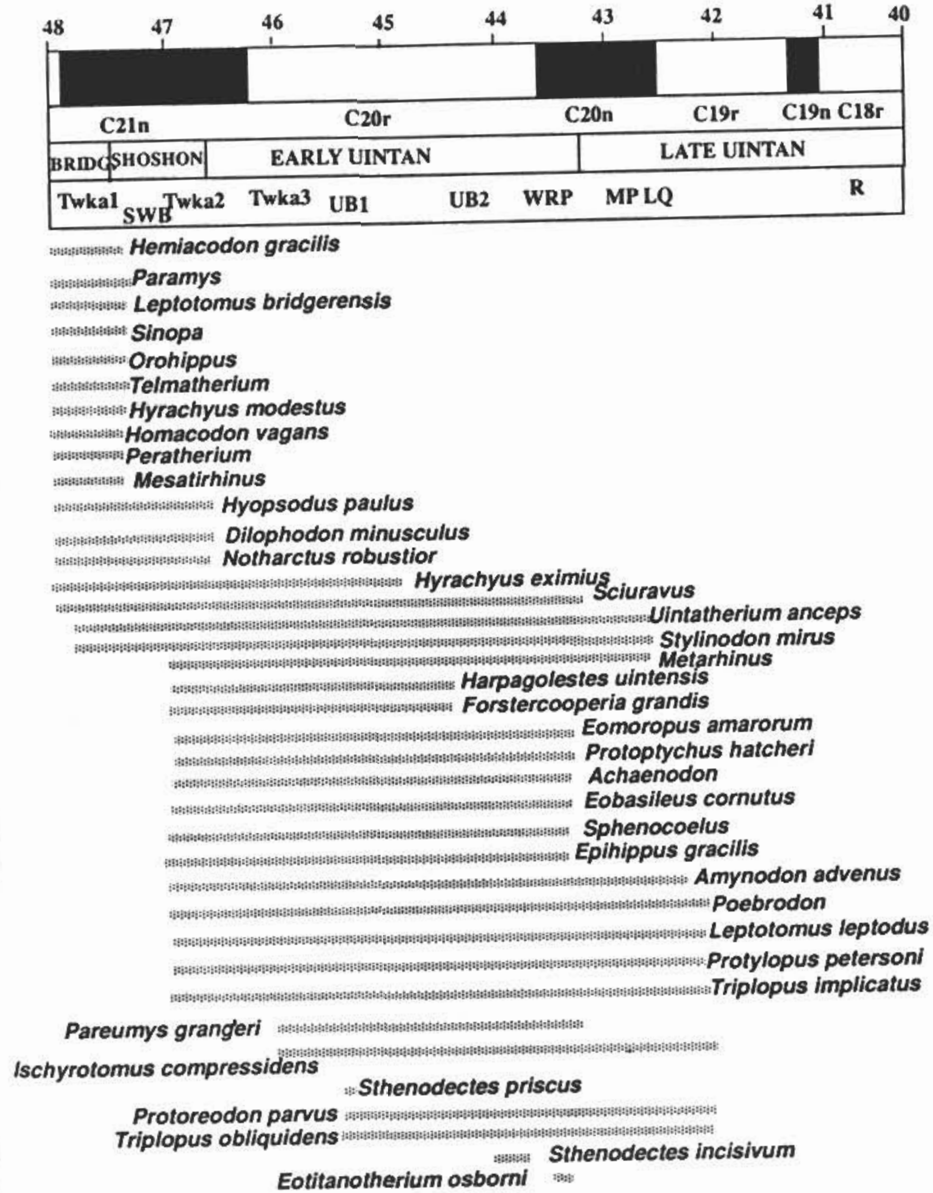
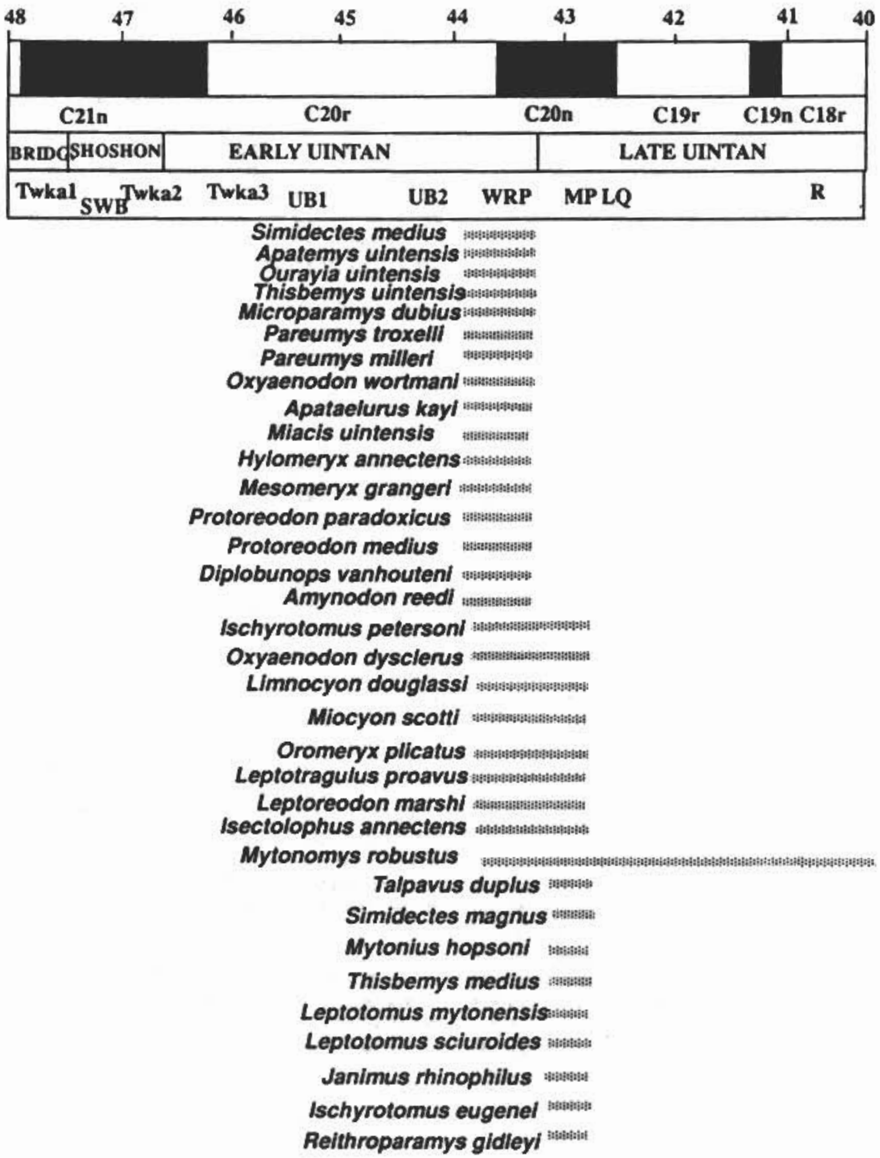


Figure 8. Local stratigraphic ranges (teilzones) of Uintan mammals in the Washakie, Sand Wash, and Uinta Basins, based on data from Table 1 and McCarroll et al. (this volume, Chapter 2) and Stucky et al. (this volume, Chapter 3). Time scale after Berggren et al. (1995); other abbreviations as in Fig. 7.


48 47 46 45 44 43 42 41 40
C21n C20r C20n C19r C19n C18r
BRIDG SHOSHON EARLY UINTAN LATE UINTAN
Twka1 SWB Twka2 Twka3 UB1 UB2 WRP MP LQ R
Simidectes medius
Apatemys uintensis
Ourayia uintensis
Thisbemys uintensis
Microparamys dubius
Pareumys troxelli
Pareumys milleri
Oxyaenodon wortmani
Apataelurus kayi
Miacis uintensis
Hylomeryx annectens
Mesomeryx grangeri
Protoreodon paradoxicus
Protoreodon medius
Diplobunops vanhouteni
Amynodon reedi
Ischyrotomus petersoni
Oxyaenodon dysclerus
Limnocyon douglassi
Miocyon scotti
Oromeryx plicatus
Leptotragulus proavus
Leptoreodon marshi
Isectolophus annectens
Mytonomys robustus
Talpavus duplus
Simidectes magnus
Mytonius hopsoni
Thisbemys medius
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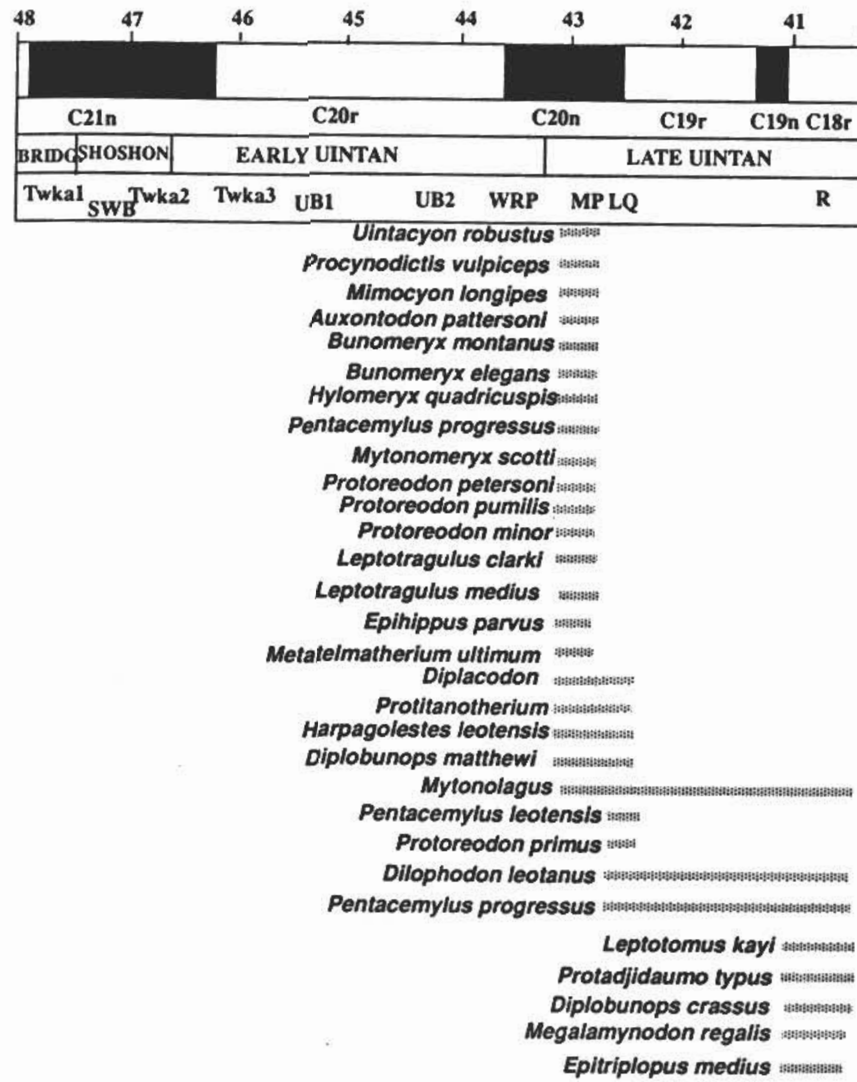
Leptotomus sciuroides
Janimus rhinophilus
Ischyrotomus eugenei
Reithroparamys gidleyi


48 47 46 45 44 43 42 41 40
C21n C20r C20n C19r C19n C18r
BRIDG SHOSHON EARLY UINTAN LATE UINTAN
Twka1 SWB Twka2 Twka3 UB1 UB2 WRP MP LQ R
Uintacyon robustus
Procynodictis vulpiceps
Mimocyon longipes
Auxontodon pattersoni
Bunomeryx montanus
Bunomeryx elegans
Hylomeryx quadricuspis
Pentacemylus progressus
Mytonomeryx scotti
Protoreodon petersoni
Protoreodon pumilis
Protoreodon minor
Leptotragulus clarki
Leptotragulus medius
Epihippus parvus
Metatelmatherium ultimum
Diplacodon
Protitanotherium
Harpagolestes leotensis
Diplobunops matthewi
Mytonolagus
Pentacemylus leotensis
Protoreodon primus
Dilophodon leotanus
Pentacemylus progressus
Leptotomus kayi
Protadjidaumo typus
Diplobunops crassus
Megalamynodon regalis
Epitriplopus medius

Duchesne River Formation and Duchesnean

As discussed above (and is apparent from Table 1 and Fig. 8), the faunas of the Duchesne River Formation are so scarce, and their biostratigraphic levels are so poorly constrained, that it is pointless to suggest a range-zone biostratigraphy in the Uinta Basin. This is much better done in the Sespe Formation of California (see Kelly, 1990, and Prothero et al., this volume, Chapter 8) and the Trans-Pecos Texas region (see Wilson, 1986; Lucas, 1992; and the summary chapter to this volume).

CONCLUSIONS

Although confusing stratigraphic problems, and the lack of precise biostratigraphic data associated with many specimens, have long hampered our understanding of the Uintan, magnetic stratigraphy and detailed stratigraphic re-examination of the collections makes refinements possible. It seems that the Uintan can be subdivided into at least five discrete intervals:

Earliest Uintan ("Shoshonian") spans late Chron C21n-early Chron C20r (about 46.5-46 Ma), and is best represented by faunas in the Tepee Trail Formation of northwest Wyoming, the middle Adobe Town Member of the Washakie Formation in the Washakie and Sand Wash basins, the Friars Formation in the San Diego area (Walsh et al., this volume, Chapter 6; Flynn, 1986, pp. 379-380), and the Whistler's Squat l.f. in Trans-Pecos Texas.

Uinta B1 ("*Metarhinus* zone" of Osborn, 1929) spans early Chron C20r (45-46 Ma). It is sparsely fossiliferous, but has some distinctive taxa. The fossils of the upper Adobe Town Member of the Washakie Formation may also correlate with this interval.

Uinta B2 ("*Eobasileus-Dolichorhinus* zone" of Osborn, 1929) spans late Chron C20r and early Chron C20n (43.5-45.0 Ma), and includes many distinctive taxa (especially the collections of smaller mammals from White River Pocket). Most "Uinta B" correlatives (Black and Dawson, 1966; Krishtalka et al., 1987) appear to fall in this time interval.

Uinta C ("*Diplacodon* zone" of Osborn, 1929) spans most of Chron C20n (42.5-43.5 Ma), including the extensive faunas of Myton Pocket, Kennedy Hole, and Skull Pass, Leota, and Thorne quarries. Most "Uinta C" faunas of other authors (Black and Dawson, 1966; Krishtalka et al., 1987) probably correlate with this interval, or with the unfossiliferous upper Myton Member (which spans early Chron C19r, 42.0-42.5 Ma).

Randlett horizon (in the Brennan Basin Member of the Duchesne River Formation of Andersen and Picard, 1972) includes latest Uintan faunas, and correlates with early Chron C19n-C18r (40.0-41.0 Ma). Correlative faunas might include the Candelaria l.f. of Trans-Pecos Texas.

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APPENDIX

The routes of the various stratigraphic sections taken in the Uinta Basin are described below. The general geology of these areas has been mapped by Cashion (1967) and Rowley et al. (1985). Further details will be deposited in the Archives of the Department of Vertebrate Paleontology of the American Museum of Natural History.

Northeastern basin.—The first section was taken in the eastern Uinta Basin, and ran through Riggs's (1912, fig. 1), Peterson's (1924, fig. 1), and Osborn's (1929, fig. 63) sections at Wagonhound Canyon, near Bonanza, Utah, and then up through Coyote Basin to Kennedy Hole. At first glance these sections appear to be clearly diagrammed, but in actuality the thicknesses and the route of the section given by these authors are only approximate. In the field it was difficult to trace the route of the original sections, or determine the exact position of the key beds that separate Uinta "A" from "B1," or "B1" from "B2." However, after much double-checking and backtracking from known landmarks, a section was obtained which closely approximated the original sections in thicknesses and lithologic details.

The Wagonhound Canyon section began at the level of the White River at the mouth of the canyon, taking the bottom three sites in the uppermost part of the Evacuation Creek Member of the Green River Formation. The section then proceeded up the dirt road through the Uinta "A" sandstones in Wagonhound Canyon (NE and SE of NE NW Sec. 2, T10S R24E, Southam Canyon 7.5' quadrangle, Uintah County, Utah). At the top of the roadcuts, the route of section then proceeded westward up the ridges (SE SE SW Sec. 35, T9S R24E) to the highest point in the area (NE SW SE Sec. 34). Over 900 feet of section, including all of Uinta "A" and "B1" was measured. Projecting the highest beds of this section down the dip slope to the north, the next part of the section was taken in a northeasterly direction in the flats around Bonanza and Coyote Basin. The upper part of "B1" was measured in SW SW SW NW Sec. 23, T9S, R24E, Bonanza 7.5' quadrangle, and then continued through "B2" in ridges located in SW SW NW Sec. 13, SW SW SW SW Sec. 12, SE NW NE Sec. 11, culminating in the prominent ledge known as the "*Amynodon* Sandstone" (see Riggs, 1912, fig. 2; Osborn, 1929, fig. 64) in NE SW SW Sec. 34, T8S R24E and Center NW SW Sec. 24, just east of road from benchmark 5350. Moving down the dip slope of the "*Amynodon* Sandstone," the section was resumed in Uinta "C" mudstone badlands (the "Devil's Playground") just to the north (NE SW SW to SE SW NE Sec. 21, T8S R24E, Bonanza 7.5' quadrangle). This section culminated just below the color change (at the 5388 benchmark) from gray bentonitic "popcorn" claystones of Uinta "C" to the red and yellow clays of the Duchesne River Formation.

Over 400 feet of the Brennan Basin Member of the Duchesne River Formation was taken in several sections in the Kennedy Hole area (SW NW SE Sec. 17, T8S R24E Bonanza 7.5' quadrangle and finishing in SW SW NE Sec. 17, T8S R24E, Dinosaur NW 7.5' quadrangle), then continuing from NW SE SE Sec. 6, T8S R24E, Dinosaur NW 7.5' quadrangle, to NE SE SE of the same section. This was the highest continuous exposure of Duchesne River Formation in the area, and the rest of the formation could not be sampled because the exposures disappear completely under the sod-covered bench for miles to the north.

North-central basin.—Many important Carnegie Museum localities, including White River Pocket, and Leota, Thorne, and Skull Pass quarries, are located along a north-south transect through the central Uinta Basin. Kay (in Peterson and Kay, 1931, Plate IX, and Kay and Garwood, 1953, p. 19) gave the location of these quarries and a route of section on a very crudely drawn, large-scale map of the area. When that route was traced, however, much of it proved to have no exposures whatsoever, and other parts were completely inaccessible. Like the cartoonish stratigraphic sections of Riggs and Osborn in the eastern basin, the generalized stratigraphic sections of Kay (in Kay, 1934, Plate XLVI, and Peterson and Kay, 1931, Plate X) were very inaccurate and all the details had to be carefully remeasured and redocumented in the field. Consequently, I picked a route that gave better exposures and closely paralleled the route indicated by Kay (1953). Rather than follow the road north to Ouray, which had no continuous outcrop along the top of the soil-covered bench, I followed the Willow Creek drainage, starting 150 feet below the contact with the Green River Formation. A series of sections was patched together along the east bank of Willow Creek, starting with SE NE SW Sec. 12, T11S R20E, Big Pack Mountain 7.5' quadrangle. The second leg was taken in SE SE SW Sec. 10 along the road up "Turkey Trail Hill," then traced west along the bed which caps the bench in the area to another outcrop along Willow Creek where the next 100 feet of Uinta Formation were exposed (NE SW SE Sec. 30, T9S R20E, Ouray 7.5' quadrangle). The Willow Creek section concluded in SW NE NE Sec. 19 in the same quadrangle. The highest level was then projected northeast to the area of White River Pocket (SE SW SE Sec. 5, T9S R20E, Ouray 7.5' quadrangle, just west of road), where the main White River Pocket section was taken.

The sandstone capping the Uinta "B" rocks at White River Pocket was then projected to the north, and the section was resumed in SE SE Sec. 19, T4S R3E, Ouray 7.5' quadrangle, where the lower part of Uinta "C" could be measured. The next segment was taken in SW SW NW NW Sec. 8, T4S R3E, Pelican Lake 7.5' quadrangle. A series of sections was then taken along the east-facing bluffs west of Leota Bottom (site of Leota Quarry), in segments located in SW SE SE Sec. 2, T8S R20E, Pelican Lake 7.5' quadrangle, then in NW SW NW Sec. 1, T8S R20E, Brennan Basin 7.5' quadrangle, followed by NE NW SW Sec. 36, T7S R20E in the same quadrangle, ending in the base of the Brennan Basin Member of the Duchesne River Formation ("unit 1" of the type section of the Brennan Basin Member of Andersen and Picard, 1972, p. 26). An additional 300 feet of that member (spanning Andersen and Picard's units 2-5) were measured and sampled in NW NE NE Sec. 18 and NW SW SE Sec. 7, T7S R21E, Brennan Basin 7.5' quadrangle. At this point, the section was discontinued, because the sandstones were too hard for hand sampling, the shales were too poorly exposed, and every unit had a deep red hematitic stain. In our 1986 reconnaissance sampling, almost all of our deep red Duchesne River samples proved to have an intractable chemical overprinting due to hematite. Hence, further sampling in the Duchesne River Formation was abandoned.

A third section in the central Uinta Basin ran through the Myton Pocket area, 15 miles east of Ouray, and 7 miles west of the town of Myton. Fortunately, this locality has been carefully measured and studied in recent times by Hamblin (1987). Approximately 360 feet of section of Uinta "C" ("Myton Member") were taken in SW SE NE Sec. 12 (lower half) and concluded in NW SW SW Sec. 6 (upper half), T4S R1E of the Uintah Special Meridian, Windy Ridge 7.5' quadrangle, Uintah County, Utah.

Western basin.—In the western portion of the Uinta

Basin, the fluvial sandstones and mudstones are replaced by the relict lacustrine facies of Eocene Lake Uinta. Instead of Uinta "A" sandstones, the Evacuation Creek Member of the Green River Formation is overlain by the "saline facies" and "sandstone and limestone facies" of the Uinta Formation (Dane, 1954, 1955; Ray et al., 1956). The most complete section through the region is in Indian Canyon, southwest of Duchesne, in Duchesne County, Utah. A brief sketch of the section was published by Dane (1954, fig. 2, column 5), and the stratigraphic relationships were summarized in Franczyk et al. (1989, fig. 14). A detailed, unpublished stratigraphic section through Indian Canyon made by J. R. Dyni and W. B. Cashion was graciously provided for our research by Dr. Dyni, and our stratigraphic section followed theirs closely. This section and its nomenclature are also cited by Mauger (1977), who attempted to date several ash layers in the Indian Canyon.

The section began on the distinctive "Horse Bench Sandstone Bed" (bed 221 of Dyni and Cashion) of Dane (1954, 1955), which can be traced eastward through the Evacuation Creek Member across most of the basin, and is apparently equivalent to the base of Uinta "A" in the east (Francyzk et al., 1989, fig. 14). The first segment (section 6 of Dyni and Cashion) was located in west side of the left fork of Indian Canyon, east half of the NW Sec. 22, T6S R7W, Jones Hollow 7.5' quadrangle, Duchesne County, Utah. This segment ran from the Horse Bench Sandstone to the base of the saline facies of the Uinta Formation (unit 297 of Dyni and Cashion), covering the upper 460 feet of the Evacuation Creek Member. The second segment (Dyni and Cashion, section 7, units 298-350) along the bluffs on the west side of Indian Canyon, was located in NW SW Sec. 12 in the same map; it covered 360 feet of the lower saline facies. The third segment (section 8 of Dyni and Cashion), also on the west side of the left fork of Indian Canyon in SE SE Sec. 1, T6S R7W, Lance Canyon 7.5' quadrangle, covered units 351-390 of Dyni and Cashion. The fourth segment (Dyni and Cashion section 9, units 390-428) was located in the NW SW Sec. 22, T5S R6W, Buck Knoll 7.5' quadrangle; units 429-456 were collected in SW NE Sec. 22. The fifth segment (Dyni and Cashion, section 10, units 457-484) covers the uppermost 330 feet of the saline facies, and was located in NW NW NW Sec. 28, T4S R5W, Duchesne SW 7.5' quadrangle. The sixth segment covered the basal 200 feet of the limestone and sandstone facies of the Uinta Formation (units 485-503 of Dyni and Cashion), and was located in a west-trending dry wash 1 mile east of Indian Canyon in NE SW Sec. 14, T4S R5W, Duchesne 7.5' quadrangle. The remaining portion of the sandstone and limestone facies was not sampled because of difficulty of access and poor continuity of exposures.