3. Magnetic Stratigraphy, Sedimentology, and Mammalian Faunas of the Early Uintan Washakie Formation, Sand Wash Basin, Northwestern Colorado

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ABSTRACT

The Sand Wash Basin in northwestern Colorado is a southern sub-basin of the Washakie Basin of Wyoming. It contains several hundred meters of the middle Eocene Washakie Formation, overlying a thick sequence of the lacustrine Green River Formation. Late Bridgerian and earliest Uintan mammalian faunas have been recovered from several localities within the basin. Key biochronological indicators of the earliest Uintan age of the fauna include the earliest agriochoerids (*Protoreodon*), oromerycids (*Oromeryx*), as well as hyracodontids (*Triplopus*) and eomyids (*Namatomys*).

Abundant petrified wood, nonmarine stromatolites, gastropods, bivalves, fish, turtles, and crocodilians show that the Washakie Formation in the Sand Wash Basin was deposited in a marginal lacustrine-fluvial setting. Paleocurrents indicate sediment transport from the north, and the composition of the sandstones is mostly devitrified volcaniclastics derived from the Absaroka volcanic field of northwest Wyoming, or possibly the Challis volcanic field of Idaho. No sediments appear to be derived from the nearby Uinta uplift to the west.

The lower part of the sequence is all of reversed magnetic polarity, and the upper part is of normal polarity. Based on correlations with the revised magnetic stratigraphy of the Washakie Basin, the Sand Wash Basin sequence was deposited during Chrons C21r and C21n (47-48 Ma).

INTRODUCTION

During the latest Cretaceous through early Eocene, the Laramide Orogeny caused Rocky Mountain intermontane basins to subside and collect thick piles of terrestrial sediments (Dickinson et al., 1988). Many of these basins also yield our most prolific assemblages of Eocene fossil mammals (Krishtalka et al., 1987). During the early and early middle Eocene (Wasatchian and Bridgerian North American land mammal "ages"), thick lacustrine deposits of the Green River Formation accumulated in many of these basins (especially the greater Green River Basin of Wyoming, the Uinta Basin of Utah, and the Piceance Basin of Colorado). As the Green River lake system contracted, it was replaced by fluvial deposits which continued to fill many of the basins (e.g., the Bridger Formation in the Bridger Basin of Wyoming, the Uinta Formation in the Uinta Basin of Utah, and the Washakie Formation in the Washakie Basin of Wyoming).

Most of these basins have been collected intensively for fossil vertebrates, and some have been studied in considerable detail. Until recently, however, the Sand Wash Basin in northwestern Colorado received much less attention. The first fossils were collected by Earl Douglass and J. LeRoy Kay of the Carnegie Museum in 1922, 1923, and 1924, and by Denver Museum parties in 1924 and 1925; three short papers were published on these collections (Abel and Cook, 1925; Cook, 1926a, 1926b). Little further collecting or publication on the fossils of the Sand Wash Basin occurred for about fifty years until parties from the Carnegie Museum and University of Colorado Museum began to revisit the old localities and discover new ones in the 1960s (summarized by West and Dawson, 1975). From 1972-1976, the Sand Wash Basin was again collected by Denver Museum parties. Recent work by the Carnegie Museum in 1988, and by Denver Museum parties from 1989-1994, produced major new collections.

The collections from the Sand Wash Basin are particularly important because they supplement and extend the collections from other basins. In particular, the "type" sections in the Uinta Basin of Utah yield few earliest Uintan fossils from Uinta Formation "A." This span of time seems to be better represented in the Washakie Basin of Wyoming, where Flynn (1986) recognized the "Shoshonian" land mammal "subage" for the earliest Uintan (this volume, Chapter 2). Other areas of this age include those from southern California and the Togwotee Pass and Lysite Mountain areas in northern Wyoming. As discussed below, the Sand Wash collections are apparently the same age as the earliest Uintan ("Shoshonian") faunas from the Washakie Basin to the north, so they augment our understanding of this poorly sampled interval of the mammalian record.

GEOLOGIC SETTING

The Sand Wash Basin is a Laramide structure of about 600 square miles in Moffat County, Colorado (Fig. 1). Although it is presently separated from the larger Washakie Basin to the north in Wyoming by Cherokee Ridge (a younger structural arch), it is considered a sub-basin of the Washakie Basin (Roehler, 1973, 1992a; Dickinson et al., 1988), since the two were originally a single basin. The stratigraphic sequences of the two areas are so similar that the marker bed nomenclature coined by Roehler (1973) for the Washakie Basin in Wyoming can be used south of the border in Colorado. The only published geologic studies of the Sand Wash Basin were U.S.G.S. maps of Lone Mountain (McKay, 1974) and Maybell (McKay and Bergin, 1974) 7.5' quadrangles.

Most of the limited research in the Sand Wash Basin focused on the Green River Formation because of its economic importance as a source of oil. McKay (1974) and McKay and Bergin (1974) mapped about 1200 feet of the Laney and Tipton members of the Green River Formation, which interfinger with the underlying lower Eocene Wasatch Formation. These same maps show about 400 feet of "Bridger" Formation overlying the Green River Formation, especially in Lone Mountain Quadrangle. Since the Sand Wash mammalian faunas were relatively poorly known at the time, and the rocks do bear some resemblance to the type Bridger Formation, this assignment was not unreasonable. Since that work, Roehler (1973, 1992a) has distinguished the Uintan rocks of the Washakie Basin from the type Bridger Formation and formally named them the Washakie Formation, following Granger (1909). However, he did not formally designate the same rocks in the Sand Wash Basin as "Washakie Formation" (Roehler, 1992b, p. E26). Nevertheless, we believe that the "Bridger" Formation in the Sand Wash Basin should also be referred to the Washakie Formation because of its lithological similarity to the Washakie Formation in the adjacent sub-basin in Wyoming.

Although McKay (1974) and McKay and Bergin (1974) recognize a lower and upper part of their "Bridger" Formation, only the upper part yields mammalian fossils. The "lower Bridger" Formation, as mapped by these geologists, is actually much closer in lithology to the laminated Green River shales, and interfingers with the Green River Formation in the area. In Wyoming, Roehler (1992a, fig. 6) identifies the lateral equivalent of these Colorado beds (beds 519-620 in the Washakie Basin) as Washakie Formation, so there may be some justification for distinguishing the "lower Bridger" Formation of the Sand Wash Basin from the classic Green River shales. However, for our study, only the "upper Bridger" (= upper Washakie) yielded mammalian fossils, and so our paleomagnetic studies focused on this part of the formation.

Some time after the upper Washakie Formation was deposited in the Sand Wash Basin, it underwent structural deformation, because the beds along the southern rim of the basin are faulted and tilted as much as 66° to the south (McKay, 1974). Middle Eocene beds are overlain by the middle-upper Miocene Brown's Park Formation with an angular unconformity. Thus, most of the deformation must have taken place after the late middle Eocene. It was probably a result of the final phase of Laramide deformation, which caused late Uintan and Duchesnean uplift to the west in the Uinta Basin (Andersen and Picard, 1972; Dickinson et al., 1986, 1988). The Brown's Park Formation, in turn, was also slightly deformed and faulted by Plio-Pleistocene tectonic activity related to the renewed uplift of the Rocky Mountains.

SEDIMENTOLOGY

Like the Washakie Formation to the north (Roehler, 1992a), the upper Washakie Formation in the Sand Wash Basin is full of sedimentary evidence of a marginal lacustrine-fluvial depositional environment. It consists of about 450 feet (150 m) of grayish-brown and purple tuffaceous mudstones, with greenish and lavender cross-bedded sandstones. The mudstones are poorly bedded, and do not show the fine-scale lamination characteristic of the Green River Formation in this area. Consequently, these probably represent floodplain and lake margin mudstones, rather than the classic finely laminated lake shales found lower in the section.

The shallow depth of the water in this basin is indicated by a number of beds of silicified lacustrine stromatolites found in the mudstones; some of the domed stromatolites are 10-50 cm across. Such stromatolites are also common in the Washakie (Roehler, 1992a) and Uinta basins (Bradley, 1929; Ryder et al., 1976). Further evidence of the habitat is provided by the abundant fossils of freshwater bivalves and gastropods (*Goniobasis*, *Biomphalaria*), fish such as garpike (*Lepisosteus*), bowfin (*Amia*), and ictalurid catfish (*Astephus*, *Rhineastes*), aquatic turtles (*Baena*, *"Trionyx,"* *Plastomenus*), crocodiles (*Allognathosuchus*, *Pristichampsus*), varanid (*Saniwa*) and anguid lizards, and snakes.

The abundance of sandstones in the section also attests to the higher energies represented by the upper Washakie Formation (compared to the Green River shales). Both tabular and trough cross-stratification were observed in the sandstones, and some units show striking aggrading ripples ("climbing ripple drift") indicative of large sediment volumes settling rapidly out of the stream flow. Most sandstone bodies are narrow and lenticular, although in some places they form large channel complexes with an architecture of anastomosing incised channels.

Taken together, all of this evidence strongly indicates that the upper Washakie Formation in the Sand Wash Basin was deposited on the margins of a receding Green

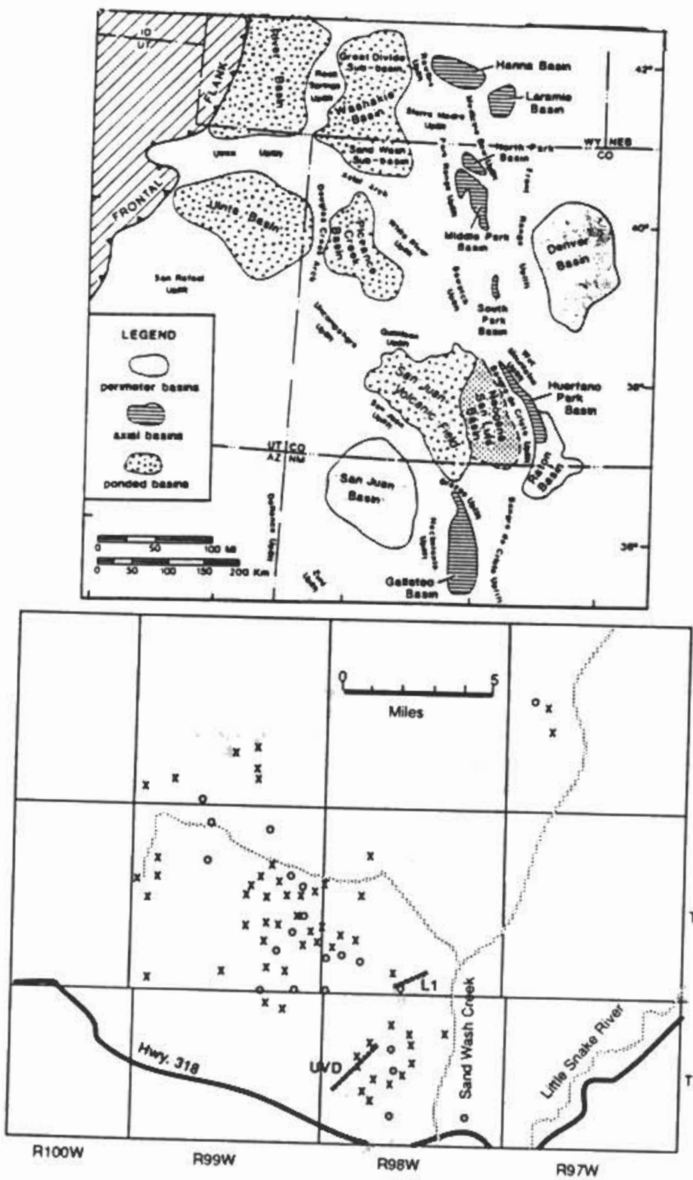

Figure 1. (*Top*) Index map showing location of Sand Wash Basin with respect to other Laramide structures in the Rocky Mountains (after Dickinson et al., 1988). (*Bottom*) Detail of fossiliferous portion of Sand Wash Basin, modified from West and Dawson (1975). "o" indicates localities shown by West and Dawson (1975, fig. 2); "x" indicates recently discovered DMNH localities. Exact location of these fossil sites is availabe to qualified investigators. Bold patterned lines show routes of measured magnetostratigraphic sections: L1 = "locality 1"; UVD = Upper Vaughn Draw.

River lake system (Lake Gosiute). In fact, the combination of channel sandstone complexes, gray-green mudstones, freshwater mollusks, and stromatolites is typical of the "marginal lacustrine-deltaic" facies of Ryder et al. (1976, p. 505), described from the margins of the Green River Formation in the Uinta Basin.

Paleocurrents were measured on 45 different sets of cross-beds and all showed a strong southerly trend (mean direction = 179.7° ± 50.9°); this is concordant with the directions reported by Surdam and Stanley (1980, fig. 1) for the same area. Several thin sections of the sandstones were examined and point counted (minimum 300 points). All contained between 40-80% devitrified glassy volcanic rock fragments, by far the dominant component in the sandstone. Most of the quartz (15-30% of most slides) is also angular and apparently volcanic in origin. In this respect, they are very similar to the volcaniclastic sandstones described by Roehler (1992a) from the Adobe Town Member (≈ upper member) of the Washakie Formation in the Washakie Basin. Many of our thin sections closely resembled the tuffaceous channel sandstone described by Roehler (1992a, fig. 19) from Bed 677 of the Adobe Town Member. These rocks are part of the upper middle Eocene "volcanic lithic sandstone petrofacies" of Surdam and Stanley (1979, 1980). Clearly, the bulk of the sediments supplied to the Sand Wash Basin came from volcanic fields to the north. The likeliest source is the massive Absaroka eruptions occurring in northwestern Wyoming at that time (Smedes and Prostka, 1973; Surdam and Stanley, 1979, 1980; Johnson, 1985).

According to Surdam and Stanley (1979, 1980) and Johnson (1985), the "volcanic lithic sandstone petrofacies" apparently spread southward in such volume that it swamped local sources. From paleocurrents and petrologic evidence, Surdam and Stanley (1980, fig. 1) and Dickinson et al. (1988, fig. 12) inferred that the river systems in the early Uintan drained south out of the southeastern Lake Gosiute (= Sand Wash Basin) into the Piceance Basin, then westerly into the Uinta Basin. Indeed, paleocurrents and river channels in the Uinta "A" member of the Uinta Formation trend westerly (Stagner, 1941; Dane, 1954; Cashion, 1967). From its sources in north-central Wyoming to the greater Green River Basin (forming the Washakie Formation), the "volcanic lithic sandstone petrofacies" can be traced over the divide into the Piceance Creek Basin, and ultimately eastward into the Uinta Basin of Utah (depositing the Uinta Formation "A-B" sandstones). As it did so, it contributed to the infilling and the final desiccation of the Green River lake system.

It is surprising, however, that there is no indication of sediments from the nearby Uinta Mountain uplift to the southwest of the Sand Wash Basin. No Proterozoic quartzite fragments or reworked Paleozoic sediments ("Paleogene quartzolithic petrofacies" of Dickinson et al., 1986) so characteristic of these mountains (Andersen and Picard, 1972, 1974; Dickinson et al., 1986; Bruhn et al., 1983; Picard and High, 1972) were observed. Because the Uinta Mountains apparently did not begin shedding sediment into the Uinta Basin to the south until the Duchesnean (Andersen and Picard, 1972, 1974), they must not have been emergent enough in the early Uintan to compete with the flood of volcanic debris from the north.

MAMMALIAN FAUNA

Since the most recent review of the mammalian fauna from the Washakie Formation in the Sand Wash Basin by West and Dawson (1975), field parties from the Denver Museum and Carnegie Museum have discovered an additional 18 mammalian species (Table 1). West and Dawson considered the fauna to be intermediate between the Bridgerian and Uintan land mammal "ages." They suggested that the fauna from the northwestern part of the basin, which consisted of predominately large mammals, was different in age and composition from that recovered in the southeastern part, which consisted of smaller mammals. Essentially, the larger mammals were typical of the Uintan and the smaller ones of the Bridgerian. Three possible explanations for these differences were offered: (1) inadequate collecting of small mammals in the northwestern part of the basin; (2) stratigraphic distance separating the strata in the two regions; and (3) recovery of taxa from different facies and paleoenvironments. They favored a composite explanation of (2) and (3), suggesting that "perhaps there is a time difference accompanied by ecologic variation" (West and Dawson, 1975, p. 252).

Recent collecting expeditions have recovered both small and large mammals from the northwestern and southeastern parts of the basin in both channel sandstones and overbank mudstones modified into paleosols. There is no question that the larger animals are well represented in channel sandstones and conglomerates exposed more commonly in the northwestern part of the basin. The smallest mammal known from the channel sandstones is *Notharctus robustior* (West and Dawson Locality 2) but this species is also known from the southeastern part as well, and occurs in both the Bridgerian and Uintan sequence of the Bridger Basin (Gazin, 1976; Evanoff et al., 1994; P. Robinson, personal communication to RKS) and the early Uintan sequence at Lysite Mountain, Wyoming (RKS, unpublished data, CMNH collections). Finer-grained overbank mudstones have yielded specimens of large mammals such as uintatheres and titanotheres, and small mammals in both parts of the basin also, thus suggesting that bias due to depositional regime is not a factor.

Almost all of the specimens reported by West and Dawson (1975) and the newer collections come from above the Robin's Egg Blue Tuff (REBT) of Roehler (1973), which crops out in the northern part of the basin (Sec. 30, T10N, R98W—see Fig. 1). Only one

Table 1. Vertebrate fauna of the Washakie Formation, Sand Wash Basin, northwestern Colorado. Taxa added to the fauna since the most recent synopsis are marked with an asterisk (*).

OSTEICHTHYES
- SEMIONOTIFORMES
  - Lepisosteidae
    - **Lepisosteus* sp.
- AMIIFORMES
  - Amiidae
    - **Amia* sp.
- CYPRINIFORMES
  - Catostomidae
    - *Catostomidae sp.
- SILURIFORMES
  - Ariidae
    - **Rhineastes peltatus*
  - Ictaluridae
    - *"*Rhineastes*" *smithi*
    - **Astephus* sp.

REPTILIA
- CHELONIA
  - Baenidae
    - **Baena arenosa*
  - Dermatemydidae
    - **Baptemys wyomingensis*
  - Testudinidae
    - **Echmatemys septaria*
    - **Echmatemys* sp.
- SQUAMATA
  - Anguidae
    - *Anguidae sp.
  - Varanidae
    - **Saniwa* sp.
- OPHIDIA
  - *Ophidia sp.
- CROCODILIA
  - Crocodylidae
    - **Allognathosuchus polydon*
    - **Crocodylus* sp.
    - **Pristichampsus* sp.

MAMMALIA
- MARSUPIALIA
  - Didelphidae
    - *Peratherium knighti* (Krishtalka and Stucky, 1983)
    - **Peratherium innominatum*
- LEPTICTIDA
  - Leptictidae
    - *Leptictidae sp.
- PANTOLESTA
  - Pantolestidae
    - *Pantolestes natans*
- INSECTIVORA
  - Geolabididae
    - **Centetodon* sp.
  - Apternodontidae
    - *Apternodontidae sp.
- DINOCERATA
  - Uintatheriidae
    - *Eobasileus cornutus*
- DERMOPTERA
  - Microsyopidae
    - **Microsyops annectens*
    - **Microsyops* sp.
- PRIMATES
  - Adapidae
    - *Notharctus robustior*
  - Omomyidae
    - *Hemiacodon* sp. (=*Washakius* sp. of West and Dawson, 1975)
    - *Omomyidae sp.
- CARNIVORA
  - Miacidae
    - *Uintacyon vorax*
    - *Viverravus minutus*
    - *Viverravus* sp.
  - Amphicyonidae
    - *?Amphicyonidae sp.
- RODENTIA
  - Ischyromyidae
    - *Leptotomus bridgerensis*
    - **Leptotomus* sp.
    - **Thisbemys* sp.
    - Ischyromyidae sp.
  - Sciuravidae
    - **Sciuravus* sp.
    - *Tillomys* sp. cf. *T. senex*
  - Eomyidae
    - **Namatomys* sp.
- ARCHAIC UNGULATES
  - Hyopsodontidae
    - *Hyopsodus markmani* (=*H. despiciens* of West and Dawson, 1975)
- ARTIODACTYLA
  - Homacodontinae
    - *Hylomeryx* sp. (=*Homacodon* sp. cf. *H. vagans* of West and Dawson, 1975)
  - Helohyidae
    - Helohyidae, n. gen., n. sp. (=*Parahyus* sp. of West and Dawson, 1975)
  - Agriochoeridae
    - **Protoreodon* sp.
    - *cf. Agriochoeridae, n. gen., n. sp.
  - Oromerycidae
    - **Oromeryx* sp.
- MESONYCHIA
  - Meonychidae
    - **Mesonyx* sp.
- PERISSODACTYLA
  - Equidae
    - **Eppihippus parvus*
    - *Orohippus sylvaticus*
  - Brontotheriidae[1]
    - *Metarhinus* sp.
    - *Tanyorhinus blairi*
    - *Tanyorhinus bridgeri*
    - *Tanyorhinus harundivorax*
    - *Tanyorhinus* sp.
    - *Telmatherium acola*
    - *Telmatherium advocata*
    - *Manteoceras foris*
    - *Manteoceras pratensis*
  - Isectolophidae
    - *Isectolophus annectens*
  - Helaletidae
    - **Dilophodon* sp.
  - Hyracodontidae
    - *Hyrachyus eximius* or *Forstercooperia grandis*
    - *Triplopus implicatus* (= *Hyrachyus* small species of West and Dawson, 1975)

[1]The plethora of taxa listed here are greater than the actual diversity (See West and Dawson, 1975; Mader, 1989). The group is currently under revision by Bryn Mader.

locality reported by West and Dawson, their Locality 20, lies below the REBT and preserves specimens of *Peratherium* and *Hemiacodon* (= *Washakius* of West and Dawson, 1975). Several additional specimens in Denver Museum collections from this area near Lang Springs are identified as *Hyopsodus*, a tapir, *Microsyops*, and a uintathere. The fauna from the Sand Wash Basin from below the REBT is too incomplete to determine if that part of the sequence is Bridgerian or Uintan in age, but it should be noted that no taxa characteristic of the Uintan are known.

The fauna from horizons above the REBT (Fig. 1) is typical of the earliest Uintan, or "Shoshonian" from California and Wyoming (Flynn, 1986; Stucky and Snyder, 1992). Especially significant are new records of *Epihippus parvus* (West and Dawson Loc. 16), *Protoreodon* (West and Dawson Loc. 3), *Oromeryx* (West and Dawson Loc. 9 and 12), and *Namatomys* (West and Dawson Loc. 12). New identifications include *Hylomeryx* and *Triplopus*, which were identified by West and Dawson (1975, pp. 247, 251) as *Homacodon* sp. cf. *H. vagans*, and *Hyrachyus* small species, respectively. Additional specimens in Denver Museum and University of Colorado Museum collections are referred to these taxa. We agree with West and Dawson (1975) that the titanotheres and *Eobasileus cornutus* (Wheeler, 1961) are also suggestive of a Uintan age.

We have some reservations with regard to the biostratigraphic significance of the hyracodontid taxa. Many characters which define Uintan hyracodontids are also indicated as transitional between late Bridgerian *H. modestus* and Uintan *Triplopus* (Radinsky, 1967a, 1967b). Specimens assigned here to *Triplopus implicatus* are based on a relatively higher crown height of the lower molars, and a reduced metacone and lengthened postmetacrista on M2. A larger hyracodontid representing either *Hyrachyus eximius* (typical of the late Bridgerian and early Uintan) or *Forstercooperia grandis* (typical of the Uintan) is also present, but the isolated teeth assigned here are insufficiently diagnostic. A revision of Eocene hyracodontids is needed to clarify the utility of genera in this family for biostratigraphic interpretations. This is also true of the brontotheres, which are currently under study (see Mader, 1989).

Several other new records may eventually prove to be significant for age determination upon further study. An associated maxilla and mandible are tentatively identified as an amphicyonid, which would be the earliest appearance of this family. A mandible with m1-2 appears to represent a new agriochoerid. The *Parahyus* sp. (DMNH 1764) of West and Dawson (1975, p. 25) represents a new genus of helohyid artiodactyl (Snyder, 1993). Other taxa reported from the Sand Wash fauna for the first time here are typical of both the Uintan and Bridgerian.

The new identifications and records from the localities that lie above the REBT in the Sand Wash Basin include taxa which typify the earliest Uintan or "Shoshonian" (Flynn, 1986; Stucky 1992; Evanoff et al., 1994; see also Gazin, 1955, and Radinsky, 1967a). The fauna from both the northwestern and southeastern Sand Wash Basin is comparable in taxonomic content to that from Bridger E (Evanoff et al., 1994), Bone Bed A of the Tepee Trail Formation, Togwotee Pass area, Wyoming (McKenna 1980; Flynn, 1986), Washakie B, and the Poway assemblage of southern California (Flynn, 1986), and potentially Whistler Squat, Texas (Wilson, 1986). *Epihippus*, *Triplopus*, *Namatomys*, *Protoreodon*, and *Oromeryx* characterize the Uintan land mammal "age" and their first appearance marks the beginning of the Uintan and the Shoshonian. Taxa such as *Auxontodon*, *Diplobunops*, *Bunomeryx*, and *Leptotragulus* are absent from the Sand Wash fauna but do occur in Uinta B2. This suggests that, within the Rocky Mountain region, the Shoshonian is distinct.

MAGNETIC STRATIGRAPHY

Two main stratigraphic sections were collected for magnetic analysis (Fig. 1). The lower sequence (200 feet of section) was collected near Denver Museum "Locality 1" (DMNH 296), and represented the localities in this area and at nearby "Turtle Hill" (DMNH 276). This section started at the Tbl/Tbu contact (McKay, 1974) (NE NW SW Sec. 9, T8N R98W, Lone Mountain 7.5' quadrangle, Moffat County, Colorado) and ran up section and due west to the crest of the hill with benchmark 6297 (NE SW NW of the same section). From the crest of this hill, the dip of the bedding was projected to the southwest, and the section was resumed in the bottom of Upper Vaughn Draw. This upper section (about 220 feet thick) started in SE SW SW Sec. 8, and ran southwesterly along the exposures at the east edge of the grassy bench, culminating in NE NW SE Sec. 18. Because of obvious faulting, the section was terminated at this point, since we could not determine if the remaining sequence repeated what we had already sampled, or might be separated from our previous section by a gap of unknown length.

In addition, two paleomagnetic sites were collected from isolated exposures of the distinctive Robin's Egg Blue Tuff (REBT) found in both the Sand Wash and Washakie basins (Bed 579 of Roehler, 1973). These sites were located about nine miles due north of the main section (in NW NW NE Sec. 30, T10N R98W, Sheepherder Spring 7.5' quadrangle, Moffat County, Colorado). According to Roehler (1973, pp. D62-63), approximately 470 feet of section separate the Robin's Egg Blue Tuff (Bed 579) with the "Rim above Adobe Town Rim" (Bed 600, which is approximately equivalent to the base of our "Locality 1" section) in the Washakie Basin. Unfortunately, in the Sand Wash Basin the exposures between these two areas were so poor and covered that it was impossible to connect them with continuous sampling. Based on the projected dip of the REBT and overlying tuffaceous mudstones and

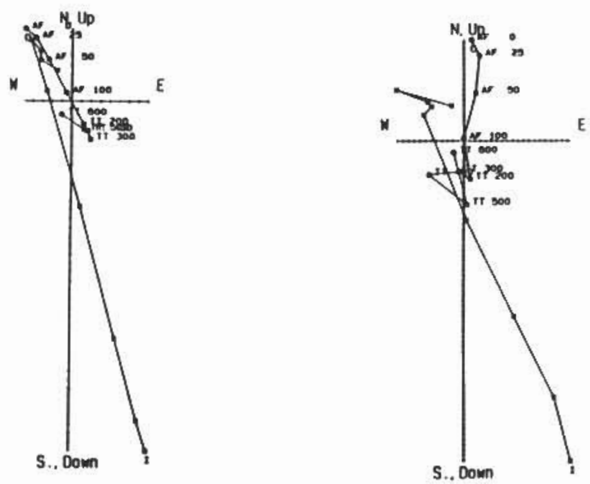

Figure 2. Vector demagnetization plots of selected AF and thermal demagnetization results from the Washakie Formation. Circles indicate horizontal component, + symbol is the vertical component. Sample on left had a normal overprint that was removed by 300°C. Sample on right had a normal overprint removed by 200°C.

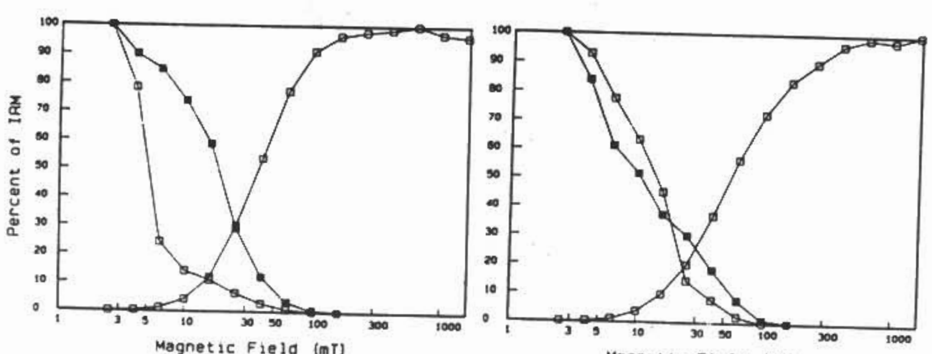

Figure 3. IRM acquisition and Lowrie-Fuller tests of selected samples from the Washakie Formation (see text and Pluhar et al., 1991, for further details). Solid boxes are ARM intensities at each AF demagnetization step, open boxes are IRM intensities. Note that during IRM acquisition (ascending curve on right), both samples reached saturation at about 300 mT, indicating the presence of magnetite. 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.

sandstones, there are probably no more than 200 feet of section that remained unsampled between the REBT and the lowest fossiliferous Uintan beds where our section began.

Twenty-five magnetic sites (three samples per site) were collected with simple hand tools, stratigraphically spaced about 7 m (22 feet) apart. Samples were trimmed on a band saw with a tungsten-carbide blade and run at the paleomagnetic laboratory of the California Institute of Technology. After measurement of NRM (natural remanent magnetization), samples were demagnetized in alternating fields (AF) at 25, 50, and 100 Gauss to remove any possible multidomain components. Each sample was then subjected to thermal demagnetization from 200-600°C in steps of 100°C.

The behavior of representative samples is shown in Figure 2. Under AF demagnetization, the magnetic intensity of most samples decreased significantly, showing that a low-coercivity mineral such as magnetite is a major carrier of the remanence. Thermal demagnetization was used to remove overprints caused by high-coercivity, low-blocking-temperature iron hydroxide mineral, such as goethite, which dehydrates by 200°C. Indeed, overprinted reversed sites first revealed reversed directions at about 200°C, and a stable reversed component was typically isolated at 400-500°C. This was the component used in further analysis. Very little of the remanence was left above 580°C (the Curie point of magnetite), indicating that most of the magnetic signal is carried by magnetite and not by hematite.

Analyses of IRM (isothermal remanent magnetization) acquisition further confirmed that magnetite was the primary carrier of the remanence. Most rocks (Fig. 3) reached saturation IRM values at 100-300 mT (millitesla), a characteristic of magnetite. A modified Lowrie-Fuller ARM (anhysteretic remanent magnetization) test (e.g., Johnson et al., 1975) was also conducted during 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 most samples, the ARM (black squares in Fig. 3) 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. However, in a few samples, the IRM was more resistant to AF demagnetization than the ARM, showing that multidomain grains were also present. Thin sections of representative samples were examined under reflected light. In several slides, euhedral magnetite grains with oxidized rims of hematite could be seen.

Once a characteristic magnetic component had been obtained for each sample, the vectors were averaged using 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.

To determine if the stable remanence was primary or secondary, a reversal test for stability was conducted. The Fisher mean of the normal sites (I = 349.0, D = 46.4, k = 18.2, α_{95} = 11.6) was antipodal to the mean for reversed sites (I = 181.0, D = -50.2, k = 7.8, α_{95}= 19.7), showing that the magnetization is primary depositional remanence.

The magnetic stratigraphy of the Sand Wash sections is shown in Figure 4. Both sites at the "Robin's Egg Blue Tuff" locality were reversed in polarity. Except for two sites, all of the rocks in the "Locality 1" section were also reversed. Most of the "Upper Vaughn Draw" section was of normal polarity (with a two-site reversed zone in the middle).

The interpretation of this polarity pattern is shown in Figure 5. Because the Sand Wash mammals can be correlated to the earliest Uintan faunas in the nearby Washakie Basin, that section (Flynn, 1986; McCarroll et al., this volume, Chapter 2) was used as a standard. As shown by McCarroll et al. (this volume, Chapter 2, fig. 3), the REBT occurs in an interval of reversed polarity originally labeled "B3–" by Flynn (1986). Earliest Uintan ("Shoshonian") faunas occur at the base of Twka2, and near the base of Flynn's (1986) "C+" normal magnetozone. Typical early Uintan faunas occur higher in Twka2.

Thus, it appears that our two sites of reversed polarity around the REBT match the pattern reported for the Washakie Basin. However, the presence of "Shoshonian" fossils in rocks of reversed polarity in the Sand Wash Basin seems to contradict the pattern seen in the Washakie Basin. This may be resolved in one of two ways:

1) Twka1 (the lower Adobe Town Member of the Washakie Formation) is indicated as being "Late Bridgerian" by McCarroll et al. (this volume, Chapter 2, fig. 3). However, these authors point out that the upper part of Twka1 is sparsely fossiliferous, especially with respect to the larger mammal taxa that are critical to recognizing the Uintan. Thus, our "Locality 1" section, with its reversed polarity could actually correlate with the upper part of Twka1 (magnetozone "B5-" of Flynn, 1986), and the Vaughn Draw section would correlate with the base of normal magnetozone C+.

2) McCarroll et al. (this volume, Chapter 2) point out that there is a 90 m (300 foot) gap between the Adobe Town and Skull Creek sections of Flynn (1986), so that the polarity of the lower part of Flynn's (1986) magnetozone C+ is not actually known. This interval also yields a "Shoshonian" fauna. It is possible that the

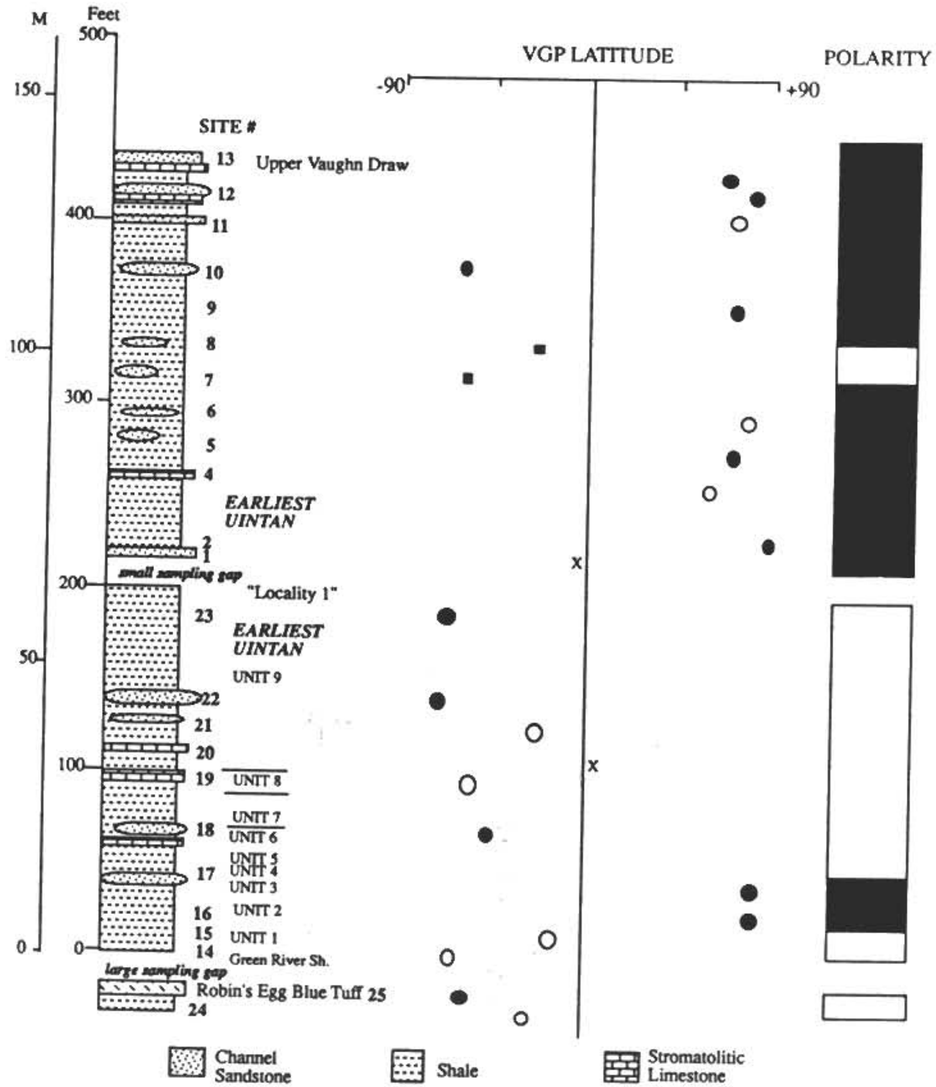

Figure 4. Magnetostratigraphy of the Locality 1 and Upper Vaughn Draw sections in the Sand Wash Basin (see Fig. 1). Solid circles = Class I sites (statistically significant) of Opdyke et al. (1977); solid squares = Class II sites (one sample missing); open circles = Class III sites (one sample divergent); x = indeterminate sites.

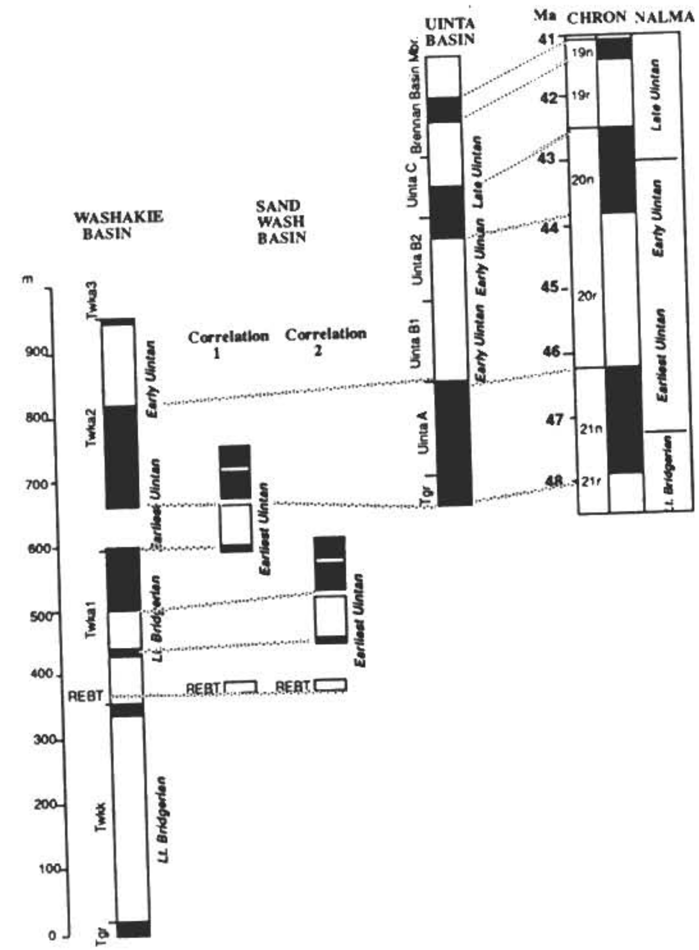

Figure 5. Possible correlations of the Sand Wash Basin magnetostratigraphy to other Uintan strata and to the magnetic polarity time scale of Berggren et al. (1995). Washakie Basin after McCarroll et al. (this volume, Chapter 2); Uinta Basin after Prothero (this volume, Chapter 1). REBT = Robin's Egg Blue Tuff; Twkk = Kinney Rim Member of the Washakie Formation; Twka = Adobe Town Member of the Washakie Formation, units 1, 2, and 3.

unsampled gap in magnetozone C+ is actually of reversed polarity and thus could correlate with out "Locality 1" reversed section. The Vaughn Draw section would again correlate with the higher part of magnetozone C+.

Whichever interpretation is adopted, the correlation of our sections with the magnetic polarity time scale hinges on the interpretation of the Washakie Basin section. As discussed by Walsh (this volume, Chapter 4), Walsh et al. (this volume, Chapter 6), and Prothero and Emry (summary chapter of this volume), the evidence is now quite strong that the normal magnetozone C+ in the Washakie Basin correlates with Chron C21n (46.3-47.9 Ma). This places the REBT in late Chron C21r, and the rest of the section in either C21r or C21n. Thus, the Sand Wash Basin section appears to span the interval from about 48.2 Ma to about 47 Ma.

ACKNOWLEDGMENTS

The paleomagnetic aspects of this project were supported by NSF grant EAR91-17819 to Prothero. Curation and storage of the DMNH fossil material was supported by the Bureau of Land Managment and by NSF grant DEB92-1817 to Stucky. We thank Erin Wilson and Joby Campbell for their help with sampling, and Dr. Joseph Kirschvink for graciously allowing access to his paleomagnetic laboratory. We would especially like to thank the students in the DMNH Certification Program in Paleontology for all their help with collecting, and Harley Armstrong and Hal Keesling of the Bureau of Land Management for their support of the field work. The manuscript was reviewed by Emmett Evanoff, John Flynn, Jay Lillegraven, Steve McCarroll, Malcolm McKenna, and Steve Walsh.

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