5

The Chadronian, Orellan, and Whitneyan North American Land Mammal Ages

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IN THE 16 YEARS SINCE EMRY, BJORK, and Russell (1987) reviewed the Chadronian, Orellan, and Whitneyan land mammal ages for the original version of this volume, an enormous amount of information has been published concerning this interval of time. Many of the crucial sections have been studied by means of magnetic stratigraphy, and many new $^{40}Ar/^{39}Ar$ dates have been analyzed, which have radically changed our concept of the correlation of these beds (Swisher and Prothero 1990; Prothero and Swisher 1992; Prothero 1996b; Prothero and Whittlesey 1998). Systematic reviews of most of the biostratigraphically informative taxa have been completed (see chapters in Prothero and Emry 1996b), allowing a formal range zone biostratigraphy to be erected for most of this interval (Prothero and Emry 1996a; Prothero and Whittlesey 1998). Calibrated by means of magnetostratigraphy, these biostratigraphic zones now offer very high-resolution dating of most of this time interval. In Emry et al. (1987), it was not possible to resolve many events to the nearest 2–3 million years, but the current high-resolution chronostratigraphic framework now allows many events in better-studied sections to be dated to the nearest 100,000 years or less.

In addition to the improvements in chronostratigraphy, the new dates have radically changed our correlation of the Chadronian, Orellan, and Whitneyan land mammal ages to the global time scale. When these terms were originally coined by the Wood committee (1941), they were thought to correlate with the early, middle, and late Oligocene, respectively. But the new $^{40}Ar/^{39}Ar$ dates, combined with the magnetostratigraphy (Swisher and Prothero 1990; Prothero and Swisher 1992), and changes in the dating of the global time scale (Berggren et al. 1992, 1995) showed that the Chadronian correlates with the late Eocene, the Orellan and Whitneyan with the early Oligocene, and the Arikareean (long considered early Miocene) with the late Oligocene and earliest Miocene (as first shown by Evernden et al. 1964 and Tedford et al. 1987). Thus the original concept of the Chadronian, Orellan, and Whitneyan land mammal ages as the "Oligocene" chapter in the original book has lost its meaning. This chapter now covers the late Eocene to early Oligocene, and the rest of the Eocene and Oligocene is covered in other chapters. Nevertheless, the Chadronian, Orellan, and Whitneyan land mammal ages are important because they represent the best-studied terrestrial record of the Eocene–Oligocene transition in the world and are therefore an important data set for studying the climatic changes that occurred when the global climate shifted from greenhouse to icehouse states (Prothero 1994; Prothero and Emry 1996b; Prothero and Heaton 1996; Prothero 1999).

LITHOSTRATIGRAPHY OF CHADRONIAN, ORELLAN, AND WHITNEYAN STRATA

In this chapter, we will not repeat the historical introduction to the White River Group (figure 5.1), more fully discussed in Emry et al. (1987), or much of the stratigraphic background discussed in the latter part of that chapter. Instead, we will summarize the recent developments in

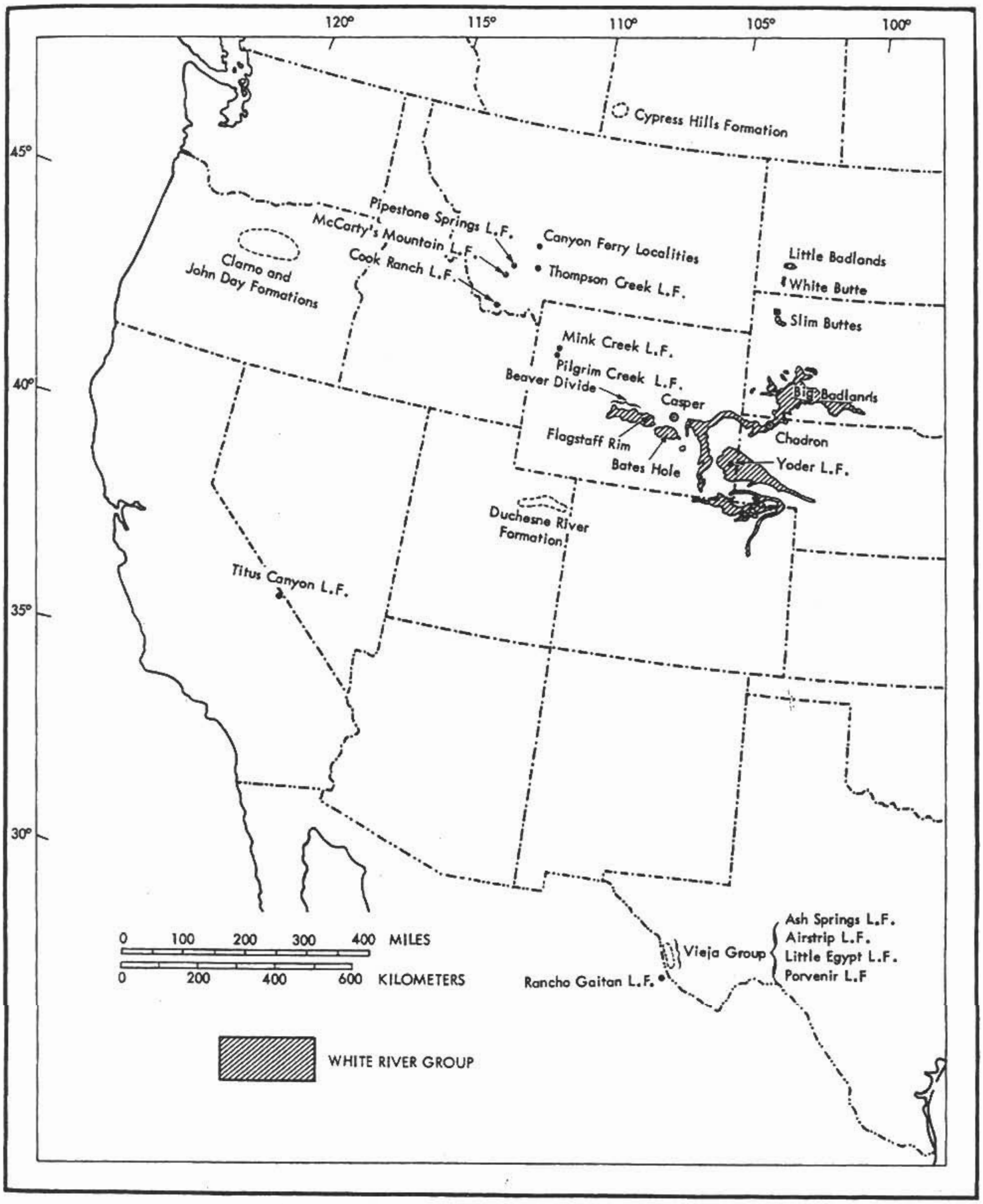

FIGURE 5.1 Index map showing location of rock units mentioned in text (after Emry et al. 1987). L.F., Local Fauna.

biostratigraphy, magnetostratigraphy, and $^{40}Ar/^{39}Ar$ dating that were published since 1987 (Swisher and Prothero 1990; Prothero and Swisher 1992; various chapters in Prothero and Emry 1996b, including Prothero and Emry 1996a; Prothero and Whittlesey 1998).

Some important changes in the lithostratigraphic framework have taken place, however (figure 5.2). Terry (1998) proposed a new lithostratigraphic framework for the lower part of the White River Group in South Dakota and Nebraska. The lowest part of the former Chadron Formation in South Dakota (containing the Interior and Weta paleosols) was named the Chamberlain Pass Formation. Of the three members of the Chadron Formation recognized in South Dakota by Clark (1937), only the Peanut Peak Member is recognized in Nebraska. Terry (1998) rejects the old correlation of the Ahearn and Crazy Johnson Members with Chadron A and B in Nebraska. Chadron B and C and Orella A in Nebraska (*sensu* Schultz and Stout 1955, 1961) are now placed in the new Big Cottonwood Creek Member of the Chadron Formation by Terry (1998) and Terry and LaGarry (1998).

LaGarry (1998) also proposed revisions of the Brule Formation in Nebraska. As just mentioned, "Orella A" in Nebraska has been reassigned to the Big Cottonwood Creek Member of the Chadron Formation. With this change, the Orellan North American land mammal age (NALMA) now coincides even better with the Orella Member as redefined. LaGarry (1998) redefined the boundary between the Orella and Whitney members to a position slightly lower in the section.

Finally, Swinehart et al. (1985) and Tedford et al. (1996) recognized a unit above the Whitney Member of the Brule Formation that they informally called the "brown siltstone" member. Many of the rocks that were once assigned to the upper Whitney Member or lower Gering Formation by Schultz and Stout (1955, 1961) were reassigned to this unit.

GEOGRAPHY OF THE CHADRONIAN, ORELLAN, AND WHITNEYAN NALMAS

All three of these NALMAs were originally based of parts of the White River Group and its contained faunas in northwestern Nebraska and southwestern South Dakota (Wood et al. 1941). With the exception of the earliest Chadronian, the subdivisions of these units that we now recognize are still based on parts of the White River Group and its faunas, although several of the subdivisions are based on White River sequences that are well outside the original type areas of the whole NALMAs. This primarily reflects the fact that faunas of Chadronian age are much better known in these other areas. Therefore it seems worthwhile to generalize briefly about the geographic distribution of the White River Group and the non–White River faunal correlates.

The White River Group is exposed widely in southwestern South Dakota and northwestern Nebraska and north of the Pine Ridge escarpment in adjacent Niobrara County, Wyoming (figure 5.1). From there it can be traced, nearly continuously, westward to the vicinity of Douglas, Wyoming, and from there southward east of the Laramie Range nearly to the Colorado border and westward north of the Laramie Range to the vicinity of Glenrock. The White River Group crops out extensively in the valley of the North Platte River and its tributaries in western Nebraska and eastern Wyoming. In northeastern Colorado, extensive outcrops are found along the south-facing escarpment where the High Plains break off into the Colorado Piedmont. In northwestern South Dakota, southeastern Montana, and southwestern North Dakota, isolated remnants of White River are preserved, mainly in the upper parts of buttes and higher elevations. Figure 5.1 indicates the approximate areal extent, at the surface, of the White River Group.

Intermontane basins of central Wyoming have extensive White River deposits that are not continuous with the main body of the White River Group farther east. In the Bates Hole Area, at Flagstaff Rim at the southeastern end of the Wind River Basin, and at Beaver Divide along the southern margin of the Wind River Basin, the White River deposits have the general lithologic characteristics that justify the White River terminology but are generally so uniform that they are not subdivided lithologically and are locally treated as a formation rather than group. At their westernmost limit, deposits that can be recognized lithologically as White River lap onto the eastern end of the Wind River Range and extend from there southeast into the northwestern edge of the Great Divide Basin in Wyoming and northeast along Beaver Divide. These areas of White River Formation undoubtedly are remnants of a blanketing deposit that once extended north across the Wind River Basin and continued northeast across the Powder River Basin (where remnants remain at the top of Pumpkin Buttes) and east into the classic areas of White River in eastern Wyoming, western Nebraska, and southwestern South Dakota. The White River deposits retain their general lithologic character over such a broad area (across what would have been separate depositional basins with respect to fluvial components) because the bulk of the formation consists of eolian volcaniclastics, transported and deposited across this broad area irrespective of the fluvial systems.

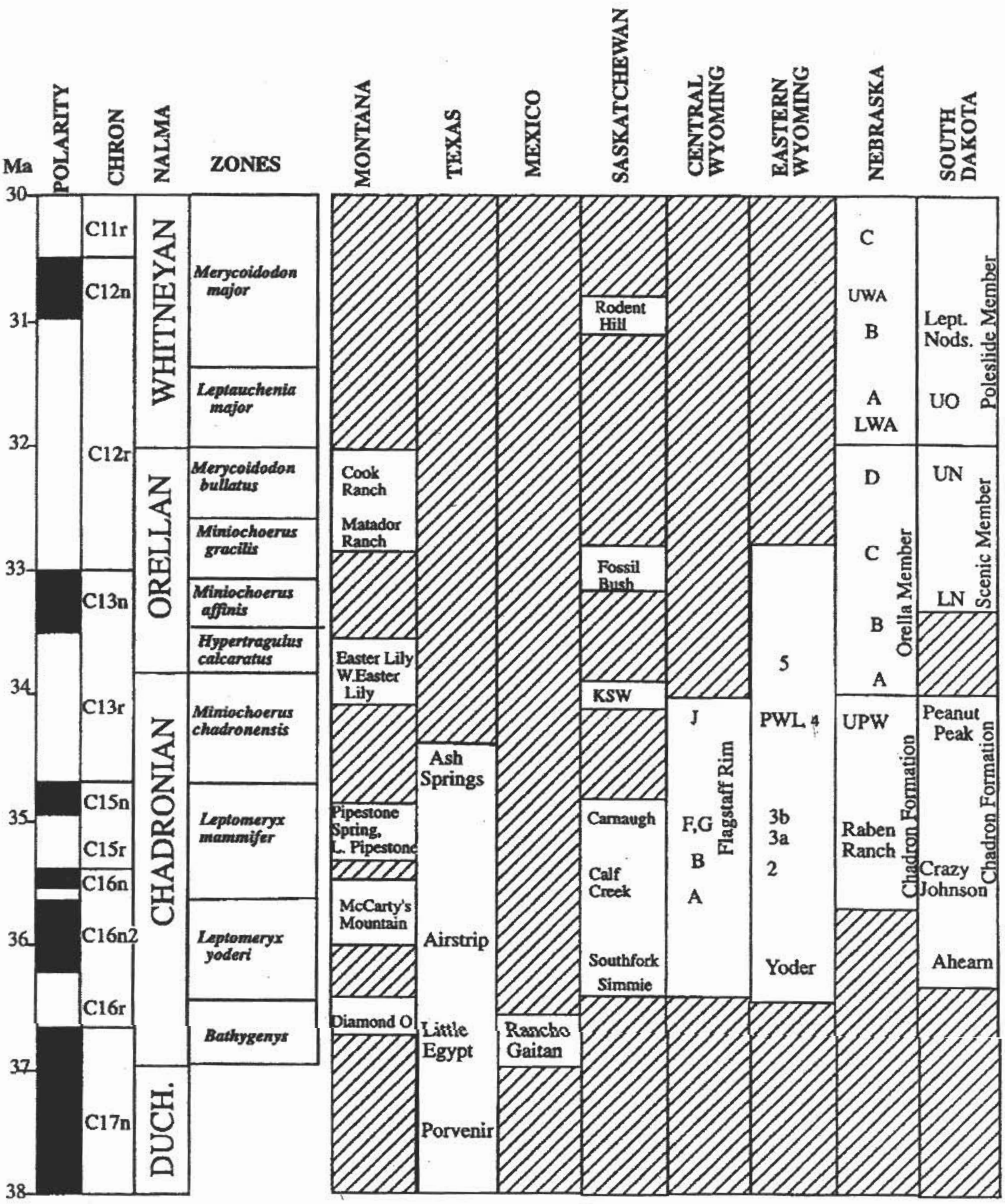

FIGURE 5.2 Correlation chart of deposits of Chadronian, Orellan, and Whitneyan age in North America. Time scale after Berggren et al. (1995), Prothero and Emry (1996a), and Prothero and Whittlesey (1998). Lithostratigraphic and magnetostratigraphic correlations after Emry et al. (1987), Swisher and Prothero (1990), Prothero and Swisher (1992), Prothero (1996a, 1996b), Tabrum et al. (1996), Tedford et al. (1996), Prothero and Whittlesey (1998), Terry (1998), and various other chapters in Prothero and Emry (1996b). KSW, Keasey Springs West; Lept. Nods., *Leptauchenia* Nodules; LN, Lower Nodules; LWA, Lower Whitney Ash; PWL, Persistent (= Purplish) White Layer; UN, Upper Nodules; UO, Upper Oreodon Beds; UPW, Upper Purplish White Layer; UWA, Upper Whitney Ash.

Chadronian faunas occur in several areas in rocks that are beyond the geographic limits of the White River Group. Among the more important of these are the Chambers Tuff (with the Porvenir and Little Egypt local faunas) and the Capote Mountain Tuff (with the Airstrip Local Fauna) of the Vieja Group in Trans-Pecos Texas. Other important Chadronian faunas occur in the Cypress Hills Formation in southwestern Saskatchewan and in the Climbing Arrow, Dunbar Creek, and Renova formations (the latter with the important Pipestone Springs Local Fauna), all in southwestern Montana (Tabrum et al. 1996). Mammalian assemblages from these units can be correlated, with varying degrees of precision, with the White River faunal sequence. The Vieja Group of Trans-Pecos Texas is especially important for the recognition and definition of earlier Chadronian subdivisions.

Through the Chadronian–Whitneyan interval, the known geographic range of faunas becomes progressively limited. Orellan faunas occur in southwestern Montana in the Dunbar Creek Formation of the Three Forks, Clarkston, and South Townsend basins, in the Dunbar Creek Member of the Renova Formation in the Jefferson Basin, and in the Cook Ranch Local Fauna east of Lima. Otherwise, Orellan faunas are largely limited to the Brule Formation in its typical areas: isolated localities in southwestern North Dakota, northwestern South Dakota, the Scenic Member in the Big Badlands of South Dakota, the Orella Member in western Nebraska and eastern Wyoming, and the equivalent Cedar Creek Member in northeastern Colorado.

Whitneyan faunas are even more limited geographically, essentially to the Brule Formation: the Whitney Member in western Nebraska and eastern Wyoming, the Vista Member in northeastern Colorado, and the Poleslide Member in South Dakota. Possible outliers are the Cedar Ridge Local Fauna in the Badwater Creek area in the northeastern part of the Wind River Basin of Wyoming (Black 1968; Setoguchi 1978) and the J-95 Local Fauna (Patton 1969) in northern Florida.

To our knowledge, no assemblages of Chadronian or Whitneyan land mammals occur in deposits that can be related unambiguously to any marine sequence. Orellan mammals have been reported from the lower Oligocene Byram Formation, Mississippi (Manning et al., 1986; Manning, 1997). Correlation with other chronologies is accomplished principally through radiometric dates and magnetic polarity stratigraphy. It does appear that brontotheres, whose latest occurrences caused confusion in defining and recognizing the Chadronian–Orellan boundary, can be rehabilitated as a useful biochronologic taxon; the extinction of brontotheres appears now to have been a global event at the end of the Eocene and thus provides supporting evidence for correlating the Chadronian–Orellan boundary with the Eocene–Oligocene boundary.

CHADRONIAN

The original definition of the Chadronian by Wood et al. (1941) has caused considerable confusion about recognizing the Chadronian–Orellan boundary. Wood et al. (1941:11) wrote that "the Chadronian is based on the Chadron formation, type locality near Chadron, Nebraska, type area, northwestern Nebraska and southwestern South Dakota, includes the old term '*Titanotherium* beds,' used in its most extended sense. It may also be defined, faunally, as the time during which *Mesohippus* and titanotheres coexisted." As several authors have pointed out (Emry et al. 1987; Prothero and Whittlesey 1998), this definition combines lithostratigraphy (the geochron of the Chadron Formation) and biochronology (the overlapping ranges of *Mesohippus* and brontotheres, or titanotheres). As long as *Mesohippus* was not known in strata older than the Chadron Formation and brontotheres were not known above the Chadron Formation, the dual definition was not internally inconsistent and remained workable.

Confusion regarding the Chadronian–Orellan boundary results ultimately from the uncritical definition of the Chadron Formation–Orella Member boundary by Schultz and Stout (1938). In the Toadstool Park area of northwestern Nebraska (the type localities for the Orella and Whitney members of the Brule Formation), the uppermost of several "purplish white layers" (volcanic ash beds) was defined by Schultz and Stout (1938, 1955) as marking the top of the Chadron Formation. What is apparently the same purplish white ash occurs widely in the Seaman Hills area to the west in Niobrara County, Wyoming, and can be traced eastward into Sioux County, Nebraska, where it occurs in a sequence similar to that at the Orella type locality. In the Seaman Hills area, the lithology is the same above and below this ash bed, so there is no logical reason to place a formational, lithologic boundary at this ash bed. Moreover, as mentioned by Emry et al. (1987) and Prothero and Whittlesey (1998), brontothere (titanothere) bones have been found up to 25 feet above the ash bed in the Seaman Hills area. On September 6, 1953, Morris Skinner (unpublished section book, vol. 5, pp. 9–11, in Department of Vertebrate Paleontology Archives, American Museum of Natural History) discovered titanothere bones in a channel-fill deposit that cut down from about 6.5 m (20 feet) above the "Persistent White Layer" (PWL), Skinner's term for the "purplish white layer" of Schultz and Stout. In his unpublished 1960 summary of Seaman Hills stratigraphy, Skinner indicated "Chadronian age at least to here" at the level 6.5 m (20 feet) above the PWL. There are other occurrences of brontotheres (titanotheres) that would be above the top of the Chadron Formation as it was recognized by Schultz and Stout (1938, 1955). Emry et al. (1987) and Prothero and Whittlesey (1998) mention another occurrence in the White River southeast of Douglas, Wyoming, about 25 feet above a white ash bed that Skinner called the "100' correlator white zone" and Evanoff et al. (1992) call the "5 tuff," which is presumed to be the same ash bed as the upper PWL of Schultz and Stout. Even Schultz and Stout (1955, figure 10) indicate a titanothere metapodial in a channel sandstone incised from about 7 feet above the upper PWL at Scottsbluff National Monument in the Platte Valley of western Nebraska, and in a footnote (1955:27) they comment that "all parts of the Chadron and the lowest parts of the Brule (basal Orella or Orella A) should be expected to yield titanothere remains."

It is important to note that Skinner did not consider these brontothere occurrences to be in the Brule Formation. On the contrary, in his section books and the unpublished summary mentioned earlier and in his daily diaries that he maintained, Skinner referred to the beds above the PWL (in northwestern Nebraska and Niobrara County, Wyoming) as the "Trunk Butte Member of the Chadron Formation." In the Seaman Hills area in Niobrara County, Wyoming, Skinner recognized about 30 m (100 feet) of this unit above the PWL and lesser thicknesses to the eastward into Nebraska as far as the vicinity of Chadron (Trunk Butte is southwest of Chadron). Skinner's name for this unit was never published, but Terry and LaGarry (1998) applied the name *Big Cottonwood Creek Member* of the Chadron Formation to this body of rock.

Thus the apparent inconsistency in the definition of the Chadronian by Wood et al. (1941) really resulted from the uncritical definition of the top of the Chadron Formation by Schultz and Stout (1938, 1955). In the Toadstool Park area, the base of the Toadstool Park channel sequence is disconformable, and at some places the channel sequence has cut nearly to the level of the PWL, but as Terry and LaGarry (1998) clearly show, and Skinner had recognized long before, lateral to the channel sequence the Chadron Formation extends well above the PWL. The Chadronian–Orellan boundary as it was determined by Prothero and Whittlesey (1998) in the Douglas, Wyoming, sequence and in the Seaman Hills sequence includes these latest known brontothere occurrences.

Emry et al. (1987) reviewed the problems with the original Wood committee definition of the Chadronian and made some suggestions for an improved definition of this time interval. They recommended that the Chadronian be defined in faunal or biostratigraphic terms and argued that lithostratigraphic units had no role in the definition of a biochronologic unit. One of the major problems at that time was that there was much debate and confusion over how to distinguish the Chadronian from the preceding Duchesnean age and whether the Duchesnean could be distinguished at all. Some authors (Emry 1981; Wilson 1984, 1986) even recommended that the early Duchesnean be considered a subage of the Uintan and the late Duchesnean a subage of the Chadronian. But subsequent authors (Kelly 1990; Lucas 1992) pointed out the distinctiveness of the Duchesnean, and since then its biostratigraphy and chronostratigraphy have become much better understood (several chapters in Prothero and Emry 1996b).

Prothero and Emry (1996a) reviewed the latest biostratigraphic, magnetostratigraphic, and geochronologic data of the Chadronian and proposed a revised definition. The Chadron Formation in South Dakota and Nebraska proved to be too poorly fossiliferous and its biostratigraphy too poorly resolved to serve as the basis for the chronostratigraphy of the Chadronian. Instead, Prothero and Emry (1996a) recommended that the faunas of much better sections in Trans-Pecos Texas and at Flagstaff Rim and Douglas, Wyoming, serve as the chronostratigraphic standards for the Chadronian.

Prothero and Emry (1996a) designated the first appearance of *Bathygenys, Merycoidodon dunagani, Brachyrhynchocyon* (formerly *Daphoenocyon*) *dodgei*, and *Archaeotherium* as the best indicators of the beginning of the Chadronian, with *Bathygenys* as the defining taxon and the rest as characterizing taxa. In Trans-Pecos Texas, these distinctive earliest Chadronian taxa all occur in the Little Egypt Local Fauna, which lies immediately above the late Duchesnean Porvenir Local Fauna. Both faunas are bracketed by $^{40}Ar/^{39}Ar$ dates of 37.8 ± 0.15 Ma and 36.7 ± 0.07 Ma, placing the Duchesnean–Chadronian boundary at approximately 37.0 Ma (and thus coincident with the middle–late Eocene boundary on the time scale of Berggren et al. 1995). If a stratotype were to be designated for this boundary, then the Trans-Pecos region of Texas is the only suitable place.

Because of the problem with the highly variable and infrequent occurrence of the latest surviving brontotheres with respect to the top of the Chadron Formation, the original Wood committee (1941) definition of the end of the Chadronian is insufficient by itself, and although it can be part of the definition, it is impractical as a means of recognizing the end of Chadronian time. Prothero and Whittlesey (1998) instead recommended that the Chadronian–Orellan boundary be placed at the first appearance of the distinctive taxon *Hypertragulus calcaratus,* along with the first appearance of a number of additional reference taxa. This boundary is discussed further later in this chapter.

SUBDIVISIONS OF THE CHADRONIAN

As reviewed by Emry et al. (1987), early concepts of the Chadronian essentially used lithostratigraphic units as de facto subdivisions of the time interval. Clark (1937, 1954) proposed a threefold division of the Chadron Formation in the Big Badlands of South Dakota into Ahearn, Crazy Johnson, and Peanut Peak members and suggested that these could also serve as time divisions of the Chadronian. Schultz and Stout (1955, 1961) designated informal members A, B, and C of the Chadron Formation in the Toadstool Park area of Nebraska. These rocks were also subdivided by the oreodont faunal zones of Schultz and Falkenbach (1968). The stratigraphic schemes of Schultz and Stout (1955, 1961) have not stood the test of time, with revised definitions (Terry 1998) placing Orella A in the Chadron Formation and changing the correlation with South Dakota radically from earlier concepts. Unfortunately, both the Clark (1954) and Schultz and Stout (1955, 1961) schemes used lithostratigraphic units for essentially biochronologic and biostratigraphic concepts, so they were fundamentally unsound. In addition, the actual stratigraphic range of the key fossils in these units was poorly documented, so they were unsuitable for a detailed range zone biostratigraphy. A much better, more complete section with excellent biostratigraphic data representing most of the Chadronian occurs at Flagstaff Rim, Wyoming (Emry 1973, 1992; Emry et al. 1987), and this serves as the basis for the much of the present zonation of the Chadronian.

Prothero and Emry (1996a) suggested a subdivision of the Chadronian into four biostratigraphically defined intervals, based on the best available lithostratigraphic sections known and calibrated by magnetostratigraphy and $^{40}Ar/^{39}Ar$ dating. These four intervals were known informally as earliest, late early, middle, and late Chadronian. Each of these four intervals is about 1 million years in duration, except for the earliest Chadronian, which is only about500,000 years in duration. Although possible biostratigraphic index taxa were suggested, no formal biostratigraphic zones were erected in that publication. In this chapter, we will finish this procedure by formally designating these zones.

Earliest Chadronian (36.5–37.0 Ma) Prothero and Emry (1996a) suggested that the biochronologic interval represented by the Little Egypt Local Fauna of Texas and Rancho Gaitan Local Fauna in Chihuahua, Mexico, be considered earliest Chadronian. This interval might be represented by the very base of the section at Flagstaff Rim, Wyoming, but the faunal evidence is very limited. Based on the local magnetostratigraphy (Prothero 1996a), this interval falls entirely in magnetic chron C16r, so it apparently spans the time interval from 36.5 to 37.0 Ma. As discussed earlier, the first appearances of *Bathygenys* and several other index taxa characterize this interval, so if a formal biostratigraphic zonation were needed, it could be known as the *Bathygenys* Interval Zone, and its stratotype is here designated as the Reeves Bonebed section (Wilson 1978, figure 9; Prothero 1996a) in Trans-Pecos Texas.

Late Early Chadronian (35.7–36.5 Ma) This interval is much more completely represented and geographically widespread than the earliest Chadronian. The main reference section is at Flagstaff Rim, Wyoming (from just above the base of the section to 50 feet below Ash B), and the principal correlatives are the McCarty's Mountain Local Fauna of Montana, the faunas of the Ahearn Member in South Dakota, and the Yoder Local Fauna of Wyoming. Based on the magnetostratigraphy, this interval correlates with magnetic chron C15n2 (35.7–36.2 Ma). Ash B has been $^{40}Ar/^{39}Ar$ dated at 35.9 ± 0.2 Ma (Prothero and Swisher 1992) or 35.41 ± 0.14 Ma (Obradovich et al. 1995), with the more recent Obradovich date taking into account some laboratory problems with Swisher's date and better fitting all the other age constraints. This places an upper age constraint on the late early Chadronian.

Prothero and Emry (1996a) gave a list of taxa that first appear in and are limited to this interval, including *Palaeolagus primus, Merycoidodon presidioensis, Pseudoprotoceras semicinctus, Litoyoderimys lustrorum, Yoderimys stewarti,* and *Leptomeryx yoderi.* In addition, a number of taxa (including *Daphoenictis tedfordi, Hyaenodon montanus, Ischyromys veterior, Centetodon chadronensis, Parvitragulus priscus, Patriomanis americanus, Trigenicus profectus,* and *Sinclairella dakotensis*) first occur at this time but range into the middle Chadronian. Prothero and Emry (1996a) suggested that this interval be named the *Leptomeryx yoderi* Interval Zone, with its type section in the main Flagstaff Rim section along Little Lone Tree Gulch (Emry 1973).

Middle Chadronian (34.7–35.7 Ma) The middle Chadronian is much better known than the two earlier Chadronian time intervals. It is typified by the large fossil collections recovered from the interval from 50 feet below Ash B to 50 feet above Ash G at Flagstaff Rim, Wyoming (Emry 1973, 1992). There are several principal correlatives, including the Pipestone Springs and Little Pipestone Creek local faunas of Montana (Tabrum et al. 1996), the Raben Ranch Local Fauna of Nebraska (Ostrander 1985), and the fauna of the Crazy Johnson Member of South Dakota. These beds all appear to correlate with magnetic chrons C15n–C15r (34.7–35.7 Ma). This interval has been dated not only by the $^{40}Ar/^{39}Ar$ date on Ash B cited earlier but also by dates of 35.7 ± 0.1 Ma (biotite) and 35.8 ± 0.04 Ma (anorthoclase) on Ash F and 35.6 ± 0.06 Ma (biotite) and 35.7 ± 0.03 Ma (anorthoclase) on Ash G (Swisher and Prothero 1992).

Prothero and Emry (1996a) noted a number of taxa that are limited to this interval, including *Leptomeryx mammifer, Zemiodontomys burkei, Miniochoerus forsythae, Prosciurus vetustus, Hyaenodon microdon, Hyaenodon megalodon, Chadrolagus emryi,* and *Frictops emryi.* A number of taxa first appear in the middle Chadronian and range into younger strata, including *Palaeolagus temnodon, Dinictis felina, Meliakrounomys, Eutypomys magnus, Mesohippus westoni, Leptomeryx speciosus, Pseudoprotoceras longinaris,* large *Ischyromys, Hoplophoneus mentalis, Miohippus grandis,* and *Megalagus brachyodon.* Emry et al. (1987) and Prothero and Emry (1996a) recommended that *Leptomeryx mammifer* be designated the index fossil of this zone (which could be called the *Leptomeryx mammifer* Interval Zone), with a type section in the Flagstaff Rim section from 50 feet below Ash B to 50 feet above Ash G. We so designate it in this chapter.

Late Chadronian (34.7–33.7 Ma) The Flagstaff Rim section is sparsely fossiliferous from about 50 feet above Ash G, so Prothero and Emry (1996a) suggested the section below the PWL (= Ash J at Flagstaff Rim, the 4 tuff at Douglas, Wyoming, according to Larson and Evanoff 1998) in the Seaman Hills section, north of Lusk, Wyoming, better typifies this interval. Additional referred sections include the Douglas section below the 4 tuff (Evanoff et al. 1992), the late Chadronian in western Nebraska (Ostrander 1985; Terry 1998), the Peanut Peak Member in South Dakota, and possibly the Ash Spring Local Fauna in Texas. All of these strata appear to correlate with late chron C13r–C15n (33.7–34.7 Ma). Ash J at Flagstaff Rim has been $^{40}Ar/^{39}Ar$ dated at 34.7 ± 0.04 Ma (Prothero and Swisher 1992) or 34.36 ± 0.11 Ma (Obradovich et al. 1995). As discussed earlier, the Obradovich date probably is more reliable.

Only a few taxa, such as *Pseudoprotoceras taylori,* are limited to the late Chadronian at Flagstaff Rim (Emry 1992). In other late Chadronian sections, the interval is marked by the first occurrences of *Merycoidodon culbertsoni, Poebrotherium franki, Miniochoerus chadronensis, Ischyromys typus, Mesohippus exoletus, Mesohippus bairdi,* and *Scottimus viduus.* A number of taxa last appear in this interval and terminate near the Chadronian–Orellan boundary, including Brontotheriidae, *Xenocranium, Pseudocylindrodon, Toxotherium, Palaeolagus temnodon, Hoplophoneus mentalis, Miohippus grandis, Mesohippus westoni, Eotylopus reedi, Poebrotherium eximium,* and *Archaeotherium coarctatum.* Prothero and Emry (1996a) recommended that *Miniochoerus chadronensis* is the best candidate for index fossil in this interval because it is abundant, distinctive, and limited to the late Chadronian. Thus the late Chadronian could be designated as the *Miniochoerus chadronensis* Interval Zone and typified by the Seaman Hills section in Niobrara County, Wyoming. We formally designate the type section of the *Miniochoerus chadronensis* Interval Zone as the interval from 25 m below to 7 m above the PWL in the Boner Ranch section (SW sec. 9, T35N R61W, South Oat Creek 7.5' Quadrangle, Niobrara County, Wyoming; see Prothero and Whittlesey 1998, figure 5).

ORELLAN

The Wood committee (1941:11) based the Orellan on "the Orella member of the Brule Formation, type locality, Orella, northwestern Nebraska, southwestern South Dakota and eastern Wyoming; includes the old term, '*Oreodon* beds,' used in the most extended sense." Once again, the Wood committee based a biochronologic concept on a lithostratigraphic unit, which is no longer acceptable in modern stratigraphic practice (Emry et al. 1987). In addition, Terry (1998) transferred Schultz and Stout's (1955, 1961) "Orella A" to the Chadron Formation, so that the Chadron–Orella lithostratigraphic boundary now closely corresponds to the Chadronian–Orellan biochronologic and biostratigraphic boundary. Emry et al. (1987:139) pointed out that the "old term '*Oreodon* beds' used in the broadest sense" applies to many rocks not considered Orellan. As discussed by Prothero and Whittlesey (1998), the Wood committee's (1941) original criteria for recognizing the Chadronian–Orellan boundary (the last occurrence of brontotheres and the top of the Chadron Formation) is also unsuitable, but with Terry's revision, this definition is no longer in conflict because at least four documented occurrences of brontotheres are now known above the Chadron–Brule contact of Schultz and Stout (1955, 1961) but within the Chadron Formation as redefined by Terry (1998).

For these reasons, Prothero and Whittlesey (1998) recommended redefining the Chadronian–Orellan boundary as the first appearance of *Hypertragulus calcaratus*, with the first appearances of *Leptomeryx evansi, Palaeolagus intermedius*, and small *Miniochoerus chadronensis* (= "*M. douglasensis*" of Stevens 1977) serving as characterizing biostratigraphic datums. The last appearance of *Poebrotherium eximium* and *Miohippus grandis* (with brontotheres being used only in a secondary role) can also be used to mark this boundary. The Chadronian–Orellan boundary falls in the upper part of magnetic chron C13r, 7 m (20 feet) above the 5 tuff at Douglas, Wyoming, and the same distance above the PWL in the Seaman Hills, near Lusk, Wyoming. Swisher and Prothero (1990) and Prothero and Swisher (1992) reported a $^{40}Ar/^{39}Ar$ date of 33.91 ± 0.058 Ma on the 5 tuff, and, based on the Berggren et al. (1995) time scale, the Chadronian–Orellan boundary falls very close to 33.7 Ma, or the Eocene–Oligocene boundary.

SUBDIVISIONS OF THE ORELLAN

Emry et al. (1987) reviewed the earlier attempts to subdivide the Orellan, based on the lithostratigraphy of the Orella Member or on the "oreodont faunal zones" of Schultz and Falkenbach (1968), and showed that they were inadequate as then constituted. Korth (1989) proposed a biostratigraphy of the Orellan, again based on the Orella Member in Nebraska, but as Prothero and Whittlesey (1998) pointed out, there were several problems with this zonation. First of all, it was based on the University of Nebraska collections, most of which do not offer stratigraphic resolution of taxa in the alphabetically labeled units in the Orella Member, so the "biostratigraphic zones" of Korth (1989) are essentially equivalent to lithostratigraphic units. In addition, Prothero and Whittlesey (1998) found problems with several of the zonal indicator taxa proposed by Korth (1989). Finally, Korth's (1989) biostratigraphic zones lacked several key criteria (such as type sections) required by the North American Code of Stratigraphic Nomenclature (North American Commission on Stratigraphic Nomenclature 1983).

For these reasons, Prothero and Whittlesey (1998) proposed a division of the Orellan into four successive biostratigraphic zones, complete with defining and characterizing taxa based on the fine-scale biostratigraphic data available from the Frick Collection at numerous localities and including all information required by the code, including type sections. Thus the Orellan is now based on formal biostratigraphic zones as required by the code and can now be considered a stage and age in the sense of the code rather than an informal biochronologic unit.

Earliest Orellan *Hypertragulus calcaratus* Interval Zone (33.7–33.4 Ma) As discussed by Prothero and Whittlesey (1998), the earliest Orellan is now marked by the first appearance of *Hypertragulus calcaratus* and characterized by the first appearances of *Leptomeryx evansi* and *Palaeolagus intermedius*. Its upper limit is marked by the first appearance of the indicator of the next zone, *Miniochoerus affinis*. The type section for this interval zone was designated as the strata from 7 to 17 m (20–50 feet) above the 5 tuff in the Douglas area (full details given in Prothero and Whittlesey 1998:55). This zone is also known from the Seaman Hills section near Lusk, Wyoming. It is correlated with the latest part of magnetic chron C13r and the earliest part of chron C13n (33.7–33.4 Ma).

Late Early Orellan *Miniochoerus affinis* Interval Zone (33.4–33.1 Ma) Prothero and Whittlesey (1998:55) recognized an interval defined by the first appearance of the oreodont *Miniochoerus affinis* and characterized by the first appearances of *Eumys elegans, Pelycomys brulanus, Adjidaumo minutus, Cedromus wardi*, and *Hoplophoneus occidentalis*. This end of this interval is also marked by the last appearance of *Ischyromys parvidens* and the first appearance of *Miniochoerus gracilis*. They designated the type section of the *Miniochoerus affinis* Interval Zone as the strata between 17 and 27 m (63–80 feet) above the PWL in the Boner Ranch section in the Seaman Hills, near Lusk, Wyoming. Principal referred sections include the interval between 17 and 25 m (50–75 feet) above the 5 tuff in Douglas, Wyoming (Evanoff et al. 1992), portions of Orella B in Toadstool Park, Nebraska, and the Lower Nodular Zone in the Big Badlands of South Dakota. These strata correlate with the later part of magnetic chron C13n (33.4–33.1 Ma).

Early Late Orellan *Miniochoerus gracilis* Interval Zone (33.1–32.5 Ma) Prothero and Whittlesey (1998:56) recognized a zone defined by the first appearance of the dwarfed oreodont *Miniochoerus gracilis* and characterized by the first appearance of *Mesohippus barbouri, Agnotocastor readingi, Paradjidaumo validus, Eutypomys thomsoni*, and *Eumys parvidens*. Its end is marked by the last appearance of *Ischyromys parvidens* and the first appearance of the next zonal indicator, *Merycoidodon bullatus*. They designated the type section as the strata 27–50 m (80–150 feet) above the PWL at Boner Ranch in the Seaman Hills, near Lusk, Wyoming. Principal reference sections included Orella C in Toadstool Park, Nebraska, and the strata just above the Lower *Oreodon* Beds but below the Upper *Oreodon* Beds in the Big Badlands of South Dakota. This zone correlates with the latest part of chron C13n and the early part of chron C12r (33.1–32.5 Ma).

Latest Orellan *Merycoidodon bullatus* Interval Zone (32.5–32.0 Ma) The latest Orellan is marked by a large number of distinctive taxa. Prothero and Whittlesey (1998:56) recognized a biostratigraphic zone based on the first appearance of the large-bulla oreodont *Merycoidodon bullatus* and characterized by the first appearance of *Miniochoerus starkensis, Palaeolagus burkei, Prosciurus magnus, Ecclesimus tenuiceps, Tenudomys basilaris, Pelycomys placidus, Heliscomys vetus, Heliscomys mcgrewi, Wilsoneumys planidens,* and *Campestrallomys annectens*. A large number of characteristically Orellan taxa last appear in this interval, including *Hyaenodon crucians, Ischyromys typus, Paratylopus labiatus, Archaeotherium mortoni, Thinohyus lentus, Stibarus quadricuspis, Leptochoerus emilyae, Subhyracodon occidentalis, "Hesperocyon" coloradensis, Prosciurus, Pelycomys, Protosciurus, Oligospermophilus, Eutypomys, Adjidaumo, Paradjidaumo, Heliscomys, Wilsoneumys, Eoeumys, Tenudomys, Pipestoneomys, Megalagus, Palaeolagus intermedius, Centetodon marginalis, Leptictis haydeni, Herpetotherium fugax, Copedelphys stevensoni, Nanodelphys hunti,* and all surviving species of *Mesohippus* (*M. bairdi, M. exoletus, M. westoni,* and *M. barbouri*). This concentration of last appearances (especially of micromammals) may be partially an artifact of poor collecting and lack of screenwashing from strata of the early Whitneyan and may be modified by range extensions once adequate sampling is done. However, for most of the larger mammals, this is not the case, and these taxa almost certainly last occur in this zone.

Prothero and Whittlesey (1998) designated the type section of this zone as the Upper Nodular Zone on the east side of Sheep Mountain Table in the Big Badlands (full details given in Prothero and Whittlesey 1998:56). Principal reference sections include the upper part of Orella C and Orella D in the Toadstool Park area, Nebraska, and the upper part of the Cedar Creek Member in Colorado. These beds correlate with the early part of magnetic chron C12r (32.0–32.5 Ma).

WHITNEYAN

Wood et al. (1941:11) based the Whitneyan "on the Whitney Member of the Brule Formation, type locality, Whitney, northwestern Nebraska, type area, northwestern Nebraska, southwestern South Dakota and eastern Wyoming, including the old term, '*Protoceras–Leptauchenia* beds,' used in the most extended sense." As Emry et al. (1987) pointed out, there were numerous problems with this definition, not the least of which is the fact that it bases a biochronologic interval of time on a lithostratigraphic unit. They recommended that the Whitneyan be defined on biostratigraphic criteria and suggested some possibilities for an appropriate set of criteria.

The multiple sections and high-resolution biostratigraphic data for the Orellan allowed Prothero and Whittlesey (1998) to finely subdivide it into four zones, each less than a million years in duration. Unfortunately, such data are not yet available for the Whitneyan. Most of the best biostratigraphic data come from the Poleslide Member of the Brule Formation in the Big Badlands of South Dakota, which was typically subdivided into the Upper *Oreodon, Protoceras,* and *Leptauchenia* beds of Osborn (1907), Osborn and Matthew (1909), Wanless (1923), Skinner (unpublished field notes), and many other workers. A smaller biostratigraphic database comes from the Whitney Member of the Brule Formation in northwestern Nebraska, which was subdivided into units A, B, and C by Schultz and Stout (1955, 1961). Because fossils usually were zoned only to one of the three subdivisions of the Whitneyan in these regions, the Whitneyan cannot be more finely subdivided than the original data resolution allows. In addition, Whitneyan fossils are much scarcer and more sparsely distributed than they are in the Orellan, further hampering fine-scale biostratigraphic zonation. Finally, the Whitneyan is known well only from two regions (Nebraska and South Dakota), with lesser collections from Colorado, North Dakota, and Wyoming, so many of the key index taxa only occur in one place.

SUBDIVISIONS OF THE WHITNEYAN

Prothero and Whittlesey (1998) proposed a formal division of the Whitneyan into two biostratigraphic zones, based on the excellent biostratigraphic data now available from the Frick Collection. These zones include the following.

Early Whitneyan *Leptauchenia major* Interval Zone (32.0–31.4 Ma) A number of taxa are typical of the early Whitneyan, including abundant *Leptauchenia decora* (the traditional indicator of this zone but known to occur rarely in older rocks) and the first occurrences of *Leptauchenia major, Hyracodon leidyanus, Paratylopus primaevus, Paralabis cedrensis, Diceratherium tridactylum, Protapirus obliquidens, Ectopocynus antiquus, Oxetocyon cuspidatus, Cynodesmus thooides, Agnotocastor praetereadens,* and *Oropyctis pediasius.* Last occurrences in this zone include *Miniochoerus starkensis, Stibarus obtusilobus, Hyaenodon horridus, Cedromus wilsoni, Metadjidaumo hendryi, Agnotocastor praetereadens,* and *Oropyctis pediasius.* Prothero and Whittlesey (1998) designated a type section for this zone as the Upper *Oreodon* Beds (0–30 m, or 0–90 feet, above the Scenic-Poleslide contact) on the south side of Sheep Mountain Table in the Big Badlands of South Dakota (see Prothero and Whittlesey 1998:56 for details). Its principal reference section is Whitney A in the Toadstool Park area, Nebraska, and the lower part of the Vista Member in Colorado. This zone correlates with the middle of magnetic chron C12r (32.0–31.4 Ma). It is calibrated by the Lower Whitney Ash, which was $^{40}Ar/^{39}Ar$ dated at 31.8 ± 0.023 Ma (Swisher and Prothero 1990; Prothero and Swisher 1992).

Late Whitneyan *Merycoidodon major* Interval Zone (31.4–30.0 Ma) The traditional "*Protoceras* beds" and "*Leptauchenia* beds" of the Big Badlands yield an essentially homogeneous fauna, as does Whitney B–C in Nebraska. For that reason, Prothero and Whittlesey (1998) were not able to maintain this distinction based on lithostratigraphy rather than faunal change. Instead, they recognized a single late Whitneyan zone, defined by the first appearance of the distinctive large oreodont *Merycoidodon major* and characterized by the first appearances of *Protoceras celer* (the traditional zonal indicator but known only from the channel sandstones in the Big Badlands); the camel *Pseudolabis dakotensis;* the horses *Miohippus intermedius, Miohippus annectens, Miohippus equinanus,* and *Miohippus gidleyi;* and *Hoplophoneus dakotensis, Eusmilus cerebralis, Nimravus brachyops, Hyaenodon brevirostrus, Eumys brachyodus,* and *Scottimus lophatus.* Last occurrences include *Palaeolagus burkei.* Prothero and Whittlesey (1998) designated this interval as the *Merycoidodon major* Interval Zone, with its type section as the strata between 30 and 103 m (90–310 feet) above the Scenic-Poleslide contact on the south side of Sheep Mountain Table in the Big Badlands (see Prothero and Whittlesey 1998:57 for full details). This interval correlates with late chron C12r to early chron C11r (31.4–30.0 Ma). It is calibrated by the Upper Whitney Ash, which was $^{40}Ar/^{39}Ar$ dated at 30.58 ± 0.61 Ma, and by the overlying Nonpareil Ash in the Arikareean, which was dated at 30.05 ± 0.19 Ma (Swisher and Prothero 1990; Prothero and Swisher 1992).

WHITNEYAN-ARIKAREEAN BOUNDARY

Tedford et al. (1996) reviewed the abundant new data on strata spanning the Whitneyan–Arikareean boundary, including the previously undescribed "brown siltstone member" of the White River Group above the Whitney Member in Nebraska. After reviewing all the available biostratigraphic data, they placed the end of the Whitneyan and beginning of the Arikareean at the first appearance of *Nanotragulus loomsi, Palaeolagus hypsodus, Palaeocastor nebrascensis, Leidymys blacki,* and *Mesoreodon minor.* These taxa first occur low in the Sharps Formation in South Dakota (near the Rockyford Ash) and near the second Nonpareil Ash Zone of the "brown siltstone" in Nebraska. This boundary occurs near the base of chron C11n (30.0 Ma). The end of the Whitneyan is also marked by the last occurrences of a number of taxa typical of the White River Chronofauna, including *Leptomeryx, Merycoidodon, Paratylopus, Paralabis, Perchoerus, Heptacodon, Leptochoerus, Colodon, Protapirus, Hesperocyon, Osbornodon, Dinictis, Paradjidaumo, Eumys,* and *Scottimus.*

CONCLUSION

Although the fossils of the White River Group have been known for more than 150 years, only recently has it been possible to use these collections for classic range zone biostratigraphy. The enormous, stratigraphically zoned collections made by the Frick Laboratory and the stratigraphic research of Frick workers such as Morris Skinner finally made that achievement possible. The additional breakthroughs of magnetic stratigraphy and $^{40}Ar/^{39}Ar$ dating allowed numerical dating, detailed correlation of individual sections, and calibration of these biostratigraphic zones to the global time scale. Consequently, some the great potential of the White River Group, with its excellent sections, abundant ashes, and enormous fossil collections, can now be realized.

We now have four biostratigraphically distinctive intervals in the Chadronian, four formally proposed range zones in the Orellan, and two formal zones in the Whitneyan. For the Orellan and Whitneyan, at least, this means that these land mammal ages are actually based on biostratigraphic zones and stages, and so they are true stage/age units in the sense of the North American Code of Stratigraphic Nomenclature (North American Commission on Stratigraphic Nomenclature 1983). The Chadronian subdivisions have not yet been formally proposed, but Prothero and Emry (1996a) and this chapter have indicated the best candidates for the zonal index fossils and for type sections. Each of the four Chadronian, four Orellan, and two Whitneyan intervals are quite short, most less than a million years in duration, which offers the first high-resolution, well-calibrated chronostratigraphy for the White River Group. Such high-resolution data have already proven useful for a number of evolutionary and paleoclimatic studies (Prothero and Heaton 1996; Prothero 1999), where precise dating of faunal events is necessary.

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