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HOW ISOCHRONOUS ARE MAMMALIAN BIOSTRATIGRAPHIC EVENTS?

Donald R. Prothero

Dept. Vertebrate Paleontology, American Museum of Natural History, New York, NY 10024

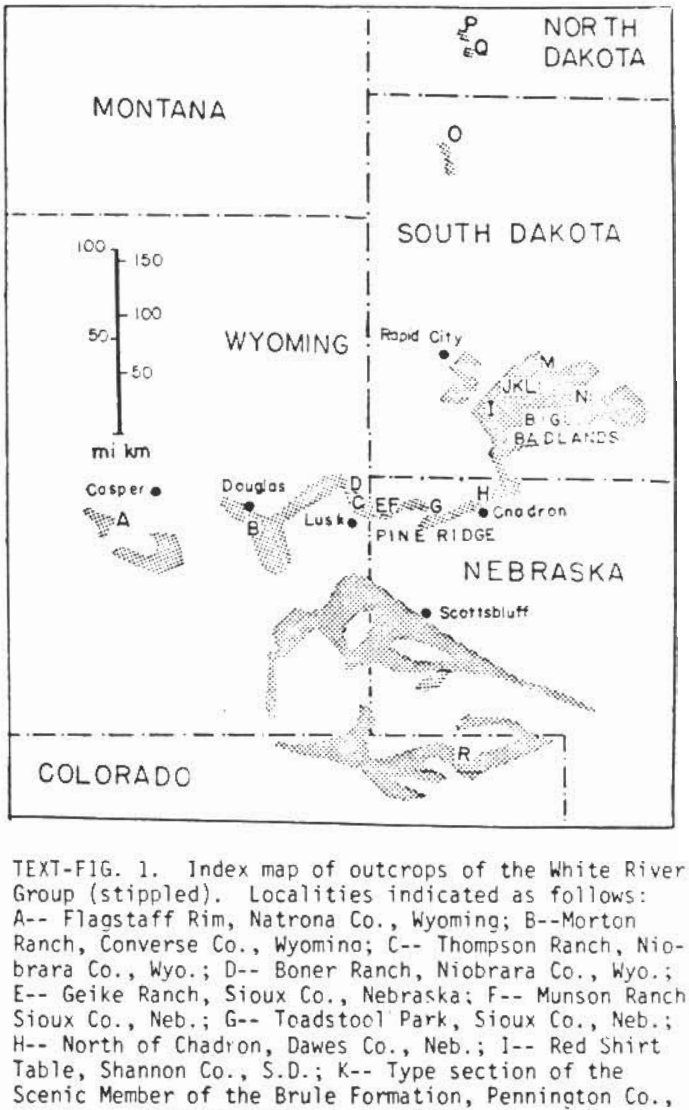
ABSTRACT--A biostratigraphic zonation of mammals from the medial Oligocene (latest Chadronian-Orellan-early Whitneyan) was developed for the White River Group of the Dakotas, Wyoming, Nebraska, and Colorado. This zonation was tested against the magnetostratigraphy of each section. With only minor exceptions, individual biostratigraphic datums in the zonation of each section occurred in the same polarity zones. Thus, Oligocene mammalian biostratigraphic events appear to be isochronous within the resolution of the system.

INTRODUCTION

In his anniversary address to the Geological Society of London (1862), Thomas Henry Huxley proposed the term "homotaxis" (from the Greek ὁμοιος "same" and τάξις "order") for the similarity of order of occurrence of fossils in two or more stratified sequences. Huxley proposed the term to avoid the implication that homotaxial sequences were necessarily synchronous. The time significance of homotaxial sequences has been much discussed by biostratigraphers (e.g. Harper, 1980; O'Rourke, 1976; Scott, 1965; Bell, 1959). Rarely, however, has it been possible to test the synchroneity of homotaxial sequences.

To test this hypothesis of synchroneity, one must have a higher-resolution form of time control, independent of the biostratigraphy. Some high-resolution events that have been used include: 1) paleomagnetic reversals in deep-sea cores (e.g. Hays et al., 1969); 2) isotopic events in deep-sea cores (e.g. Haq et al., 1980; Hays and Shackleton, 1976); 3) bentonites (e.g. Kauffman, 1970); and 4) radiometric dates (Kauffman, 1970; Churkin et al., 1977). In the microfossil and macroinvertebrate examples given above, the sequences have generally proven to be synchronous within the resolution of the technique. To my knowledge, however, no attempt has been made to critically test the isochroneity of vertebrate biostratigraphic events.

Paleomagnetic reversals, which are worldwide and geologically instantaneous, could be used as time planes with which one could test mammalian biostratigraphy. The ideal way to make this test would be to develop a biostratigraphy and magnetostratigraphy for an area that is abundantly fossiliferous, with numerous continuous, thick, well-exposed sections over a wide geographic area. The Oligocene White River Group of the High Plains (Text-fig. 1) meets these criteria better than almost any other part of the vertebrate record. Indeed, the White River Badlands remain among the most fossiliferous vertebrate-bearing beds known. It is also necessary to have precise stratigraphic control on nearly every specimen. Fortunately, thanks to the diligent attention paid to stratigraphy by the workers of the Frick Laboratory, the Frick White River collections in the American Museum of Natural History have the necessary level of stratigraphic resolution. Specimens are usually zoned to local stratigraphic markers (frequently ash beds), and the stratigraphic data on each Frick specimen is often reliable to the nearest five feet or less.



TEXT-FIG. 1. Index map of outcrops of the White River Group (stippled). Localities indicated as follows: A-- Flagstaff Rim, Natrona Co., Wyoming; B--Morton Ranch, Converse Co., Wyoming; C-- Thompson Ranch, Niobrara Co., Wyo.; D-- Boner Ranch, Niobrara Co., Wyo.; E-- Geike Ranch, Sioux Co., Nebraska; F-- Munson Ranch, Sioux Co., Neb.; G-- Toadstool Park, Sioux Co., Neb.; H-- North of Chadron, Dawes Co., Neb.; I-- Red Shirt Table, Shannon Co., S.D.; K-- Type section of the Scenic Member of the Brule Formation, Pennington Co., S.D.; L-- Chamberlain Pass, Pennington Co., S.D.; M-- Sage Creek Basin, Pennington Co., S.D.; N-- Cedar Pass, Jackson Co., S.D.; O-- Slim Buttes, Harding Co., S.D.; P-- Little Badlands, Stark Co., N.D.; Q-- Fitterer Ranch, Stark Co., N.D.; R-- Chimney Canyons, Logan Co. Colorado.

BIOSTRATIGRAPHY

The most abundantly fossiliferous interval in the White River Oligocene, the late Chadronian-Orellan-early Whitneyan, was chosen for analysis. Our paleomagnetic studies (Prothero et al., in press) have shown that this interval spans over two million years, from about 30.0 to 32.5 Ma (million years before present). Several groups of land mammals which lived then are represented by abundant Frick specimens in the American Museum collections. These medial Oligocene beds are unusual for vertebrate-bearing deposits in that they are abundantly fossiliferous throughout most of the section, with relatively few barren intervals. Thus, conditions appear ideal for developing a full biostratigraphic zonation from local range zone data.

The most abundant, rapidly changing, and thus most useful groups are the following:

1. Titanotheres: The last appearance of titanotheres (Family Brontotheriidae) has traditionally been one of the criteria for the Chadronian-Orellan boundary (Wood et al., 1941; Emry et al., in press). Since titanotheres are the largest mammals present in the White River Group, even fragmentary remains are readily spotted in surface collecting and easily identifiable.

2. Oreodonts: Oreodonts are so abundant in the Orellan that these rocks were once known as the "Oreodon beds." The larger oreodont, *Merycoidodon culbertsonii*, occurs throughout the Orellan. In the late Orellan, it acquires an inflated auditory bulla. The smaller oreodont, *Miniochoerus*, decreases so rapidly in size through the Orellan that correlation can be made on basis of size.

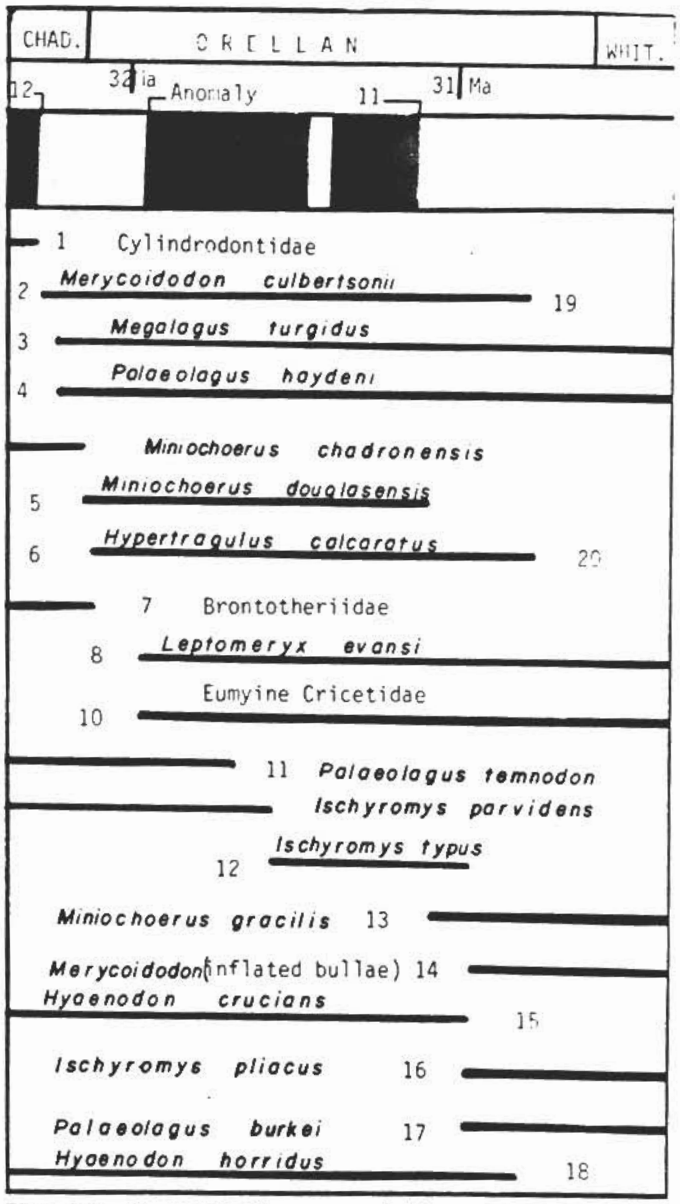
3. Other artiodactyls: The small deerlike ruminant *Hypertragulus calcaratus* is known only from the Orellan. A slightly larger deerlike ruminant, *Leptomeryx*, changes from the primitive Chadronian form to the typical Orellan taxon, *Leptomeryx evansi*, during the interval in question. The chief character distinguishing these two species is a change in the form of the third lower premolar (Emry, 1970). The camel *Poebrotherium* shows at least three distinct species in this interval.

4. Rabbits: Several species of rabbitsoccur in great abundance in the Orellan. *Palaeolagus haydeni* is the most abundant in the early Orellan. A smaller form, *Palaeolagus burkei*, first appears in the late Orellan. The last appearance of the Chadronian rabbit *Palaeolagus temnodon* is also useful. A larger rabbit, *Megalagus turgidus*, is also present but fairly rare (Gawne, 1978; Wood, 1940; Dawson, 1958).

5. Rodents: The most abundant and rapidly changing rodent is *Ischyromys*. Using the species definitions of Wood (1980), the small, latest Chadronian form *Ischyromys parvidens* is followed in the earliest Orellan by the slightly larger *I. typus*, and then in the mid-Orellan by the largest and last form, *I. pliacus*. The first appearance of eumyine cricetid rodents (Martin, 1980) and the last appearance of the characteristically Chadronian cylindrodont rodents (Emry, 1970) are also useful events in this interval.

6. Other taxa: The first appearance of the insectivore *Leptictis dakotensis* occurs in the earliest Orellan. The creodonts *Hyaenodon crucians* and *Hyaenodon horridus* both become extinct in the Orellan (Mellett, 1977). The rare carnivore *Paleogale lagophaga* occurs at a single level where it is known.

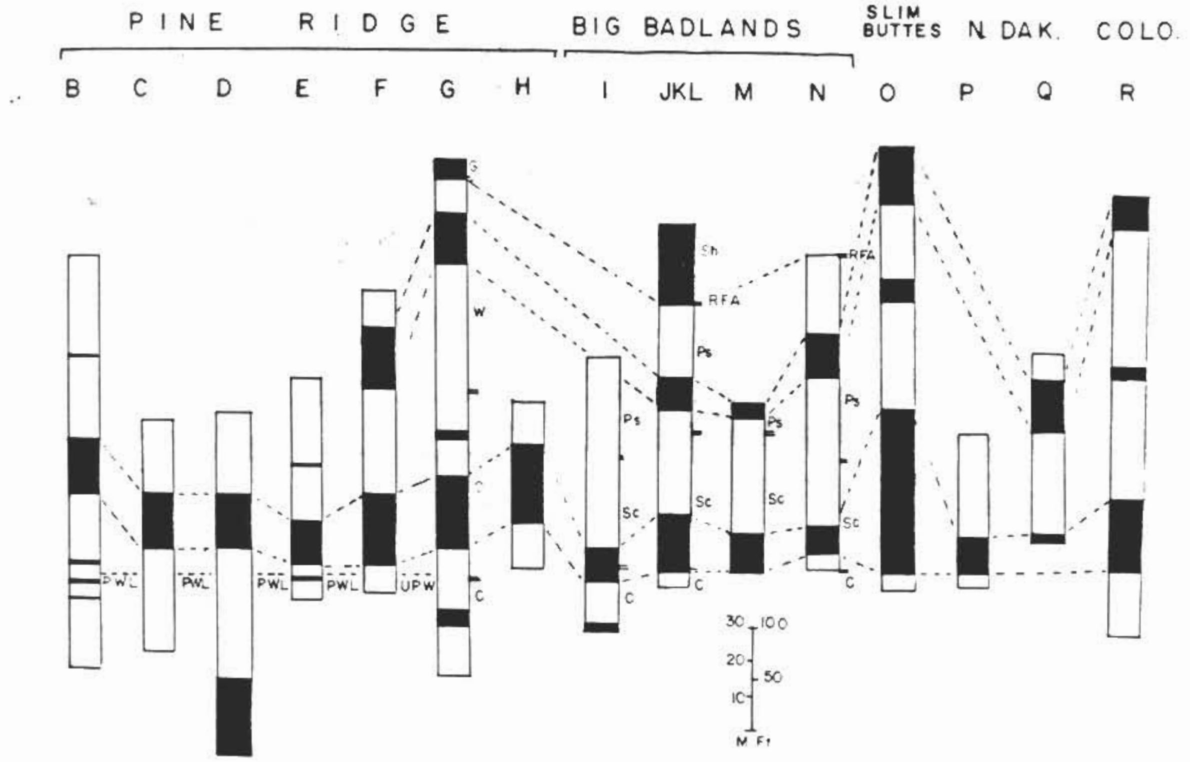
Composite ranges for these taxa are shown in Text-fig. 2, plotted against their position in the magnetic polarity timescale. The sequence of biostratigraphic datums is listed in Table 1.



TEXT-FIG. 2--Temporal ranges of biostratigraphically-significant taxa in the medial Oligocene, plotted against their position on the magnetic polarity timescale. North American Land Mammal "Ages", magnetic anomaly numbers, and absolute ages in million years shown at top. For numbers, see Table 1.

PALEOMAGNETIC ANALYSIS

The White River Group is also ideally suited for paleomagnetic stratigraphy. The lithology is mostly nodular or ashy siltstone, easily sampled by simple hand tools. It is also fine-grained enough that multidomain grains present no problem. In this study, over twenty fossiliferous White River sections in the Dakotas, Nebraska, Wyoming and Colorado were sampled at 5.5 foot (1.7 meter) intervals, with three samples per site (Text-figs. 1, 3). This resulted in a total of over 800 sites and some 2400 samples, spanning more

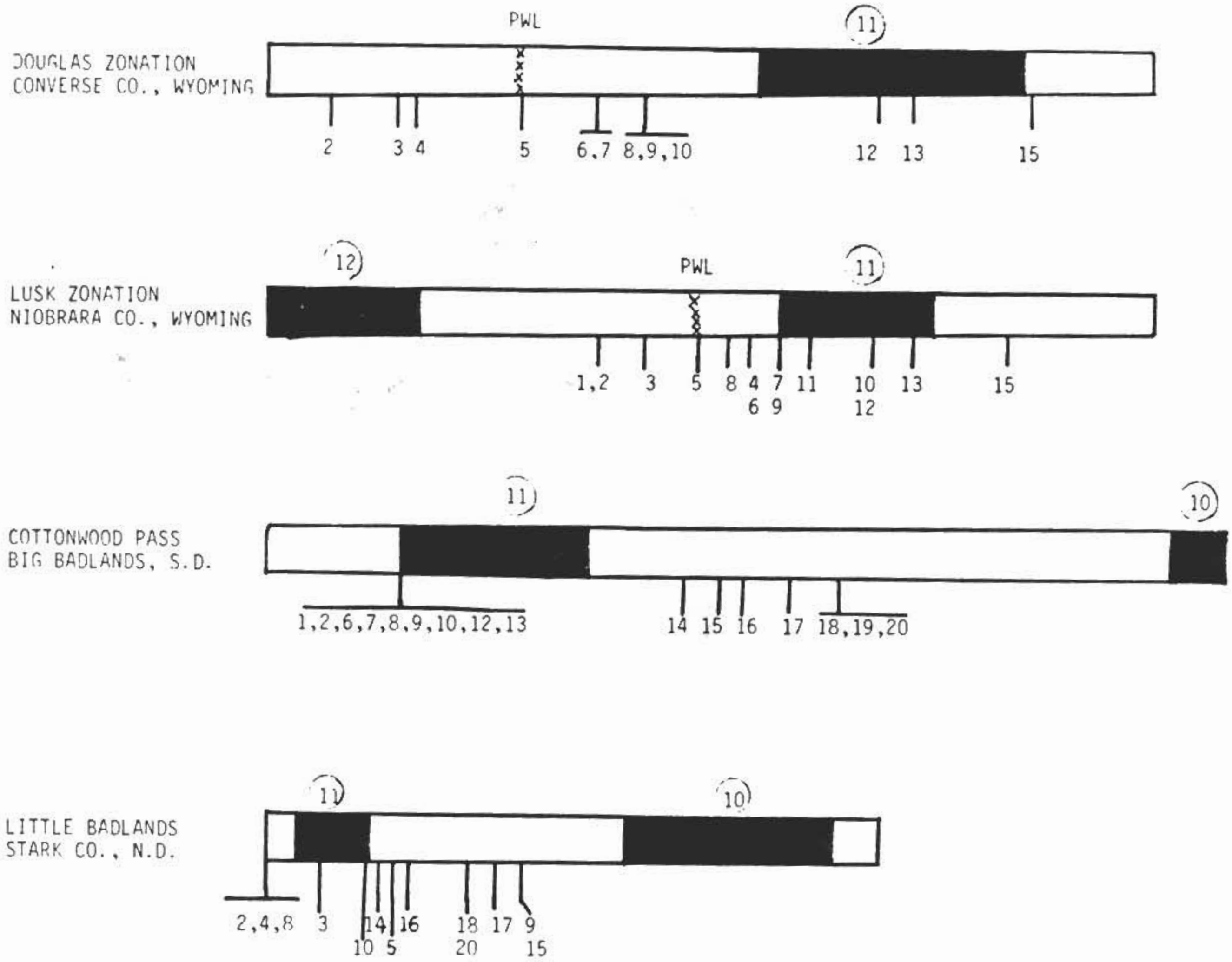


TEXT-FIG. 3-- Polarity interpretations for 17 late Chadronian-Orellan-Whitneyan-Arikareean sections in Wyoming, Nebraska, the Dakotas, and Colorado. Section locations are shown in Text-fig. 1. Solid bars indicate normal polarity; open bars are of reversed polarity. Correlations based on biostratigraphic studies discussed in text. Datum is contact between the Chadron and Brule Formations, or its equivalents. Double line indicates formation boundaries. Abbreviations are as follows: C-- Chadron Formation; G-- Gering Formation, Arikaree Group; O-- Orella Member, Brule Formation; Ps-- Poleslide Member, Brule Formation; PWL-- Purplish White Layer, a marker ash; RFA-- Rockyford Ash; Sc-- Scenic Member, Brule Formation; Sh-- Sharps Formation, Arikaree Group; W-- Whitney Member, Brule Formation; UPW-- Upper Purplish White layer, Toadstool Park, Nebraska.

than 4800 feet (1500 m) of section. Samples were cut down with a tungsten-carbide band saw blade and measured in an ScT cryogenic magnetometer at Woods Hole Oceanographic Institution and Lamont-Doherty Geological Observatory. Both thermal and alternating field demagnetization were necessary to obtain a reasonable polarity interpretation on over 90% of the sites. Further details of the paleomagnetic analysis are presented elsewhere (Prothero et al., in press). The primary result of the analysis was that a consistent pattern of magnetic reversal was obtained: a latest Chadronian normal interval we correlate with anomaly 12; an early Orellan normal interval we correlate with anomaly 11; a mid-Whitneyan normal interval we correlate with anomaly 10. The base of the Arikareean Land Mammal "Age" seems to correspond to the base of anomaly 9.

RESULTS

The biostratigraphic events listed in Table 1 are plotted in stratigraphic position in Text-fig. 4. Four key sections are shown: the Douglas composite zonation, Converse Co., Wyoming (Section B in Text-figs. 1, 3); the Lusk composite zonation, Niobrara Co., Wyoming (Sections C-D, Text-figs. 1,3); the Cottonwood Pass composite zonation, from the Big Badlands of South Dakota (Sections J-K-L, Text-figs. 1,3); and the Fitterer Ranch-Little Badlands composite zonation, Stark Co., North Dakota (Sections P-Q, Text-figs. 1,3). Results for the Slim Buttes (Section O), Toadstool Park (Section G), and Colorado (Section R) zonations were still in progress at the deadline for this manuscript. Superimposed on each of these biostratigraphic zona-



TEXT-FIG. 4--Biostratigraphic datum levels and polarity stratigraphy of four key sections discussed in text. Circled numbers refer to magnetic anomaly number; other numbers are biostratigraphic datums listed in Table 1. PWL= Purplish White Layer, a persistent marker ash.

tions is the magnetic polarity signal. The most continuously fossiliferous sequences are those at Lusk and Douglas. In these two sections, the sequence of biostratigraphic datums is nearly identical, and all datums fall in the same polarity intervals except one. The exception is the first appearance of eumyine cricetid rodents (Datum 10), which occurs below anomaly 11 in Douglas but within it at Lusk. This discrepancy is probably an artifact of collection, since eumyines are very small and tend to be scarce from these two localities.

In the Big Badlands section, all of the events that occurred around anomaly 11 in Wyoming are clustered at the base of anomaly 11. This clearly seems to indicate that a large hiatus is present at the base of anomaly 11 (the base of the Lower Nodular Zone in the Big Badlands), resulting in truncated ranges. Later Orellan and Whitneyan datums are present in the Big Badlands sections that do not show up in the Wyoming sections, which apparently do not range into that interval.

The North Dakota collections are much smaller than those from the other areas, and most of the interval is barren. Thus, the sequence appears scrambled by comparison with the Wyoming and South Dakota sections, and many ranges appear shorter here than elsewhere. In addition, some taxa that are abundant in other areas are surprisingly absent in North Dakota (e.g. *Hypertragulus calcaratus*), possibly indicating some ecologic or geographic differences between North Dakota and the areas to the south. Given these limitations, only four datums in North Dakota occur in the wrong polarity zone. These are the first appearances of *Megalagus turgidus, Miniochoerus douglasensis, Paleogale lagophaga,* and eumyine cricetids (Datums 3, 5, 9, and 10 respectively). All of these taxa are extremely rare in the lower levels in North Dakota, so these anomalous ranges are probably truncated due to lack of sampling. Datums in the most abundant taxa, and those representing evolutionary first occurrences, are consistent with the pattern seen in other areas.

Thus, the overall biostratigraphic zonation in the medial Oligocene is only contradicted by the magnetostratigraphy in a few instances. These exceptions all appear to be due to lack of collection of very rare taxa. The most reliable biostratigraphic events (e.g. evolutionary first occurrences in continuous, abundant lineages) consistently fall in the same magnetic polarity zones from section to section. Within the resolution of this system, then, mammalian biostratigraphic events appear to be isochronous.

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TABLE 1

Biostratigraphic datum levels (FAD= first appearance datum; LAD= last appearance datum).

1. LAD Cylindrodontidae
2. FAD *Merycoidodon culbertsonii*
3. FAD *Megalagus turgidus*
4. FAD *Palaeolagus haydeni*
5. FAD *Miniochoerus douglasensis*
6. FAD *Hypertragulus calcaratus*
7. LAD Brontotheriidae
8. FAD *Leptomeryx evansi*
9. FAD *Paleogale lagophaga*
10. FAD Eumyine Cricetidae
11. LAD *Palaeolagus temnodon*
12. FAD *Ischyromys typus*
13. FAD *Miniochoerus gracilis*
14. FAD *Merycoidodon* (inflated bullae)
15. LAD *Hyaenodon crucians*
16. FAD *Ischyromys pliacus*
17. FAD *Palaeolagus burkei*
18. LAD *Hyaenodon horridus*
19. LAD *Merycoidodon culbertsonii*
20. LAD *Hypertragulus calcaratus*

Dear Colleague:

Since the deadline for this manuscript, the biostratigraphic zonation has been considerably refined. Attached are some figures which show the increased resolution of biostratigraphic datums around polarity transitions, and strengthen the conclusions of this paper.

BASE OF CHRON C11N (Anomaly 11)

Just before Anomaly 11: LAD Brontotheriidae, LAD *Poebrotherium eximium*, transition from *Leptomeryx speciosus* to *L. evansi*

Just above base of Anomaly 11: transition from *Miniochoerus douglasensis* to *M. gracilis*, FAD of *Eumys elegans*, FAD of *Eumys obliquidens*.

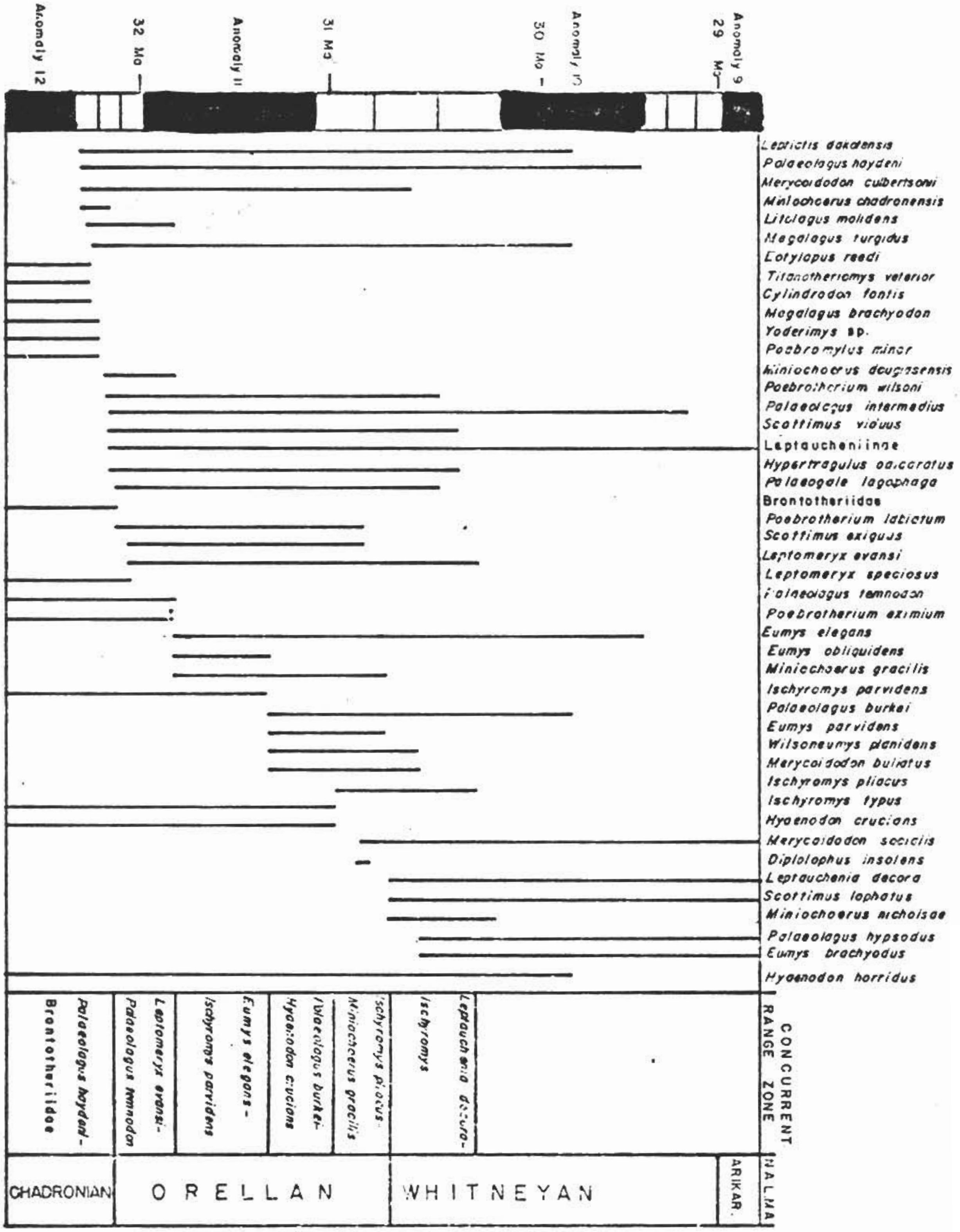
TOP OF CHRON C11N (Anomaly 11)

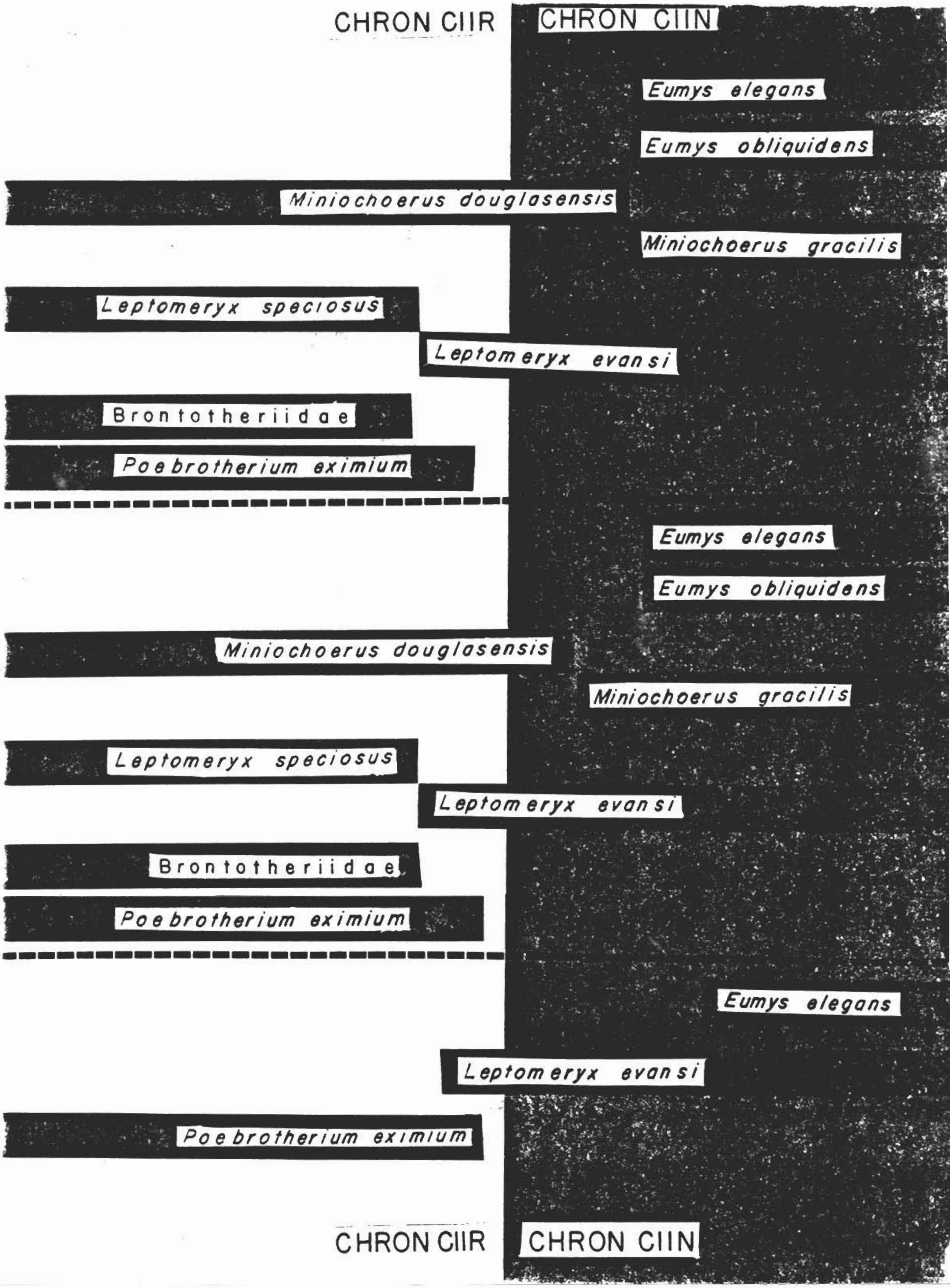
Just below top of Anomaly 11: LAD *Eumys obliquidens*

Just above top of Anomaly 11: transition from *Ischyromys typus* to *I. pliacus*, transitinn from *Miniochoerus gracilis* to *M. nicholsae*, FAD *Wilsoneumys planidens*, FAD *Eumys parvidens*

Occurrence variable (probably due to poor sampling):
LAD *Hyaenodon crucians*, FAD *Palaeolagus burkei*

Biostratigraphic ranges plotted against the magnetic polarity timescale for the remaining taxa of the study are shown in Fig. 171.


Anomaly 12
32 Ma
Anomaly 11
31 Ma
30 Ma
Anomaly 10
29 Ma
Anomaly 9
Leptictis dakotensis
Palaeolagus haydeni
Merycoidodon culbertsoni
Miniochoerus chadronensis
Litolagus molidens
Megalagus turgidus
Eotylopus reedi
Titanotheriomys veterior
Cylindrodon fontis
Megalagus brachyodon
Yoderimys sp.
Poebromylus minor
Miniochoerus douglasensis
Poebrotherium wilsoni
Palaeolagus intermedius
Scottimus viduus
Leptaucheniinae
Hypertragulus calcaratus
Palaeogale lagophaga
Brontotheriidae
Poebrotherium labiatum
Scottimus exiguus
Leptomeryx evansi
Leptomeryx speciosus
Palaeolagus temnodon
Poebrotherium eximium
Eumys elegans
Eumys obliquidens
Miniochoerus gracilis
Ischyromys parvidens
Palaeolagus burkei
Eumys parvidens
Wilsoneumys planidens
Merycoidodon bullatus
Ischyromys pliacus
Ischyromys typus
Hyaenodon crucians
Merycoidodon socialis
Diplolophus insolens
Leptauchenia decora
Scottimus lophatus
Miniochoerus nicholsae
Palaeolagus hypsodus
Eumys brachyodus
Hyaenodon horridus
Brontotheriidae
Palaeolagus haydeni-
Palaeolagus temnodon
Leptomeryx evansi-
Ischyromys parvidens
Eumys elegans-
Hyaenodon crucians
Palaeolagus burkei-
Miniochoerus gracilis
Ischyromys pliacus-
Ischyromys
Leptauchenia decora-
CONCURRENT RANGE ZONE
CHADRONIAN
ORELLAN
WHITNEYAN
ARIKAR.
NALMA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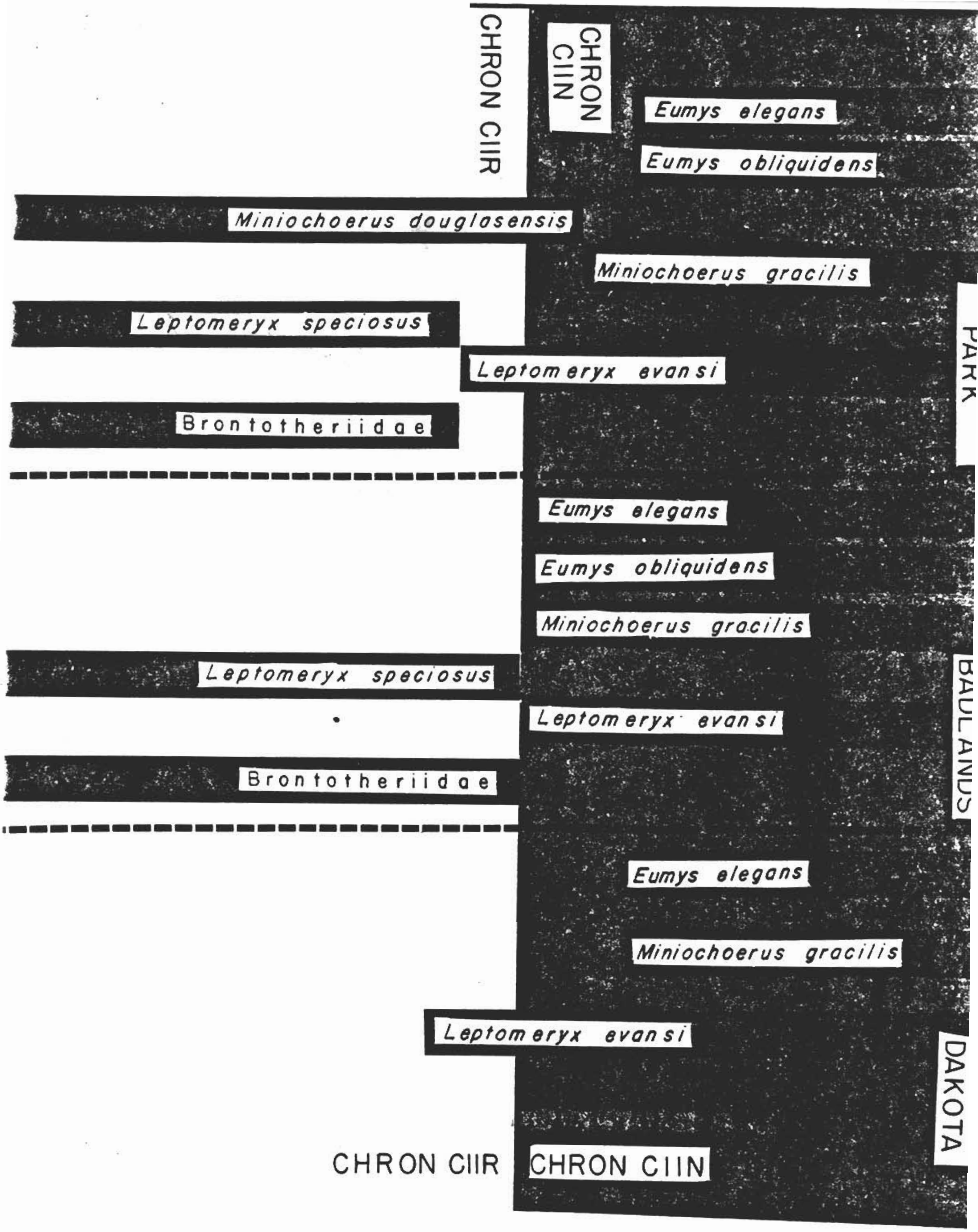
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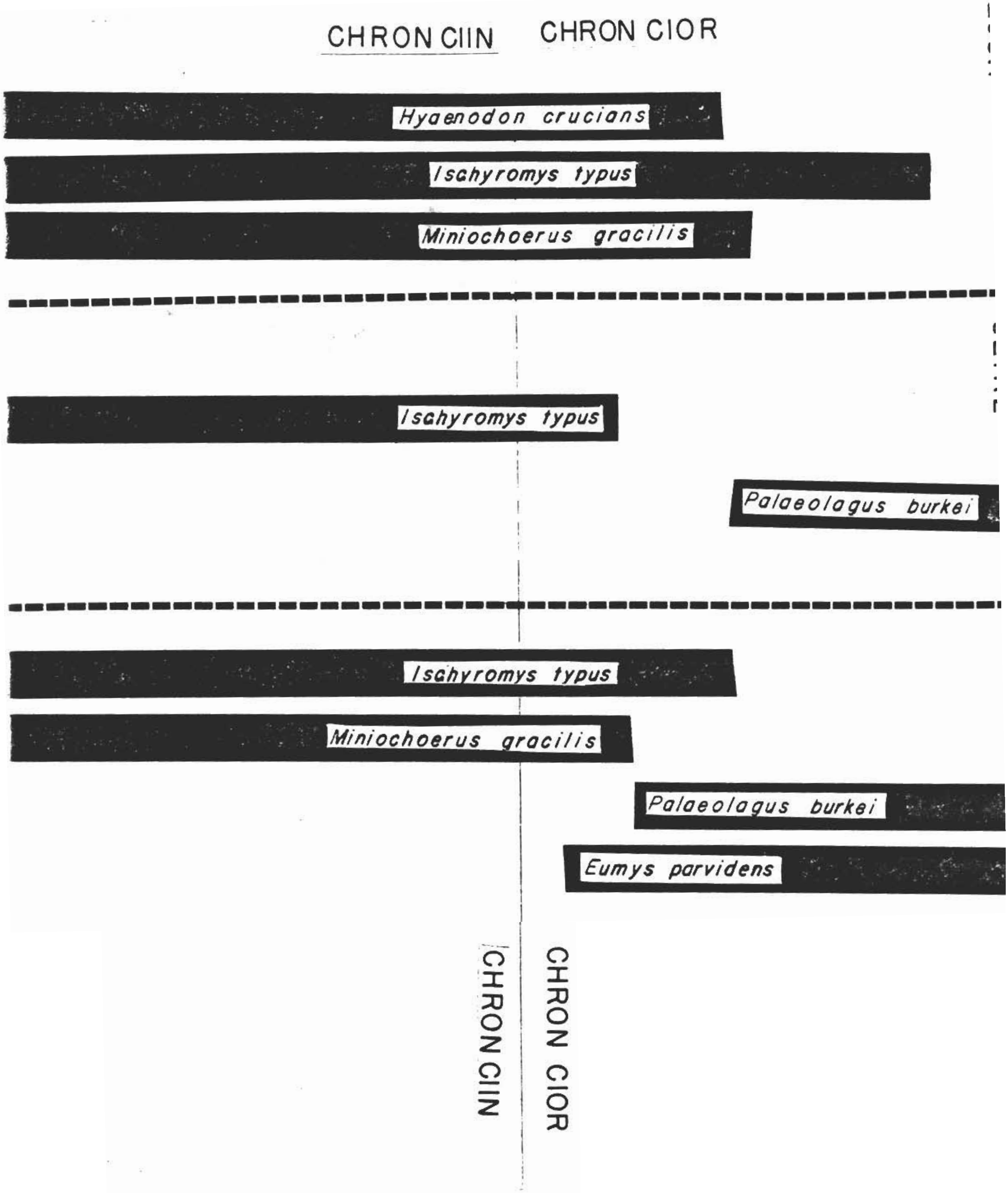
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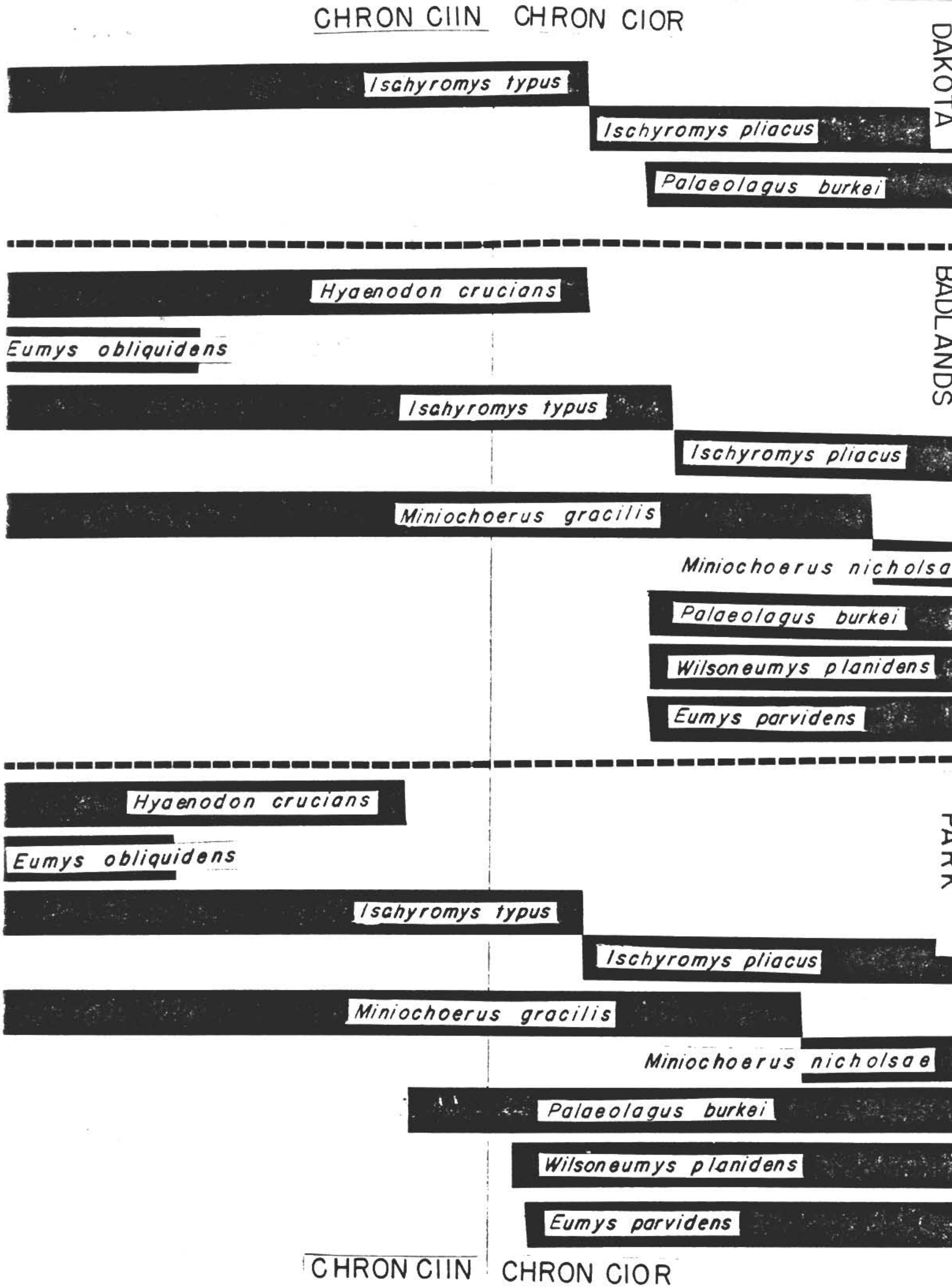
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Ischyromys pliacus
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Miniochoerus nicholsa
Palaeolagus burkei
Wilsoneumys planidens
Eumys parvidens
PARK
Hyaenodon crucians
Eumys obliquidens
Ischyromys typus
Ischyromys pliacus
Miniochoerus gracilis
Miniochoerus nicholsae
Palaeolagus burkei
Wilsoneumys planidens
Eumys parvidens
CHRON CIIN
CHRON CIOR