AN OVERVIEW OF THE TERRESTRIAL EARLY TERTIARY OF SOUTHERN NORTH AMERICA — FOSSIL SITES AND PALEOPEDOLOGY

JUDITH A. SCHIEBOUT
DEPARTMENT OF GEOLOGY
LOUISIANA STATE UNIVERSITY

ABSTRACT

Increasingly detailed stratigraphic work in intermontane basins from Montana to Texas has revealed significant differences between northern and southern early Tertiary terrestrial faunas of western North America. Paleontological data from southern California, Mexico, New Mexico, and west Texas allows analysis of the effects of topography and climate on southern faunal distribution. Endemism in the Paleocene and Eocene of southern California and the Paleocene of west Texas can be attributed in part to geographic isolation. Observed differences between northern and southern faunas are tied to climatic differences, which are traceable from locality to locality using paleopedology. For example, Paleocene fluvial mudstones in west Texas and New Mexico show prominent red and black banding. Red layers are rich in soil-formed calcite nodules. Red color-banding and nodules are not widespread in northern localities until the early Eocene, indicating a northward spread of warm, variable climate. Migrations of animals, triggered by such climatic changes, may be responsible for abrupt faunal changes in the northern intermontane basins.

Early Tertiary fossil vertebrate sites are scarce east of the Big Bend region of Texas now, but within a decade lignite strip mining in east Texas, Louisiana, and Arkansas will be producing outcrops. The best hope for finding extensive early Tertiary terrestrial faunas in eastern North America lies in the Gulf Coast.

The early Tertiary Gulf Coast may have served as a source for new forms migrating to the west and north. The Paleocene and early Eocene faunas of the southeastern U. S. can be expected to have strong European affinities, and the late Eocene to have close ties to western North America. The Paleocene faunas of west Texas show less resemblance to those of France, which were similar in latitude, than the high degree of similarity of early Eocene animals of Europe and western North America would have suggested. Evidently, neither the slow-to-open North Atlantic nor the long distances were insurmountable barriers to many mammals before the end of the early Eocene. The Cretaceous interior seaway split North America and served as a barrier to migration between west and east Texas. The effects of this separation may have lingered throughout the Paleocene.

INTRODUCTION

Several recent developments make this a good time to look both backwards and forwards at the terrestrial Paleocene and Eocene of southern North America. A revision of terrestrial Cenozoic chronology edited by M.O. Woodburne is in preparation and should be published within 1979 or 1980 (Woodburne, 1978, pers. comm.). Although many aspects of this summing up of available data on Cenozoic chronology will be highly controversial, it should serve as a reference point for decades, as its predecessor by Wood *et al.* (1941) did. A great deal of new stratigraphic data has become available recently. Detailed stratigraphic studies such as those of Gingerich (1976) are making possible a much greater precision in examining past evolutionary and paleoecologic events. New dating and fossil-collecting techniques and changes in the legal status of pre-Pleistocene fossils also provide an increasingly detailed background against which attempts can be made to correlate paleontological data on animal distributions with information on small scale environmental changes, available from studies of depositional environments and paleopedology.

ADVANCES IN TERRESTRIAL PALEONTOLOGY

Screen washing for microvertebrate fossils (Hibbard, 1949; McKenna, 1962) is increasing the value of vertebrate fossils as stratigraphic tools. It greatly increases sample sizes and recovers rare material from sediments essentially barren to surface hunting and quarrying. For example, a screen washing of approximately one ton of sediment from a single Paleocene site in west Texas yielded 19 genera (Schiebout, 1974), three times the total previously known from the whole formation (Wilson, 1967). New techniques of sorting fossils from concentrate (screen wash residue), such as the heavy liquid method reported by Murray and Lezak (1977), will make this technique more and more useful.

New dating techniques and increasing application of old ones are producing a more reliable framework for reconstruction of early Tertiary events. For example, radiometric dating of volcanic rocks intercalated with vertebrate-bearing sediments is producing better resolution of the age of many classic sites. A magnetic reversal scale for the terrestrial early Tertiary is also being developed (Berggren *et al.*, 1978; Lindsay *et al.*, 1978).

Widespread acceptance of the idea of plate tectonics has revolutionized paleogeography and spurred interaction of paleocologists in testing reconstruction of continental positions and latitudes. The recent work of Dawson *et al.* (1976) and West *et al.* (1977) in the Eureka Sound Formation of Ellesmere Island is an example of "continental drift" providing incentive for investigation of a new and unusual area for vertebrate fossils. Drift theory and paleobotanical evidence had led McKenna (1972a, 1972b, 1972c, 1975) to consider an early Tertiary North Atlantic migration route for terrestrial animals between North America and Europe. Dawson *et al.* (1976) reported a small Eocene fauna of vertebrates which supports the idea that a warm temperate climate extended to 80° north latitude. A symposium entitled "Cenozoic History in and around the northern Atlantic and Arctic Oceans" at the 1978 Geological Society of America Annual Meeting drew workers interested in reconstructing early Tertiary conditions in this region from a wide variety of disciplines. The early Eocene (Wasatchian) mammalian faunas of North America show at last 50% generic similarity to those of Europe; such similarity is not repeated again and drops to 10% in the Bridgerian (Dawson *et al.*, 1976), suggesting that this marks the severance of the North America-to-Europe migration route (see summary of Berggren *et al.*, 1978).

Both problems and opportunities arise from changes in the legal status of vertebrate fossils and from extensive mining and other disturbances that will affect early Tertiary terrestrial deposits more and more frequently in the future. A debate is underway between federal officials and the paleontological community regarding the applicability of such legislation as the Antiquities Act of 1906, the National Environmental Protection Act, and the Moss-Bennett Bill to those paleontological materials not associated with anthropological or archaeological material. The National Heritage Act of 1972 specifically includes paleontological materials for protection, and new legislation specifically aimed at providing salvage procedure for such fossils can be expected in a few years (Mc Kinney, 1978, pers. comm.). Marshall (1976) provided a review of the legal status of paleontology in the U.S. at that time.

At present, regulation often means that scientists and conscientious amateurs are excluded from areas where vandals and ill-trained amateurs continue to roam at will. As the historical, scientific, and aesthetic values of vertebrate fossils are gradually communicated to the bureaucracy responsible for regulating antiquities, better cooperation between government agencies and scientists should develop. As paleontologic remains come to be regarded as a natural resource, they can no longer be blithely ignored by miners and land developers. Availability of funds for survey and salvage, long a boon to archeologists, is beginning to extend to paleontologists. An example is the Bureau of Land Management-sponsored survey in 1977 by the University of New Mexico and Louisiana State University of 4½ million acres of land in the San Juan Basin (Kues *et al.*, 1977). Cretaceous and early Tertiary paleontologic resources threatened by coal strip mining were the specific target of the study (Fig. 2). Opportunities for employment for paleontologists, particularly vertebrate paleontologists, with governmental agencies and industry are likely to increase in the future and museums can expect large, sometimes overwhelming, increases in specimens recovered in salvage work. A concurrent flood of new data on the

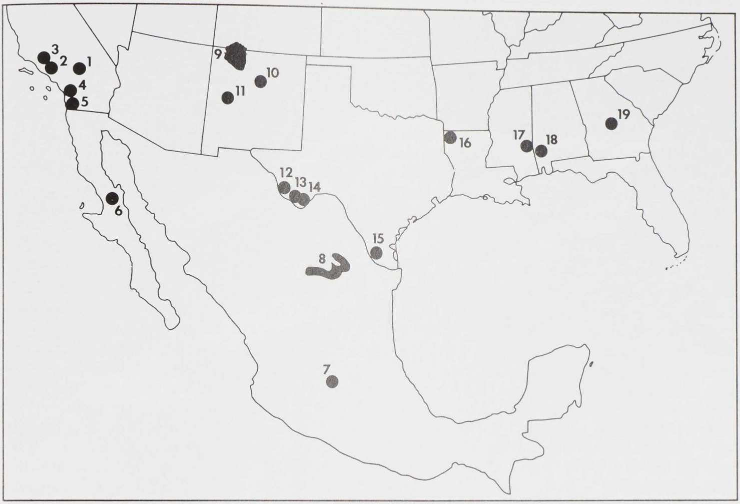


Figure 1. Index Map to Paleontological and Paleopedological Localities. *Paleocene:* 1, Goler Formation locality; 5, San Diego County; 6, Punta Prieta; 9, San Juan Basin; 14, Big Bend National Park; 16, Caddo Parish. *Eocene:* 2 & 3, Ventura Basin; 4 Carlsbad; 5, San Diego; 7, Guanajuato; 8, Parras and La Popa Basins; 9 San Juan Basin; 10, Galisteo Formation locality; 11, Baca Formation locality; 12, Vieja; 13, Agua Fria; 14, Big Bend National Park; 15, Laredo; 17, Clark County; 18, Little Stave Creek; 19, Twiggs County.

early Tertiary of North American can also be expected.

A fossil "gold rush" in the last quarter of the 19th century set the stage for modern work on the terrestrial early Tertiary of North America. Deposits that are still considered the best terrestrial fossil-bearing Paleocene and Eocene sites in the world were discovered in the American west, and fossils streamed back from Wyoming, Colorado, and New Mexico, to eastern museums. The Cope-Marsh feud raged, leaving a legacy of over-split early Tertiary taxa. The concepts of the North American Land Mammal Ages of the Paleocene and Eocene, which are currently in use, developed through work on the fossils preserved in the intermontane basins of Wyoming, Colorado, and New Mexico. Wood *et al.* (1941) attempted to standardize these subdivisions as biostratigraphic units but the definitions of many remained tied to well-known rock units and the names remain a link to western history. The redefinition now in progress should bring use of these terms more into line with modern stratigraphic practice. From oldest to youngest, the Paleocene is divided into the following Land Mammal Ages: Puercan, Torrejonian, and Tiffanian. The Eocene is divided into the Wasatchian, Bridgerian, Uintan and Duchesnean. Some specialists consider the Clarkforkian wholly Eocene and others partly Paleocene and partly Eocene. Future papers on its placement can be expected shortly (Sloan, 1978, pers. comm.; Gingerich, 1978, pers. comm.).

PALEOCENE AND EOCENE PALEOCLIMATE

The emerging large-scale picture of North American Paleocene and Eocene paleoclimate is a synthesis of many lines of evidence. Frakes and Kemp (1972) sum-

Figure 2. Skull of *Claenodon ferox* in place as discovered in the Naciemiento Formation on the 1977 paleontological survey in the San Juan Basin. Specimen is approximately 13 cm long. Photo by A. K. Schrodt.

marized information on Paleocene and Eocene climate worldwide and integrated it with plate tectonic data. Wolfe (1978) provided a summary of foliar physiognomy data in tracing North American Tertiary large scale climatic changes, which he attributes to changes in the earth's inclination. Paleobotanical data derived from palynology and the study of leaf form, and paleontological data derived from a slowly developing picture of animal migrations and from the ranges of animals with temperature-limited distributions, such as crocodiles and alligators, must be joined with data on paleogeography. For example, Miocene Basin-and-Range faulting produced generally north-south trending ranges that isolated parts of the American southwest from moisture-bearing winds and produced a degree of aridity not seen in the early Tertiary. The lack of polar ice caps, considered by Savin (1975) to have formed in the Miocene, would also have produced a less latitudinally-stratified early Tertiary climate in which the subtropical conditions postulated for Ellesmere island could fit.

Work by Sloan (1969) and Van Valen

and Sloan (1977) has documented early-Tertiary animal distribution patterns, which may have been climate-controlled. Sloan (1969) recognized distinctive northern and southern Paleocene faunas separated by an east-west line running through southern Wyoming. A large Paleocene fauna from Trans-Pecos Texas, the southernmost large assemblage of mammals of this age from North America, agrees with some of his generalizations (Schiebout, 1974, p. 44). New information suggests that the continental divide may have shifted from west to east of the San Juan Basin in the Tiffanian (Sloan, 1977, pers. comm.) so that elements previously considered "northern" in the west Texas fauna may in reality be due to both faunas being east of the divide. This could explain puzzling differences between the Paleocene faunas of west Texas and the San Juan Basin, 850 kilometers away. Van Valen and Sloan (1977) considered the shift in faunas marking the Cretaceous-Tertiary boundary in Montana to be the result of a shift southward of temperate coniferous forest displacing subtropical deciduous ones. Savin (1975) provided oxygen isotope data for late Cretaceous cooling; McLean (1978) postulated a brief, intense warm spell at the Cretaceous-Tertiary boundary. The fauna that marks the base of the Eocene in the well-studied northern intermontane basins is considered to have shifted in response to a northward spread of subtropical climates after a warm temperate interval in the Tiffanian (Sloan, 1969). Gingerich (1977, p. 497) discussed the correlation between major climatic warming periods seen in the early Eocene, early Oligocene, early Miocene, and early Pliocene, and high latitude intercontinental migration such as that noted between North America and Europe in the Wasatchian. Estes (1976) briefly discussed the effect of early Tertiary climatic shifts on the lower vertebrates of North America.

No single fixed north-south geographic barrier is known for the early Tertiary of the American west. The northern extent of the San Juan Basin of new Mexico and Colorado has been selected as the northern boundary delineating the "south" for the purposes of detailed discussion of sites in this paper. No single line could separate all northern and southern features, and northern and southern faunas are known to have shifted. The San Juan Basin Paleocene and Eocene faunas are among the best known southern early Tertiary deposits of North America. They, and deposits further south both east and west of the Paleocene continental divide, can serve to characterize southern sites and associated paleopedological climatic indicators.

Information on paleopedology is beginning to be used in conjunction with paleontological data to reconstruct local climates for individual Paleocene vertebrate localities. Soil-formed color banding in overbank mudstones has been recognized as a climate indicator by vertebrate paleontologists for over 60 years. Sinclair and Granger (1911, p. 116-117) considered color banding in mudstones in the Eocene and Oligocene of the Wind River and Bighorn basins to be a result of recurring moist and arid climatic cycles. Color banding has been used to reconstruct details of temperature and rainfall for individual early Tertiary paleontological sites only in the last decade (Schiebout, 1970, 1974, 1978; Bown, 1975, 1977). For example, Schiebout (1970, 1974), working in the Paleocene of West Texas, described color banding in overbank muds of the fluvial Black Peaks Formation as indicative of alternating wet and dry post-depositional conditions of greater than seasonal duration in a semitropical to tropical climate (Fig. 3). Red bands rich in soil-formed microcrystaline calcium carbonate nodules developed during dry periods when flood-deposited alluvium dried out and water tables were low. Black layers, colored by organic matter, formed in wet periods when the water table stayed at or above the alluvial surface, producing reducing conditions. During these periods, the floodplain may have resembled parts of the modern Amazon Basin (Sioli, 1951, p. 279) and the Atchafalaya Basin of Louisiana where heavy forests grow in standing water. According to Van Houten (1948, 1973), discussing North American early Tertiary banded beds, recently-deposited alluvium would have been drab, probably brownish in color and the eventual red color would have been a result of dehydration of inherited iron oxides plus in-place oxidation of iron-bearing minerals in the floodplain soils. Gray zones and mottled areas were the product of reduction.

Figure 3. Color banding in mudstone of the Paleocene Black Peaks Formation in Big Bend National Park, Texas. Two red layers are separated by light gray layers from a prominent black band (arrow). Meter stick for scale.

The presence of calcium carbonate nodules is becoming widely recognized as an indicator of semiaridity (Steele, 1974; Mc Bride, 1974, 1975; Pierce and Peterson, 1975). According to Freytet (1973), nodule formation occurs in the zone of oscillation of a phreatic water table. Cracks, narrowing toward the outside of the nodule, are common in nodules of the west Texas Paleocene. The cracks indicate wetting and drying, and thus are consistent with Freytet's model of nodule formation. The exact role of calcium carbonate availability in nodule formation remains to be clarified. For example, thick Pleistocene caliches in the Jornada Basin of New Mexico are attributed by Seager and Hawley (1973) to leaching of abundant wind-deposited carbonate dust from upper soil layers. Carbonate availability may greatly modify the time needed to form nodules and the range of climates in which they can form.

The color bands are not facies indicators as such because they are post-depositional features. Regional climatic factors, including amount and periodicity of rainfall and annual temperature means and ranges, affect the pattern of ground water changes, as do local features such as avulsions. Both banding and the formation of nodule-rich zones would be affected by geomorphology, *i.e.*, floodplain relief. Schumm (1968, 1977) assigned a major role in fluvial geomorphology to stabilization of floodplains by vegetation, which is strongly affected by climate. Results of local tectonism may eventually become clearly understood for the sites discussed in the remainder of this paper, allowing recognition of small scale climatic changes.

SITES OF THE SOUTHWEST

Paleocene and Eocene localities of southern North America will be considered in an effort to extract faunal and paleopedological clues concerning the factors controlling the faunal character of the south, in this section and the following one. Localities will be considered roughly in sequence from the west where data is moderately abundant to the east where it is very sparse. For a discussion of all North American Paleocene localities see Russell (1967). Figure 1 gives localities discussed in the following sections.

California

The only Paleocene mammalian remains from southern California constitute the Laudate faunule from the Goler Formation (Fig. 1, no. 1). The 2000-meter-thick Goler Formation has yielded only three identifiable mammal teeth. According to McKenna (1960) they belong to three species, only one of which can unquestionably be referred to a previously known genus. The faunule is possibly Torrejonian in age. According to McKenna (1960), the location of the Laudate faunule west of the Paleocene continental divide accounts for its containing two genera not known from further east and one which may have been present in California before its dispersal eastward.

Figure 4. An Eocene (Uintan) site in San Diego County, California. Students from San Diego State University collect fossil mammals from gray mudstone of the Mission Valley Formation. To the north, Jurassic rocks form highlands as they did in the Eocene.

West of the San Andreas fault system in San Diego County (Fig. 1, no. 5), red paleosols developed on Jurassic and Cretaceous rocks. They underlie Eocene mammal-bearing rocks, which have been intensively studied. They have been interpreted as laterites, probably Paleocene with a possibility that some may be late Cretaceous or early Eocene, by Peterson and Abbott (1975) and Abbott *et al.* (1976). These investigators consider the paleosols indicative of a humid tropical climate with greater than 120 cm annual rainfall, a climate warmer than the Eocene climate and the modern climate of the area. These paleosols certainly indicate a climatic difference from that under which the overlying Eocene rocks accumulated because the latter lack the striking red color. Movement on the San Andreas fault may have been as much as 200 km, so that climatic conclusions based on the laterite or on the overlying Eocene deposits must be considered as applying to lower latitudes in Mexico during the Paleocene.

Three areas of exposure of mammal-bearing terrestrial Eocene rocks are available from southern California. Exposures in San Diego County (Fig. 1, no. 4,5) are fluvial and alluvial fan coastal deposits intertonguing with marine rocks. These rocks have provided a rare opportunity for comparison of the terrestrial biostratigraphic chronology with the marine microfossil and megafossil subdivisions of the Eocene. Fluvial, alluvial fan, and lacustrine deposits of the Ventura Basin to the north filled an east-west trending trough (Golz, 1976, fig. 1). Recent work on the Eocene of southern California, including a salvage program in San Diego County under the direction of Jason A. Lilligraven, has produced a sequence of papers on these Uintan deposits (Fig. 4). Several authors have found evidence of endemism in Southern California Eocene faunas. Many species of Artiodactyls not known from deposits further east indicate the presence of geologic and ecologic barriers encouraging speciation according to Golz (1976). The far smaller collection of San Diego County perissodactyls also shows some evidence of endemism (Schiebout, 1977). Black and Dawson (1965) considered small rodents and primates to indicate endemism, but small reptiles do not, according to Schatzinger (1975). Lillegraven's (1976) study of small insectivores suggested that a continuous forest cover was available from San Diego County eastward to sites in the Rocky Mountains and high plains. A possible explanation for endemism in some groups and not in others could lie in local climate, clues to which lie in the paleosols. Unlike the older underlying rocks, middle and late Eocene rocks of San Diego County lack red color but are rich in microcrystalline calcium carbonate nodules. Pierce and Peterson (1975, p. 75) postulated a change in climate from the older, hot, humid conditions (temperature 20-25°C, rainfall over 120 cm) to warm semiarid conditions (38-64 cm of rainfall) with a pronounced dry season. Some animals could have been confined to riparian forests and others could have ventured into drier interfluvial areas. Endemism seems most pronounced in those animals that would range beyond small forest belts. On the whole, the California Paleocene and Eocene data suggests that local microclimates and Laramide uplifts could have had major effects on early Tertiary mammal distributions.

Mexico

A fossil locality from Baja California (Fig. 1, no. 6) is the southernmost site yielding Paleocene mammals from North America. Like other sites lying west of the San Andreas Fault zone, it surely lay further south at the time of deposition. The locality has yielded a barylambdid pantodont, *Esthonyx*, and a primitive *Hyracotherium*, and is approximately Tiffanian in age (Morris, 1968; Ferrusquia, 1978).

Mexican Paleocene and Eocene paleosols east of the San Andreas Fault Zone give indications of the early Tertiary climate that are valuable for comparisons to the vertebrate-bearing localities lying in intermontane basins to the north. In the Late Cretaceous and Paleocene, the Parras and La Popa basins of northeast Mexico received approximately 6000 m of terrigenous sediment (McBride *et al.*, 1975, p. 1663). The delta plain sediments of the Upper Cretaceous-Paleocene Difunta Group in these basins are rich in red or reddish brown mudstones, which contain abundant soil-formed nodules. The red color is caused by post-depositional oxidation during dry seasons, induced by strong seasonal aridity, when the water table was low in an overall warm subhumid to semiarid climate (McBride *et al.*, 1975, p. 497). Caliche nodules are particularly common in coarse material topping upward-coarsening sequences interpreted as caused by gradual filling of lakes and swamps (McBride, 1975, p. 499-500). An Eocene vertebrate site in western Mexico at Guanajuato has yielded two rodents and a tapir forelimb from a site having red sediment (Fries *et al.*, 1955; Black and Stephens, 1973; Ferrusquia, 1978).

New Mexico

The concept of the Paleocene developed through studies of North American western intermontane deposits, and none played a greater role than those of the San Juan Basin in northwestern New Mexico and adjacent Colorado (Fig. 1, no. 9). The Puercan and Torrejonian Land Mammal Ages were originally defined on San Juan Basin mammal sites and faunas. Paleocene sites in the San Juan Basin number in the hundreds, and fossils from these localities are housed in many of the major museums of North America. Salvage work in the mainly fluvial Nacimiento Formation, made necessary by strip mining of coal contained in the underlying Cretaceous Kirtland and Fruitland Formations, can be expected to greatly increase our knowledge of Paleocene faunas in this area. Overbank mudstones of the Nacimiento (Fig. 5) and San Jose Formations show prominent color banding with bright red beds becoming more common upsection (Simpson, 1948, 1950). In the Nacimiento Formation red bands are rare in sediments bearing Puercan faunas but common in some sediments bearing Torrejonian fossils, while rare in others (Simpson, 1950). Soil-formed calcium carbonate nodules are locally common. According to Simpson (1948, p. 368-369), the banded mudstones of the upper portion of the San Jose Formation contain more red beds and are brighter in color, in general, than those of the lower San Jose Formation.

Figure 5. Two prominent red mudstone layers (arrow) at Barrel Springs, co-typical area for the Torrejonian Land Mammal Age of the Paleocene. Nacimiento Formation of the San Juan Basin.

Preliminary study of Eocene fossils of the San Jose Formation, which overlies the Nacimiento Formation in the San Juan Basin, fossils from the Galisteo Formation exposed in the Rio Grand Valley, (Fig. 1, no. 10) and fossils from the Baca Formation of central western New Mexico, (Fig. 1, no. 11) is underway. The San Jose Formation contains Wasatchian vertebrates (Simpson, 1948), and is currently yielding specimens from new sites (Lucas, 1977, pers. comm.). The Galisteo Formation has yielded a few fossils indicating a possible age range from Wasatchian to Duchesnean (Stearns, 1943; Robinson, 1957; Mellett, 1976). Stearns (1943) interpreted the color banding in the Galisteo Formation, including red bands, as formed in a warm climate with variable rainfall. The Baca Formation ranges in age from late Cretaceous to early Oligocene. Rocks containing Bridgerian fossils in the Baca Formation north of Datil are interbedded with red mudstone rich in soil-formed carbonate nodules. The Galisteo and the Baca Formation are both capped with volcanic rocks, recording the onset of local volcanism.

Texas

Work by John A. Wilson and colleagues in three areas of Trans-Pecos Texas has uncovered the southernmost large early Tertiary mammal faunas known from North America. The Vieja and the Agua Fria areas have yielded Eocene fossils; Big Bend National Park has yielded both Paleocene and Eocene sites. Work is in progress by Testamada on magnetic reversal chronology of the Trans-Pecos volcanic field (Wilson, 1978, pers. comm.).

Color banding and calcareous nodules characterize the overbank deposits of fluvial rocks of Maestrichtian to Wasatchian age in Big Bend National Park (Wilson, 1967; Schiebout, 1974; Lawson, 1972). Late Cretaceous and early Tertiary rocks in the park were subdivided by Maxwell *et al.* (1967) into the Javelina Formation, which contains Maestrichtian dinosaurs and pterosaurs (Lawson, 1972), the Black Peaks Formation, which contains Tiffanian to Clarkforkian mammalian faunas (Fig. 6; Schiebout, 1974), and the Hannold Hill Formation, which has yielded a Wasatchian fauna (Wilson, 1967). Some typically

Figure 6. Sinkhole in color banded fluvial mudstone of the Paleocene Black Peaks Formation. Microcrystalline calcium carbonate nodules are abundantly visible on eroded surfaces and in the scree in the foreground.

Torrejonian taxa are present in the Black Peaks Formation, but the Puercan faunas as found in the San Juan Basin are absent or at last have not been recovered. The Canoe Formation, which marks the beginning of local tectonic activity in the Big Bend region, contains a sparse, possibly Bridgerian, mammal fauna (Wilson, 1967). The Canoe Formation includes coarse conglomerates, unlike the underlying deposits.

Paleobotanical evidence substantiates climatic variability as partially responsible for the color banding in the late Cretaceous Paleocene and Eocene rocks in Big Bend National Park. Some Paleocene fossil wood from the Black Peaks Formation shows seasonal rings and some does not (M.L. Abbott, 1974, pers. comm.). Riparian forests would not have suffered in dry periods as interfluvial ones would have. Lawson (1972, p. 71) studied a pollen flora of 37 species from one locality in Big Bend National Park, which he considered most closely contemporary to floras of the Paleocene Tullock and Lebo Formations, and concluded that it lived under a climatic regime of thermal equability and seasonal precipitation.

Eocene fossil-bearing sites in the Vieja area of west Texas (Fig. 1, no. 12) have received comprehensive treatment in a paper by Wilson (1977). The Vieja faunas have been published in several systematic works including Wilson (1971a, b; 1974, 1977), Wilson and Szalay (1976), Forsten (1971a,b), Harris (1967), McGrew (1971), Wood (1974) and Novacek (1976). Study of the Agua Fria region (Fig. 1, no. 13) by Wilson and others is under way.

The Vieja Group Uintan and Chadronian fossils occur in volcaniclastic rocks, and local volcanism was a major feature of the region. Temperatures were warm enough to make possible the presence of crocodiles in some braided streams; however, they were not abundant (Wilson, 1977). Harris (1967) and Wilson (1977) noted the presence of caliche in Chadronian (early Oligocene) beds at Ash Spring and postulated a gradual drying trend for the Eocene and Oligocene Vieja Group as a whole.

A single mammal mandible, which has been recovered from the mid-Eocene Cook Mountain Formation at Lake Casa Blanca in Laredo, Webb County, Texas (Fig. 1, no. 15), is under study by John A. Wilson. He identifies it as belonging to *Leptoreodon* cf. *marshi* (Wilson, 1978, pers. comm.).

The prominent color banding seen in the early Tertiary deposits of New Mexico and Big Bend National Park, Texas, is not widespread in Wyoming until the early Eocene. Climatic change is likely to have played a major role in triggering changes from drab to red banded beds. Red color and carbonate nodules of the Willwood Formation are a good example. Neasham and Vondra (1972) and Bown (1977) attributed the red banding of fluvial overbank facies of the mid-basin region to fluctuation of the water table. Red layers are described as produced in interfluvial areas where sedimentation rates were low in a warm, humid climate with periodic dry seasons (Neasham and Vondra, 1972, p. 2178-2179). Red banding is also prominent in the Indian Meadows Formation (probably Wasatchian) and in some Eocene rocks of the Green River Basin (Picard and High, 1968). On the other hand, Braunagel and Stanley (1977) described Eocene variegated redbeds in the Cathedral Bluffs Tongue of the Wasatch Formation in Wyoming that were controlled mainly by local depositional events, rather than post-depositional conditions. According to Braunagel and Stanley (1977), upward-fining couplets of green iron-poor siltstone overlain by red claystone represent individual floods on an alluvial plain near a lake. According to Dorr and Gingerich (1978, pers. comm.) the boundary between drab beds and variegated redbeds in the Chappo Member of the Wasatch Formation is sharply time-transgressive in the Fossil Basin of Wyoming. Redbeds first appear in the middle Tiffanian in the Fossil Basin; in the Hoback and Bighorn Basins they first appear in the Clarkforkian (Dorr, 1978, pers. comm.). When color banding is water-table-controlled both local basinal conditions and climate will be important in determining the color of overbank mudstones.

THE SOUTHEAST

The southeast, here defined as beginning in eastern Texas, is considered as a unit (Fig. 7). Accidental discovery has played a major role in early Tertiary vertebrate finds in southeastern North America; therefore, terrestrial vertebrate finds and terrestrial environmental studies are rare at the moment. The only Paleocene terrestrial vertebrate find known from the southeast is the facial and palatal part of a small skull, on the basis of which Simpson (1932) named *Anisonchus fortunatus*. The specimen was recovered from a well core in Caddo Parish, Louisiana (Fig. 1, no. 16) from an approximate depth of 750 m (Simpson, 1932). Few Eocene mammals have been reported from the southeast in the literature. One of these is a titanothere from the Lisbon Formation of Clark County, Mississippi (Fig. 1, no. 17; Gazin and Sullivan, 1942). These authors named *Notiotitanops mississippiensis* on the basis of this specimen. One molar of the tillodont *Anchippus*, possibly Bridgerian, was recovered from the Shark River marine marl of New Jersey (Gazin, 1953). A single miacid tooth has been recovered from the base of the Gosport Sand, which overlies the Lisbon Formation at the Little Stave Creek site in Clark County, Alabama (Fig. 1, no. 18; J. Thurmond, 1977, pers. comm.). A fauna of marine and terrestrial animals has been recovered from upper Eocene estuarine sediments of the Twiggs Clay in Georgia (Fig. 1, no. 19). The snake fauna indicates semitropical or tropical conditions (Holman, 1977). A terrestrial mammal fauna from this site is under study by M. Voorhies (Voorhies, 1978, pers. comm.).

Palynological data on the paleoclimate of the Paleocene and Eocene of the Gulf Coast indicates the presence of temperate as well as subtropical elements (Gray, 1960; Jones, 1961; Elsik, 1965; Nichols and Traverse, 1969; Fredericksen, 1973). The possibility exists that the Eocene temperate elements are really part of upland floras, perhaps from as far away as the Appalachians, admixed with coastal plain floras (Nichols and Traverse, 1969). Graham (1972) considered temperate plant communities of the eastern escarpment of the Mexican plateau, some members of which are present in the Eocene of the Mississippi Embayment, to have moved progressively

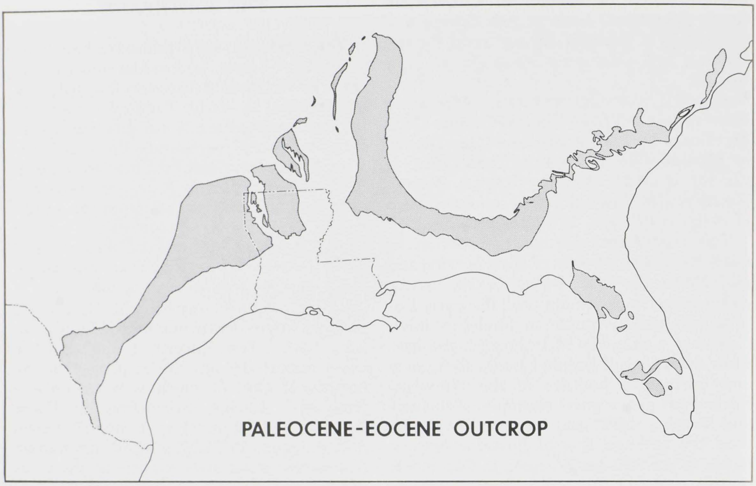
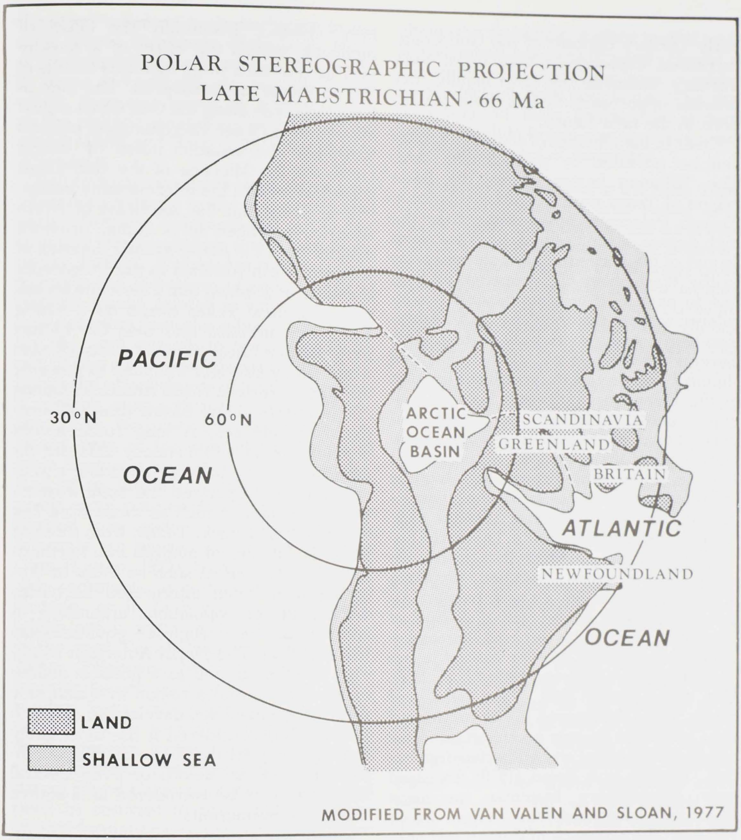


Figure 7. Paleocene and Eocene rocks of the southeast.

southward to reach Mexico in the Miocene. The work of Dilcher (1973) on less readily transportable plant megafossils from the middle Eocene of Kentucky and Tennessee indicates that some of the temperate elements were part of the coastal plain flora. Foliar physiognomy of floras from clay pits dug in Eocene abandoned channel deposits, including leaf margin and leaf size analysis, indicates a temperature regime of equable warm-temperate to cool-subtropical, and a moisture regime of seasonably dry to slightly moist (Dilcher, 1973). Dilcher (1973) also reported wood with growth rings indicating seasonal fluctuations. Wolfe (1978), also working on foliar physiognomy, postulated a cooling trend from early Paleocene Tropical Rain Forest conditions in north Louisiana to late Paleocene Paratropical Rain Forest conditions, followed by an early Eocene warming trend in the Mississippi Embayment. The middle Eocene floras studied by Dilcher (1973) are considered to be dry subtropical by Wolfe (1978). These floras indicate a pronounced drying trend from Paleocene to middle Eocene in the Mississippi Embayment (Wolfe, 1978). This Eocene drying trend seen on the southern coastal plain supports the idea that the warmth and at least seasonal dryness reflected in soil-forming processes in the Eocene of northern intermontane basins, such as those in Wyoming, was due in part to mid-continent-wide climatic changes.

Less is known of early Tertiary paleopedology for the southeast than is known for the southwest. In a discussion of the origin of bauxite, Harder (1949) described scattered bauxite deposits of Paleocene and Eocene age, which occur in a belt along the east side of the Mississippi Embayment from southwestern Georgia to central Arkansas, and concluded that a warm, humid climate with alternating wet and dry seasons favored the formation of such bauxites.

Hope for future finds of southeastern mammals is greatly increased by the prospect of lignite mining in the Paleocene and Eocene rocks exposed along the west side of the Mississippi Embayment. Strip mining will produce extensive outcrops where soil cover had previously prevented paleontological work. Tens of thousands of acres are already leased preparatory to mining



MODIFIED FROM VAN VALEN AND SLOAN, 1977

Figure 8. Late Cretaceous distribution of land and sea for the northern hemisphere.

in east Texas, Louisiana and Arkansas. The pace and scale of this mining is likely to surpass anything seen up to the present time in east Texas. A test mine started in the spring of 1978 excavated Eocene lignite in Red River Parish, Louisiana. There is a possibility of recovering Paleocene as well as Eocene mammals from Louisiana. Murray (1948) named three Paleocene formations cropping out in northwest Louisiana the Naborton, Logansport and Hall Summit formations. Each contains fluvial, deltaic and lignite deposits (Murray, 1948, p. 88-134).

DISCUSSION

Recognition of early Tertiary geographic features (Fig. 8) and faunal and floral migration patterns make possible some predictions regarding the future paleontologic and paleoecologic role of the terrestrial early Tertiary deposits of the Gulf Coast. Increased exposure of Gulf Coast early Tertiary sediments by strip mining may provide opportunity to test these predictions in the near future.

Clues to the affinities of southeast faunas can be provided by paleoclimatic data. The Tiffanian faunas of the Big Bend region of Texas show far less similarity to French Paleocene assemblages than the high degree of similarity of the Wasatchian faunas of the northern intermontane basins to the Wasatchian of Europe would lead one to expect. If continental drift is considered to have disrupted the North American-Europe migration route in the middle Eocene (Dawson *et al.*, 1976), this route should be expected to have been useable in the Paleocene and early Eocene. Evidence exists, however, for climate and vegetational shifts, particularly a northward shift of the subtropics in the earliest Eocene, which would make high latitude intercontinental routes particularly attractice in the early Eocene (Sloan, 1969; Hickey, 1977; Wolfe, 1978). The early Eocene similarities suggest that mere distance, for example, between Wyoming and Europe, was not a major barrier. An interior seaway linked with the Gulf of Mexico in roughly the same position as the Cretaceous interior seaway existed in the early Tiffanian (McGrew, 1963; Sloan, 1969; Fox and Olsson, 1969, Van Valen and Sloan, 1977). Lilligraven (1969) considered the Cretaceous seaway an important factor affecting marsupial and eutherian distribution. Krause and Baird (1979) discussed very fragmentary mammal specimens from east Texas and New Jersey, which establish the presence of therian and nontherian mammals in North America, east of the seaway in the Late Cretaceous. The Paleocene seaway would have had major effects on climate and base level as well as geographic effects as a barrier. These effects may have lingered after its withdrawal.

The isolating effects of highlands are probably partially responsible for endemism in California in the Paleocene (Mc Kenna, 1960) and Eocene (Golz, 1976), and in west Texas (Schiebout, 1974), which may have been affected by a Tiffanian shift of the continental divide (Sloan, 1977, pers. comm.). Eventually the effect of highlands versus the effect of a seaway may be analysed when mammal faunas of the southeast are recovered. The lack of local highlands along the Gulf Coast should allow a much freer interchange of animals more like the situation noted by Wilson (1956) for the Miocene of the Gulf Coast than that seen in the intermontane basins.

It is likely that the southeast of North America belonged to a faunal province distinct from the better-known deposits of western North America in the Paleocene. It can be anticipated that Paleocene faunas east of central Texas would have strong European affinities and that the faunas from the late Eocene east of central Texas would show stronger affinities to those of the classic western North American faunas of the intermontane basins than to European assemblages. A long route across northern areas with distinctly different climate, or a long passage including a seaway barrier, separated the southwestern Paleocene faunas such as those from Big Bend National Park, Texas, from those of Europe. Influxes of animals into northern intermontane basins such as those in Wyoming have been interpreted as northward shifts of populations originating in subtropical or tropical environments (Sloan, 1969). The North American southeast is often ignored as a possible source of immigrants and a region in which new forms may have been developing, although Wood (1977) considered it the most likely area of origin for the Rodentia. The southeast, as well as Mexico or even Central America, must be considered as a source region for immigrants.

Other generalizations about the significance of southern faunas yet to be found can be made. Southern regions can be expected to have had overall more stable environmental conditions and, therefore, a greater faunal diversity and a higher number of animal specialists then northern regions. Both marine and terrestrial faunas show this trend (Bretsky and Lorenz, 1970; J. W. Wilson, 1974). Some biostratigraphic zones, useful in the north, will not be recognizable in the south. Differing characterizations for northern and southern areas will be required for some Paleocene zones. For example, a zonation defined on pantodonts, the most common large herbivore in the west Texas Paleocene (Schiebout, 1974), or periptychids would prove more useful in Texas and probably also in areas further south, than one based on primates, such as the elegant zonations produced by Gingerich (1976) and Rose (1977) from work in Wyoming.

Soil forming processes produce diagenic alterations that are useful to the terrestrial early Tertiary paleoecologist in understanding the conditions under which deposits formed. Calcareous nodules form today in the B horizon of pedocal soils in regions where rainfall is sufficient to remove calcium from the A horizon by leaching, but not enough to wash carbonates out of the soil zones. Temperature determines the effectiveness of rainfall, because it controls evaporation (Pierce and Peterson, 1975). Nodular layers appear to form in the part of the soil where the water table fluctuates because of seasonal aridity. Red layers found in banded overbank deposits require an environment in which inherited iron oxide or iron oxide-bearing minerals are altered further by oxidation (Van Houten, 1973). Nodules may occur in gray sediments, as in the California coastal Eocene, or in both red and gray beds, which are in intimate association as seen in the west Texas Paleocene. In the west Texas Paleocene beds the nodules and nodular layers are best developed in the reddest beds, suggesting that intensification of one or several of the nodule-producing factors triggers the production of red coloration. The Eocene Sespe Formation of inland California contains variegated beds in contrast to the slightly younger coastal formations, so the controlling factor may be the lower temperature and/or the higher rainfall near the coast. Small climatic changes through time may be responsible. Peterson and Abbott (1975) postulated a cooler depositional temperature for coastal Eocene beds of California than for the underlying red sediments.

Changes in the level and stability of the water table, which appear responsible for the color banding, indicate considerable variability with time in the floodplain environment. Identical overbank deposits assume a very different appearance if the post-depositional water tables lie at or above the floodplain surface than if interfluvial areas are well-drained. Height of the water table would also have considerable affect on flora and fauna. The time necessary to form pedological features such as nodule layers also provides a clue to details of rates of deposition.

Paleopedological data in the early Tertiary of North America does reflect large scale climatic shifts such as the northward shift of subtropical climate at the beginning of the Eocene. Changes in the water table, which produce the striking color banding of red, gray and black in many fluvial deposits, may indicate widespread climatic changes or smaller shifts of greater than seasonal duration. Soil-formed features such as thick color bands are often more widespread than any fluvial facies and usually, being water-table-controlled, they represent synchronous surfaces that had little original relief. Color bands have long been used informally as stratigraphic markers. For example, prominent black beds were useful in tying together localities in the west Texas Paleocene (Schiebout, 1970). If local effects, caused by changes in the positioning of major channels and accompanying changes in sediment supply, can be separated from the effects of climatic patterns, a powerful stratigraphic tool would result, allowing correlation beyond single outcrop areas. Soils have begun to be used as stratigraphic markers as well as climate indicators. For example, Ortlam (1971), working in the Triassic and Permian of Germany, traced red-violet layers to produce correlations useful over all of southern Germany. Buurman (1975) has collected data on a variety of uses being made of paleopedology.

Accurate notation of mudstone color and the presence and type of nodules by workers in the early Tertiary continental deposits can produce a great deal of information valuable to the paleoecologist, phylogeneticist, and stratigrapher. Vertebrate paleontologists should be sure to record such data for their localities and stratigraphic sections. Workers in the terrestrial Paleocene and Eocene should become as alert to paleopedological features as workers in the terrestrial Pleistocene are.

ACKNOWLEDGMENTS

Facilities at the University of Texas, Louisiana State University, and San Diego State University have been used in my research on the southern early Tertiary. My work in New Mexico has been supported by funds from the New Mexico Bureau of Mines and Mineral Resources, the Society of the Sigma Xi, and Bureau of Land Management Grant YA-512-CT7-50. Work in Texas has been supported by the University of Texas Geology Foundation, by Geological Society of America Research Grant no. 1357-70, and by the Louisiana State University Department of Geology. A Summer Faculty Research Grant from LSU for 1977 supported work in Texas and New Mexico. Work in Big Bend National Park was conducted under Antiquities Act permits issued to the Texas Memorial Museum (1968-1972) and to the Louisiana State University Museum of Geoscience (1976-1978).

I wish to thank John A. Wilson who always emphasized the importance of depositional environments to a vertebrate paleontologist and Malcolm C. McKenna who first alerted me to the uses of paleopedology when I was a graduate student. John A. Wilson and Earle F. McBride of the University of Texas at Austin, Margaret S. and James B. Stevens of Lamar University, Robert E. Sloan of the University of Minnesota, and Richard H. Kesel of Louisiana State University read the manuscript and provided helpful suggestions. Bruce J. MacFadden of the University of Florida, Philip D. Gingerich and John A. Dorr of the University of Michigan, and Thompson M. Stout of the University of Nebraska brought to my attention work which I would otherwise overlooked. I am very grateful to the colleagues mentioned above and all others who have helped me in gathering data. I remain responsible for errors and oversights in this paper.

LITERATURE CITED

ABBOTT, P. L., J. A. MINCH, and G. L. PETERSON, 1976, Pre-Eocene paleosol south of Tijuana, Baja California, Mexico: Jour. Sed. Pet., v. 46, p. 355-361.

BERGGREN, W. A., M. C. McKENNA, J. HARDENBOL, and JOHN D. OBRADOVICH, 1978, Revised Paleogene polarity time scale: Jour. Geology, v. 86, p. 67-81.

BLACK, C. C., and M. R. DAWSON, 1966, A review of late Eocene mammalian faunas from North America: Amer. Jour. Sci., v. 264, p. 321-349.

BLACK, C. C., and J. J. STEPHENS III, 1973, Rodent from the Paleogene of Guanajuato, Mexico: Occasional Papers, The Museum, Texas Tech. Univ., v. 14, p. 1-10.

BOWN, T. M., 1975, Paleocene and lower Eocene rocks in the Sand Creek — No Water Creek Area, Washakie County, Wyoming: Twenty-seventh Ann. Field Conference, Wyoming Geol. Assoc. Guidebook, p. 55-61.

BOWN, T. M., 1977, Geology and mammalian paleontology of the Sand Creek facies, lower Willwood Formation (early Eocene), Washakie Co., Wyoming: Univ. Wyoming Ph.D. dissertation, unpubl., 567 p.

BRAUNAGEL, L. H. and K. O. STANLEY, 1977, Origin of variegated redbeds in the Cathedral Bluffs Tongue of the Wasatch Formation (Eocene), Wyoming: Jour. Sed. Pet., v. 47, p. 1201-1219.

BRETSKY, P. W. and D. M. LORENZ, 1970, Adaptive response to environmental stability; a unifying concept in paleoecology: Geol. Soc. Amer., Bull., v. 81, p. 2449-2456.

BUURMAN, P., 1975, Possibilities of palaeopedology: Sedimentology, v. 22, p. 289-298.

DAWSON, M. R., R. M. WEST, W. LANGSTON, JR. and J.H. HUTCHISON, 1976, Paeogene terrestrial vertebrates; northernmost occurrence, Ellesmere Island, Canada: Science, v. 192, p. 781-782.

DILCHER, P. L., 1973, A paleoclimatic interpretation of the Eocene floras of southeastern North America *in* GRAHAM, A. (ed.), Vegetation and vegetational history of northern Latin America. Elsevier, Amsterdam, p. 39-59.

ELSIK, W. C., 1965, Palynology of the lower Eocene Rockdale Formation, Wilcox Group, Milam and Robertson Counties, Texas: Texas A&M Univ. Ph.D. dissertation, unpubl., 253 p.

ESTES, RICHARD, 1976, Middle Paleocene lower vertebrates from the Tongue River Formation, southeastern Montana: Jour. Paleontology, v. 50, p. 500-520.

FERRUSQUIA-VILLAFRANCA, ISMAEL, 1978, Distribution of Cenozoic vertebrate faunas in middle America and problems of migration between North and South America: Inst. Geologia, Univ. Natl. Auton. Mexico, Bol. 101, p. 197-329.

FORSTEN, A., 1971a, Early Tertiary vertebrate faunas, Vieja Group, Trans-Pecos Texas. Equidae; Part 1, *Epihippus* from the Vieja Group, Trans-Pecos Texas: Pearce-Sellards Ser. no. 18, Texas Mem. Mus., p. 1-5.

FORSTEN, A., 1971b, Early Tertiary vertebrate faunas, Vieja Group, Trans-Pecos Texas. Equidae; Part 3, Comparison of populations of *Mesohippus* from Trans-Pecos Texas and the Big Badlands, South Dakota: Pearce-Sellards Ser. no. 18, Texas Mem. Mus., p. 12-15.

FOX, S. K., JR., and R. K. OLSSON, 1969, Danian planktonic foraminifera from the Cannonball Formation in North Dakota: Jour. Paleontology, v. 43, p. 1397-1403.

FRAKES, L. A., and E. M. KEMP, 1972, Influence of continental positions on early Tertiary climates: Nature, v. 240, p. 97-100.

FREDERICKSEN, N. O., 1973, Late Eocene flora of the northern Gulf Coast, (abst.): Geoscience and Man, v. 11, p. 156-167.

FREYTET, P., 1973, Petrography and paleoenvironment of continental carbonate deposits with particular reference to the Upper Cretaceous and lower Eocene of Languedoc (Southern France): Sedimentary Geology, v. 10, p. 25-60.

FRIES, C., C. W. HIBBARD, and D. H. DUNKLE, 1955, Early Cenozoic Vertebrates in the red conglomerate at Guanajuato, Mexico: Smiths. Misc. Coll., v. 123, p. 1-25.

GAZIN, C. L., and J. M. SULLIVAN, 1942, A new titanothere from the Eocene of Mississippi, with notes on the correlation between the marine Eocene of the Gulf coastal plain and continental Eocene of the Rocky Mountain region: Smiths. Misc. Coll., v. 101, p. 1-13.

GAZIN, C. L., 1953, The Tillodontia; an early Tertiary order of mammals: Smiths. Misc. Coll., v. 121, 110 p.

GINGERICH, P. D., 1976, Cranial anatomy and evolution of early Tertiary Plesiadapidae (Mammalia, Primates): Univ. Michigan, Papers on Paleontology, no. 15, 141 p.

GINGERICH, P. D., 1977, Patterns of evolution in the mammalian fossil record *in* HALLAM, A. (ed.), Patterns of Evolution. Elsevier, Amsterdam, p. 469-500.

GOLZ, D. J., 1976, Eocene Artiodactyla of southern California: Los Angeles County Mus. Nat. Hist., Sci. Bull., v. 26, 85 p.

GRAHAM, A., 1972, Tertiary history of vegetation about the Caribbean Basin (abst.): Geoscience and Man, v. 9, p. 74.

GRAY, J., 1960, Temperate pollen genera in the Eocene (Claiborne) flora, Alabama: Science, v. 132, p. 808-810.

HARDER, E. C., 1949, Stratigraphy and origin of bauxite deposits: Geol. Soc. Amer., Bull., v. 60, p. 887-908.

HARRIS, J. M., 1967, Oligocene vertebrates from western Jeff Davis County, Trans-Pecos Texas: Univ. Texas Master's thesis, unpubl., 165 p.

HIBBARD, C. W., 1949, Techniques of collecting microvertebrate fossils: Contrib. Mus. Paleontology Univ. Michigan, v. 8, p. 7-19.

HICKEY, L. J., 1977, Stratigraphy and paleobotany of the Golden Valley Formation (early Tertiary) of western North Dakota: Geol Soc. Amer., Mem. 150, 183 p.

HOLMAN, J. A., 1977, Upper Eocene snakes (Reptilia, Serpentes) from Georgia: Jour. Herpetology, v. 11, no. 2, p. 141-145.

JONES, E. L., 1961, Environmental significance of palynomorphs from lower Eocene sediments of Arkansas: Science, v. 134, p. 1366.

KRAUSE, D.W., and DONALD BAIRD, 1979, Late Cretaceous mammals east of the North American Western Interior Seaway: Jour. Paleontology (in press).

KUES, B., J. FROEHLICH, J. A. SCHIEBOUT, and S. LUCAS, 1977, Paleontological survey, resource assessment, and mitigation plan for the Bisti-Star Lake area, northwestern New Mexico: Open-file report to the Bureau of Land Management, Albuquerque, New Mexico, 1519 p.

LAWSON, D. A., 1972, Paleoecology of the Tornillo Formation, Big Bend National Park, Brewster County Texas: Univ. Texas Master's thesis, unpubl., 182 p.

LILLIGRAVEN, J. A., 1969, Latest Cretaceous mammals of upper part of Edmonton Formation of Alberta, Canada, and review of marsupial-placental dichotomy in mammalian evolution: Paleont. Contribs., Univ. Kansas, Art. 50, (Vertebrata 12), 122 p.

LILLEGRAVEN, J. A., 1976, Didelphids (Marsupalia) and *Uintasorex* (? Primates) from later Eocene sediments of San Diego County, California: San Diego Soc. Nat. Hist., Trans., v. 18, p. 85-112.

LINDSAY, E. H., L. L. JACOBS, and R. F. BUTLER, 1978, Biostratigraphy and magnetostratigraphy of Paleocene terrestrial deposits, San Juan Basin, New Mexico: Geology, v. 6, p. 425-429.

MARSHALL, L. G., 1976, Paleontological salvage and federal legislation: Jour. Paleontology, v. 50, p. 346-348.

McBRIDE, E. F., 1974, Significance of color in red, green, purple, olive, brown, and gray beds of Difunta Group, northeastern Mexico: Jour. Sed. Pet., v. 44, p. 760-773.

McBRIDE, E. F., A. E. WEIDIE, and J. A. WOLLEBEN, 1975, Deltaic and associated deposits of Difunta Group (Late Cretaceous to Paleocene), Parras and La Popa Basins, Northeastern Mexico *in* BROUSSARD, M. L., (ed.), Deltas—Models for Exploration: Houston Geol. Soc., p. 484-522.

McGREW, P. O., 1963, Environmental significance of sharks in the Shotgun Fauna, Paleocene of Wyoming: Univ. Wyoming Contrib. Geol., v. 2, p. 39-41.

McGREW, P. O., 1971, Early Tertiary vertebrate faunas, Vieja Group, Trans-Pecos Texas. Equidae; Part 2, *Mesohippus* from the

Vieja Group, Trans-Pecos Texas: Pearce-Sellards Ser. no. 18, Texas Mem. Mus., p. 6-11.

McKENNA, M. C., 1960, A continental Paleocene vertebrate fauna from California: Amer. Mus. Novit., no. 2024, 20 p.

McKENNA, M. C., 1960, Fossil Mammalia from the Early Wasatchian Four Mile Fauna, Eocene of Northwestern Colorado: Univ. California Publs. Geol. Sci., v. 37, p. 1-130.

McKENNA, M. C., 1962, Collecting small fossils by washing and screening: Curator, v. 5, p. 221-235.

McKENNA, M. C., 1972a, Was Europe connected directly to North America prior to the middle Eocene *in* DOBZHANSKY, T., M. K. HECHT, and W. C. STEEVE (eds.): Evol. Biol., v. 6, p. 179-188.

McKENNA, M. C., 1972b, Eocene final separation of the Eurasian and Greenland-North American landmass: 24th Int. Geol. Cong., Section 7, p. 275-281.

McKENNA, M. C., 1972c, Vertebrate paleontology of the Togwotee Pass area, northwestern Wyoming *in* WEST, R. M., Coordinator: Guidebook-Field Conference on Tertiary Biostratigraphy of southern and western Wyoming, Aug. 5-10, 1972 (Soc. Vert. Paleont.), p. 80-101.

McKENNA, M. C., 1975, Fossil mammals and early Eocene north Atlantic land continuity: Annals Missouri Bot. Garden, v. 62, p. 335-353.

McLEAN, D. M., 1978, A terminal Mesozoic "greenhouse"; lessons from the past: Science, v. 201, p. 401-406.

MELLETT, J. S., 1976, Paleobiology of North American *Hyaenodon* (Mammalia, Creodonta): Contrib. Vertebrate Evol., v. 1, 134 p.

MORRIS, W. J., 1968, a new early Tertiary perissodactyl *Hyracotherium seekinsi* from Baja California: Los Angeles County Mus. Contrib. Sci., v. 151, p. 1-11.

MURRAY, G. E., JR., 1948, Geology of DeSoto and Red River Parishes: Louisiana Geol. Survey, Bull. 25, 312 p.

MURRAY, P. A., and J. LEZAK, 1977, Recovery of vertebrate microfossils with tetrabromoethane: Curator, v. 20, p. 15-22.

NEASHAM, J. W., and C. F. VONDRA, 1972, Stratigraphy and petrology of the lower Eocene Willwood Formation, Bighorn Basin, Wyoming: Geol. Soc. Amer., Bull., v. 83, p. 2167-2180.

NICHOLS, D. J. and A. TRAVERSE, 1969, Palynology, petrology, and depositional environments of some early Tertiary lignites in Texas: Geoscience and Man, v. 3, p. 37-48.

NOVACEK, M. J., 1976, Early Tertiary vertebrate faunas, Vieja Group, Trans-Pecos Texas. Insectivora: Pearce-Sellards Ser. no. 12, Texas Mem. Mus., 18 p.

ORTLAM, DIETER, 1971, Paleosols and their significance in stratigraphy and applied geology in the Permian and Triassic of southern Germany *in* YAALON, D. H. (ed.), Paleopedology; origin, nature, and dating of paleosols. Isr. Univ. Press, Jerusalem, p. 321-327.

PETERSON, G. L. and P. L. ABBOTT, 1975, Paleocene age of lateritic paleosol, western San Diego County, California *in* ROSS, A. and R. J. DOWLEN (eds.), Studies on the Geology of Camp Pendleton, and western San Diego County California: San Diego Assoc. Geologists Field Trip Guidebook, 90 p.

PICARD, M. D., and L. R. HIGH, 1968, Sedimentological cycles in the Green River Formation (Eocene) Uinta Basin, Utah: Jour. Sed. Pet., v. 38, p. 378-383.

PIERCE, S. E. and G. L. PETERSON, 1975, Paleoclimatic implications of caliche in the non-marine Friars and Mission Valley Formations, southwestern California *in* ROSS, A. and R. J. DOWLEN (eds.), Studies on the Geology of Camp Pendleton and western San Diego County, California: San Diego Assoc. Geologists Field Trip Guidebook, p. 71-76.

ROBINSON, P., 1957, Age of the Galisteo Formation, Sante Fe County, New Mexico, Amer. Assoc. Petrol. Geol., Bull., v. 41, p. 757.

ROSE, K. D., 1977, Evolution of carpolestid primates and chronology of the North American middle and late Paleocene: Jour. Paleontology, v. 51, p. 536-542.

RUSSELL, D. E., 1967, Le Paleocene Continental d'Amerique Du Nord: Mem. Mus. Natl. Hist. Nat., ser. C, v. 16, p. 1-99.

SAVIN, S. M., 1975, The history of the earth's surface temperature during the past 100 million years: Ann. Rev. Earth and Planetary Sci., v. 5, p. 319-355.

SCHATZINGER, R. A., 1975, Later Eocene (Uintan) lizards from the greater San Diego area, California: San Diego State Univ. Master's thesis, unpubl., 212 p.

SCHIEBOUT, J. A., 1970, Sedimentology of Paleocene Black Peaks Formaton, western Tornillo Flat, Big Bend National Park, Texas: Univ. Texas Master's thesis, unpubl., 114 p.

SCHIEBOUT, J. A., 1974, Vertebrate paleontology and paleoecology of Paleocene Black Peaks Formation, Big Bend National Park, Texas: Texas Mem. Mus., Bull. 24, 88 p.

SCHIEBOUT, J. A., 1977, Eocene Perissodactyla from the La Jolla and Poway Groups, San Diego County, California: San Diego Soc. Nat. Hist., Trans., v. 18, p. 217-227.

SCHIEBOUT, J. A., 1978, An overview of early Tertiary terrestrial paleogeography of the North American southwest and Gulf Coast (abst.): Gulf Coast Assoc. Geol. Soc., Trans., v. 28, p. 459.

SCHUMM, S. A., 1968, Speculations concerning paleohydrologic controls of terrestrial sedimentation: Geol. Soc. Amer., Bull., v. 79, p. 1573-1588.

SCHUMM, S. A., 1977, The Fluvial System. John Wiley and Sons, New York, 338 p.

SEAGER, W. R. and J. W. HAWLEY, 1973, Geology of Rincon Quadrangle, New Mexico: New Mexico Bur. Mines and Min. Res., Bull. 101, 42 p.

SIMPSON, G. G., 1932, A new Paleocene mammal from a deep well in Louisiana: U.S. Natl. Mus., Proc., v. 82, no. 2, 4 p.

SIMPSON, G. G., 1948, The Eocene of the San Juan Basin, New Mexico: Amer. Jour. Sci., v. 246, p. 257-282, 363-385.

SIMPSON, G. G., 1950, Lower Tertiary formations and vertebrate faunas of the San Juan Basin: New Mexico Geol. Soc., First Field Conf., p. 85-89.

SINCLAIR, W. J. and W. GRANGER, 1911, Eocene and Oligocene of the Wind River and Bighorn Basins: Amer. Mus. Nat. Hist., Bull., v. 30, p. 83-117.

SIOLI, H., 1951, Zum Alterungsprozess von Flussen und Flusstypen im Amazonasgebiet: Archiv fur Hydrobiologie, v. 45, no. 3, p. 267-283.

SLOAN, R. E., 1969, Cretaceous and Paleocene terrestrial communities of western North America: North Amer. Paleo. Convention, Proc., Part E, p. 427-453.

STEARNS, C. E., 1943, The Galisteo Formation of north-central New Mexico: Jour. Geology, v. 51, p. 301-319.

STEELE, R. J., 1974, Cornstone (fossil caliche) — its origin, stratigraphic and sedimentologic importance in the New Red Sandstone, western Scotland: Jour. Geology, v. 82, p. 371-382.

VAN HOUTEN, F. B., 1948, Origin of red-banded early Cenozoic deposits in Rocky Mountain Region: Amer. Assoc. Petrol. Geol., Bull., v. 32, p. 2083-2126.

VAN HOUTEN, F. B., 1973, Origin of red beds — A review — 1961-1972: Ann. Rev. Earth and Planetary Sci., v. 1, p. 39-61.

VAN VALEN, L. and R. E. SLOAN, 1977, Ecology and the extinction of the dinosaurs: Evolutionary Theory, v. 2, p. 37-64.

WEST, R. M., M. R. DAWSON, and J. H. HUTCHISON, 1977, Fossils from the Paleocene Eureka Sound Formation, N.W.T., Canada; occurrence, climatic and paleogeographic implications *in* R. M. WEST (ed.), Paleontology and Plate Tectonics: Milwaukee Public Museum Spec. Publ. Biol. Geol., no. 2, p. 77-93.

WILSON, J. A., 1956, Miocene formations and vertebrate biostratigraphic units, Texas coastal plain: Amer. Assoc. Petrol. Geol., Bull., v. 40, p. 2233-2246.

WILSON, J. A., 1967, Early Tertiary mammals, *in* Geology of Big Bend National Park, Brewster County, Texas: MAXWELL, R.A., J. T. LONSDALE, R. T. HAZZARD, and J. A. WILSON, Univ. Texas Bureau Econ. Geol., Publ. 671, p. 157-169.

WILSON, J. A., 1971a, Early Tertiary vertebrate faunas, Vieja Group, Trans-Pecos Texas. Agriochoeridae and Merycoidodontidae: Texas Mem. Mus., Bull. 18, 83 p.

WILSON, J. A., 1971b, Early Tertiary vertebrate faunas, Vieja Group, Trans-Pecos Texas. Entelodontidae: Pearce-Sellards Ser. no. 17, Texas Mem. Mus., 17 p.

WILSON, J. A., 1974, Early Tertiary vertebrate faunas, Vieja Group and Buck Hill Group, Trans-Pecos Texas. Protoceratidae, Camelidae, Hypertragulidae: Texas Mem. Mus., Bull. 23, 34 p.

WILSON, J. A., 1977a, Early Tertiary vertebrate faunas Big Bend area, Trans-Pecos Texas. Brontotheriidae: Pearce-Sellards Ser. no. 25, Texas Mem. Mus., 15 p.

WILSON, J. A., 1977b, Stratigraphic occurrence and correlation of early Tertiary vertebrate faunas, Trans-Pecos Texas: Texas Mem. Mus., Bull. 25, 42 p.

WILSON, J. A., and F. S. SZALAY, 1976, New adapid primate of European affinities from Texas: Folia Primat., v. 25, no. 4, p. 294-312.

WILSON, J. W. III, 1974, Analytical Zoogeography of North American mammals: Evolution, v. 28, p. 124-140.

WOLFE, J. A., 1978, A paleobotanical interpretation of Tertiary climates in the northern hemisphere: Amer. Scientist, v. 66, p. 694-703.

WOOD, H. E., R. W. CHANEY, J. CLARK, E. H. COLBERT, G. L. JEPSEN, J. B. REESIDE, JR., and C. STOCK, 1941, Nomenclature and correlation of the North American continental Tertiary: Geol. Soc. Amer., Bull., v. 52, p. 1-48.

WOOD, A. E., 1974, Early Tertiary vertebrate faunas, Vieja Group, Trans-Pecos Texas. Rodentia: Texas Mem. Mus., Bull. 21, 112 p.

WOOD, A.E., 1977, The Rodentia as clues to Cenozoic migrations between the Americas and Europe and Africa: Milwaukee Public Museum Spec. Publ. Biol. Geol., no. 2, p. 95-109.

November 9, 1979

(Continued from p. 74)

*1927. The Veneridae of eastern America, Cenozoic and Recent: Paleont. Amer., vol. 1, no. 5, p. 209-522, pls. 32-76. [Text published March, 1927; plates, February, 1929.]

1928. A new fauna from the Cook Mountain Eocene near Smithville, Bastrop County, Texas: Jour. Paleont., vol. 2, p. 20-31, pls. 6-7.

1936. Timothy Abbott Conrad . . . by Harry E. Wheeler. Bull. Amer. Paleont., vol. 23, no. 77: Review *in* Bull. A.A.P.G., vol. 20, p. 321-322.

1935. Marquis de Gregorio's Claiborne types: Nautilus, vol. 50, p. 100.

1936. Unpublished poem by T.A. Conrad: Science, vol. 84, no. 2167, p. 40.

1936. Conrad, the reticent: Nature Magazine, vol. 28, p. 273-274.

*1937. The Claibornian Scaphopoda, Gastropoda and Dibranchiate Cephalopoda of the southern United States: Bull. Amer. Paleont., vol. 7, no. 32, 730 p., 90 pls.

1938. Nomenclatural notes on Eocene Mollusca: Bull. Amer. Paleont., vol. 24, no. 81, 7 p.

1938. Neocene Spondyli from the southern United States and tropical America: Paleont. Amer.: vol. 2, no. 8, 18 p., 3 pls.

1939. *Basilosaurus* in Arkansas: Bull. A.A.P.G., vol. 23, p. 1228-1229.

1940. *Anevda*, new name for *Advena* Palmer, 1937, not Gude, 1913: Jour. Paleont., vol. 14, p. 285.

1940. Some natural history descriptions of Jamaica: Sci. Monthly, vol. 51, p. 321-328.

*1941. The Geology and Paleontology of the Cuenca-Azogues -Biblian region, Provinces of Canar and Azuay, Ecuador: Bull. Amer. Paleont., vol. 26, no. 100, 62 p., 9 pls. (with Ralph A. Liddle).

1942. Tales of ancient whales: Nature Magazine, vol. 35, p. 213, 214, 221.

1942. Substitutes for molluscan homonyms: Jour. Paleont., vol. 16, p. 674.

1942. Notes on the name *Litiopa melanostoma* and distribution of the species: Nautilus, vol. 55, p. 128-130.

1944. Notes on Eocene Gastropods, chiefly Claibornian: Bull. Amer. Paleont., vol. 28, no. 112, 26 p., 2 pls.

1944. *Litiopa melanostoma* Rang, a correction of distribution: Nautilus, vol. 58, p. 70-71.

1945. Molluscan types in the Carpenter Collection in the Redpath Museum: Nautilus, vol. 58, p. 97-102.

1945. Marquis de Gregorio's Claiborne types: Nautilus, vol. 59, p. 34-35.

*1945. Fossil fresh-water Mollusca from the State of Monagas: Bull. Amer. Paleont., vol. 31, no. 118, 34 p., 2 pls.

*1946. The Mollusca of the Jackson Eocene of the Mississippi Embayment (Sabine River to Alabama River): Bull. Amer. Paleont., vol. 30, no. 117, Pt. II, p. 207-563, pls. 26-65.

1946. *Saltermya*, new name for *Anthracomya* Salter 1861, not Rondani, 1856: Jour. Paleont., vol. 20, p. 518.

1947. Fun with fossils: Sci. Monthly, vol. 64, p. 385-388.

1947. Manuscript notes by P.P. Carpenter on D'Orbigny's series of Cuban shells in the British Museum: Mem. Soc. Cubana Hist. Nat., vol. 20, no. 8, p. 89-104.

1948. Dorothy K. Palmer Memorial: Jour. Paleont., vol. 22, p. 518-519.

1950. Notes and illustrations of type and comparative specimens of Recent Pacific pelecypods: Jour. de Conchyl., vol. 90, p. 190-194, 1 pl.

*1951. Catalog of the first duplicate series of the Reigen Collection of Mazatlan shells in the State Museum at Albany, New York: New York State Mus., Bull. 342, 76 p., 1 pl.

(Continued on p. 104)