Reports

Paleocene Hyracothere from Polecat Bench Formation, Wyoming

Abstract. *A lower jaw of an eohippus* (Hyracotherium *cf.* H. angustidens) *from late Paleocene strata in Wyoming has extended the geological record of fossil horses into pre-Eocene time and suggests that the order Perissodactyla had an origin earlier than that heretofore conjectured. This specimen, together with equid teeth also possibly of late Paleocene age from Baja California, indicates that early perissodactyls were widespread on the North American continent before the Eocene epoch. Late Paleocene and early Eocene deposits of northwestern Wyoming have yielded many vertebrate rarities and "first or earliest occurrences" which require reappraisals of inter- and intracontinental dispersal patterns of the vertebrate groups involved.*

A lower jaw of a fossil horse, found in 1962 in the upper part of the Paleocene Polecat Bench Formation of northwest Wyoming, has stimulated a reconsideration of the origin and early zoogeography of the hippomorph perissodactyls. This specimen, referred to as *Hyracotherium* cf. *H. angustidens*, has also resulted in intensive search for more parts of the same individual (Princeton University Museum of Natural History No. 18316) and for additional representatives of the same taxon in the area of discovery.

Prior to this find the oldest known fossil horses were from rocks of early Eocene (Wasatchian-Sparnacian) age, and hence this extension backward in time of the geologic range of the order Perissodactyla into the Paleocene invalidates the common assumption that the odd-toed ungulates "migrated" or dispersed to the Nearctic region from Eurasia or elsewhere at the beginning of Eocene time. An alternative postulation derives the first (as yet unfound) perissodactyls from some other (as yet unidentified) group in North America and assumes that the artiodactyls and certain condylarths and primates that first appear in the Nearctic record early in the Eocene epoch entered North America independently and not as members of a great faunal movement by either the North Atlantic or the Asian routes illustrated by Kurten (*1*).

All these attempts to explain known paleozoogeographic records are based more on the absence of data than on actual evidence, and such speculations are frequently proved wrong by a lucky discovery. Discovery of one undoubted early Paleocene equid tooth in Asia or Europe would immediately remold the concept that the nascent perissodactyls were cradled in the Nearctic. To elucidate zoogeographic and phylogenetic histories, additional fossils are needed from the geologic zones where the records are now the leanest, particularly those of Cretaceous and Paleocene time.

Many groups of fossil collectors have prospected for vertebrate remains in the more than 200 square miles (520 km^2) of the arid Sand Coulee hydrographic basin, tributary of Clark's Fork of the Yellowstone River, in the Bighorn Basin, for it contains many extensive exposures of bare badland topography in Paleocene and Eocene rocks. Unfortunately, fossils are relatively rare in this region. Nowhere else in the world, however, has such a complete sequence of terrestrial Paleocene rocks with a series of several faunas been discovered. This fact has influenced the development of a continued program of searching in the region, during at least part of each summer since 1927, by Princeton University (*2*). The cumulative yield of surface recoveries and extensive quarrying now numbers many thousands of specimens. With them it is possible to arrange the fragmentary traces of several phylogenies through most of the millions of years represented by the 3500 feet (1065 m) of Paleocene strata.

Specimen PU 18316 was found about 12 miles (19.3 km) northwest of Powell, Park County, Wyoming, in the northwest quarter of Section 26, Township 57 North, Range 100 West, in the badlands on the west side of Polecat Bench. At this spot [about 4600 feet (1400 m) above sea level] the surface is developed in somber gray mudstones that have a dip of a few degrees toward the southwest, about 2500 to 2800 feet (760 to 850 m) above the base and 700 to 1000 feet (215 to 300 m) below the top of the Polecat Bench Formation. This rock level is within the Silver Coulee beds, and a few feet stratigraphically above the "Princeton Quarry" [about 1.5 miles (2.4 km) to the northwest] in Section 21 which has produced hundreds of small jaws and other skeletal remains (*3*).

Specimens representing several taxa of fish, amphibians, reptiles, and birds have been found in the "Princeton Quarry" level as have remains of the mammalian groups in Table 1. Details of classification of some forms in Table 1 are subject to varied opinion (*4*).

Table 1 is an assemblage of late Paleocene forms, approximately equivalent in evolutionary status to the Tiffanian North American Land Mammal age and to the Thanetian Stage in Europe. Some of the genera are known from lower levels, and many of them continued beyond Paleocene time into the Eocene, but the fauna as a unit assemblage of taxa is distinctly limited to late Paleocene time. Rocks and fossils in the "Princeton Quarry" indicate a marshy stream-border environment, less heavily forested than the coal swamp area that lay about 20 miles (32 km) to the northwest at Bear Creek, Montana, where an approximately contemporary Tiffanian fauna occurs.

On a map published in 1947 [and reprinted in 1954 without revision by the United States Geological Survey (*5*)] the Paleocene rocks in the area are simply indicated as "Fort Union formation." This designation continued the archaic practice of using the term "Fort Union" as a verbal receptacle for any somber-colored rocks of Paleocene (or near-Paleocene) age. This usage, repeatedly rejected (*3, 6*), is inaccurate and confusing, and it violates the rules and concepts of good stratigraphic studies, but it has been defended because it simplifies nomenclature. Simplification is achieved by ignoring and thus avoiding some difficult lithologic and cartographic problems and by indicating correlations that are, in part at least, recognized as erroneous. In 1965 Pierce (*7*) continued to relegate the Paleocene rocks in the Sand Coulee basin to the "Fort Union" stratigraphic wastebasket.

The physical characteristics of PU 18316 were studied with care in order to weigh the possibility that the notes on its provenience and association with other specimens might be in error and that, through some confusion, it actually came from sediments of Eocene age. The closest Eocene rocks, however, in exposures of the Willwood Formation, are about 7 miles (11 km) away and, although they are stratigraphically higher by several hundred to a thousand feet (~ 300 m), they outcrop at altitudes lower than the locality of the specimen under consideration. In fact the outcrop areas in the region and the roads to them are disposed in such a way that the fossil collectors in their program of repeated intensive searches there almost never work in both the Paleocene and the Eocene exposures on the same day. This fact is of some significance because the recoveries of each day of prospecting are habitually assorted and labeled each evening. Such a practice diminishes the probability of accidental mislabeling (*8*).

In its preservation and crystallographic structure (as revealed by x-ray diffraction analysis) this unique jaw is closely similar to other mammalian fossils from the attributed Paleocene locality and less similar to most of the Eocene bones from the closest Willwood localities. Enamel on the teeth of the specimen is very dark gray-brown, almost black, whereas the dentine and roots are much lighter buff and gray. The bone shows various shades of mottled light to dark gray and brown and in some areas is peppered with dark spots. In detail this entire color pattern is unusual for bones and teeth from any locality other than the one which is recorded as the source of the specimen.

Specimen PU 18316 (*Hyracotherium* cf. *H. angustidens*, Fig. 1, right mandibular fragment with p4, m1, m2, m3, and part of posterior root of p3) was found in four separate pieces. The anterior two fragments have a mutual contact on the lingual surface of the mandible, and the identity between the appression facets on the posterior end of m2 and the anterior end of m3, respectively, leaves no doubt of their association. The fragment bearing the coronoid process contains part of the alveolus for m3.

The premolar cuspids are here designated by molar-cusp terminology, merely for convenience, and not to indicate homology with the molar series. The protoconid and metaconid of the fourth premolar are large, well-defined, rather closely appressed cuspids, the protoconid being more anterior in position than the metaconid. Between the protoconid and the less massive metaconid is a narrow commissure, expressed mainly on the anterior surface of the trigonid. This commissure descends anteriorly and slightly lingually to meet a second commissure which lies along the lingual side of, and continues on around the lingual end of, the paralophid. Just labial to this, the paralophid is crossed by a short groove which may have extended across the anterior end of the tooth, delimiting a short anterior cingulum. The critical area has been worn away by appression between p4 and the now missing p3. The hypoconid, lower than protoconid or metaconid, is the largest cuspid of the talonid. It lies in the posterolabial quadrant of the tooth and is connected by the metalophid to the base of the protoconid, near the midposterior surface of the trigonid. A much shorter, posterolingually directed crest connects the hypoconid to the hypoconulid. The latter is a small pointed cuspid at the most posterior point on the tooth, near the midline. On the posterior surface of the hypoconid there is a triangular wear facet. A small basin on the talonid lies lingual to the metalophid and anterior to the hypoconulid. The entoconid is probably represented by the very low, round conulid lying on the tooth margin at the lingual edge of the basin. Wear on the hypoconulid is slight, and the entoconid is unworn. A short labial cingulum extends between the base of the protoconid and that of the hypoconid.

The first molar, as indicated in Table 2, is about 25 percent longer than wide with a length-width ratio (100 × width/length) of 75. All four major cuspids are well developed although the apex of each is worn off, the tooth being in a more advanced stage of wear than the premolar. In the trigonid, the protoconid lies slightly anterior to the metaconid; the paralophid is more weakly developed than in p4, although this situation may be more apparent than real because of the degree of wear on m1. As in p4, the worn anterolabial surface of the protoconid in m1 is flat, and the unworn anterolingual surface of the metaconid is rounded, as seen in occlusal view (Fig. 1). A remnant of

Table 1. Princeton quarry mammals.

- Allotheria (multituberculates)
  - Multituberculata
    - Ptilodontidae
      - *_Ectypodus laytoni_
      - _Ectypodus hazeni_
      - _Ectypodus powelli_
      - _Mimetodon churchilli_
      - *_Prochetodon cavus_
    - Eucosmodontidae
      - *_Microcosmodon conus_
      - _Pentacosmodon pronus_
- Metatheria (marsupial mammals)
  - Marsupialia
    - Didelphidae
      - *_Peradectes_ sp.
- Eutheria (placental mammals)
  - Insectivora
    - Solenodontidae
      - ?_Apternodus_ sp.
    - Leptictidae
      - ?_Prodiacodon_ sp.
      - *_Diacodon minutus_
      - _Myrmecoboides_ sp.
    - Adapisoricidae
      - *_Leptacodon packi_
    - Apatemyidae
      - Apatemyid (undescribed)
  - Primates
    - Plesiadapidae
      - *_Plesiadapis fodinatus_
    - Carpolestidae
      - *_Carpolestes dubius_
    - Paromomyidae
      - *_Phenacolemur pagei_
  - Taeniodonta
    - Stylinodontidae
      - _Lampadophorus_ sp.
  - Edentata
    - Metacheiromyidae
      - ?_Palaeanodon_ sp.
  - Carnivora
    - Miacidae
      - *_Protictis_ (_Protictis_) sp.
      - _Protictis_ (_Bryanictis_) sp.
      - _Protictis_ (_Simpsonictis_) sp.
  - Notoungulata
    - Arctostylopidae
      - _Arctostylops_ sp.
  - Condylarthra
    - Arctocyonidae
      - *_Thryptacodon_ sp.
      - *_Tricentes_ sp.
    - Mesonychidae
      - *_Dissacus_ sp.
    - Hyopsodontidae
      - _Litolestes ignotus_
      - _Phenacodaptes sabulosus_
    - Phenacodontidae
      - *_Phenacodus_ sp.
      - *_Ectocion_ sp.
  - Pantodonta
    - Titanoideidae
      - _Titanoides primaevus_
      - _Titanoides gidleyi_
      - _Titanoides magnus_
    - Barylambdidae
      - _Haplolambda quinni_
      - *_Leptolambda schmidti_
  - Dinocerata
    - Uintatheriidae
      - *_Probathyopsis praecursor_
      - _Bathyopsoides_ cf. _B. harrisorum_

* Representatives of the taxa indicated by asterisks in the list have been found within a short distance, stratigraphically and geographically, of the hyracothere jaw, PU 18316.

the longitudinal commissure between the protoconid and metaconid is still visible on the anterior surface of the trigonid. A second commissure extends along the base of the paralophid as it does in p4. There is no anterior cingulum and no trace of a paraconid.

Table 2. Tooth dimension of PU 18316.

Dimensions (mm)	p4	m1	m2	m3	p4-m3	m1-m3
Length	6.8	7.6	8.6	10.8	32.5	26.0
Width trigonid	4.7	5.4	6.1	6.2		
Width talonid	4.7	5.7	6.3	6.1		
Height protoconid	4.6	3.9	3.9	4.5		
Height metaconid	4.5	3.6	5.0	5.1		
Height hypoconid	3.4	3.2	3.8	4.0		
Height entoconid	2.5	3.2	4.1	3.9		
Height hypoconulid				3.6		
Length-width index	69	75	73	56		

In the talonid, the metalophid extends anterolingually from the hypoconid to the midposterior surface of the trigonid. The hypoconid lies slightly anterior to the entoconid. The hypoconulid occurs as a small rounded cuspid posterolingual to the hypoconid at the midline of the tooth. A shallow triangular basin is enclosed between the trigonid, metalophid, and entoconid. A weak commissure descends anterolingually into the basin from the midpoint of the hypolophid. Another commissure curves around the posterior base of the hypoconid, separating it from the relatively small posterior cingulum which extends labially and slightly anteriorly from the hypoconulid. There is no lingual cingulum; a narrow labial cingulum extends for a short distance anterior to, and for a greater distance posterior to, the base of the protoconid. In general, the four major cuspids are broadly based and subconical; the entoconid is more pyramidal than the other three.

The second molar is about 27 percent longer than wide, has a length-width ratio of 73, and is constructed essentially like m1; m2 is less worn than m1 and the apices of its cuspids are more clearly defined. In addition to being slightly larger than m1, m2 differs in having more strongly developed labial cingula anterior and posterior to the base of the protoconid, in having an elongate and slightly arcuate commissure which separates the entoconid from the hypoconid and hypoconulid, and in that the lingual base of the entoconid extends more lingually relative to the metaconid.

The protolophid is poorly developed; although the tips of the protoconid and metaconid are now worn down, they most probably would have extended somewhat above the point at which the two cuspids coalesce into the protolophid. In this stage of wear there is no evidence that a twinned metaconid-metastylid was ever present. To judge from the condition of m3, it was not.

Both the hypoconid and entoconid are less worn than the protoconid and the metaconid. The hypolophid is clearly disrupted by a commissure which separates the entoconid from the hypoconid and hypoconulid. Although the entoconid is somewhat pyramidal and bladelike, with its transverse crest sloping downward toward the commissure, the hypoconid is broadly conical with only a very short, low, basal connection to the hypoconulid. The crestlike nature of the connection between the hypoconid and hypoconulid is emphasized by the small wear facet which has been developed on the posterolingual portion of the hypoconid. The metalophid extends anterolingually from the anterior surface of the hypoconid and joins the base of the trigonid near the midline of the tooth. The hypoconulid is only slightly worn in this tooth. Its labial and lingual surfaces slope downward from a short slightly posterolabially directed dorsal crest.

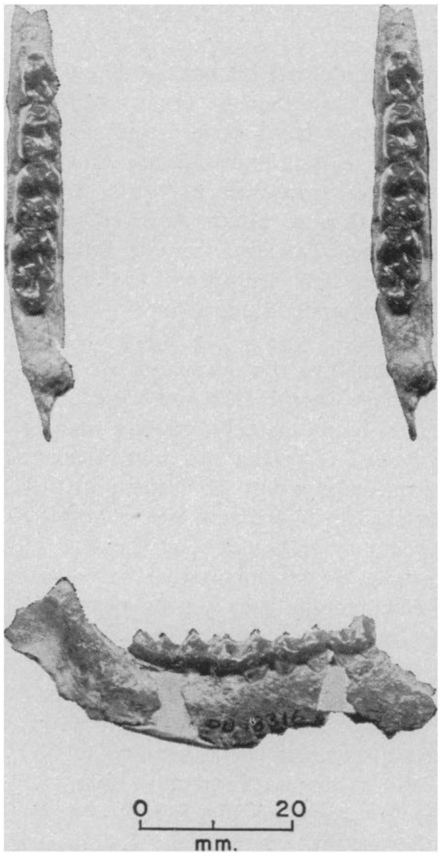

Fig. 1. (Above) Stereogram, occlusal view, of right mandible of *Hyracotherium* cf. *H. angustidens*, PU 18316 (unmagnified). (Below) Labial aspect of PU 18316. Light colored plaster indicates restored areas (unmagnified).

On the third molar the cuspids of the trigonid are nearly unworn so their true heights should be closely approximated by the values in Table 2. The talonid is lengthened by the development of the massive hypoconulid so that the tooth is about 44 percent longer than wide and has a length-width ratio of 56. The trigonid is essentially like that of m2; similarities in the conical protoconid and metaconid and the rather poorly developed protolophid are readily apparent. The metalophid is similar to that of m2, whereas the hypolophid is even less well developed. Somewhat bladelike, the entoconid and the conical hypoconid resemble the cuspids of m2, but in m3 the connection between the hypoconid and hypoconulid and the separation between the hypoconid and entoconid is even more prominent. The subconical hypoconulid is equal in general massiveness and height to the hypoconid and entoconid. A labial cingulum is continuous from the anterolabial base of the paralophid to the posterolabial corner of the hypoconulid. Unworn enamel on the labial and lingual sides of m3 is slightly "wrinkled." Enamel of m1 is smooth and in an intermediate stage of m2.

On the bone of the mandible, an arcuate groove extends posterolingually from the posterolabial edge of the hypoconulid of m3, and curves posterolabially and upward along the anterior surface of the coronoid process. In *Equus* this area of the mandible accomodates part of the origin of the buccinator and depressor labii inferioris (*9*). On the labial surface of the mandible, the superior border of the mental foramen lies below the middle of p3.

In his analysis of moderately large samples of *Hyracotherium* teeth, Kitts (*10*) recognized three species on the basis of the structure of p3 and p4. Unfortunately the upper teeth of PU 18316 are not known, but dimensions of the lower teeth fall within the ranges for *Hyracotherium angustidens* (early Wasatchian; Graybull beds). Dimensions of PU 18316 are similar to those of some, but not all, analogous teeth of *H. vasacciense*. The Princeton specimen is smaller than *H. craspedotum*, except for the widths of m1 and m2. The latter two species are known from the late Wasatchian Lysite and Lost Cabin beds, and equivalents (*10*). Specimen PU 18316 is referred to *H. angustidens* on the basis of its dimensions. In its other dental characters, PU 18316 is a rather typical or common kind of hyracothere.

The Princeton specimen has lower crowned and slightly simpler teeth (no evidence of a twinned metaconid-metastylid) than the norm, but it is not outside the range of variation of specimens of *H. angustidens* in the Princeton collections. Other characters which could be cited to separate PU 18316 from some, but not all, Princeton specimens of *H. angustidens* include: presence of a hypoconulid on p4 and broadly convex base of entoconid on m3 extending lingually beyond that of the metaconid.

The Sand Coulee area is noted for its yield of novelties. In 1913 Stein found there a lower jaw which for 50 years was the only known representative of the order Notoungulata in North America. Records of the specimen (American Museum of Natural History No. 16830, a left dentary of *Arctostylops steini*) appear to be almost purposely vague—"Head of Big Sand Coulee (upper beds), Clark Fork Basin, Wyoming." In describing the jaw, Matthew (*11*) stated that it was from the "Lower Gray Bull beds" and also that it was from the "upper part of the Wasatch exposures." These data may seem contradictory because in the area, "Gray Bull beds and Wasatch exposures" are now almost synonymous for "early Eocene sediments." The former two terms are applied at present to the lower part of the Willwood Formation, but 50 years ago another term, "Sand Coulee beds," now obsolete, was given to the lower part of the Gray Bull beds. The "upper part of the Wasatch exposures" could thus also be the lower part of the Gray Bull beds without contradiction.

Until 1966, not another scrap of *Arctostylops* was recovered despite frequent and intensive searches. Fossils of many groups of notoungulates are abundant in less ancient rocks in South America and occur in older (Late Paleocene) sediments in Asia—a distribution pattern that has elicited much discussion about mammalian dispersion in early Tertiary time. Realizing the significance of accurate records of the provenience of the North American notoungulate, Matthew stated in 1915 (*11*, p. 429) that "to verify the discovery and to exclude the possible suggestion that the specimen might have been secured by Mr. Stein when with Dr. Loomis's expedition to Patagonia a few years earlier, and by some accident mislaid and subsequently mixed up with his Bighorn basin collection, I obtained from him and from his assistant Mr. Turner detailed accounts of the exact locality and circumstances of the discovery. While it is unnecessary to spread these letters [now lost] upon the record they are sufficient to render it absolutely certain that no such confusion occurred. . . ." Despite this emphatic disclaimer many expressions of surprise were heard, during the next 50 years, that no more specimens of notoungulates were found in North America.

All suspicion that Stein's discovery might be tainted by chicanery or by confusion of records was dispelled when the skull and jaws of a small notoungulate (?*Arctostylops* sp.) were found in Silver Coulee late Paleocene strata near the site of PU 18316 (*12*). This poorly preserved specimen, PU 20397, may be the oldest known notoungulate, and it suggests that the dispersal of the order may have been from North America to Asia and to South America rather than from Asia to North America and then to South America. Such speculations, however, contain little information and are subject to instant change when additional specimens are discovered.

Regrettably, the remnants of what must have been a rich and varied subtropical fauna in early Tertiary time in northwest Wyoming are now meager. Several other groups of vertebrates that flourished then are now known only by a specimen or two among the tens of thousands of fragments that have been collected in the area during dozens of field seasons of search. A few teeth (PU 13245) of one of these significant "uniques," the oldest known chalicothere *Paleomoropus* Radinsky (*13*), were discovered at a locality in the Eocene Willwood Formation about 12 miles southwest of PU 18316, and not farther from where Stein found the famous jaw. Another "one-of-a-kind," a vertebra of the earliest known cryptobranchid salamander *Piceoerpeton* Meszoely (*14*) was found in the same region.

These and other rare fossils in the area emphasize the probability that our records of dispersion and evolution of early Tertiary vertebrates are still too thin for us to postulate detailed patterns of geographic distribution or of genetic deployment. Paleozoogeographic speculations are easily made with feeble records, but hard to document, and the temptation to visualize the Clark's Fork region as the original dispersion center for chalicotheres and notoungulates, and the place where perissodactyloid genes produced the first equid phenotype, must be resisted. Nor can we say that the cryptobranchids and the rodents (*15*) originated there merely because that is where the oldest known representatives of these taxa have been found. So far, the earliest edentate has also come to light in a quarry in the same area.

Representatives of 13 of the 24 recognized orders of terrestrial eutherian mammals (extant and extinct) have now been found in the Paleocene Polecat Bench Formation which yielded PU 18316, and a 14th order, Artiodactyla, makes its earliest appearance in the adjacent earliest Eocene Willwood Formation. Of the eight orders of living terrestrial eutheres that are indigenous to North America, six are represented in the vertebrate fossil collections of rocks dating from late Paleocene to early Eocene (about 50 to 60 million years old) in the area within a 25-mile (40 km) radius of PU 18316, and in this same small region five of the 14 surviving orders of land-living eutheres make their earliest known appearance. At present, a known total of eight of these 14 orders are represented in this little biogeologic cradle in the Wyoming desert.

Study of the larger Paleocene condylarths, such as the species of *Ectocion* and of *Phenacodus* creates the impression that these and other groups at that time formed great clusters of closely related populations with the potential for rapid changes and morphic adjustments as ecologic situations fluctuated. Among the atypical Paleocene forms from the Polecat Bench area of Wyoming are a few teeth of phenacodonts that appear to be diverging away from typical condylarth structures toward early brontotherine tooth configurations.

Eocene hyracotheres which are reasonably and conveniently put at the base of the family tree of horses have many close resemblances to early tapirs and, less obviously, to early rhinoceroses, brontotheres, and chalicotheres, and to some condylarths. The occurrence of *Hyracotherium* cf. *H. angustidens* in the late Paleocene does little to delineate the relationships of the major groups (superfamilies) of perissodactyls. Contemporary representatives of these groups are needed before an accurate determination of early perissodactyl evolution can be made.

After the first version of this paper was written and while we were withholding it from publication, in the conservative hope that more samples of Paleocene hyracotheres would be found in the Polecat Bench Formation, we learned that W. J. Morris had made an important discovery of the upper teeth of hyracotheres in rocks near Punta Prieta, Baja California, which he believes to be of late Paleocene (or early Eocene) date (*16*). These specimens were recovered from strata above those yielding representatives of *Esthonyx* (a late Paleocene–early Eocene taxon elsewhere) and below bones of "barylambdids," a family of pantodonts restricted in the United States to rocks of Paleocene age and occurring in Asia in Eocene sediments. Morris assigns the Baja assemblage to the late Paleocene on the basis of the structures of the equid molars and of the tillodont (*Esthonyx*) teeth.

It is impossible at present to make close comparisons of the age of the Mexican Paleocene hyracotheres reported by Morris with that from Wyoming, but each such occurrence of a pre-Eocene equid not only helps validate the obvious fact that perissodactyls had a long evolutionary history before Wasatchian-Sparnacian time, but also increases hope that many more of the earlier eohippids will be found.

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Silicate Spherules from Tunguska Impact Area: Electron Microprobe Analysis

Abstract. *The major oxide composition of four silicate spherules from the area of forest devastated by the explosion of the Tunguska meteorite has been determined by electron microprobe analysis. In general, the spherules have compositions similar to that of igneous glass except for the low iron and the high calcium oxide content of the three spherules that have a low content of silicon dioxide. None of the spherules seem to have compositions similar to the silicate portion of any major meteorite group.*

On 30 June 1908, a meteorite flashed through the earth's atmosphere and exploded above a forest in the basin of the Podkamennaya Tunguska River, Central Siberia (60°55′N,101°57′E), devastating an area 20 to 30 km in radius (*1, 2*).

Soil samples collected from the devastated area yielded magnetic and silicate spherules. Statistical analysis of the distribution of the metallic spherules indicates that the areas of relative enrichment cannot be explained by background variations, thus indicating that the magnetic and silicate spherules are associated with the explosion of the Tunguska meteorite (*3*).

In some cases, the silicate spherules have metallic spherules attached to or included in them. Thus Soviet investigators believe that the siliceous and magnetic spherules were formed simultaneously from parent material of a heterogeneous nature (*4*).

After the discovery of microtektites associated with the Australasian tektite-strewn field (*5*), Glass and Heezen suggested (*6*) that the microtektites (and tektites) might have had an origin similar to that of the Tunguska silicate spherules. Nine samples of these spherules (*7*) were obtained for examination.

All nine of the spherules are about 80 to 100 μ in diameter. They are all spheroidal in shape, but a few are irregular with conical protrusions. The spherules are transparent and colorless. In transmitted light most of them contain dark areas due to numerous small bubble cavities; two of the spherules contain no bubble cavities.

Four of the silicate spherules were randomly selected for microprobe analysis. The spherules were individually mounted in epoxy aluminum cylinders (inside diameter, 0.64 cm). They were ground to expose a section and polished with successively finer abrasives so as to produce a flat, smooth surface. The samples and standards were then vacuum-coated with a thin layer of carbon. Each specimen was analyzed for nine oxides in the following groups of three: Fe-K-Na, Ca-Si-Al, and Mn-Ti-Mg (*8*). In addition, the spectrum was scanned from 1.1 to 9.9 Å and peaks were observed only for those elements listed above (Table 1).

Based on calculations of standard deviations, the precision (at a 90 percent confidence level) for samples 111, 112, and 747 is 1 to 4 percent of the amount present for SiO_2, Al_2O_3, MgO, CaO, TiO_2, and MnO. In sample 753 the precision is 2 to 6 percent of the amount present. The precision for sodium oxide and potassium oxide in sample 111 is about 30 percent of the amount present. In samples 112, 747, and 753 the precision for sodium oxide and potassium oxide is 6 to 9 percent of the amount present. The precision for iron is 4 to 5 percent of the amount present in samples 111 and 112, and 20 percent of the amount present in