was limited to the analysis of terrestrial samples in order to avoid possible contamination from extraterrestrial samples, which usually cause a memory effect for ^3He. The chemical compositions of gaseous samples were measured by gas chromatography.

The observed $^3He/^4He$ and $^4He/^{20}Ne$ ratios are listed in Table 1 together with the measured concentrations of N_2, CH_4, CO_2, and helium. The elevations of the sampling sites and their distances from the central cone of the volcano are also listed. Except for samples 2 and 6, the oxygen contents of the samples were less than 0.2 percent. Thus the direct contamination of atmospheric air during sampling was negligibly small. The major chemical constituent in most samples was CO_2; sample 1 was composed of N_2 and CO_2.

The observed $^3He/^4He$ ratios are in good agreement with the magmatic $^3He/^4He$ ratios observed in subduction zones (*3*). The highest $^3He/^4He$ ratio of 8.61×10^{-6} (6.15 R_{atm}, where R_{atm} is the atmospheric $^3He/^4He$ ratio, 1.40×10^{-6}) was observed for the gas sample from Nigorigo hot spring, the sampling site closest (4.2 km) to the central cone. This value is identical to the value (6.14 R_{atm}) observed in the central region of Hakone Volcano (*4*). The $^3He/^4He$ ratios decrease with distance from the cone. The ratio (1.71 R_{atm}) at Shikanoyu hot spring (25.4 km away from the cone) was the lowest of all the samples but was higher than R_{atm}, thus suggesting the addition of ^3He originating in the mantle.

Figure 2 indicates the correlation between the $^3He/^4He$ ratio (R/R_{atm}) and the distance of the sampling site from the cone. No simple correlation was observed between the $^4He/^{20}Ne$ ratio and the distance. If the decrease in the $^3He/^4He$ ratio is attributed to mixing with atmospheric helium, the observed $^4He/^{20}Ne$ ratio should decrease as the $^3He/^4He$ ratio decreases. In the present case, however, there is no correlation between the $^3He/^4He$ ratio and the $^4He/^{20}Ne$ ratio. Accordingly, the observed $^3He/^4He$ variation may be ascribed to dilution of magmatic helium by radiogenic helium derived from the basement rock.

A contribution of about 10 percent mantle-derived helium can be observed about 25 km away from the cone. The effective range of ^3He leakage for an independent volcano of a size similar to Mount Ontake may be some 30 km, based on the $^3He/^4He$ ratio measurement. The radius of 30 km is significantly larger than the topographic feature of the volcanic edifice, about 5 km.

During volcanic activity, appreciable amounts of magmatic gases are released from deep in the earth into the atmosphere. Most of the gases derived from the magma reservoir are emitted from the central cone of a volcano through conduits, or they may be partially derived from basalts. Some of the gases are also released to the atmosphere through fissures or any permeable channels. There exists a kind of fluid flow, which may act as a carrier for primordial helium.

The $^3He/^4He$ ratio is decreased by dilution with radiogenic helium, as the gas has passed through the crustal rock region where radiogenic helium is enriched. The contribution of radiogenic to primordial helium varies, depending upon the velocity and volume of the ascending fluid flow. The decreasing trend of the $^3He/^4He$ ratio with increasing distance from the cone may be attributed to the change in the mixing ratio of a more primitive helium in the fluid flow and a more radiogenic helium from the crustal rock.

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Early Eocene Vertebrates from Baja California: Evidence for Intracontinental Age Correlations

Abstract. *Newly discovered fossils support a Wasatchian (early Eocene) age for the Punta Prieta vertebrate fauna of Baja California and reveal the utility of land mammal ages on a continental scale. Dispersal scenarios for late Paleocene and early Eocene vertebrates usually invoke heterochrony for similar, but geographically separated, faunas or taxa. Such heterochrony is not supported by independent geochronologies or adequate geographic samples.*

The provincial land mammal ages for North America proposed by Wood *et al.* (*1*) in 1941, although subject to continued refinement, are widely recognized by vertebrate paleontologists. Several investigators (*2, 3*) have now suggested that geographically separated faunas of similar taxonomic composition assigned to the same provincial age are not always time-equivalent or that faunas thought to represent successive ages may overlap temporally. To what extent, then, are North American land mammal ages useful in geochronology? More precisely, can such time units be applied on a regional, continental, or even intercontinental scale?

The establishment and refinement of the Clarkforkian (latest Paleocene–earliest Eocene) and Wasatchian (early Eocene) Land Mammal ages (*4, 5*) derive from faunas restricted to depositional basins of the Rocky Mountain region of the western United States (Fig. 1). The discovery of new vertebrate fossils from Baja California provides a rare test for the discrimination of these ages on a broader geographic scale. Information on this fauna is also relevant to diverse theories for mammalian dispersal during the Early Tertiary.

The fossil locality is a limited area of badlands surrounding the prominent Lomas las Tetas de Cabra ("Occidental Buttes" of Gastil) (*6*). The area is approximately 25 km south of the town of Punta Prieta, Baja California Norte, Mexico. Fossils occur in terrestrial, variegated sands and siltstones that belong to an unnamed formation (*6, 7*). To the west, these strata intertongue with fossiliferous shallow and deep water marine units (*6*).

The mammals originally collected from the Punta Prieta region (*7*) include *Hyracotherium seekinsi*, *Esthonyx* sp., a barylambdid pantodont (new taxon, similar to *Barylambda*), and a juvenile creodont (Table 1). This small assemblage was tentatively assigned a Clarkforkian age, with the qualification that the fauna could range from Tiffanian (late Paleocene) to Wasatchian in age (*7*).

Vertebrate fossils collected from this

Table 1. Early Tertiary vertebrate taxa, Baja California, Mexico, compared with occurrences of mammals (*4, 5, 9*) and nonmammals (*4, 8*) in type Clarkforkian and Wasatchian assemblages. "X" indicates the presence of taxon in fauna and "?" indicates very rare or dubious occurrence. The Big Bend Clarkforkian fauna is of unresolved age and is not listed here.

Punta Prieta taxa	Type Clarkforkian	Wasatchian
Chondrichthyes		
Carcharinidae, cf. *Galeorhinus*		
Amphibia		
Caudata, new? genus		
Reptilia		
Iguanidae		X
Varanidae, cf. *Saniwa*	?	X
Boidae	X	X
Mammalia		
Didelphidae, new genus		
Esthonychidae, *Esthonyx* sp.	X	X
Barylambdidae, new? genus		
Equidae, *Hyracotherium*		X
Meniscotheriidae, *Meniscotherium*	?	X
Hyopsodontidae, *Hyopsodus*	?	X
Creodonta, indet.	X	X

area in May 1983 permit a revised and more precise assignment of Wasatchian age for the Punta Prieta fauna. The new sample includes the first lower dentition of *Hyracotherium seekinsi, Meniscotherium, Hyopsodus*, a new didelphine marsupial, a varanid cf. *Saniwa*, an iguanid, and a boid (Table 1) (*8*). The beginning of the Wasatchian has been defined (*4, 5*) as the simultaneous first appearance of Perissodactyla (*Hyracotherium*), Artiodactyla (*Diacodexis*), the primates *Cantius* and *Teilhardina*, and hyaenodont creodonts. The first appearance of *Hyopsodus* and *Meniscotherium* is also noted as an effective indicator of Wasatchian age (*4, 5*). *Hyracotherium* is not known before the Wasatchian (*9*). *Hyopsodus* is almost exclusively Wasatchian; only two specimens are known from type Clarkforkian strata (Clark's Fork Basin) (*4*), and this genus is one of the most common taxa in Wasatchian assemblages of the Rocky Mountain region. *Meniscotherium* apparently first appears in the Wasatchian rather than the Clarkforkian or earlier (*5*).

On the basis of these distributions, the presence of *Hyracotherium, Hyopsodus*, and *Meniscotherium* indicates a Wasatchian Land Mammal Age for the Punta Prieta fauna. Of the remaining taxa, only the barylambdid suggests a Clarkforkian or earlier age (*4*), although this group and the didelphine marsupial are represented in Baja by endemic taxa (Table 1) (*7*). *Esthonyx* and the creodont might be temporally significant at the species and family level, respectively. These taxa, however, require more precise identification (*7*). Distributions of the nonmammalian vertebrates from Baja are poorly known for the Early Tertiary, and their geochronologic significance is moot (*4, 8*).

These faunal comparisons underscore the usefulness of land mammal ages for temporal correlation on a continental scale. The distinction of the Wasatchian from the Clarkforkian now seems feasible outside the Rocky Mountain region, where these intervals were defined (*4, 5*). More precise temporal correlation may require independent evidence of age (radioisotopic, paleomagnetic, marine invertebrate, microplanktonic, or synthetic geochronologies).

The possibility remains that similar, but geographically distant, vertebrate faunas are not necessarily the same age. Faunal similarity could be then a product of large-scale migration between heterochronous faunas or taxa. How plausible is this explanation for the similarity of certain late Paleocene to early Eocene vertebrate faunas of North America? One dispersal scenario assumes that *Hyracotherium* appeared in the "Clarkforkian-aged" Punta Prieta fauna and subsequently migrated to the Wasatchian-aged faunas in the Rocky Mountain region (*7*). Also suggested is the southward displacement of middle Paleocene ancestors of Wasatchian taxa during a late Paleocene climatic deterioration in the United States and the reinvasion of the descendants (for example, *Hyracotherium*) with the increased tropicality of more northern latitudes during the early Eocene (*10, 11*).

Alternatives to a neotropical source for the North American Wasatchian fauna have also been proposed. Godinot (*12*) noted the presence of typical Wasatchian taxa from the Sparnacian of France. More primitive stages of evolution of *Plesiadapis* have been cited for the correlation of the European Sparnacian with the North American Clarkforkian. Citing this correlation and other evidence (*13*), Godinot argued for the large-scale migration of mammals from Europe to North America during this late Paleocene–early Eocene interval. Hickey *et al.* (*2*) proposed that Wasatchian vertebrates occurred in the late Paleocene of Ellesmere Island, arctic Canada, and subsequently migrated to lower latitudes of North America and Europe (*14*). Other reported sources for elements of the Wasatchian fauna include Asia and Africa (*11*).

Thus, all possible areas of origin and migration routes for the Wasatchian fauna of the western United States have been proposed. Such proposals have

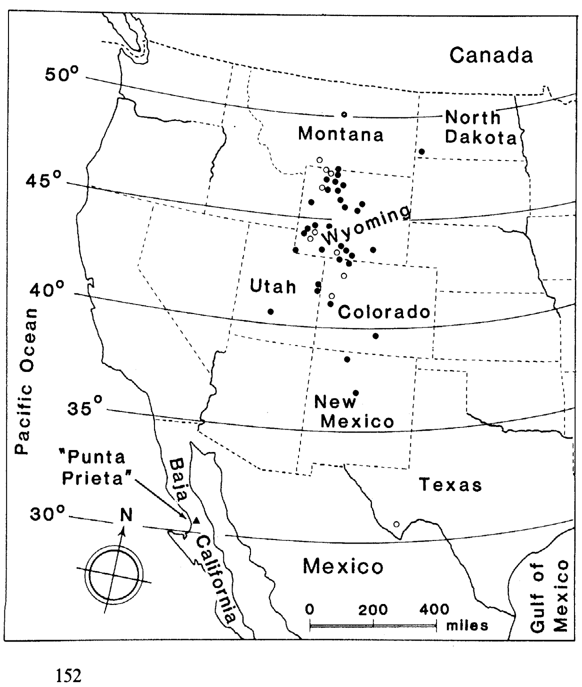

Fig. 1. Paleogeographic map of Clarkforkian (open circles) and Wasatchian (closed circles) localities from the United States and Mexico. Paleolatitudes are based on the time-averaged 50-million-year pole position (83.1°N, 178.2°E) for North America (*15*). The map does not account for at least 2.5° of Neogene northward motion of Baja California resulting from the opening of the Gulf of California. In the early Eocene, the Punta Prieta area was at least 2.5° farther south than is shown here.

been inspired by the new information of Early Tertiary faunas outside the Rocky Mountain region. Nevertheless, the abundance of contradictory scenarios, as well as shortcomings of age correlations (*14*), indicate the ambiguity or absence of the faunal data for dispersal events. A century of empirical studies support the synchrony of faunas that characterize land mammal ages and the temporally discrete nature of these ages. Therefore, closely similar faunas must be regarded as roughly contemporaneous unless there is clear, independent evidence to the contrary. Complicated scenarios for dispersal of Wasatchian vertebrates are unjustified, at least until we have an established independent geochronology and much better data on the geography of faunal succession for the late Paleocene and early Eocene of Holarctica.

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13. Godinot (*12*) argued that several taxa from France in addition to *Plesiadapis* were more primitive, and thus older, than congeneric North American species.
14. Only two recent studies (*2, 3*) propose heterochrony for a given North American land mammal age on the basis of independent geochronologic evidence. The magnetostratigraphic evidence for the temporal correlations of Hickey *et al.* (*2*) is poorly documented and does not provide an independently defined geochronology (D. V. Kent, M. C. McKenna, N. D. Opdyke, J. J. Flynn, B. J. MacFadden, *Science*, in press). Revision of the Butler *et al.* study (*3*) now provides strong support for the synchrony of a particular North American land mammal age.
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Topography from Single Radar Images

Abstract. *A mathematical theory and a corresponding numerical procedure have been developed to produce digital topography from radar images as digital photometric arrays. Thus, as radargrammetry is to photogrammetry, so radarclinometry is to photoclinometry. Photoclinometry encompasses a fundamental indeterminacy principle even for terrain that is homogeneous in normal albedo, because the surface normal consistent with a given reflected specific intensity is not unique. A geometric locus of such normal directions is implied, which generates a surface. For microwave backscatter, in specific application to radarclinometry, this surface is a cone whose half-angle is the incidence angle, whose axis contains the radar, and whose apex coincides with the terrain point. Although the indeterminacy can be removed if a properly directed profile of ground truth is available as a constraint, such is seldom the case. In its absence, an auxiliary assumption, such as that the strike line runs perpendicular to the illumination line, is needed. If metric integrity is a goal, then this is an absurd assumption. Herein, "the hypothesis of local cylindricity" has been assumed, a premise regarding the nature of topographic curvature that seems more realistic and that makes possible the production of topography as a set of parallel line integrals.*

When the Venus Radar Mapper orbits the perennially beclouded cytherean globe later in this decade, the first opportunity will present itself for high-resolution mapping of her surface. It is hoped that the data products of this mission will include topographic maps with a resolution comparable to that of the radar images. The capacity for obtaining such results by the necessary target date is not a foregone conclusion. Application of the traditional methods of photogrammetry to parallactic pairs of radar images presents serious practical problems because of the peculiar nature of radar images. Studies of such problems are presently under way.

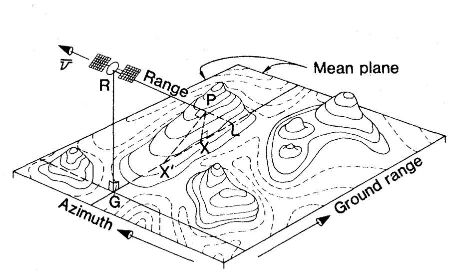

Fig. 1. Illustration of radar image formation. The solid elevation contours lie above the mean plane of the topography; the dashed contours lie below the mean plane. The dashed portions of straight lines lie below the terrain surface. Point P is an arbitrary point of terrain. Its range from the radar is $\overline{RP}$; $\triangle RGL$ and all its interior triangles are right triangles; $\overline{PX}$ is the topographic height; $\overline{X'X}$ is the ground-range mapping distortion of the radar image; and $\bar{v}$ is the orbital velocity. Azimuth, as defined by radar engineers, is a rectilinear coordinate and not be confused with the angle familiar to astronomers and surveyors.

In a parallel effort toward maximizing the probability of attaining this goal, I have developed an operational theory for determining topography from a single radar image rather than a stereometric pair. The method is thus not based on the paralactic depth perception implied, albeit in a peculiar way, by images of the same terrain formed when the radar is in two different orbital revolutions. Nor is it based on a depth perception deriving in any direct way from the fundamental range-finding characteristic of radar. The method, which I call radarclinometry (*1*), is photometric or, in deference to the long wavelength, radiometric in nature.

The radar reflectance of a surface element corresponding to a particular image pixel depends not only on the chemical and microphysical state of the surface but also on the incidence angle, the angle between the local direction to the radar and the local direction perpendicular to the terrain surface. If it can be assumed that the radar ephemeris and antenna