Journal of Vertebrate Paleontology
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t917000010

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Online publication date: 02 December 2010

To cite this Article Scott, Eric , Stafford Jr., Thomas W. , Graham, Russell W. and Martin, Larry D.(2010) 'Morphology and metrics, isotopes and dates: determining the validity of *Equus laurentius* Hay, 1913', Journal of Vertebrate Paleontology, 30: 6, 1840 — 1847

To link to this Article: DOI: 10.1080/02724634.2010.520780

URL: http://dx.doi.org/10.1080/02724634.2010.520780

Journal of Vertebrate Paleontology 30(6):1840–1847, November 2010

ARTICLE

MORPHOLOGY AND METRICS, ISOTOPES AND DATES: DETERMINING THE VALIDITY OF *EQUUS LAURENTIUS* HAY, 1913

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ABSTRACT—Direct radiocarbon dating and stable isotope and biometric analyses are evidence that the holotype of *Equus laurentius* Hay, 1913 comprises the skull and jaw of two different horses that are less than 500 years old. The size and morphology of the specimens fall within the range of like elements of modern *Equus caballus* Linnaeus, 1758. The mandibular cheek teeth exhibit bit wear, demonstrating that the mandible is that of a domestic animal. The taxonomy of the purportedly late Pleistocene species is therefore resolved, and *Equus laurentius* Hay is a junior synonym of *Equus caballus* Linnaeus. *Equus laurentius* and its holotype are neither taxonomically nor phylogenetically pertinent to studies of North American Pleistocene *Equus*.

INTRODUCTION

An ongoing dating program by Graham, Stafford, and Holmes Semken to establish the timing of the late Pleistocene megafaunal extinction included the analysis of the holotype skull and mandible of the equid species *Equus laurentius* Hay, 1913 (Fig. 1). The results were historic-era radiocarbon ages suggesting that the holotype of *E. laurentius* was not a Pleistocene horse and was instead a historic specimen. The following report presents more detailed geochemical and biometric analyses on both the cranium and mandible of the holotype of *E. laurentius*, which consists of portions of two different individual animals (Winans, 1985, 1989).

The species *Equus laurentius* was named from a skull and mandible recovered in 1910 by H. T. Martin from a sandbar on the north side of the Kansas River near Lawrence in Douglas County, Kansas (Hay, 1913). The specimen (KUMNH 347) was presumed to be of Pleistocene age because it was found in apparent association with a femur assigned to *Smilodon* Lund, 1842, from the same sandbar (Hay, 1913:584). Additional support for this interpretation was the recovery of a specimen of Pleistocene bison assigned to *Bison kansensis* McClung, 1904 (= *Bison occidentalis* Lucas, 1898; see McDonald, 1981), in a similar depositional setting from a gravel bar about 1 mile north of the site yielding *E. laurentius* and *Smilodon*. *E. laurentius* was considered by Hay (1913) to be a horse similar in size to smaller domestic breeds, with rather small cheek teeth exhibiting relatively simple enamel infoldings or plications.

Matthew (1926), referring parenthetically to *Equus laurentius* in his bibliographic citation of Hay's (1913) work, stated that the species was "based upon a recent skull mistakenly supposed by the author [Hay] to be of Pleistocene age" (Matthew, 1926:180). Hay (1927) rejected this contention, observing that the degree of mineralization on the holotype of *E. laurentius* was too extensive for the specimen to be recent. Hay (1927) also re-emphasized the apparent contemporaneity of the holotype skull and mandible with *Smilodon*, a genus known to be of Pleistocene age. Hay's (1927) brief metric analysis of the holotype, using indices initially defined and recommended by Osborn (1912), failed to distinguish *E. laurentius* from two other Pleistocene horses, *E. lambei* Hay, 1917, and *E. niobrarensis* Hay, 1913 or from two extant horses, *E.* "*przewalskii*" (= *E. ferus przewalskii*; see Nowak, 1991) and the domestic *E. caballus*. Hay (1927) focused on dental morphology for his taxonomic attributions. Noting some minor variations in enamel complexity between the holotype of *E. laurentius* and a modern horse skull, Hay (1927) maintained that *E. laurentius* was a valid species of Pleistocene age, requesting that "… those who regard [the holotype of *E. laurentius*] as a part of a modern horse shall present evidences therefor" (Hay, 1927:7).

Savage (1951) reinforced the conclusions of Matthew (1926) and considered KUMNH 347 to be a fully modern horse and *Equus laurentius* a junior synonym of *E. caballus*. Savage's study did not discuss the morphology of the holotype in detail, but proposed that the skull "was a feral horse, trapped in river quicksand and subsequently permineralized in a relatively short time" (Savage, 1951:252). Most students of North American Pleistocene horse phylogeny followed this interpretation for almost four decades. One exception, Quinn's (1957) review of Pleistocene fossil horses from Texas, preferred to consider Hay's taxon valid at the subspecific level, as *E. caballus laurentius*. Regarding the geologic age of the specimen, Quinn (1957:24) stated that "[i]t is more reasonable to consider the validity of *E. laurentius* as a fossil than to assume the skull … belongs to a recent or modern horse (less than 400 years old, requiring investigation of the speed of bone fossilization.)". This effectively argued for the presence of *E. caballus* in North America during the Pleistocene. The taxa *E. niobrarensis alaskae* Hay, 1913, and *E. lambei* were also considered to represent *E. caballus laurentius* (Quinn, 1957).

In a dissertation advancing a landmark revision of North American Pleistocene *Equus*, Winans (1985) recognized five

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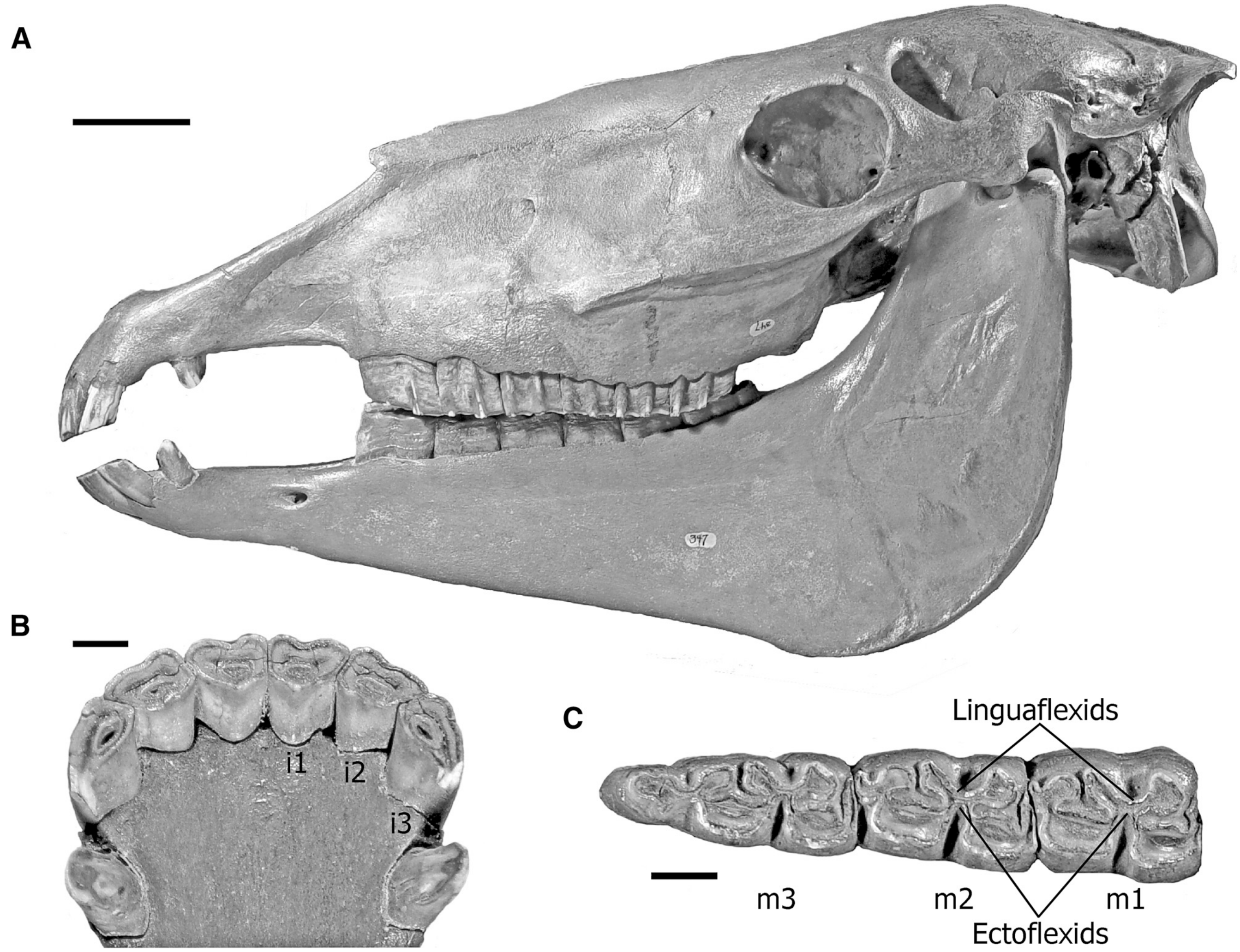

FIGURE 1. **A**, Holotype skull and mandible of *Equus laurentius* Hay, 1913 (KUMNH 347), lateral view, in occlusion. The upper cheek tooth row is visibly shorter than the lower, and the incisors cannot come into occlusion without dislocating the temperomandibular articulation. Scale bar equals 5 cm. **B**, Mandibular symphysis and lower incisor battery of KUMNH 347, occlusal view. Well-developed and fully closed infundibula are present in all incisors, as in *E. caballus*. Scale bar equals 1 cm. **C**, Lower right molars of KUMNH 347, occlusal view. Anterior is to the right. Features discussed in the text are labeled. The 'U'-shaped linguaflexids and the ectoflexids that slightly penetrate the molar isthmus on m1 and m2 are identical to the condition observed in *E. caballus*. Scale bar equals 1 cm.

metrically defined groups of extinct equids. Acknowledging that the taxonomic rank of these groups was difficult to assess, and that more than one species might be represented in each group, Winans (1985) nevertheless explicitly assumed that the groups represented actual species, and that only five valid species of extinct *Equus* were present in North America during the Plio-Pleistocene—*E. shoshonensis* Gidley, 1930; *E. scotti* Gidley, 1900; *E. francisci* Hay, 1915; *E. alaskae* (Hay), 1913; and *E. mexicanus* Hibbard, 1955. Regarding *E. laurentius*, Winans (1985) agreed with the conclusions of Matthew (1926) and Savage (1951), and considered KUMNH 347 to be modern and *E. laurentius* to be a junior synonym of *E. caballus*. Winans (1985) also proposed that the holotype skull and mandible of *E. laurentius* were from two different individuals, a point not raised by previous authors.

The subsequent, condensed publication of the results of Winans' (1985) revision (Winans, 1989) pulled back from her earlier conclusions, conservatively recognizing five metrically defined 'species groups' and conceding that there may have been more than five species of Pleistocene North American *Equus*. Winans (1989) again emphasized the possibility "that some of the [species] groups . . . defined encompass more than one species" (Winans, 1989:295). The species groups were named based upon "the most senior type specimen included in the group" (Winans, 1989:292). The fossils assigned by Winans in her 1985 dissertation to the species *E. mexicanus* were placed by Winans (1989) in her '*E. laurentius* species group,' with no explanation for the change. This is particularly perplexing because Winans (1989:293) continued to consider the holotype specimen for *E. laurentius* to be of likely Holocene age.

The reason behind this amended taxonomy can be found elsewhere in the same volume as Winans' study. Hulbert's (1989) cladistic analysis of late Neogene equines from North America concluded that the genus *Dinohippus* possessed no unique apomorphic characters, was paraphyletic, and formed a morphocline culminating in *Equus*. Hulbert (1989) resolved this paraphyly by suggesting that in a strict cladistic framework, all species previously assigned to *Dinohippus* should be placed in *Equus*. The nomen *Dinohippus mexicanus* (Lance), 1950, would

TABLE 1. AMS ^{14}C measurements and calibrated dates (AD) for KUMNH 347 bone samples.

Skeletal element	Lab number	Chemical fraction (Year dated)	Fraction of modern ± 1 SD	Age, ^{14}C years BP ±1 SD (Lab number)	Calibrated date (2σ, 95.4% confidence interval)
Medial right ramus	NSRL-2112	XAD-collagen (1995)	0.9857 ± 0.0066	120 ± 60 (CAMS-20005)	1668–1954 CAL AD
Medial right ramus	SR-6365	XAD-collagen (2003)	0.9634 ± 0.0038	300 ± 35 (CAMS-95522)	1485–1659 CAL AD
Proximal left nasal	SR-6366	XAD-collagen (2003)	0.9707 ± 0.0039	240 ± 35 (CAMS-95523)	1523–1951 CAL AD

Calibrated values are from CALIB and are based on IntCal04. Calibrated dates are full range values for the measured radiocarbon age and do not take into account historical data relating to the specimens' discovery or first appearance of Spanish horses in the New World or their probable appearance in Kansas.

thus be amended to *Equus mexicanus* (Lance), 1950, which would have priority over *Equus mexicanus* Hibbard, 1955—the species employed by Winans (1985) in erecting her '*Equus mexicanus* species group.' Winans (1989) attempted to forestall any ensuing confusion on this point by considering the holotype of *E. laurentius*, rather than that of *E. mexicanus* Hibbard, as the most senior type specimen in her metric group.

Unfortunately, this approach engendered confusion of a different sort, exacerbated by subsequent studies that employed Winans (1989) species groups as if they were actual species—or at least as if the species names employed by Winans (1989) were valid. The inclusion of the large horse from Rancho La Brea in Winans' (1989) *Equus laurentius* species group is an example. The large Rancho La Brea equid was initially assigned to the species *Equus occidentalis* Leidy, 1865, by Merriam (1913), but subsequent studies (e.g., Miller, 1971; Winans, 1985; Scott, 2004) have observed that this taxon is technically invalid. This invalidity has proven frustrating for students of Pleistocene North American horses, largely because of the excellent preservation and abundance of the equid fossils from Rancho La Brea and the consequent importance of the fossil sample. Including the large Rancho La Brea horse in Winans' (1989) *E. laurentius* species group satisfied paleontologists seeking a species name to apply to the sample (e.g., Duckler and Van Valkenburgh, 1998; Pinsof, 1998), and so *E. laurentius* was considered a valid late Pleistocene equid species (MacFadden, 1992). However, these studies failed to differentiate between strict synonymy and Winans' (1989) more conservative use of species groups, also failing to take into account Winans' (1985, 1989) consideration that the holotype of *E. laurentius* was a recent horse.

Azzaroli (1995) subsumed *Equus laurentius* into *E. caballus*, citing Matthew's (1926) claim that KUMNH 347 was a domestic horse. Later, Azzaroli (1998) amended his synonymy, considering *E. laurentius* to be a junior synonym of *Equus ferus* Boddaert, 1785—a species proposed by Gentry et al. (1996) to distinguish wild true horses from domesticated or feral *E. caballus*. The International Commission on Zoological Nomenclature (ICZN) accepted this interpretation in 2003 (Opinion 2027, Case 3010) (Gentry et al., 2004). Therefore if KUMNH 347 was a feral or domestic horse, it would fall into *E. caballus*; if from a wild or non-domesticated equid, the specimens would be placed in *E. ferus*. Azzaroli's (1998) assignment of KUMNH 347 to *E. ferus* implies he considered the specimen to be from a wild animal, but his more detailed discussion asserted simply that it belongs to either *E. caballus* or *E. ferus*. Our study shows that KUMNH 347 is best assigned to domestic *E. caballus*.

MATERIALS AND METHODS

The holotype skull and mandible of *Equus laurentius* (KUMNH 347) were examined in the collections of the Division of Vertebrate Paleontology, Natural History Museum and Biodiversity Research Center, University of Kansas, Lawrence, Kansas. Stafford first examined the skull and mandible of *Equus laurentius* (KUMNH 347) in 1993 and determined by ^{14}C dating in 1995 that the mandible had a radiocarbon age of only 120 years (Table 1). Because the holotype could have comprised a Pleistocene fossil skull and the mandible a modern individual, Stafford sampled the skull, and resampled the mandible in 2003. These results are summarized in Table 1. Scott examined the holotype skull and mandible in 2003 and his studies are combined with the geochemical data to accurately interpret the geological age and taxonomic relationships of the holotype.

Geochemical studies included chemical taphonomic data on the physical condition of the bones, the behavior of the bone protein during chemical purification, and stable isotope analyses to assess the animal's diet. Samples of bone for accelerator mass spectrometry (AMS) dating were taken by using a manual, 0.8 mm-kerf jeweler's saw. Exactly 313 mg from the upper medial portion of the right horizontal ramus, just inside the right m3, and 284 mg of the anterior right nasal were used for ^{14}C dating and stable isotope analysis. Procedures for AMS radiocarbon dating were based on Stafford et al. (1991). AMS radiocarbon measurements were made at the Center for Accelerator Mass Spectrometry (CAMS), Lawrence Livermore National Laboratory, Livermore, California.

The morphology of the specimen was assessed with emphasis on characters proposed by Bennett (1980) to delineate among Pleistocene equids. Measurements followed procedures outlined by Von den Driesch (1976) and Eisenmann et al. (1988) as appropriate. Data were acquired using Mitutoyo Digimatic calipers connected by a Mitutoyo USB digital interface to a Toshiba 2405-S201 Satellite laptop. Digital photos were acquired with a Sony DSC F717 Cybershot camera.

RESULTS

Radiocarbon and Stable Isotope Analyses

AMS ^{14}C measurements, stable isotope analyses, and laboratory chemical data are summarized in Tables 1 through 3. The first date was determined in 1995 and was 120 ± 60 RC yr. BP (CAMS-20005) on the right ramus (NSRL-2112). To determine if the holotype was a combination of both modern and ancient skeletal elements, the holotype skull and mandible were resampled in 2003. The second measurements provide dates on samples chemically purified at the same time and run in the same target wheel at the Lawrence Livermore National Laboratory's AMS facility. This approach minimizes variation that might occur between measurements spaced days or months apart. The second series of dates were 300 ± 60 RC yr. BP (CAMS-95522) on the right ramus and 240 ± 35 RC yr. BP (CAMS-95523) on the proximal left nasal. The three ^{14}C measurements and calibrated (calendar) ages calculated for these results are compiled in Table 1.

Stable carbon and nitrogen isotope analyses on purified collagen gelatin are given in Table 2. Averaged $\delta^{13}C$ values for the mandible (SR-6335) and nasal bone (SR-6336) were −11.55‰ and −10.63‰, respectively. The $\delta^{15}N$ value for the mandible was +6.05‰ and the $\delta^{15}N$ for the nasal bone was +6.89‰. The isotopic differences between the mandible and skull collagen

TABLE 2. Stable isotope analyses on bone collagen from KUMNH 347.

Specimen	∂[13]C ‰ (PDB)	∂[15]N ‰ (AIR)	C/N
Medial right ramus (NSRL-2112)	−11.7‰	—	—
Medial right ramus (SR-6335)	−11.65‰	+6.11‰	—
	−11.45‰	+5.99‰	3.24
Average	−11.55‰	+6.05‰	
Proximal left nasal (SR-6336)	−10.72‰	+6.85‰	—
	−10.54‰	+6.92‰	3.27
Average	−10.63‰	+6.89‰	
Per mil difference, ramus vs. nasal (SR-6335 vs. SR-6336)	+0.92‰	+0.84‰	

The first sample taken from the right ramus in 1995 is lab number NSRL-2112; the second sample, taken in 2003, is SR-6335. The skull was sampled in 2003 as SR-6336.

values were +0.92‰ for δ^{13}C and +0.84‰ for δ^{15}N (Table 2). The stable isotope values for the mandible (SR-6335) and nasal bone (SR-6336) are used for final interpretations; however, the first analysis on the mandible (NSRL-2112) yielded a δ^{13}C value of −11.7‰, a value statistically indistinguishable from the −11.55‰ value obtained the second time the ramus was tested.

The chemical data in Table 3 are the descriptions of collagen and chemical yields for the chemical purification of bone collagen. The bones of both the skull and mandible were very dark brown on the exterior 100 to 200 μm of the bone. Interior bone was white, waxy, and hard. After decalcification, the dark surface discoloration persisted as gray collagen; interior decalcified collagen was white. The physical appearance of the collagen after decalcification and KOH extraction was similar to modern bone collagen because the percent-of-modern collagen pseudomorph after decalcification was ≥97%. Weight percent yield of decalcified collagen was similar to modern bone. The data represent values expected for modern or near-modern cortical bone that yields a 100% pseudomorph of its original geometry after decalcification and contains 20 to 22 weight percent collagen. Finally, the C/N values for the collagen were 3.24 and 3.27, ratios that are obtained for modern, decalcified bone collagen.

Biometrics and Morphology

Examination of the skull and mandible confirmed that in size (Hay, 1913, 1927), KUMNH 347 resembles some living races of *Equus caballus*. Measurements of the skull are presented in Table 5 with measurements from *E. ferus* (Przewalski's horse), various breeds of extant *E. caballus* (Willoughby, 1974), and fossils of *E.* "*occidentalis*" from Rancho La Brea. KUMNH 347 compares most favorably in size with thoroughbreds (five measurements) and *E. ferus* (five measurements), while resembling *E.* "*occidentalis*" in only one.

Morphologically, KUMNH 347 exhibits several characters accorded by Bennett (1980) to *Equus caballus*. On the skull (Fig. 1A), the frontals are anteroposteriorly and transversely flat across the dorsal surface, showing no evidence of frontal doming. Basicranial flexion is not pronounced. The bony 'fan' comprising the mastoid, the paramastoid, and the mastoid process of the temporal bone is unfolded. The paramastoid processes and the mastoid portion of the temporal bone can be clearly observed in dorsal view lateral to the crista temporalis, despite the fact that this latter feature is itself broadened. The crista temporalis also lacks any definitive excavation along its length that, in dorsal view, would reveal the external auditory meatus. The meatus is situated close behind the glenoid, angled slightly anteriorly, and only partly visible in dorsal view. The lambdoid crest is formed by nearly parallel lines of bone. The infundibula of all lower incisors are present and closed (Fig. 1B). The molar ectoflexids enter into the molar isthmus, but do not pass through it fully; the linguaflexids are broad, deep, and 'U'-shaped; the metastylids are angular (Fig. 1C).

In addition to the above characters, the mandible of KUMNH 347 is relatively flat along the ventral borders of the horizontal rami (Fig. 1A). Although this character was not listed by Bennett (1980), Pleistocene North American *Equus* generally exhibits dorsoventrally convex rami, with the deepest part of the jaw located ventral to the middle of the cheek tooth row.

Winans (1985) suggested that the skull and mandible were from different individuals, although data supporting this interpretation were not presented. The upper cheek tooth row is distinctly shorter anteroposteriorly than the lower cheek tooth row. The condyloid processes of the mandible do not articulate cleanly with the mandibular fossae. The incisors do not occlude without dislocating the mandible. The skull and mandible do not exhibit any indications of postmortem distortion that might account for these size and occlusal differences.

The anterior (nonocclusal) edges of the left and right p2 have the enamel worn completely away to reveal a thin strip of the underlying dentine with parallel edges (Fig. 2). The height of the wear strip is approximately 10.0 mm on the left p2, 13.5 mm on the right p2. The anterior occlusal surface of the left p2 is also rather pitted, and worn at an angle to the occlusal plain; the bevel or wear facet measures 2.81 mm from the projected occlusal plane. None of the other cheek teeth exhibits similar wear. Neither P2 shows any similar wear.

DISCUSSION

A radiocarbon date of less than 500 years in age was the first empirical corroboration of the interpretation (Matthew, 1926; Savage, 1951; Winans, 1985) that the holotype mandible and skull of *Equus laurentius* Hay, 1913 (KUMNH 347), were modern, rather than late Pleistocene equid material. Additional dates coupled with biometric data and physical observations provide conclusive evidence about the true nature and geologic age of KUMNH 347.

TABLE 3. Chemical data from purification of bone for AMS ^{14}C dating.

Skeletal element	Lab number	Chemical fraction (Year dated)	Mass bone, g	% KOH pseudomorph	KOH collagen yield, wt%	Gelatin solubility,%
Medial right ramus	NSRL-2112	XAD-collagen (1995)	1.00	97%	19.4%	29.2%
Medial right ramus	SR-6365	XAD-collagen (2003)	0.312	99%	18.9%	100%
Proximal left nasal	SR-6366	XAD-collagen (2003)	0.284	99%	24.7%	99.9%

TABLE 4. Radiocarbon measurements and 2σ calendar range ages based on historical information, and stable isotope values for KUMNH 347.

Skeletal element	Sample type	∂^{13}C ‰ (PDB)	∂^{15}N ‰ (AIR)	Age, ^{14}C years BP ±1 SD (Lab number)	Calibrated date, AD (2σ, 95.4% confidence interval)
(1) Medial right ramus (NSRL-2112)	XAD-collagen (1995)	−11.7‰	ND	120 ± 60 (CAMS-20005)	1668–1910 CAL AD
(2) Medial right ramus (SR-6335)	XAD-collagen (2003)	−11.55‰	+6.05‰	300 ± 35 (CAMS-95522)	1540–1659 CAL AD
Average, N = 2					
(3) Proximal left nasal (SR-6336)	XAD-collagen (2003)	−10.63‰	+6.89‰	240 ± 35 (CAMS-95523)	1540–1910 CAL AD
Average, N = 2					
(2) Ramus vs. (3) nasal		+0.92‰	+0.84‰		

The first radiocarbon date, 120 ± 60 RC yr (CAMS-20005), indicated that at least the mandible was from a recent equid. The subsequent two additional dates are those used for the discussion of the geologic age of KUMNH 347 because these two measurements were made on bone chemically purified at the same time and dated consecutively in the same sample wheel at the Lawrence Livermore AMS facility. When small age differences must be assessed between samples, the samples should be analyzed during a single AMS run cycle to minimize measurement variations occurring between different sample runs.

Tables 4 and 6 summarize radiocarbon and isotope data used to interpret the geological ages of the mandible (SR-6365) and skull (SR-6366). Although the uncalibrated ^{14}C ages (300 ± 35 RC yr and 240 ± 35 RC yr) appear to indicate that the mandible and skull date to the late 17th or early 18th centuries AD, calibration of the dates yields longer time spans (Table 1).

Based on initial calendar corrections of the dates (Table 1) the mandible has a 2σ (95.4% confidence interval) calibrated date range of 1485 to 1659 CAL AD; the skull calibrates as 1523 to 1951 AD. Historical information narrows the age range. First, the most recent date for the remains is 1910 AD, the discovery date of the holotype specimens (Hay, 1913). Second, while 1492 AD is the oldest possible date for Spanish horse, a later date estimate is 1540 AD, the beginning of the Coronado Expeditions into the American midwest and southwest (Winship, 1904). Therefore the most probable date ranges at 95.4% confidence interval are 1540 to 1659 CAL for the mandible and 1540 to 1805 CAL AD for the skull (Table 6).

FIGURE 2. Anterior portion of mandible of KUMNH 347, oblique view, showing the leading (non-articular) edges and the occlusal surfaces of the left and right p2. Anterior is to lower left. **A**, Beveling and pitting on the anterior 1/3 of the occlusal surfaces of both p2s suggests bit wear (after Brown and Anthony, 1998; Anthony et al., 2006). **B**, Enamel has been completely worn away from the leading non-articular edge of each p2; this also indicates bit wear (after Bendry, 2007; Outram et al., 2009). These features demonstrate that this mandible is from a domestic, bitted horse.

Because calibrating ^{14}C dates after 1400 AD give large date ranges due to secular variation and the Suess effect after 1800 AD, establishing that one or two different individuals are represented by the skull and mandible is more accurately accomplished by using the stable isotope analyses. For the holotype, the δ^{13}C values differ by +0.92‰ and the δ^{15}N values differ by +0.84‰ between the mandible and nasal bone. Bone proteins in a living animal's bones will be within 0.1‰ of each other. The isotope results are therefore the best evidence for demonstrating empirically that the skeletal elements are from two different individual animals. Measurement precision for the stable isotope results is ±0.02‰, whereas the maximum variation for chemically well-preserved bones from the same individual is ±0.2‰ based on within-individual variation and variation caused by diagenesis during burial. Because the mandible and skull have near-modern collagen contents, as based on chemical yields and C/N values (Tables 2 and 3), diagenetic change on collagen isotope values is unlikely. Therefore 0.9‰ and 0.8‰ differences in C and N stable isotope values, respectively, are values that would result from two different individual horses with different diets being represented.

The morphology and radiometric age of KUMNH 347 confirm that the specimens represent *Equus caballus* and not a Pleistocene horse. This conclusion has been advanced previously (e.g., Matthew, 1926; Savage, 1951; Winans, 1985), but has to date not been fully accepted by other students of Pleistocene North American *Equus*. This is in part because KUMNH 347 has not been thoroughly described until now. Hay (1913, 1927) was primarily concerned only with skull and mandible size, as well as with upper cheek tooth enamel plications; these characteristics are not entirely sufficient to discriminate among equid species (Gidley, 1901; Savage, 1951; Scott, 2004). Further, although Hay's interpretation was challenged several times (Matthew, 1926; Savage, 1951; Winans, 1985), these studies provided little morphologic or metric data to support their interpretations. Another factor was the misperception that the specimen was mineralized, coupled with the assumption that such mineralization could not happen quickly (Hay, 1927; Quinn, 1957). Mineralization was inferred because the mandible and skull were dark brown, suggesting antiquity. The presence of mineralization or permineralization was inferred by the bones' 'high' density, which is actually the normal mass and density of near-modern bone. Compared to other fossils from the river, the bones appeared to have higher density, which combined with the dark color caused the misinterpretation that the bones were fossilized and of Pleistocene age.

Physical attributes of KUMNH 347 also offer features that may prove useful in determining whether craniodental remains of *Equus* are historic rather than prehistoric in age. In particular,

TABLE 5. Select measurements for modern breeds of domestic equids, Przewalski's horse, and extinct *Equus* "*occidentalis*" from Rancho La Brea, compared with KUMNH 347.

Name/breed	N	1	5	10	12	14	15	23	24
Arabian	1	511	200	*66*	136	152	412	*65*	*54*
Thoroughbred	1	*503*	223	*66*	*133*	173	*381*	*63*	59
Shetland	1	384	164	*65*	99	70	296	48	26
Draft	3	556–613	226–256	70–82	136–151	177–215	437–476	66–74	58–65
Percheron	1	596	234	74	139	185	470	67	57
Draft mule	1	560	246	*62*	135	*162*	447	61	50
Przewalski	2	*476–499*	*211–214*	67–69	120–128	167*	*375–396*	59	*52–55*
E. "*occidentalis*"	7	532–557	223–248	73–96	*121–144*	174–202	412–446	59–66	55–59
KUMNH 347	1	490	209	64	133	165	386	65	53

Data for modern breeds and Przewalski's horse from Willoughby (1974); data for *E.* "*occidentalis*" and KUMNH 347 acquired by Scott for this study. Measurements with an asterisk are those most similar to KUMNH 347. Measurements: 1 = basilar length; 5 = frontal breadth; 10 = premaxillary breadth; 12 = distance from vomer to foramen magnum; 14 = anteroposterior length of upper cheek tooth series; 15 = distance from anterior premaxilla to posterior edge of orbit; 23 = anteroposterior diameter of orbit; 24 = dorsoventral diameter of orbit.

the unusual macroscopic wear on the left and right p2 is a clear indicator of the presence of a bit during the animal's life, demonstrating domestication. The pitting and beveling evident on the left p2 resembles bit wear described previously (Brown and Anthony, 1998; Anthony et al., 2006) as damage occurring on the occlusal surfaces of the p2 when a horse chews the bit. Beveling is measured by placing a straightedge across the crests of the metaconid and metastylid and projecting it forward past the anterior edge of the p2, then measuring the shortest direct dorsoventral distance from the projected edge to the point where the occlusal surface meets the anterior edge of the tooth; this measurement is then rounded to the nearest 0.5 mm (Brown and Anthony, 1998). The threshold proposed for bit-induced beveling (Brown and Anthony, 1998; Anthony et al., 2006) is 3.0 mm. The distance of 2.81 mm measured from KUMNH 347, rounded to the nearest 0.5 mm, meets this threshold exactly.

The macroscopic wear patterns observed on the anterior, nonocclusal edges of the left and right p2 (Fig. 2) are also interpreted to represent bit wear, or wear caused by the abrasion of a bit against the anterior edge of the p2 in bitted horses. The wear patterns observed on KUMNH 347 are closely similar to those considered to represent bit wear in modern and archaeological samples of *Equus* (Bendry, 2007; Outram et al., 2009). Because no other similar wear is evident anywhere else on the specimen, abrasion or wear as a result of depositional, erosional, or other taphonomic processes can be ruled out.

Several studies (e.g., Levine, 1999; Levine et al., 2000; Benecke and von den Driesch, 2003; Olsen, 2003) have challenged the efficacy of pitting and beveling of the occlusal surface of the anterior premolars as evidence of bit use. However, the observed combination on KUMNH 347 of both the beveling and pitting of the left p2, and the anterior, nonocclusal wear on both the left and the right p2, strongly indicate that a bit was present during the animal's life.

Radiometric dates obtained from KUMNH 347 demonstrate conclusively that the skull and mandible are historic rather than Pleistocene. We emphasize that documenting the observed wear on the p2s would have indicated the historic, domestic status of the mandible of KUMNH 347 even in the absence of radiometric dates. We therefore recommend that these features may be employed when assessing the relative geologic age of purported fossil equids.

The presence of bit wear indicates that the mandible of KUMNH 347 is from a domesticated animal. The specimen

TABLE 6. AMS radiocarbon dates, probability distributions for calibrated date ranges, and conclusions regarding the AD ranges most probable for the mandible and skull samples dated for KUMNH 347.

Specimen	^{14}C age, RC year ± 1 SD	Calibrated dates, CAL AD	2σ, 95.4% CI	Comments	Conclusions
Medial right ramus (NSRL-2112)	120 ± 60	1668–1781	0.404	—	0.980 probability of dating between 1668 and 1910 AD
		1797–1948	0.586	Exclude 1911 to 1948 because the holotype was discovered in 1910 AD	
		1950–1954	0.101	Holotype discovery (1910 AD) predates this time period	
Medial right ramus (SR-6335)	300 ± 35	1485–1659	1.00	—	1.00 probability of dating between 1540 and 1659 AD
Proximal left nasal (SR-6336)	240 ± 35	1523–1572	0.101	Coronado Expedition, 1540–1542	0.921 probability of dating between 1540 and 1805 AD
		1630–1683	0.482	—	
		1735–1805	0.338	—	
		1930–1951	0.080	Holotype discovery (1910 AD) predates this time period	

Conclusions are based on the earliest date possible for introduction of Spanish horse into North America (1492 AD), the most probable date for Spanish horses to be introduced during Coronado's 1540–1542 AD expedition into the American Southwest and Midwest, and the discovery date (1910 AD) for KUMNH 347.

therefore does not represent a "feral pony' as proposed by Savage (1951). For this reason, *Equus laurentius* is a junior synonym of *E. caballus*, not *E. ferus* as indicated by Azzaroli (1998), because the name *E. ferus* is employed only for wild horses, whereas for feral or domesticated horses *E. caballus* is correct.

Because the holotype skull and mandible of *Equus laurentius* are actually specimens of modern *Equus caballus*, the continued use of Winan's (1989) '*Equus laurentius* species group' for North American Pleistocene horses is no longer tenable. Determining a new designation for this group is problematic. Winans' own earlier (1985) dissertation preferred the species name *Equus mexicanus* Hibbard, 1955, for this group; however, as noted, a strict cladistic interpretation leads to assignment of all species previously assigned to *Dinohippus* to the genus *Equus* in order to avoid paraphyly (following Hulbert, 1989).

The present study prefers not to apply the species name *Equus mexicanus* to Winans' (1989) '*Equus laurentius* species group,' pending better resolution of the relationship between *Equus* and *Dinohippus*. Nor are any other names for this group advanced at present, because any metrically defined 'species groups' that fail to distinguish domestic *E. caballus* from extinct North American Pleistocene horses likely have limited utility. Determining the correct species designation for animals in this group is beyond the scope of the present study, and efforts to resolve this issue are underway (Scott, in preparation).

The history of study of *Equus laurentius* demonstrates the continuing need for rigor in studies of ancient *Equus*; had the holotype been fully described and diagnosed at any time over the past century, much confusion would have been avoided. In order to reliably diagnose Pleistocene equid species, specimens must be fully described, with metrics and morphology presented in combination and pertinent discrete characters established to empirically define species, enabling their placement in a rigorous and informative phylogenetic framework.

CONCLUSIONS

Hay (1927:7), in defending his taxon *Equus laurentius*, requested "those who regard [the holotype of *E. laurentius*] as a part of a modern horse shall present evidences therefor." This study definitively answers Hay's challenge. Based upon size, morphology, stable isotope values, and ^{14}C ages, the holotype skull and mandible of the species *Equus laurentius* Hay, 1913, are determined to represent separate individuals of the modern domestic horse species *Equus caballus*. AMS dating demonstrates that the bones are less than 500 years old. The presence of bit wear on the left and right p2 suggests that the mandible at least was from a domestic horse, rather than a 'feral pony' as suggested by Savage (1951). The name *Equus laurentius* should no longer be applied in any manner to any North American Pleistocene horses.

ACKNOWLEDGMENTS

Funding for the AMS dates was provided by National Science Foundation grant NSF EAR 91–18683, the Denver Museum of Nature and Science, Stafford Research Laboratories, and Mary Scott of Carmel, California. Access to comparative samples of *Equus* "*occidentalis*" from Rancho La Brea was provided by Christopher A. Shaw of the George C. Page Museum and Kevin L. Seymour of the Royal Ontario Museum. The authors thank Kim Scott of the Department of Biology, California State University, San Bernardino, as well as Kathleen Springer and J. Christopher Sagebiel of the San Bernardino County Museum, for critiquing portions of this study. The manuscript was reviewed by two anonymous reviewers who are thanked for their efforts. David Anthony of the Institute of Ancient Equid Studies, Department of Anthropology, Hartwick College, New York, is thanked for his comments and observations regarding bit wear in ancient horses.

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Submitted May 1, 2009; accepted June 8, 2010.