Equidae from the Baynunah Formation

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Abstract—We report 87 specimens of hipparionine horse from the Baynunah Formation, United Arab Emirates. The dominate species is referred to “*Hipparion*” *abudhabiense*. “*Hipparion*” *abudhabiense* is represented by mandibles, mandibular and maxillary cheek teeth and a variety of postcranial bones, some of which are complete. Baynunah Formation early wear cheek teeth suggest that “*Hipparion*” *abudhabiense* was higher crowned than Central European *Hippotherium primigenium* with a maximum crown height of 60-65 mm. AUH 270, the type mandible is characterized as having a short, broad symphysis with horizontally aligned incisors. While the previous view was that this mandible suggested an evolutionary relationship with Greek *Hipparion dietrichi*, a fragmentary but otherwise elongate metacarpal III (AUH 1499) exhibits a close similarity to Akkasdagi (7.1 Ma) and Calta (4.0 Ma) “*Plesiohipparion*” cf. *longipes*. There is a rare, smaller species of hipparion that compares favorably in its size and morphology to Greek and Iranian members of the *Cremohipparion matthewi-nikosi* lineage. The Baynunah hipparion fauna supports a correlation of ca. 7 Ma, and a potential biogeographic affinity with Greece, Turkey, Iran and possibly Northern Kazakhstan.

Running Head: Equidae

Introduction

Fossils of hipparionin equids have been collected from the Baynunah Formation of Abu Dhabi Emirate for over 30 years. Most notably, a joint Natural History Museum, London – Yale University research team led by Peter Whybrow and Andrew Hill respectively, was active from 1986-1994, and a Yale-ADACH (Abu Dhabi Authority for Culture and Heritage, currently the Department of Tourism and Culture) project has been active since 2006 (Hill 1999; Hill et al. 2012; Bibi et al. 2013, this volume-a; Beech et al. this volume). Over 30 years, some 197 specimens of fossil hipparion, many of which are fragmentary, have been collected from the late Miocene Baynunah Formation, UAE (Fig. 16.1). Eisenmann and Whybrow (1999) reported 41 specimens of “*Hipparion*” including maxillary and mandibular teeth, limb bones and fragmentary mandibles. The authors recognized two “*Hipparion*” taxa, one small or middle sized, and one larger. The current study is based on 84 specimens that have varying degrees of diagnostic characters. Table 16.1 provides a list of Baynunah hipparion specimens with Bernor et al.’s (this contribution) species determinations and Eisenmann and Whybrow's (1999) species determinations. Differences between these two are due largely to size subjectivity. Table 16.2 gives measurements on our sample of the Baynunah hipparions.

FIGURE 16.1 NEAR HERE. ONE COLUMN WIDTH

Methods

Statistical analysis—Systat 12 was used to calculate bivariate plots of calcaneum, astragalus, metacarpal III, metatarsal III and 1st Phalanx III using the Höwenegg sample of *Hippotherium primigenium* as a standard for calculating 95% confidence ellipses.

Abbreviations and conventions—Ma: mega-annum in the geochronologic time scale. Ages in m.y. usually based on radioisotopic analyses or magnetostratigraphic analyses. North Africa: localities may be referred to the MN biochronologic time scale. Western Eurasia: Vallesian, Turolian, and Ruscinian; intervals of the European land mammal age sequence, commonly termed units (sensu Fahlbusch

1991). Measurement Table Abbreviations Sex: M = male; F = female; ? = unknown. Sex can be defined by the size of a canine tooth, male being large, female being small.

Side: lt. = left; rt. = right.

Element abbreviations—CALC = calcaneum; AST = astragalus; MCIII = metacarpal III; MTIII = metatarsal III; MPIII = metapodial III; 1PHIII = 1st phalanx III and 2PHIII = 2nd phalanx III (central digit) of either the anterior or posterior limb, which are difficult to distinguish in hipparion. Maxillary tooth – uppercase (I, C, P or M); mandibular tooth – lower case (i, c, p or m).

Systat plot abbreviations—M1-M38 refers to measurements as described by Eisenmann *et al.* (1988) and Bernor *et al.* (1997). Bernor *et al.* (2016) and Bernor and Sen (2017) have recently considered these taxa and have reviewed them accordingly.

References given below include measurements of those samples. Statistical plots include abbreviations by locality. These abbreviations are as follows:

a = Akkasdagi, Turkey (7.1 Ma) Koufos & Vlachou (2005), Scott & Maga (2005), Bernor & Sen (2017)

b = Sahabi, Libya (ca. 7 Ma) Bernor *et al.* (2012)

C = China *Plesiohipparion* spp, (5-2.5 Ma) Bernor & Sun (2015), Bernor *et al.* (2015)

D = Baynunah (ca. 7 Ma) this manuscript

e = Ethiopia (6-3 Ma) Bernor *et al.* (2009)

g = Germany (Höwenegg, 10.3 Ma (Bernor *et al.* 1997); Eppelsheim, 10 Ma)

k = Pikermi, Greece (8 Ma) Koufos (1987)

m = Maragheh, Iran (9-7.4 Ma) Bernor (1985), Bernor *et al.* (2016)

n = Sinap, Turkey (10.6-9.7 Ma) Bernor *et al.* (2003)

p = Pakistan (10.5-7 Ma) Wolf *et al.* (2013)

t = Tanzania (5-1 Ma) Armour-Chelu & Bernor (2011)

w = Perpignan, France (3.5 Ma) Bernor & Sen (2017)

y = Kenya (10-5 Ma) Bernor & Harris (2003)

Z = Çalta, Turkey *Proboscideipparion* (4.0 Ma) Bernor & Sen (2017)

z = Çalta, Turkey “*Plesiohipparion*” (4.0 Ma) Bernor & Sen (2017)

Taxonomic abbreviations used in log10 plots—AL— Hadar, Denen Dora Member *Eurygnathohippus hasumense*; AK_Mean – Akkasdagi “*Plesiohipparion*” cf. *longipes*; AUH – Baynunah hipparion; BH_Mean – Bou Hanifia Mean Measurements; BMNH – British Museum of Natural History (now Natural History Museum, London) – *Cremohipparion antelopinum*; Crant - *Cremohipparion antelopinum* from the late Miocene of IndoPakistan (late Miocene age); EufeiL - Type *Eurygnathohippus feibeli* from Upper Nawata, Lothagam Hill, Kenya (ca. 6.0 Ma); EufeiMA - *Eurygnathohippus feibeli* from Middle Awash, Ethiopia (ca. 6.0 Ma); EufeiS – *Eurygnathohippus feibeli* from Sahabi, Libya; Euhoo_MEAN – *Eurygnathohippus hooijeri* from Langebaanweg, South Africa (ca. 5.0 Ma); MMTT 13 – *Hipparion campbelli*, locality (MMTT13, 7.9 Ma; Bernor, 1986, 1986; Bernor et al. 2016); Pl_C_MEAN– *Plesiohipparion* sp. China (ca. 5 Ma.; Bernor et al. 2015b); SAM_MEAN – *Eurygnathohippus hooijeri* Type assemblage, Langebaanweg, South Africa (ca. 5 Ma.).

Museum collections—AMNH – American Museum of Natural History, New York (AMNH numbers); BMNH – Natural History Museum, London, England (BMNH numbers); MMTT – National Museum of Iran, Tehran (MMTT numbers); MNHN – Museum National d’Histoire Naturelle, Paris (MNHN numbers); THP – Tianjin Museum of Natural History, Tianjin, China (THP numbers).

Systematic conventions—Anatomical descriptions have been adapted from Nickel *et al.* (1986). Getty (1982) was also consulted for morphological identification and comparison. Hipparion monographs by Gromova (1952) and Gabunia (1959) are cited after the French and English translations. The nomen Hipparion has been used in a variety of ways by different authors. We follow

characterizations and definitions for hipparionine horses as most recently defined in Bernor *et al.* (2016) and Bernor and Sen (2017). We recognize the following lineages of Old World hipparionine horses: *Cormohipparion*, *Hippotherium*, *Cremohipparion*, *Hipparion*, “*Sivalhippus*”, *Eurygnathohippus* (=senior synonym of “*Stylohipparion*”), *Proboscoidipparion* and *Plesiohipparion*. These lineages have recently been reviewed by Qiu *et al.* (1987), Bernor (1985); Bernor and Harris (2003), Bernor and White (2009), Bernor *et al.* (1996, 2003, 2005, 2010, 2013, 2014, 2015a & b), Wolf *et al.* (2013), Bernor & Sun (2015), Bernor *et al.* (2016) and Bernor and Sen (2017). Bernor and Bernor *et al.* publications include measurements.

Metric procedures—Measurements are all given in millimeters and rounded to 0.1 mm. Measurement numbers (M1, M2, M3, etc.) refer to those published by Eisenmann *et al.* (1988) and Bernor *et al.* (1997) for the skulls and postcrania. Tooth measurement numbers refer to those published by Bernor *et al.* (1997). Bernor and Armour-Chelu (1999), Bernor and Harris (2003), Bernor and Scott (2003), Bernor *et al.* (1990, 2003, 2004, 2005, 2010; 2013, 2015a & b), Gilbert and Bernor (2008), Bernor and Haile Selassie (2009) and Bernor and White (2009) have compared African hipparions to an extensive series of Late Miocene-Pleistocene Eurasian and African assemblages. Bernor and Sun (2015) have recently reviewed cheek tooth ontological stages in Chinese *Plesiohipparion* and *Proboscoidipparion*.

In various studies, Eisenmann (see Eisenmann 1995 for a comprehensive summary), has used log₁₀ ratio diagrams to evaluate differences in hipparion metapodial proportions as a basis for recognizing taxa and their evolutionary relationships. Bernor *et al.* (2003) and Bernor and Harris (2003) have used multiple statistical tests, including univariate, bivariate and multivariate statistics as well as log₁₀ ratio diagrams to evaluate and resolve the alpha systematics of hipparionine horses. Bernor *et al.* (2005) used log₁₀ ratio diagrams together with multivariate statistics to evaluate metapodial and first phalangeal evidence for postcranial evolution in Ethiopian hipparions. Bernor *et al.* (2016) have used log₁₀ ratios combined with bivariate plots to integrate postcranial with cranial morphology to characterize multiple species of Maragheh, Iran hipparions. We incorporate these

previously used methodologies in this work. Our statistical analyses use the skeletal population from Höwenegg (Hegau, southern Germany, 10.3 Ma; Bernor *et al.* 1997) for calculating 95% confidence ellipses used in bivariate plots, and log10 mean standard values for all log10 ratio diagrams (MCIII, MTIII and 1PHIII).

Statistical Analysis

Bivariate plots—Table 16.2 provides measurements of the Baynunah specimens used in this analysis. These measurements were taken by R.L. Bernor.

Höwenegg, Germany (10.3 Ma; Bernor *et al.* 1997 which includes population statistics on all skulls, mandibles, dentitions and bones) is used as the population standard for calculating 95% ellipses. In addition, we include the following hipparion samples in the analysis: Sahabi, Libya (symbol b; ca. 7.5-7.0 Ma., MN 12 and 13); Yushe and Nihowan, China specimens of *Plesiohipparion* (symbol c; 6-2.5 Ma.); Middle Awash and Gona, Ethiopia (symbol e; 6-1 Ma); Eppelsheim, Germany (symbol g; ca. 10.3-10.0 Ma); Pikermi, Greece (symbol i; ca. 8 Ma); Sinap (symbol n; ca 10.7-9.9 Ma); Siwalik Hills, Pakistan (symbol p; ca. 10.7 – 6.9 Ma); late Miocene – Pleistocene of Tanzania (symbol t; ca. 7-1 Ma); Perpignan, France (symbol w; ca. 4-3 Ma); late Miocene – Pliocene of Kenya (symbol k; ca. 8-2.5 Ma); Çalta, Turkey (symbol Z for *Proboscoidipparion heintzi* and z for *Plesiohipparion longipes*; ca. 4 Ma).

Analyses of the Baynunah hipparions include bivariate plots of CALC, AST, MCIII, MTIII and 1PHIII. Analysis of dP2 was recently reported by Wolf and Bernor (2013) and Bernor *et al.* (2015). All of these skeletal elements are clearly differentiated with the exception of 1PHIII. While anterior and posterior 1PHIII can be clearly differentiated in living *Equus*, the same cannot be said for all hipparions. The Höwenegg *Hippotherium primigenium* skeletons were found in articulation and thus the anterior versus a posterior 1PHIII are known. However, the statistical differences between these phalanges are minor at best, which has led us to analyze all 1PHIII together. Some advanced African hipparions may in fact differ significantly in anterior versus posterior 1PHIII dimensions, but this has not been adequately demonstrated across individual lineages. Bivariate plots will include two

parallel sets of plots when needed: one of our entire sample; a second of the Baynunah specimens with China, Akkasdagi (7.1 Ma, Turkey) and Calta (4.0 Ma, Turkey) alone to highlight their plotted points clearly.

Calcaneum maximum length (M1) versus distal maximum breadth is plotted in Figures 16.2A and 2B. Figure 2A plots the 95% ellipse of the Höwenegg hipparions with specimens from the Dinotheriensand (g), Tanzania (t), Pakistan (p), Pikermi (k), Calta (Z) falling within the ellipse. There are specimens from Ethiopia (e), Pakistan (p) and Tanzania (t) that are large and plot above the ellipse. Baynunah (D) calcaneum falls well below the Höwenegg ellipse with small specimens from Maragheh (m), Pakistan (p), Sahabi (b), Tanzania (t) and Sinap (n) falling below the ellipse. Figure 2B clearly shows the Baynunah (D) hipparion below the ellipse, indicating its smaller size than the Höwenegg sample, and Calta (Z). The calcaneum bivariate indicates that the Baynunah hipparion is smaller than most of the Höwenegg sample.

FIGURES 16.2, 16.3 and 16.4 NEAR HERE. EACH ONE COLUMN WIDTH

Figures 16.3A and B plot maximum length (M1) versus distal articular (M5) of astragalus. Astragali are durable in the fossil record and are well represented in our sample with a scatter mostly along the Höwenegg 95% ellipse axis with larger specimens from Ethiopia (e), Tanzania (t), Pakistan (p) and Calta (z and Z) prevalent (Fig. 3A). Figure 3B plots one Baynunah astragalus at the bottom of the Höwenegg ellipse and two below the ellipse (D). There are a total of 7 astragali from Calta (z and Z) at the top, or above the Höwenegg ellipse. Distinguishing "*Plesiohipparion*" cf. *longipes* from *Proboscidihipparion heintzi* astragali is difficult to ascertain, so these assignments can only be considered estimates of affinity (re: Eisenmann and Sondaar, 1998; Bernor and Sen, 2017). The astragalus bivariate indicates that the Baynunah hipparion is smaller than most of the Höwenegg sample. Although we cannot be certain that these astragali belong to adult individuals (and have therefore attained their maximum size), size findings are congruent with comparisons using other elements. Figure 16.4A plots MCIH maximum length (M1) versus maximum distal articular width

(M11) of a large sample of hipparions in comparison to the Höwenegg ellipse. Ethiopia (e), China (C) have specimens above the Höwenegg 95% ellipse. Akkasdagi (a) and Baynunah (D) have long and slender specimens above and to the left of the ellipse, whereas Maragheh (m), Pikermi (k) have several specimens to the left of the ellipse, being more slender than the Höwenegg sample. Maragheh (m), Pakistan (p), Sinap (n), Pikermi (k), Tanzania (t) all have specimens that plot within the Höwenegg ellipse. Maragheh (m), Sinap (n) and Perpignan (w) have small specimens that plot below the ellipse. MCIIIIs with wide distal articular widths (M11) include specimens from Tanzania (t), Pakistan (p), Perpignan (w; short and wide) and Calta *Proboscidihipparion heintzi*. Figure 16.4B clearly plots the Baynunah MCIII M1 vs. M11 in a cluster of Akkasdagi (a) “*Plesiohipparion*” cf. *longipes* being nearly as long as China *Plesiohipparion houfenense*. *Proboscidihipparion heintzi* (Z) plots to the right of the Höwenegg ellipse being relatively short (M1) and wide (M11). Figure 4C plots MCIII distal articular width (M11) versus midsagittal keel diameter (M12) and shows that Baynunah plots just inside the left border of the Höwenegg ellipse and another specimen just outside the lower border of the Höwenegg ellipse. Figure 16.4D plots MTIII distal articular width (M11) versus midsagittal keel diameter (M12) and plots two Baynunah hipparions just below the Höwenegg ellipse. These fragmentary MPIII specimens overlap in their dimensions but also are incrementally smaller than the Akkasdagi hipparion and overlap and are smaller than the Höwenegg sample. There is no reason to consider any of these specimens as belonging to two different sized hipparions and therefore we refer them to “*Hipparion*” *abudhabiense*.

FIGURES 16.5 and 16.6 NEAR HERE. EACH ONE COLUMN WIDTH

AUH 1797 is a badly weathered MTIII collected by the Whybrow-Hill expedition in 1998 but not described by Whybrow and Eisenmann (1999). At the time of writing it is still in the Natural History Museum of London. We have no measurements on this specimen and can only say herein that it is elongate and slender with fragmentary proximal and distal ends.

Figures 16.5A and B plot maximum length (M1) versus proximal articular width (M4) of 1PHIII. As

with our other samples of bones cited above, there are several specimens larger than the Höwenegg ellipse from Ethiopia (e; the largest of our sample), Calta (z and Z), Pakistan (p), Tanzania (t) and Pikermi (k). There is a dense cluster of specimens within the Höwenegg ellipse (m, t, p, Z), to the right of the ellipse (Z, p, k, e), to the left of the ellipse (m, p, g) and below the ellipse (m, n, k, g). Figure 5B plots Calta *Proboscideipparion heintzi* (Z) is in the upper right corner, outside and above the Höwenegg ellipse while the Baynunah hipparions (D) plot on the left side and outside to the left of the Höwenegg ellipse.

Figure 16.6 (A-D) provides a series of log10 ratio plots of MCIII, with the mean of the Höwenegg sample used as the standard. Figure 6A plots Hadar *Eurygnathohippus hasumense* (AL155-6BB) as larger and more robust than the rest of the sample for all specimens. The log10 ratios for the rest of the sample from Langebaanweg (SAM_MEAN), Bou Hanifia (BH_MEAN), Lothagam (EufeiL) and Sahabi (EufeiS) *Eu. feibeli* are very similar: they have strongly contrasting length (M1) versus midshaft width (M3) and distal articular (M11) and supraarticular (M10) measurements. There is a very strong contrast in midshaft width (M3) versus midshaft depth (M4) which is believed reflect cursorial behavior (Bernor et al. 2003). The Bou Hanifia “*Cormohipparion africanum*” is believed to represent the primitive morphotype for Old World hipparions (Bernor and White, 2009). Figure 6B more dramatically exhibits the close identity of Bou Hanifia (BH_MEAN), Lothagam (EufeiL) and Sahabi (EufeiS) *Eu. feibeli* and Siwalik *Cremohipparion antelopinum* (Crant) in their log10 ratios with lengthening (M1), narrow midshaft width (M3) versus relatively great midshaft depth (M4) being particularly dramatic.

Bou Hanifia is primitive in its modest length. Figure 16.6C shows the substantially greater lengthening of the Baynunah MC III (AUH 1499) compared to Bou Hanifia (BH_MEAN), *Eurygnathohippus feibeli* (EufeiL and EufeiS) and *Cremohipparion antelopinum* as directly reflected in the bivariate plots. Figure 16.6D demonstrates the strong lengthening of China *Plesiohipparion houfenense* (Pl_C), Baynunah (AUH 1499) and Akkasdagi (AK_MEAN). This plot supports an attribution of the Akkasdagi and Baynunah hipparion to “*Plesiohipparion*” cf. *longipes* and their close relationship to the larger latest Miocene – early Pliocene Chinese species *Plesiohipparion houfenense*.

FIGURE 16.7 NEAR HERE. ONE COLUMN WIDTH

Figures 16.7A-C provide a log₁₀ plot of a sample of 1PHIII's. Figure 16.7A plots the two AL155 (Hadar, Ethiopia) specimens and demonstrates that they are the largest and most robust 1PHIIIs of our sample, particularly for measurements M3-9. The two populations of *Eurygnathohippus feibeli* from Lothagam Upper Nawata and Sahabi (EufeiL and EufeiS) are virtually identical in their dimensions, Lothagam being slightly longer. Langebaanweg *Eurygnathohippus hooijeri* has a similar log₁₀ trajectory, but is larger than Eufei. Figure 7B shows that *Cremohipparion antelopinum* (3 BMNH numbers) are all the longest of our entire sample. Maragheh *Hipparion campbelli* (2 MMTT numbers) plot very closely with African EufeiL and EufeiS. Figure 16.7C shows that all plots, EufeiMA, EufeiL, EufeiS, *Hipparion campbelli* (2 MMTT numbers and 3 Baynunah specimens) all plot very close to one another having a length (M1 and M2) very close to the Höwenegg sample, but with Eufei plotting lower in width (M3 and M4) and distal supraarticular width (M6): they are relatively slender 1PHIIIs.

Systematic Paleontology

Order PERISSODACTYLA Owen, 1848

Suborder HIPPIOMORPHA Wood, 1937

Family EQUIDAE Gray, 1821

Tribe HIPPARIONINI Quinn, 1955

"Hipparion" abudhabiense Eisenmann and Whybrow, 1999

Etymology—Named for the Emirate of Abu Dhabi, United Arab Emirates.

Holotype—AUH 270, right mandibular fragment (Eisenmann and Whybrow, 1999; Fig. 1a

& 1b; Fig. 9A and B herein).

Hypodigm—See Table 16.1.

Type locality—Jebel Dhanna, site JDH 3, Al Dhafra Region (formerly Al Gharbia, Baynunah, or Western Region) of the Emirate of Abu Dhabi, United Arab Emirates.

Age—Late Miocene, ca. 7 Ma

Geographic distribution—Abu Dhabi. Possibly related to 7.1 Ma “*Plesiohipparion*” cf. *longipes* from Akkasdagi, Turkey and Chinese *Plesiohipparion houfenense*.

TABLE 16.1 NEAR HERE.

Diagnosis—(modified from Eisenmann and Whybrow, 1999) Skull unknown. Size medium; lower cheek tooth series about 140 mm. long; mandibular corpus deep; symphysis broad and relatively short; premolar and molar row of similar length; cheek teeth hypsodont, 60-65 mm maximum height; metaconid usually rounded, metastylid usually squared with some incidence of lingual pointing; ectoflexids deep on molars and variably deep on premolars; no ectostylids apparent on any adult cheek teeth; protostylids variable being an open loop or closed elliptical-shaped ring. In maxillary cheek teeth, protocones varying from being elongate and lingually flattened in early wear, becoming small and rounded later in wear; plications and pli caballins moderately developed being most complex on the opposing borders of the pre- and postfossettes. Podials are medium size, plotting slightly below the Höwenegg 95% ellipse in most cases. Metacarpal III is extremely elongate.

FIGURE 16.8 NEAR HERE. 1.5 COLUMN WIDTH

Description—The hypodigm for Baynunah “*Hipparion*” *abudhabiense* is listed in Table 1, herein. We select representative specimens of the maxillary cheek teeth, mandibles and mandibular dentition and postcranial elements that were analyzed herein for description and figuring. Maxillary cheek teeth rendered here are AUH 644, rt. P2 (Fig. 16.8A, labial and 16.8B, occlusal),

AUH 1264, lt. M1 or 2 (Fig. 16.8C, labial) and AUH 676, rt. M1 (Fig. 16.8D, occlusal). AUH 644 is in advanced wear, having a mesostyle height (M5) of 18.2 mm. and exhibits the following salient features of its occlusal pattern: anterostyle elongate, despite its advanced wear; prefossette's distal border is relatively complex given its advanced wear, postfossette's mesial border is more complex than its distal border, distal border of prefossette linked with mesial border of postfossette (a primitive feature, Bernor et al. 2017); pli caballin is double despite its advanced wear; hypoglyph is shallowly incised. AUH 1264 is a left M1 or 2 with a crown height of 45.7 mm. (M5), preserving most of the labial surface of the crown. It is slanted distalward, with the mesiolabial cusp (paracone) being elevated to a level flush with the mesostyle giving it a high/low borderline height and rounded shape indicative of mixed feeding/grazing mesowear signature. AUH 676 is a right M1 with a crown height of 59.7 mm. This tooth is in an early stage of wear with pre- and postfossettes not yet expressing plications, mesostyle is narrow and pointed labially, protocone is elongate and flattened lingually; hypoglyph is very deeply incised; occlusal morphology reflects the early stage-of-wear of this juvenile individual. This cheek tooth suggests that the maximum crown height of "*Hipparion*" *abudhabiense* was 60-65 mm.

AUH 270 (Figs. 16.9A, labial and 16.9B, occlusal) is the type specimen of "*H*".
abudhabiense (Eisenmann and Whybrow, 1999 their fig. 19.3; Fig. 16.9A&B herein). The specimen is maintained at the Natural History Museum, London and we have depended on Eisenmann and Whybrow's (1999) description and images (secured by MB and FB) for our description herein. Bernor saw this specimen personally in Abu Dhabi during the March, 1995 conference held at Jebel Al-Dhanna, UAE but was unable to access it at the Natural History Museum, London.

FIGURE 16.9 NEAR HERE. 1.5 COLUMN WIDTH

In lateral view, the mandible preserves p2-m3, is lacking the symphysis, has its ventral margin broken but preserves the base of the ascending ramus and a portion of the ramus posterior to m3. Eisenmann and Whybrow (1999, their tab. 19.1) report that p2-p4 are 72 mm. long and m1-m3 is 70

mm. No measurement for p2-m3 is given, but the premolar and molar length measurements support their claim of a total tooth row dimension (worn individual) of about 140 mm. We estimate that a middle stage-of-wear individual would have had a total cheek tooth row dimension of about 145 mm. The individual cheek teeth have the following salient features: p2 has a shortened anterostylid due to advanced wear, metaconid is round, metastylid is square, preflexid is short with simple margins, postflexid more elongate and also with simple margins, lingualflexid V-shaped, ectoflexid deep extending to pre-postflexid; p3 has metaconid rounded, metastylid square, preflexid with mild plication, postflexid elongate and simple, lingualflexid U-shaped, ectoflexid not as deeply incised as in p2; p4 with metaconid and metastylid as in p3, lingualflexid has a deep U-shape, ectoflexid is very deeply incised separating metaconid-metastylid (primitive feature), preflexid as in p3, postflexid as in p2; m1 with a prominent, open loop- shaped protostylid, a lingually pointed metaconid, and squared metastylid, lingualflexid is a deep U-shape, pre- and postflexids have simple margins, ectoflexid is very deeply incised uniting with the lingualflexid lingually; m2 has protostylid as in m1, a rounded metaconid and pointed metastylid, lingualflexid is U-shaped, pre- and postfossettes and ectoflexid as in m1; m3 is fractured between metaconid and metastylid, has metaconid rounded, metastylid is damaged, pre- and postfossettes as in other molars, talonid has a prominent entoconid and typical hypoconulid.

AUH 1284 is a mandible with complete symphysis, incisor roots suggesting that they were horizontally aligned, fragmentary p2-m3 and base of the mandibular ramus (Fig. 16.9C, labial, 16.9D, occlusal). The occlusal view reveals a relatively broad and short symphysis lacking incisors and canine teeth, cheek tooth crowns are broken on the left series, preserving limited occlusal features on right p2 and p3, but obscured features on p4-m3. The right cheek tooth series is clearly worn. The p2 has a broken anterostylid, metaconid is rounded, metastylid square shape, pre- and postflexid shortened with simple margins due to wear, lingualflexid a shallow U-shape, ectoflexid is short. The p3 has rounded metaconid and metastylid, pre- and postflexid as in p2, lingualflexid a medium depth V-shape and ectoflexid of moderate depth, not separating pre- and postflexid. The canine's base is large suggesting that this was a male individual. The significance of this specimen is that it preserves a

moderate-to-short symphysis with a relatively broad incisor region that apparently had horizontally aligned incisors.

An additional mandible of a senile individual, AUH 452 was described and figured by Eisenmann and Whybrow (1999: their fig. 5a and b). This mandible has a short symphysis with incisor alveoli retained, a partial mandibular ramus and p2-m1. The cheek teeth are extremely worn, especially the p2 and p3 and preserve no occlusal details. A fourth mandible is known, AUH 1146, that is still encased in its plaster jacket and highly fragmented. This specimen is in need of extensive preparation and cannot be safely studied at this time.

FIGURE 16.10 NEAR HERE. 1.5 COLUMN WIDTH

In addition to the mandibles we describe and illustrate three lower cheek teeth (Fig. 16.10 A-F): AUH 1712, a right p4 (A, B), AUH 1535, a left m1 (C, D) and AUH 1560, a right m2 (E, F). AUH 1712 has straight, vertical walls typical of a p4. Figure 16.10A illustrates the labial wall and distally the serial sampling of enamel for isotopic analysis. The specimen is worn with a crown height of 54.6 mm. The occlusal surface (Fig. 16.10B) reveals that this specimen is past early wear and would have likely had a crown height greater than 60 mm. Salient occlusal features of AUH 1712 include: protostylid a closed elliptical-shaped structure; metaconid rounded, metastylid square-shape; linguaflexid a moderately deep V-shape; preflexid with slight plication on labial margin; postflexid elongate, plicated on its labial margin, extending into isthmus between metaconid and metastylid; ectoflexid moderately deep extending between pre- and postflexid. AUH 1535 has a crown height of 46.8 mm, is likewise serially sampled (Fig. 16.10C) on its mesio-labial surface. Its salient morphological features (Fig. 16.10D) include: metaconid rounded, metastylid squared with disto-labial pointing; linguaflexid has a broad U shape; preflexid with complexity on its mesial border, postflexid with simple margins; ectoflexid deeply incised invading isthmus between pre- and postflexid. AUH1560 (Fig. 16.10E-F) is worn, has wind damaged enamel and a crown height of 30.2 mm. Despite the wind damaged erosion, the following salient features are clear: protostylid is a long,

mesially open loop extending distalward on the labial surface; metaconid and metastylid are pointed lingually; pre- and postflexids have simple margins; linguaflaxid is V-shaped; ectoflexid is deep penetrating the metaconid-metastylid isthmus. None of the cheek teeth we have studied and illustrated herein exhibit an ectostylid. However, some of the lower cheek teeth have exhibited lingually pointed metaconids and metastylids.

FIGURES 16.11, 16.12, 16.13, 16.4 NEAR HERE. EACH ONE COLUMN WIDTH

Remarks—We have undertaken a statistical comparison of the Baynunah and relevant Eurasian and African hipparions using bivariate variables. MCIII and 1PHIII have, in addition, been analyzed using log10 ratio diagrams with the Höwenegg population sample being used as the mean log10 standard. The calcaneum, AUH 1609 (Fig. 16.11A and B) has been shown to be slightly smaller than the Höwenegg sample (re: Figs. 2A and 2B) which is a congruent result with mandibular cheek tooth series size. We figure a single right astragalus attributable to “*Hipparion*” *abudhabiense*, AUH 340 (Fig. 16.12A and B). Bivariate comparisons show that the Baynunah astragalus sample is again smaller than most of the Höwenegg sample (Fig. 16.3A and B) and congruent with the calcaneum and mandibular metrics. AUH 1792, left MCIII (Fig. 16.13), is fragmentary but preserves enough morphology for bivariate (Fig. 16.4A and B) and log10 ratio (Fig. 16.6A-D) analyses. The Baynunah MCIII compares very closely with Akkasdagi (Koufos and Vlachou, 2005; Turkey, 7.1 Ma) “*Plesiohipparion*” cf. *longipes* (Eisenmann and Sondaar, 1998; Bernor and Sen, 2017). Bivariate plots of MCIII and MTIII distal dimensions M12 vs. M11 show that there is not any significant size diversity in the Baynunah MPIII sample: all MPIIIs are referable to “*Hipparion*” *abudhabiense*. The log10 plots, in particular Figures 6C and D support a “best fit” attribution to “*Plesiohipparion*” cf. *longipes* closely similar to the Akkasdagi form, and, somewhat more distantly China *Plesiohipparion houfenense* (Qiu et al. 1987; Bernor and Sun, 2015; Bernor and Sen, in 2017). The 1PHIII, AUH 324 (Fig. 16.14A and B) as well as AUH 1279 and AUH 165 was found to be more slender than the Höwenegg sample (Fig. 16.5A and B) while Figures

16.7A-C shows that the Baynunah specimens are, as is *Eurygnathohippus feibeli* (Middle Awash, Lothagam and Sahabi) and Maragheh *Hipparion campbelli*, elongate and slender. These similarities are likely due to convergence evolution of elongate-slender IPHIIs. Eisenmann and Whybrow (1999) documented the presence of a second, larger species of hipparion at Baynunah. However, all the specimens they attributed that we were able to examine are, in our opinion, not significantly larger than material of "*H.*" *abudhabiense*.

"Hipparion" small sp.

Description—Eisenmann and Whybrow (1999) noted that there is a second, smaller species of hipparion at Baynunah. Tables 1 and 2 have recognized three smaller specimens in the sample: AUH 1695, lt. astragalus; AUH 261, lt. p4; AUH 397b, rt. M3. We believe that these specimens are too small to be referred to "*Hipparion*" *abudhabiense*. AUH 397b (Fig. 16.15A and B) is a rt. M3 in early wear. This tooth is small, has a crown height of only 38.1 mm, simply plicated pre- and postfossettes, pointed mesostyle, protocone triangular-shape and flattened lingually. This specimen is too small and too low crowned to be referred to "*Hipparion*" *abudhabiense*. AUH 1695 (Fig. 16.16A and B) is a small right astragalus. Juvenile astragali are notoriously difficult to differentiate from adult astragali and generally are smaller than adults. We cannot be certain that this specimen is referable to "*Hipparion*" small sp. AUH 261 is a left small p4 which might also be referable to "*Hipparion*" sp. sm(all) with a crown height of 54.3 mm (Fig. 16.17).

FIGURES 16.15, 16.16, 16.17 NEAR HERE. EACH ONE COLUMN WIDTH.

Remarks—Small hipparions are common in late Miocene Western Eurasian faunas. Bernor et al. (2016) undertook a comprehensive analysis of Maragheh hipparions and found that the small hipparion, *Cremohipparion matthewi*, was likely related to the somewhat larger form, *Cremohipparion moldavicum*. Likewise, the late Miocene Greek fauna of Samos has a multiple small taxa including

Cremohipparion matthewi and *Cremohipparion nikosi* (Bernor et al. 1996; Vlachou and Koufos 2009; Bernor et al. 2016). AUH 261 and AUH 397b are quite possibly related to the *Cremohipparion matthewi-nikosi* group. Its correlation at 7.1 Ma. is roughly congruent with the Samos Q5 hipparions.

Discussion

Eisenmann and Whybrow (1999) established the taxon *Hipparion abudhabiense* based on a fragmentary mandible, AUH 270. They claimed that the type specimen's symphysis was diagnostic and argued for an evolutionary relationship to Greek *Hipparion dietrichi*. "*Hipparion*" *abudhabiense* was diagnosed as being medium-to small in size and that there was a second larger species "*Hipparion*" sp. diagnosed as being "medium-large" in size. The current sample under consideration is considerably larger in number of specimens, has additional mandibular, cheek tooth and particularly important postcranial material. The complete, albeit fractured MCIII (AUH 1499), calcaneum (AUH 1609) and multiple astragali (Tables 16.1 and 16.2) offer new insights on the taxonomy of the Baynunah hipparions. "*Hipparion*" *abudhabiense* is a medium sized hipparion, slightly smaller than the Höwenegg population (based on 95% ellipse and log10 ratios) with extremely elongate MCIIIs comparing closely in maximum length (M1) versus distal articular width (M11) with Akkasdagi, Turkey (MN12, 7.1 Ma; Koufos and Vlachou, 2005) and Calta (MN14, ca. 4.0 Ma; Bernor and Sen, in 2017) "*Plesiohipparion*" cf. *longipes*, and by extension, Northern Kazakhstan "*Plesiohipparion*" *longipes* (MN13, ca. 7 Ma.). Our analysis of Baynunah fragmentary distal MPIIs consistently show that they are of similar size and smaller than the Höwenegg sample. Akkasdagi and Calta "*Plesiohipparion*" cf. *longipes* appears to be related to China latest Miocene - Pliocene *Plesiohipparion houfenense* and early Pleistocene Chinese *Plesiohipparion shanxiense* (Bernor et al. 2015b; Nihowan, ca. 2.0 Ma). As far as currently known, Baynunah "*Hipparion*" *abudhabiense* exhibits an MPIII morphology most similar to Akkasdagi and Calta "*Plesiohipparion*" cf. *longipes*.

We do not insist that our referral of Baynunah "*Hipparion*" *abudhabiense* to "*Plesiohipparion*" cf. *longipes* is absolutely certain. While the Baynunah MCIII M1 vs M11 dimensions plot within the Akkasdagi cluster, and close to Chinese *Plesiohipparion houfenense* it

must be noted that slenderization and lengthening of metapodial IIIs is a common theme in several Eurasian and African hipparion lineages (Bernor et al. 2003; Scott and Maga, 2005). Bernor et al. (2016) integrated crania, maxillary dentitions and metapodial III's from Maragheh and we hasten to add that even the most elongate and slender limbed forms *Cremohipparion moldavicum* and *Hipparion campbelli* did not achieve MCIII lengthening equivalent to "*Plesiohipparion*" *longipes*. Samos (Vlachou and Koufos, 2009) has a number of species with elongate- slender limbs including *Hipparion dietrichi*, the sister-taxon of *Hipparion campbelli*, the larger form *Cremohipparion proboscideum*, and smaller forms *Cremohipparion "matthewi"* and *Cremohipparion nikosi*. Integrating skull, dentition and postcranial data from Samos would be a very challenging undertaking and has, to date, not been achieved due to the complex species diversity of the equid fauna. The best chance for doing this rests with the AMNH Samos collection that has well provenanced and radioisotopically dated (Koufos et al. 2011) quarry samples. The Siwaliks also have the rare occurrence of a *Cremohipparion*, *Cr. antelopinum* known from the ca. 8 m.y. levels (Wolf et al. 2013).

Our analysis suggests that there are two species of hipparion from the Baynunah Formation. The dominant form is a medium sized species that has been referred to "*Hipparion*" *abudhabiense* with a "best fit" affinity to Akkasdagi and Calta "*Plesiohipparion*" cf. *longipes* based on the MCIII, AUH 1499. The MPIII lengthening of Abu Dhabi AUH 1499 is similar to *Plesiohipparion houfense* (China), "*Plesiohipparion*" *longipes* (Pavlodar, Kazakhstan), or "*Plesiohipparion*" cf. *longipes* (Akkasdagi [7.1 Ma.] and Calta [4.0], Turkey; Bernor and Sen, 2017), and none of these taxa have ectostylids present on the lower cheek teeth. Bernor and Sun (2015) found that Asian *Plesiohipparion* and African *Eurygnathohippus* are sister taxa and Bernor et al. (2017) have found that ectostylids on the permanent cheek teeth occur in the oldest Eurasian hipparions from the Pannonian C of Central Europe, asserting that the presence of ectostylids is a primitive character for Old World hipparions. Only African *Eurygnathohippus* retained ectostylids and evolved them further in height, length and width (Bernor et al. 2010). The second smaller taxon is rare in the Baynunah Fm. and is a dwarf form that may well be related to the Eastern Mediterranean-Southwest Asian *Cremohipparion matthewi-nikosi* group (Bernor et al. 1996; Bernor et al. 2016). Given these observations, the Baynunah Fm.

hipparions show an affinity with the late Miocene of Greece, Turkey, Iran, Kazakhstan and China. The possibility of their being directly related to eastern African *Eurygnathohippus* has not been demonstrated by the existing Baynunah equid material.

Demographically, of the almost 2000 catalogued specimens from the Baynunah Formation, Equidae are the most abundant mammalian family (10%), followed by Bovidae (7%) and Hippopotamidae (6%). Kingston (1999) and Uno and Bibi (this volume) reported stable carbon isotopic values from equid tooth enamel ranging from about -8 to +2 ‰, indicating mixed feeding (browse and grass). Taphonomically, vertebrate fossils are found within a fluvial context whereby they were transported to their final deposition (e.g. Andrews 1999).

Conclusions

There are two species of “*Hipparion*” sensu lato found within the Baynunah Formation, UAE. The dominant form is a medium-sized hipparion originally referred to by Eisenmann and Whybrow (1999) to *Hipparion abudhabiense*. These authors suggested that there was a close resemblance to Greek late Miocene species *Hipparion dietrichi* based on its size and short mandibular symphysis. Based on about twice the sample size, with augmentation of complete postcranial bones, and in particular a complete, albeit fractured metacarpal III we find that the Abu Dhabi hipparion exhibits its closest resemblance to Turkish (Akkasdagı, 7.1 Ma. and Calta, 4.0 Ma) “*Plesiohipparion*” cf. *longipes* and Northern Kazakhstan “*Plesiohipparion*” *longipes*.

“*Hipparion*” *abudhabiense* is the dominant hipparion in the Baynunah Formation. We have characterized this species as being medium size, smaller than the Höwenegg (Hegau, Germany, 10.3 Ma; Bernor et al. 1997) hipparion. The skull is unknown which makes it difficult to compare to the different lineages of hipparion. Cheek teeth show variability characteristic of hipparion taxa. Maxillary cheek teeth have protocones that vary from elongate and lingually flattened in early wear (AUH 676, rt. M1) to rounded later in wear (AUH 644, rt. P2); pre- and postfossettes that are moderately complex; mesostyle may have knife-like and pointed labially (AUH 644). Mandibular cheek teeth usually have rounded metaconid and squared metastylid but exhibits a labially pointed

morphology in AUH 1560 (rt. m2). Ectoflexid occasionally exhibits the primitive character of being deep on the premolar teeth (AUH 270 and AUH 1560). Mandibles have short, broad symphyses. The second smaller species is only indicated based on a few specimens that seem too small to be "*H.*" *abudhabiense* and their similarity to the *Cremohipparion matthewi-nikosi* clade.

Biogeographically, we favor "*Hipparion*" *abudhabiense*'s relationship to Kazakhstan "*Plesiohipparion*" *longipes* and Turkish "*Plesiohipparion*" cf. *longipes*, and more distantly, Chinese *Plesiohipparion houfenense*. We reiterate Bernor and Sun (2015) and Bernor and Sen's (2017) belief that *Plesiohipparion* is the sister taxon of African *Eurygnathohippus*. We cannot, however absolutely rule out "*Hipparion*" *abudhabiense*'s relationship to Greek *Hipparion dietrichi* nor Greek, Iranian and Siwalik *Cremohipparion*. It is likely that the rare, smaller hipparion is similar to the *Cremohipparion matthewi – nikosi* clade known from Greece, Iran and Libya (Bernor et al. under current study). Our estimation of the age of the Baynunah Fm., based on its hipparion fauna is ca. 7 Ma. As such, it is correlative with the Pavlodar, Kazakhstan, the Siwalik Dhok Pathan Formation, Akkasdagi, Turkey, the upper levels of Samos, Greece and Sahabi, Libya.

Acknowledgments

We dedicate this manuscript to the memory of Peter Whybrow and Andrew Hill who initiated their collaborative project in 1986. We further acknowledge the hours, days, weeks and years of laborious prospecting and excavations by all that worked in the Baynunah Formation collecting its vertebrate fauna. Every fragment, partial and whole bone and tooth was hard fought-for bringing together the current record of this fauna. Enough equid material has been accumulated over 30 years to allow us a window into its record. Bernor wishes to acknowledge funding support from the following research grants: EAR0125009, 1113175, 1138908, and 1558586 for the study of fossil horses and NSF:DBI:ABI Innovation 1759882 FuTRES. This is FuTRES publication number 18 (www.futres.org). Bibi was supported by a National Science Foundation (NSF) Graduate Research Fellowship, an NSF International Research Fellowship, a Leibniz-DAAD Fellowship, and a Gerstner Scholarship. Additional support has come to Bernor and Bibi from the Revealing Hominid Origins

Initiative (NSF-HOMINID, PIs T. White and F. C. Howell).

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Figure captions

Figure 16.1 Main Baynunah localities from which remains of *Hipparion* have been collected.

Figure 16.2 A, Calcaneum maximum length (M1) versus maximum breadth (M6) all localities. **B**, Baynunah and Calta. 95% ellipse of Höwenegg sample.

Figure 16.3 A, Astragalus maximum length (M1) versus distal articular breadth (M5) all localities. **B**, Baynunah and Calta. 95% ellipse of Höwenegg sample.

Figure 16.4 A, MCIII maximum length (M1) versus distal articular breadth (M11) all localities. **B**, Baynunah, Akkasdagi and Calta. **C**, distal articular width (M11) versus sagittal keel depth (M12), Baynunah, Akkasdagi and Calta. **D**, MTIII distal articular width (M11) versus sagittal keel depth (M12), Baynunah, Akkasdagi and Calta, 95% ellipse of Höwenegg sample.

Figure 16.5 A, 1PHIII maximum length (M1) versus proximal articular breadth (M4) all localities. **B**, Baynunah, Akkasdagi and Calta. 95% ellipse of Höwenegg sample.

Figure 16.6 MCIII log10 ratio diagrams. **A**, *Eurygnathohippus feibeli* Compared to African Hipparionines, MCIII Log10 Ratio, Ho Std. **B**, *Eurygnathohippus feibeli* MCIII Compared to "*Cormohipparion*" *africanum* and *Cremohipparion antelopinum*, Log10 Ratio, Ho Std. **C**, Baynunah MCIII Compared to Bou Hanifia, Lothagam, Sahabi and the Siwaliks, Log10 Ratio, Ho Std. **D**, Baynunah and Akkasdagi "*Plesiohipparion cf. longipes*", China *Plesiohipparion houfenense*, log10 ratio, Ho Std.

Figure 16.7 1PHIII log10 ratio diagrams. **A**, *Eurygnathohippus feibeli* 1PHIII Compared to African Hipparionines log10 ratio, Ho Std. **B**, *Eurygnathohippus feibeli* 1PHIII Compared to Asian elongate

limbed lineages log10 ratio, Ho Std. **C**, Baynunah 1PHIII comparison to Middle Awash, Lothagam, Sahabi and Maragheh Late Miocene Hipparions log10 ratio, Ho Std.

Figure 16.8 Maxillary Cheek Teeth. AUH 644, rt. P2 in **A**, labial and **B**, occlusal views. **C**, AUH1264, lt. M1 or 2, in labial view. **D**, AUH676, rt. M1, in occlusal view. Scale bar is 5cm.

Figure 16.9 Mandibles. AUH 270, type of "*Hipparion*" *abudhabiense*, in **A**, labial, and **B**, occlusal views. AUH1284 in **C**, labial and **D**, occlusal views. Shared scale bar for A, C, and D equals 10cm. Scale for B is 5cm.

Figure 16.10 Mandibular cheek teeth. AUH1712, rt. p4 (sampled for isotopes by K. Uno), in **A**, labial and **B**, occlusal views. AUH1535, lt. m1 (sampled for isotopes by K. Uno), in **C**, labial and **D**, occlusal views.

Figure 16.11 Calcaneum. **A**, AUH1609, medial view. **B**, cranial view.

Figure 16.12 Astragalus. **A**, AUH88, lt., distal view. **B**, AUH340, rt. distal view.

Figure 16.13 MCIII. AUH1499, cranial view.

Figure 16.14 1PHIII. **A**, AUH324, caudal view. **B**, AUH1279, caudal view.

Figure 16.15 Right M3. AUH397 in **A**, labial and **B**, occlusal views.

Figure 16.16 Astragalus. AUH1695 in **A**, cranial and **B**, distal views.

Figure 16.17 Left p4. AUH 261, labial view.

Tables

Table 16.1 Baynunah "*Hipparion*" taxonomic determinations. Abbreviations: **mand**, mandible; **MC**, metacarpal; **MT**, metatarsal; **PH**, phalanx, where 1PHIII refers to the first (i.e. proximal) phalanx on ray 3; **tm**, lower tooth; **tx**, upper tooth.

Specimen		Locality	Element	Side	This Study	Eisenmann & Whybrow 1999
AUH	23a	SHU 1	tmm2	lt.	"H" abu	
AUH	28	SHU 1	MTIV	lt.	not seen	"H" sp. lg
AUH	46	HMR 5	txP2	lt.	not seen	"H" sp. lg
AUH	72	SHU 1	tmm?	lt.	not seen	"H" abu
AUH	88	SHU 1	astragalus	lt.	"H" abu	
AUH	89	SHU 1	tibia	rt.	not seen	"H" sp. lg
AUH	115	SHU 1	tmm2	lt.	"H" abu	"H" abu
AUH	144	HMR 5	tmp?	rt.	not seen	"H" sp. lg
AUH	165	SHU 1	1PHIII	lt.	"H" abu	"H" abu
AUH	166	SHU 1	1PHIII		not seen	"H" abu
AUH	174	HMR 1	tmp?	rt.	not seen	"H" abu
AUH	176	JDH 3	MCIV	rt.	not seen	"H" sp. lg
AUH	177	JDH 3	MCIV	rt.	"H" abu	"H" sp. lg
AUH	178	JDH 5	txP3or4	rt.	not seen	"H" sp. lg
AUH	196	RDB 2	astragalus	rt.	not seen	"H" sp. lg
AUH	197	RDB 2	cuneiform	lt.	"H" abu	
AUH	203	RDB 2	txM1or2	rt.	not seen	"H" sp. lg
AUH	205	RDB 2	tmp4	lt.	"H" abu	"H" sp. lg
AUH	210	RDB 2	txP4	rt.	"H" abu?	"H" sp. lg
AUH	212	RDB 2	txM3	lt.	"H" abu	"H" sp. lg
AUH	216	RDB 2	2tms	rt.	not seen	"H" sp. lg
AUH	228	SHU 4	txM	lt.	not seen	"H" abu
AUH	229	JBR 1	txM1or2	rt.	sectioned	"H" abu
AUH	230	JBR 1	txM1or2	lt.	"H" abu	"H" abu
AUH	231a	HMR 5	txP3or4	lt.	not seen	"H" abu
AUH	246	JDH 3	navicular	lt.	"H" abu	"H" sp. lg
AUH	260	KIH 1	txM?	rt.	not seen	"H" abu
AUH	261	KIH 1	tmp4	lt.	"H" sp. sm	
AUH	264	SHU 4	txPx	lt.	not seen	"H" abu
AUH	265	JDH 4	tmp	rt.	not seen	"H" sp. lg
AUH	266a	HMR 6	tmm1or2	lt.	not seen	"H" abu
AUH	267	HMR 6	2PHIII	lt.	"H" abu	"H" sp. lg
AUH	317	KIH 1	magnum	rt.	"H" abu	
AUH	324	THM 1	1PHIII	lt.	"H" abu	
AUH	326	THM 1	MTIII	rt.	"H" abu	
AUH	340	HMR 5	astragalus	rt.	"H" abu	
AUH	362	MIM 1	txP2	lt.	"H" abu	
AUH	365	HMR 1	tmp2, tmp4	lt.	"H" abu	
AUH	397	SHU 2	txM2frag, txM3	rt.	"H" sp. sm	
AUH	399	SHU 2	2PHIII	rt.	"H" abu	
AUH	439	JDH 3	MTIII	lt.	"H" abu	
AUH	452	JDH 5	mand, tmm1, tmp4	rt.	"H" abu	"H" abu
AUH	644	JDH 3	txP2	rt.	"H" abu	
AUH	647	RDB 2	astragalus	rt.	"H" abu	
AUH	648	RDB 2	femur	lt.	"H" abu	
AUH	649	RDB 2	tmm1	lt.	"H" abu	
AUH	676	JBR 1	txM1	rt.	"H" abu	
AUH	677	SHU 4	tmm1	lt.	"H" abu	

AUH	699	SHU 4	txP2	rt.	"H" abu	
AUH	704	JDH 3	tmm1	lt.	"H" abu	
AUH	786	SHU 4	tmp2	lt.	"H" abu	
AUH	788	SHU 4	navicular	lt.	"H" abu	
AUH	1122	RDB 1	tmp4	lt.	"H" abu	
AUH	1146	RDB 1	mand	rt.	"H" abu	
AUH	1248	KIH 3	MCIII	lt.	"H" abu	
			txM1, txM2, txM3,			
AUH	1264	GAA 7	txM3, txP2, txP4,	lt. & rt.	"H" abu	
			txM1, txP4			
AUH	1279	HMR 5	1PHIII	lt.	"H" abu	
			mand, tmc, tmm1,			
AUH	1284	HMR 1	tmm2, tmm3, tmp2,	lt. & rt.	"H" abu	
			tmp3, tmp4			
AUH	1295	HMR 5	txP2	rt.	"H" abu	
AUH	1311	HAR 1	txP4	rt.	"H" abu	
AUH	1465	SHU 2	tmm1	rt.	"H" abu	
AUH	1483	SHU 4	tmm3	rt.	"H" abu	
AUH	1491	HMR 1	tibia	lt.	"H" abu	
AUH	1499	HMR 1	MCIII	lt.	"H" abu	
AUH	1535	GAA 2	tmm1	lt.	"H" abu	
AUH	1549	GAA 1	tmp4	lt.	"H" abu	
AUH	1558	GAA 1	tmm3	lt.	"H" abu	
AUH	1560	GAA 1	tmm2	rt.	"H" abu	
AUH	1566	GAA 3	txM2	rt.	"H" abu	
AUH	1571	GAA 5	MTIII	rt.	"H" abu	
AUH	1581	HAD 1	2PHIII	lt.	"H" abu	
AUH	1584	HAD 1	MTIV	lt.	"H" abu	
AUH	1595	HAD 3	MTIV	rt.	"H" abu	
AUH	1596	HAD 3	txM3	lt.	"H" abu	
AUH	1607	BYN 1	MCIIorIV	rt.	"H" abu	
AUH	1609	BYN 1	calcaneum	rt.	"H" abu	
AUH	1610	BYN 1	lunate	rt.	"H" abu	
AUH	1695	MTL 2	astragalus	lt.	"H" sp. sm	
AUH	1712	JBR	tmp4	rt.	"H" abu	
AUH	1751	SHU 4	1PHIIorIV		"H" abu	
AUH	1758	RUW SE	MTIV	rt.	"H" abu	
AUH	1763	RUW SE	tmm1	lt.	"H" abu	
AUH	1777	RUW SE	tmm3	rt.	"H" abu	
AUH	1792	SHU 12	MCIII	lt.	"H" abu	
BMNH	M50661	JBR 2	tmp3or4	lt.	not seen	"H" abu
BMNH	M50662	JBR 2	tmp2	lt.	not seen	"H" abu
BMNH	M50663	JBR 2	tmm?	rt.	not seen	"H" abu
BMNH	M50664	JBR 2	txP2frag	lt.	not seen	"H" sp. lg
BMNH	M50665	JBR 2	radius	lt.	not seen	"H" abu
BMNH	M50667	JBR 2	pelvis frag	lt.	not seen	"H" sp. lg

Table 16.2 Measurements on Baynunah “*Hipparion*” teeth. Measurement numbers (M1, M2, M3, etc.) refer to those published by Eisenmann et al. (1988) and Bernor et al. (1997). See those publications for postcranial measurements. Mandibular measurements used here: M2 = muzzle length. M3 = premolar length. M4 = molar length. M5 = lower cheek teeth length. M7 = muzzle breadth.

Tooth measurements: for upper teeth: M1 = length at occlusal level. M2 = length 10 mm above the tooth's base (in isolated teeth only). M3 = width at occlusal level, taken across mesostyle-protcone. M4 = width 10 mm above the tooth's base (in isolated teeth only). M5 = crown height measured along the mesostyle. M6 = number of plications on the anterior face of the prefossette. M7 = number of plications on the posterior face of the prefossette. M8 = number of plications on the anterior face of the postfossette. M9 = number of plications on the posterior face of the postfossette. M10 = protocone length. M11 = protocone width. For lower teeth: M1 = length at occlusal level. M2 = length 10 mm above the tooth's base (in isolated teeth only). M3 = length of metaconid-metastylid (= 'double-knot' of Eisenmann et al., 1988). M4 = length of the prefossette. M5 = length of the postfossette. M6 = W1, width of tooth across plane of ectoflexid/linguaflexid. M7 = width 10 mm above base. M8 = width across plane of metaconid and enamel band labial to protoconid. M9 = width across plane of metastylid and enamel band labial to hypoconid. M10 = crown height as measured from base to occlusal level on mesial face of the tooth. Element abbreviations as in Table 16.1.

Specimen	Taxon	Element	Side	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14
AUH 1279	"H"abu	1PHIII	lt.	60.7	54.0	26.3	36.7	26.5	26.8	30.0	18.0		35.0	35.6	19.7	17.1	
AUH 165	"H"abu	1PHIII	lt.	62.8	59.0	25.5	33.6	27.9	30.6	30.8	16.6		42.0	45.3	16.2	12.3	
AUH 324	"H"abu	1PHIII	lt.	63.9	54.9	25.9	37.2	29.0	29.7	30.8	18.3	29.4	42.4	46.8	16.8	16.2	
AUH 1751	"H"abu	1PHIIorIV	3	30.0	18.1	11.6	9.0	16.1	11.9								
AUH 1581	"H"abu	2PHIII	lt.	39.1	29.6	28.8	35.3	32.8	31.6								
AUH 267	"H"abu	2PHIII	lt.	37.6	28.2	28.8	34.1	23.3	33.0								
AUH 399	"H"abu	2PHIII	rt.	38.2		26.4	31.8		31.6								
AUH 340	"H"abu	astragalus	rt.	54.4	53.5	27.3		42.9	30.9	44.2							
AUH 88	"H"abu	astragalus	lt.	51.4	50.0	26.9	50.9	43.1	29.7	40.1							
AUH 647	"H"abu	astragalus	rt.	58.7		36.0											
AUH 1609	"H"abu	calcaneum	rt.	99.4	61.9	20.7		47.8	50.0	44.7							

[illegible]

AUH 1284	"H"abu	tmm1	rt.	19.6															
AUH 1465	"H"abu	tmm1	rt.	27.7	22.7													51. 5	
AUH 1535	"H"abu	tmm1	lt.	24.4	20.0	14. 2	7.1	10.6	12.3	11. 7	10. 1	9.9						46. 8	
AUH 1763	"H"abu	tmm1	lt.	22.2	18.5	11. 1	6.4	8.5	10.8	11. 8	9.0	9.5						43. 8	
AUH 452	"H"abu	tmm1	rt.	21.3					12.6				13. 7	10. 9					
AUH 649	"H"abu	tmm1	lt.			14. 1	8.5			12. 1	11. 1							33. 0	
AUH 677	"H"abu	tmm1	lt.	22.5	20.5	11. 1			9.3	12. 3	9.8	10. 4	50. 7						
AUH 704	"H"abu	tmm1	lt.	22.4	19.6	13. 0		6.7	11.5	11. 8		10. 6	28. 1						
AUH 115	"H"abu	tmm2	lt.	21.0		11. 5	6.4	8.6		10. 3	11. 4	10. 8	38. 5						
AUH 1284	"H"abu	tmm2	rt.																
AUH 1560	"H"abu	tmm2	rt.		24.1	14. 3	7.2	8.3	10.8	13. 7	12. 8	11. 0	30. 2						
AUH 23a	"H"abu	tmm2	lt.			13. 9	7.3	9.3										54. 4	
AUH 1284	"H"abu	tmm3	rt.																
AUH 1483	"H"abu	tmm3	rt.		22.8	11. 5	5.9	7.1	9.5	10. 0	10. 9	10. 0	30. 3						
AUH 1558	"H"abu	tmm3	lt.	22.4	25.8	8.8			8.1	8.8	5.9	5.8	46. 0						
AUH 1777	"H"abu	tmm3	rt.	23.9	24.3	11. 0	7.2	7.5	9.3	10. 8	9.9	8.2	41. 7						
AUH 1284	"H"abu	tmp2	rt.	26.5		13. 2	6.7	9.9											
AUH 365	"H"abu	tmp2	lt.			11. 6	7.1	9.8		12. 6		13. 2	21. 2						
AUH 786	"H"abu	tmp2	lt.	25.7	23.3	10. 0	5.7	8.2	13.8	13. 2	10. 1	13. 5	10. 9						
AUH 1284	"H"abu	tmp3	rt.	20.6		15. 4	8.5	8.8											
AUH 1122	"H"abu	tmp4	lt.			14. 2	6.8	11.8	12.2	17. 4	13. 2		43. 9						
AUH 1284	"H"abu	tmp4	rt.	21.1		12. 9													
AUH 365	"H"abu	tmp4	lt.		24.3	13. 3		12.3	13.3	15. 4	11. 3		48. 0						

[illegible]

AUH 210	<i>"H"abu</i>	txP4	rt.	25.3	22.8			51.7	0	0	0	0
AUH 1695	<i>H. sp.</i> <i>sm</i>	astragalus	lt.	50.6	47.1	21. 4	41. 3	35.3	26.7	36. 1		
AUH 261	<i>H. sp.</i> <i>sm</i>	tmp4	lt.			11. 9	6.8	7.8		11. 1	10. 8	54. 3
AUH 397b	<i>H. sp.</i> <i>sm</i>	txM3	rt.	18.6	19.3	13. 3	15. 8	38.1			6.0	5.0

Fig. 16.1

CALCANEUM

A

Fig. 16.2

B

ASTRAGALUS

A

Fig. 16.3

B

Fig. 16.4

Fig. 16.5

Fig. 16.6

A

Fig. 16.8

A

C

B

D

Fig. 16.9

A

C

E

B

D

F

Fig 16.10

Fig. 16.11

A

B

A

Fig. 16.12

B

A

B

Fig. 16.13

Fig. 16.14

A

B

A

Fig. 16.15

B

Fig. 16.16

A

B

Fig. 16.17