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Hippotherium malpassii (Equidae, Mammalia) from the latest Miocene (late Messinian; MN13) of Monticino gypsum quarry (Brisighella, Emilia-Romagna, Italy)

Lorenzo Rook & Raymond L. Bernor

L. Rook, Dipartimento di Scienze della Terra, Università di Firenze, Via G. La Pira 4, I-50121 Firenze, Italy; lorenzo.rook@unifi.it
R.L. Bernor, College of Medicine, Department of Anatomy, Laboratory of Evolutionary Biology, Howard University, Washington, DC 20059, USA; rbernor@howard.edu

KEY WORDS - Hippotherium*, dentition, postcranial skeleton, Messinian, Brisighella, Italy.*

ABSTRACT - We describe the Hippotherium *record from the latest Miocene (MN13) vertebrate faunal assemblage of the Monticino gypsum quarry (also known as Brisighella). This small sample would appear to be attributable to a single species of hipparionine horse. The referral to the recently described species* Hippotherium malpassii *Bernor, Kaiser, Nelson & Rook, 2011 would appear to be the best one possible. The Monticino gypsum quarry specimens correspond to the size of* Hippotherium malpassii *and show a suite of morphological features that allow their specific attribution. Formal description of the Brisighella hipparion specimens augments the previous knowledge of the Monticino gypsum quarry vertebrate fauna, one of the best-known latest Messinian fossil assemblages of continental Europe.*

RIASSUNTO - [*Hippotherium malpassii* (Equidae, Mammalia) dal Miocene terminale (Messiniano superiore; MN13) della Cava di gessi del Monticino (Brisighella, Emilia-Romagna, Italia)] - *Vengono descritti i resti fossili di* Hippotherium *della associazione faunistica del Miocene terminale (MN13 nella biocronologia continentale a mammiferi dell'Europa) proveniente della Cava di gessi del Monticino (nota anche come fauna di Brisighella). Il campione è rappresentato da un numero limitato di resti, tutti riferibili ad una singola specie di ippoterio. Il campione è attribuito alla specie* Hippotherium malpassii *Bernor, Kaiser, Nelson & Rook, 2011, recentemente descritta sulla base dell'abbondante campione fossile proveniente dal bacino di Baccinello-Cinigiano, in provincia di Grosseto. In base alle dimensioni, i resti della Cava di gessi del Monticino corrispondono alla taglia della specie* Hippotherium malpassii*. Questa attribuzione è inoltre supportata dalla presenza di una serie di tratti morfologici caratteristici. La descrizione formale dell'ippoterio di Brisighella espande la nostra conoscenza sulla fauna della Cava di gessi del Monticino, una delle associazioni faunistiche a mammiferi del Messiniano terminale meglio conosciute in Europa. A conclusione della descrizione morfologica del piccolo campione di* Hippotherium *di Brisighella viene infine discussa la peculiare distribuzione del record fossile dei perissodattili nel quadro della località a mammiferi del Miocene Superiore della Penisola Italiana.*

INTRODUCTION

The occurrence of a rich late Messinian fossil vertebrate assemblage in karst sediments associated with the Messinian evaporites in the Monticino gypsum quarry near Brisighella (Emilia-Romagna, Central Italy; Fig. 1) was first reported by Costa et al. (1986). According to local and regional geological constraints (Marabini & Vai, 1989; Vai, 1989), the vertebrate assemblage is correlated with the late Messinian Stage and European Land Mammal Age (ELMA) MN13. The vertebrate fauna has been the subject of a number of descriptive papers (De Giuli et al., 1988; De Giuli, 1989; Kotsakis, 1989; Kotsakis & Masini, 1989; Masini, 1989; Masini & Thomas, 1989; Torre, 1989; Rook et al., 1991; Rook, 1992; Masini & Rook, 1993; Rook & Masini, 1994; Delfino, 2002; Rook, 2009; Gallai & Rook, 2011).

Soon after the 1985 discovery of the paleontological site within the gypsum quarry, a proposal was advanced to create an open-air geo-paleontological museum at Brisighella (Vai, 2007). Between 2001-2004, the first preservation activities at the site were undertaken thanks to an agreement between the Regional Administration (Regione Emilia-Romagna) and the Town Administration (Comune di Brisighella), and an open-air museum of the quarry area was realized in 2005-2006. A geo-park with a 14.5 hectare environmental refuge was soon created for a variety of didactic activities, and opened to the general public in 2007 (Sami, 2007a, b).

In this paper we report on the unpublished fossil remains of a tridactyl horse (*Hippotherium*) from the Monticino gypsum quarry. This taxon, represented by limited fossil material, has not been yet formally described, although its recovery dates back to the time of the Brisighella fauna's discovery (De Giuli et al., 1988). The identification of this sample has important biochronologic and biogeographic implications. We also provide a discussion of the significance of the hipparion record in the Messinian of Italy.

GEOLOGICAL SETTING

The exposed succession within the Monticino gypsum quarry (Fig. 1) is composed, at the base, of a series of tilted gypsum layers with interbedded clays of the early Messinian Gessoso-Solfifera Formation. The gypsum was slightly eroded and subjected to a karst dissolution cycle that took place following the tectonic tilting of the strata. The deposits that infill the net of fissures intersecting the gypsum and the depressions on the upper surface of the gypsum sequence consist of marly-clays, fine grained conglomerates and sand lenses derived from the Colombacci Formation (grey pelites and variegated

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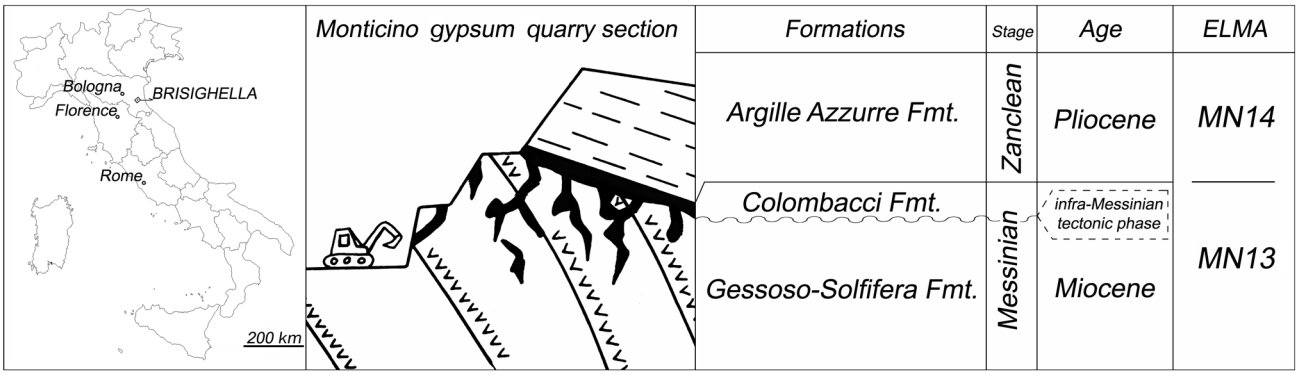

Fig. 1 - Location map (left) and outline of the geological section outcropping in the Monticino gypsum quarry (center), with formal geological units (Formations) and chronologic setting of the exposed sediments (right). The fossils vertebrates of the Monticino gypsum quarry faunal assemblages are found in the Colombacci Fmt., the deposition of which is tightly placed in time by the constraints of the geological setting. The Colombacci Fmt. is deposited on the karstic surface of the Messinian gypsum (thereafter the infra-Messinian tectonic phase that affected the Gessoso-solfifera Fmt.), and is capped as an angular conformity by the earliest Pliocene marine clays of the Argille Azzurre Fmt. (Zanclean). Modified after Marabini & Vai (1989).

marly clays with whitish to yellow thin evaporitic marly limestone; latest Messinian in age). They contain partially articulated and fragmented skeletons of large mammals, and very abundant microvertebrate remains. Several fossiliferous collecting points have been identified along the Monticino gypsum quarry outcrop (Fig. 2), some of which represent successive sampling of the same fissure that were brought to light by the progress of the quarrying activity. The Gessoso-Solfifera Formation is unconformably overlain by a thin discontinuous layer of greenish to blackish clay (0 to 1 m thick) that is considered equivalent to the later depositional phases of the Colombacci Formation and is correlated with the late Messinian. The succession is capped by up to 20 m of Early Pliocene marine gray marly clays (Argille Azzurre Formation) whose base falls in the *Sphaeroidinellopsis* Zone, and which overlie, with apparent conformity, the Colombacci Formation. We refer the reader to Vai (1989) for a more complete discussion of the geological setting of the Romagna Apennine, and to Marabini & Vai (1989) for further details on the geology of the Monticino gypsum quarry.

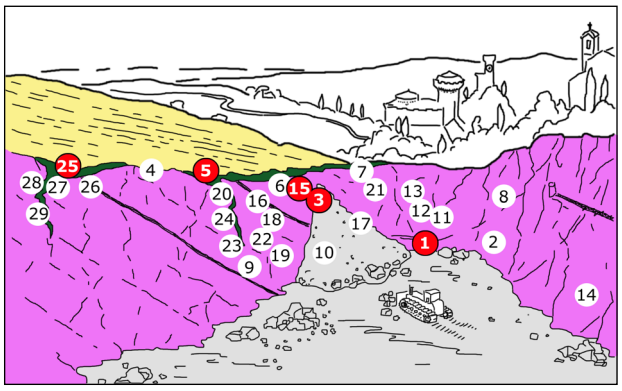

Fig. 2 - Scheme of the fossil collecting sites within the Monticino gypsum quarry outcrop. Sites that yielded *Hippotherium* are highlighted by circled numbers on a coloured background (after a sketch by M. Sami, modified from Rook & Delfino, 2007).

MATERIALS AND METHODS

Studied Material

The described specimens from Monticino gypsum quarry are housed in the MSF, whereas the comparative sample includes material from Baccinello V3, housed at the IGF and NHMB (see acronyms below).

Institutional Acronyms

"MSF" indicates the Museo Civico di Scienze Naturali "Malmerendi", Faenza, "IGF" denotes the Museo di Storia Naturale (Sezione di Geologia e Paleontologia) of the Università di Firenze, and "NHMB" refers to the Basel Naturhistorisches Museum (Switzerland).

Fossil Site Acronyms

"BRS" indicates the fossiliferous locality (=Brisighella); the number following the acronym (e.g., BRS 25) indicates the single karst fissure (Fig. 2), whereas when a second number follows (e.g., BRS 25/1) it indicates the specimen field catalogue number. "BCB V3" refers to Baccinello V3 (latest Messinian, Tuscany; Benvenuti et al., 2001; Rook et al., 2011).

Measurements

We have measured the upper and lower dentitions using standard equid measurements published by Eisenmann et al. (1988) and Bernor et al. (1997). The third metacarpal (MCIII) is too fragmentary to measure, but its general size is comparable to *Hippotherium malpassii.* Measurements of the Brisighella hipparion specimens are provided in Appendix, while teeth metrical comparison and species descriptive statistics are offered in Tab. 1. Measurement numbers (M1, M2, M3, etc.) refer to those published by Eisenmann et al. (1988; and rounded to 0.1 mm) for postcranium (also in Bernor et al., 1997), whereas tooth measurement numbers refer to those published by Bernor et al. (1997), Bernor & Franzen (1997) and Bernor & Harris (2003). The osteological nomenclature has been adapted from Nickel et al. (1986). Getty (1982) was also consulted for morphological identification and comparison.

	BRS		*H. malpassii* from Baccinello V3					
P^4	MSF119	MSF120	n	Mean	Min	Max	StD	95%CI
M1	23.0	23.6	8	25.4	21.7	27.8	2.16	±1.49
M2	19.8	19.7	7	21.1	19.4	23.6	1.78	±1.32
M3	22.7	21.5	8	22.6	20.9	25.1	1.19	±0.83
M4	20.8	20.3	6	24.3	22.7	26.2	2.10	±1.68
M5	49.1	(47.0)	7	35.3	23.3	48.1	10.10	±7.48
M10	6.4	6.0	8	5.7	4.0	7.2	1.22	±0.85
M11	3.6	4.1	8	4.4	3.4	5.6	0.74	±0.51
M_2	MSF122							
M1	20.8		9	22.5	20.7	25.1	1.70	±1.11
M2	19.5		6	21.2	19.7	22.4	1.06	±0.85
M3	13.8		10	12.2	11.3	13.4	0.67	±0.42
M4	6.7		10	6.8	4.7	8.4	1.16	±0.72
M5	7.7		10	8.4	6.4	10.6	1.30	±0.81
M6	13.6		8	11.4	8.2	14.9	2.24	±1.55
M7	11.9		7	12.4	9.3	13.3	1.41	±1.05
M8	11.4		10	10.7	9.5	12.1	0.95	±0.59
M9	10.3		8	10.0	8.8	11.7	0.95	±0.66
M10	32.3		7	35.8	25.6	45.7	7.88	±5.84

Tab. 1 - *Hippotherium* P^4 and M_2 (see Appendix for metrical variables explanation) from Monticino gypsum quarry compared to descriptive statistics of *Hippotherium malpassii* from type locality (Baccinello V3).

Taxonomic remarks

The genus nomen *Hipparion* has been used in a variety of ways by different authors. Here we follow the systematics recently provided by Bernor et al. (1996, 1997, 2011) for hipparionine horse superspecific taxa.

SYSTEMATIC PALEONTOLOGY

Suborder Hippomorpha Wood, 1937
Superfamily Equoidea Hay, 1902
Family Equidae Gray, 1821
Subfamily Equinae Steinmann & Doderlein, 1890
Tribe Hipparionini Quinn, 1955

Genus *Hippotherium* Kaup, 1832

Hippotherium malpassii Bernor, Kaiser, Nelson & Rook, 2011
(Figs 3-5)

1988 *Hipparion* sp. De Giuli et al., p. 68.
1993 *Hipparion* sp. Masini & Rook, p. 80.
2004 *Hipparion* sp. Rook & Delfino, p. 194.
2007 *Hipparion* sp. Rook & Delfino, p. 118.

Material examined - The Monticino gypsum quarry *Hippotherium* sample comprises five specimens: MFS119, left P^4 (Fig. 3a); MFS120, left P^4 (Fig. 3b); BRS 15/1, upper molar; MSF122, left M_2 (Fig. 4); MSF121, fragmentary left Metacarpal III (Fig. 5).

Site - All the described material has been collected from sites within the Monticino gypsum quarry, near Brisighella (RA), specifically from three (possibly five) single fissures: BRS 1 (MSF119), BRS 15 (BRS15/1), and BRS 25 (MSF122), while two erratic specimens (MSF120 and MSF121) possibly come from fissures BRS 3 and BRS 5 (Fig. 2).

Description - The Monticino gypsum quarry hipparion sample includes two very similar left P^4's, MSF119 (crown height = 49.1 mm) and MSF122 (crown height = 47.0 mm), that are in early middle wear (Fig. 3). Both specimens exhibit the following salient features: pre- and postfossettes have complex mesial and distal borders, but in particular the distal border of the prefossette; they have a very large, single pli; they have lenticular shaped protocones; the protocone is placed well lingual of the hypocone; the hypoglyph is deeply incised; the parastyle and mesostyle are narrow loops. The plications of the pre- and postfossettes are not as complex as some of the Baccinello sample, but this may be due to their relatively early stage of wear. Both of these teeth have paracone labial enamel borders that are high and round and equal to score #2 of Mihlbachler et al. (2011) and Wolf et al. (2012), which has the effect of producing a deep-wide groove across the mesostyle-protocone portion of the crown. As such, it may be inferred that this horse had a low abrasive diet (= large browse component) and was likely a mixed-feeder at the browsing end of the browser-grazer spectrum.

The lower molar, MSF122 (Fig. 4), is a left M_2 with a crown height of 32.3 mm. This specimen is in middle adult wear and has the following salient characters: the metaconid and metastylid are round; pre- and postflexids are labiolingually compressed and have simple margins; linguaflexid has a deep U-shaped morphology; ectoflexid is deep, fully penetrating the metaconid-metastylid junction; protoconid and metaconid have rounded margins; there is no evidence of an ectostylid or a pli caballinid; protoconid raises only about 23 mm from the base of the crown and is pointed at its tip.

There is a fragmentary metacarpal III (Fig. 5) that includes a portion of the proximal end and the fragmentary anterior two-thirds of the shaft. The specimen is too fragmentary to measure but, in general, would appear to have dimensions and proportions similar to the Baccinello sample of *Hippotherium malpassii* (see Appendix).

As an assemblage, this would appear to be material of a single species of hipparionin horse. The referral to *Hippotherium malpassii* would appear to be the best one possible. It is the size of *Hippotherium malpassii* type material (Tab. 1; Fig. 6) and has a constellation of morphological features that best fit this taxon: there is no ectostylid or pli caballinid typical of Late Miocene - early Pliocene *Eurygnathohippus*; neither the metaconid nor metastylid is pointed as is often the case in *Eurygnathohippus*; it is neither very large as in *Sivalhippus* nor very small as in *Cremohipparion*; the MCIII does not have either massive proportions as is often seen in *Sivalhippus,* nor extremely gracile proportions as seen in *Hipparion* or *Cremohipparion*. In sum, the Brisighella hipparion is best referred to *Hippotherium malpassii* recently described from Baccinello (Bernor et al., 2011).

Fig. 3 - Left P^4 of *Hippotherium malpassii* from Monticino gypsum quarry (Brisighella). a) MSF119 in distal (a1), mesial (a2), occlusal (a3), labial (a4), and lingual (a5) views. b) MSF120 in distal (b1), mesial (b2), occlusal (b3), labial (b4), and lingual (b5) views. Figures a5 and b5 illustrate the broad labio-lingual groove across the mesostyle-protocone portion of the tooth. Scale bar = 3 cm.

CONCLUSIONS

The Monticino gypsum quarry (Brisighella) karst fissure fillings complex yielded very few horse remains documented from five collecting sites (BRS 1, BRS 3, BRS 5, BRS 15, BRS 25), described herein for the first time. On the basis of morphological and morphometric comparisons we attribute the Brisighella sample to *Hippotherium malpassii*, a species recently described from the Late Miocene (Messinian) of Baccinello V3 in southern Tuscany (Bernor et al., 2011).

Fig. 4 - Left M_2 of *Hippotherium malpassii* from Monticino gypsum quarry (Brisighella). MSF122 in occlusal (a), labial (b), lingual (c), mesial (d), and distal (e) views. Scale bar = 3 cm.

The Italian Late Miocene *Hippotherium* record, although relatively poor, contributes to our knowledge of the peculiar paleobiogeographic evolution of the Italian Peninsula. During Late Turolian (Late Miocene, MN12 time equivalent), no equid (nor any perissodactyls) are known in Italy either from the so-called V2 faunal assemblages of the Tusco-Sardinian bioprovince (Monte Bamboli in Tuscany and Fiume Santo in Sardinia; Rook et al., 1999, 2006; Bernor et al., 2001; Chesi et al., 2009) or from the faunas of the Abruzzi Apulian bioprovince (Abbazzi et al., 1996; Rook et al., 2006).

The faunal turnover that characterized the continental peninsular Italy during the latest Miocene led to the extinction of all taxa typical of the Tusco-Sardinian area and was characterized by the dispersal of a faunas composed by continental European taxa, characterizing the latest Miocene Italian mammal assemblages, along the northern Apennines, from Piedmont (Ciabot Cagna,

Fig. 5 - Left metacarpal III of *Hippotherium malpassii* from Monticino gypsum quarry (Brisighella). MSF121 in cranial (a), caudal (b), proximal (c), lateral (d), and medial (e) views. Scale bar = 5 cm.

Verduno and Moncucco; Cavallo et al., 1993; Angelone et al., 2011; Colombero & Pavia, 2013) to Romagna (Brisighella, this paper) and southern Tuscany (Borro Strolla, Baccinello V3, etc.; Rook et al., 2006; Abbazzi et al., 2008). Perissodactyla were part of this renewed fauna, including tapirs (Rook & Rustioni, 1991), rhinos (Hürzeler & Engesser, 1976; De Giuli et al., 1998) and hipparions (Bernor et al., 2011; this paper). The MN13 record of the *Hippotherium* record in Italy is the youngest known for this lineage in Eurasia.

In the light of the renewed interest in the Italian *Hippotherium* record (Bernor et al., 2011; this paper), a revision of the hipparion sample from Casino - only in part figured by Forsyth Major (1875, 1877) and by Pirlot (1956), and generally referred to as part of the "*Hipparion gracile* group" (among others Alberdi, 1986; Forsten, 2002) - would be most welcome, given its possible identification as representing a form close to the species *Hippotherium malpassii.*

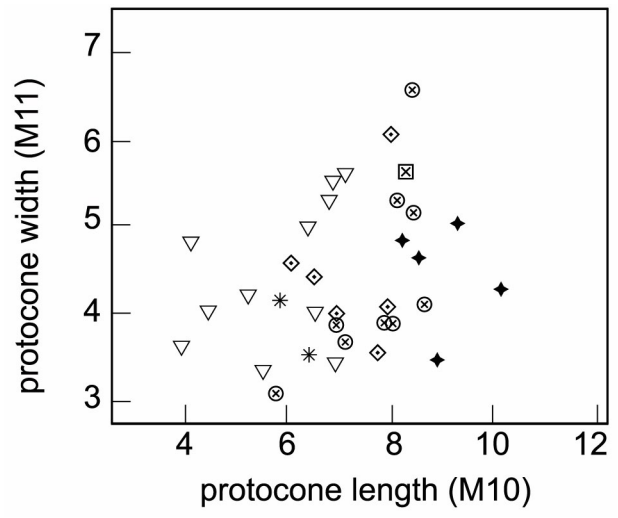

Fig. 6 - Bivariate plot of P^4 measurements. Protocone width (M11) is plotted versus protocone length (M10). BRS specimens (asterisks) are compared with a sample of Late Miocene Old World hipparions: Baccinello V3, Italy (open triangle); Gaiselberg, Austria (solid star); Höwenegg, Germany (cross circled); Sinap, Turkey (cross boxed); Baltavar, Hungary (diamond). Comparative data derived from Bernor et al. (1997, 2011).

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Appendix

Measurements of *Hippotherium* from Monticino gypsum quarry, compared with *Hippotherium* sample from Baccinello V3 (approximate measurements between parentheses)

Upper cheek teeth

M1 = length at occlusal level; M2 = length 10 mm above the tooth's base; M3 = width at occlusal level; M4 = width 10 mm above the tooth's base; 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.

Specimen #	Site	Species	tooth	side	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11
MSF 119	**BRS**	***H. malpassii***	**P4**	**L**	**23.0**	**19.8**	**22.7**	**20.8**	**49.1**	**2**	**6**	**5**	**1**	**6.4**	**3.6**
MSF 120	**BRS**	***H. malpassii***	**P4**	**L**	**23.6**	**19.7**	**21.5**	**20.3**	**(47.0)**	**2**	**6**	**4**	**1**	**6.0**	**4.1**
IGF 9400V	BCB V3	*H. malpassii*	P4	L	24.1	20.5	23.7	24.4	29.8	3	10	7	1	5.3	4.2
IGF 9406V	BCB V3	*H. malpassii*	P4	L	21.7	19.7	22.2	22.9	23.3	7	11	9	4	6.9	5.3
IGF 9408V	BCB V3	*H. malpassii*	P4	R	23.5	19.4	22.7	24.5	31.5	6	8	9	5	6.6	4.0
IGF 9413V	BCB V3	*H. malpassii*	P4	R	25.3	23.1	25.1	26.2	27.4	10	13	14	1	7.2	5.6
IGF 5286V	BCB V3	*H. malpassii*	P4	L	27.8	-	20.9	-	-	2	2	3	-	4.5	4.0
NHMBJH126F	BCB V3	*H. malpassii*	P4	R	27.6	23.4	21.9	-	42.4	1	6	4	-	4.2	4.8
NHMBJH134	BCB V3	*H. malpassii*	P4	L	27.7	23.6	22.1	25.3	44.3	1	6	4	-	4.0	3.6
NHMBJH229E	BCB V3	*H. malpassii*	P4	L	25.1	22.2	21.9	22.7	48.1	7	10	2	1	7.0	3.4

Lower cheek teeth

M1 = length at occlusal level; M2 = length 10 mm above the tooth's base; M3 = length of metaconid-metastylid; M4 = length of the prefossette; M5 = length of the postfossette; M6 = width across plane of ectoflexid/linguaflexid ; M7 = width 10 mm above the tooth's base; M8 = width across plane of metaconid and enamel band labial to protoconid; M9 = width across plane of metstylid and enamel band labial to hypoconid; M10 = crown height as measured from base to occlusal level on mesial face of the tooth.

Specimen #	Site	Species	tooth	side	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
MSF122	**BRS**	***H. malpassii***	**M2**	**L**	**20.8**	**19.5**	**13.8**	**6.7**	**7.7**	**13.6**	**11.9**	**11.4**	**10.3**	**32.3**
NHMBJH160E	BCB V3	*H.* aff. *malpassii*	M2	L	24.3	21.9	12.8	8.4	9.0	8.8	12.8	9.6	8.8	45.7
NHMBJH160M	BCB V3	*H.* aff. *malpassii*	M2	R	25.1	21.8	12.9	7.4	8.7	8.2	13.2	9.5	9.6	44.6
IGF9398V	BCB V3	*Hippotherium* sp.	M2	L	20.7	-	12.0	6.8	6.6	-	9.3	10.0	-	-
NHMBJH122A	BCB V3	*Hippotherium* sp.	M2	L	21.1	-	12.0	5.6	8.5	10.8	-	11.1	10.7	-
NHMBJH122B	BCB V3	*Hippotherium* sp.	M2	R	21.0	-	12.0	4.7	6.4	11.3	-	11.2	9.8	-
NHMBJH125C	BCB V3	*Hippotherium* sp.	M2	L	22.9	22.4	11.3	7.1	7.8	13.2	12.9	11.9	10.2	38.7
NHMBJH137	BCB V3	*Hippotherium* sp.	M2	L	24.4	19.7	13.4	8.4	10.6	12.8	13.3	10.7	10.5	36.6
NHMBJH176A	BCB V3	*Hippotherium* sp.	M2	L	21.9	20.2	12.4	6.3	9.3	14.9	13.1	12.1	11.7	25.6
NHMBJH207	BCB V3	*Hippotherium* sp.	M2	R	-	-	11.8	6.1	7.5	-	-	11.1	-	27.3
NHMBJH216	BCB V3	*Hippotherium* sp.	M2	L	21.3	20.9	11.4	6.7	9.3	11.0	12.5	9.7	9.0	32.4

Metacarpal III

M1 = maximal length; M2 = medial length; M3 = minimal breadth; M4 = depth of diaphysis at level of M3; M5 = proximal articular breadth; M6 = proximal articular depth; M7 = maximal diameter of the articular facet of the third carpal; M8 = diameter of the articular facet for the fourth carpal; M9 = diameter of the articular facet for the second carpal; M10 = distal maximal supra-articular breadth; M11 = distal maximal articular width; M12 = distal maximal depth of the keel; M13 = Distal minimal depth of the lateral condyle; M14 = distal maximal depth of the medial condyle.

Spec. #	Site	Species	side	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14
MSF121	**BRS**	***H. malpassii***	**L**	**-**	**-**	**26.9**	**22.9**	**(37.2)**	**(27.8)**	**(30.0)**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
IGF8192V	V3	*H. malpassii*	L	214.3	206.2	27.2	21.5	39.3	25.1	30.6	14.4	6.1	37.5	35.0	27.9	24.2	25.6
IGF9397V	V3	*H. malpassii*	L	216.2	209.2	27.8	22.5	42.1	29.9	36.6	12.9	7.4	40.0	38.2	30.3	25.7	26.6
NHMBJH144	V3	*H.* sp.		-	-	29.9	23.4	-	-	-	-	-	-	-	-	-	-