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1 Perissodactyla (Rhinocerotidae and Equidae) from Kanapoi

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13 Paleoenvironment

14

1 **Abstract**

2 The Kanapoi collection of Rhinocerotidae, first studied by Hooijer and Patterson (1972),
3 now consists of 25 specimens and substantial reinterpretation of their affinities is made here.
4 Kanapoi post-dates the extinction of *Brachypotherium* and the whole collection belongs to the
5 Dicerotini. It is important because it includes the type-specimen of *Diceros praecox*, a species that
6 remains poorly known, but looks slightly larger and more primitive than the modern 'black' rhino
7 *Diceros bicornis*. A second species is probably ancestral to the modern 'white' rhino *Ceratotherium*
8 *simum*; it looks identical with the Pleistocene North African *Ceratotherium mauritanicum*, of
9 which *Ceratotherium efficax* is probably a synonym. The evolution of the Dicerotini in Africa can
10 be regarded as an increasing divergence in diet and related morphofunctional adaptations in the two
11 lineages. The co-occurrence at Kanapoi of both *Diceros* and *Ceratotherium*, with distinct dietary
12 preferences, suggests some habitat heterogeneity, although the low sample size prevents robust
13 paleoecological conclusions.

14 The Equidae are also rare and consist mostly of isolated teeth. I take the most parsimonious
15 option of tentatively including all of them in a single species, whose identification is left open.
16 Dental features of eastern African Pliocene to Pleistocene hipparions may reflect increasing
17 adaptation to grazing.

18
19

1 **Introduction**

2 The Perissodactyla do not make up a high proportion of the Kanapoi large mammals, and no
3 previous publication specifically deals with them, although Hooijer and Patterson (1972) and
4 Hooijer (1975), respectively, studied the Rhinocerotidae and Equidae known at that time, together
5 with fossils from other sites. Since then, renewed research at Kanapoi has significantly increased the
6 faunal sample. The following revision is based upon the study of the material in the National
7 Museums of Kenya (KNM) during several visits between 2002 and 2016, and takes into account all
8 the material of Perissodactyla known to date. It includes no remain of the Chalicotheriidae, although
9 this family was present in Africa from the Early Miocene until the Early Pleistocene with a sparse
10 fossil record (Coombs and Cote, 2010).

12 **Materials and methods**

13 The comparisons of the Equidae are mostly based upon published literature, but the
14 Rhinocerotidae have been extensively compared with the rich collections from other Pliocene and
15 Pleistocene Kenyan sites in the KNM, as well as with the Hadar and Omo material in the National
16 Museum of Ethiopia, Addis Ababa (NME). Late Miocene rhinos were principally examined in the
17 Muséum National d'Histoire Naturelle, Paris (MNHN); Faculté des Sciences, Lyon (FSL);
18 Naturhistorisches Museum, Basel (NHMB); Natural History Museum, London (NHMUK); Natural
19 History Museum, Sofia and Asenovgrad (NHMSA); Geologisch-Paläontologisches Museum,
20 Münster (GPMM); Staatliches Museum für Naturkunde, Karlsruhe (SMNK); Staatliches Museum
21 für Naturkunde, Stuttgart (SMNS); Naturhistorisches Museum, Wien; and Natural History Museum,
22 Skopje (NHMMS). Modern specimens were examined in the KNM and MNHN.

24 **Systematic paleontology**

25 *Family Rhinocerotidae Gray, 1821*

26 Description Hooijer and Patterson (1972) assigned all the Rhinocerotidae material known from
27 Kanapoi at this time to a new species that they called *Ceratotherium praecox*, assuming that it was
28 ancestral to the modern 'white' rhinoceros, *Ceratotherium simum*. No other study devoted to the
29 Kanapoi rhinos has been published since then, although Harris et al. (2003), Geraads (2005, 2010),
30 Giaourtsakis et al. (2009), and Hernesniemi et al. (2011) discussed them briefly.

1 Whereas a few Pliocene specimens from Chad and Tunisia have been assigned to
2 '*Dicerorhinus*' (Arambourg, 1970; Likius, 2002), the only tribe present in East Africa after the
3 extinction of *Brachypotherium*, last recorded in the Apak Member of Lothagam (specimen KNM-
4 LT-90; Hooijer and Patterson, 1972), is that of the Dicerotini, with two lineages leading to the
5 seriously threatened modern African rhinos *Diceros bicornis* ('black' rhino) and *C. simum* ('white'
6 rhino). As they are closely related and often co-occur in the same sites, determining to which of
7 these branches each fossil belongs is not always easy; the Kanapoi material is critical in
8 reconstructing their histories.

9
10 Genus *Ceratotherium* Gray, 1868

11 *Ceratotherium mauritanicum* (Pomel, 1888)

12 Type: MNHN TER-2261, upper M2 from Tighennif, Algeria, Late Early Pleistocene. I refer all
13 Pliocene to lowermost Pleistocene East African representatives of *Ceratotherium* to this species
14 (see below and Geraads, 2005, 2010).

15
16 KNM-KP 30187 is the most complete remains of this species at Kanapoi (Fig. 1A). It
17 consists of several parts of a skull, unfortunately without connections between them: a posterior part
18 (occipital and auditory region), a central (orbito-frontal) part, and a piece of the left maxilla with P³-
19 P⁴ (measurements: Supplementary Online Material [SOM] Table 1). The skull was certainly long,
20 with a poorly concave dorsal profile. The teeth are almost unworn, but much broken. They are very
21 high-crowned. They both have a crochet, but P³ has no visible crista, unlike P⁴ in which a closed
22 medifossette would probably have formed in later wear. The protoloph is much longer than the
23 metaloph and curved backwards so that the protocone occupies most of the lingual part of the tooth.
24 The cingulum is well developed anteriorly, but is interrupted between the base of the protocone and
25 the base of the hypocone. The bottom of the nasal notch is above the anterior part of P³, as in
26 *C. simum*, but the infra-orbital foramen, above the anterior part of P⁴, is more anterior than in the
27 modern form and more like in fossil *Ceratotherium* from the Mediterranean late Miocene or from
28 the African Plio-Pleistocene. The orbit also reached farther anteriorly than in average *C. simum*; its
29 ventral border is rounded and slanting ventro-laterally, as in other African Dicerotini. In front of the
30 orbit, the lacrymal, nasal, maxillary, and frontal bones have an X-shape connection, as in
31 *D. bicornis*, whereas the maxilla has a suture with the frontal in adult *C. simum*. The nuchal crest is

1 broad and has a deep central notch, as in fossil forms but unlike *C. simum*. The occipital, whose
2 ventral part is missing, was certainly broader than in *Diceros*. Although it is hard to orientate this
3 cranial piece in respect to the tooth row, it is clear that this occipital was stretched caudally and that
4 the nuchal crest overhung the condyles to some extent.

5 KNM-KP 38 (Fig. 1B) is a right premolar, probably P⁴, lacking the buccal enamel and part of
6 the protocone. It is not heavily worn, but the crochet and crista meet to fully enclose the
7 medifossette. The lingual part of the protoloph curves distally but fails to meet the inflated
8 hypocone. The width of the metaloph also greatly increases lingually.

9 KNM-KP 32 is a partial mandible with P₃-M₃, with P₄ and M₃ in the process of erupting
10 (Hooijer and Patterson, 1972:Fig. 9B-C). The unworn M₂ is at least as tall as it is long, but its base is
11 still concealed in bone. This specimen was described as *Ceratotherium praecox* by Hooijer and
12 Patterson (1972), who noted that it is distinctly more hypsodont than *D. bicornis*; Harris et al. (2003)
13 also identified it as *C. praecox*, but Hernesniemi et al. (2011) considered it to be less derived than
14 the *Ceratotherium* KNM-KP 30217 and consequently assigned it to *Diceros*. In fact, it does not
15 differ significantly, neither in morphology nor in hypsodonty, from KNM-KP 30217, meaning that
16 either the lower teeth of these genera were undistinguishable at that time or, more likely, that both
17 specimens belong to *Ceratotherium*.

18 KNM-KP 30217 is probably a P₄, about as hypsodont as that of KNM-KP 32. KNM-KP 40
19 is a very incomplete upper milk tooth, probably DP³; it is only tentatively assigned here, because at
20 Hadar no robust feature distinguishes the DP³ of *Diceros* from that of *Ceratotherium*. KNM-KP
21 32868 is a very worn lower tooth, probably a P₄. KNM-KP 33 is an isolated, unworn lower molar,
22 probably M₂. It is taller than long, thus about as hypsodont as the M₂ KNM-KP 32. KNM-KP 30554
23 is a well-worn lower tooth, probably M₁. KNM-KP 49386 is a lower molar, probably M₁, in mid-
24 wear and with a tall crown. These lower teeth are not so long as those of Pleistocene and modern
25 *C. simum*, and there is no tendency for the prefossettid to close lingually, unlike in this species.

26 KNM-KP 30195 (Harris et al., 2003:Fig.14B) is a complete, robust humerus. Its size (SOM
27 Table 2) exceeds the maximum recorded size of *C. simum* (cf. Guérin, 1980:Table 8); it is similar to
28 the largest Hadar *Ceratotherium* in this regard (Geraads, 2005).

29 There is no doubt that the Kanapoi *Ceratotherium* is markedly more primitive than *C. simum*
30 in its dental morphology and that it belongs to a distinct species, but its name is disputable. It is
31 obviously not *C. praecox* (see below). Hernesniemi et al. (2011) called it *Ceratotherium efficax*

1 Dietrich, 1942, but the differences between this species, whose type is from Laetoli, and the North
2 African Pleistocene *Ceratotherium mauritanicum* (from Tighennif, Aïn Hanech, and Grotte des
3 Rhinocéros; Geraads, 2005) are quite subtle. In contrast to Hernesniemi et al. (2011), I fail to see
4 any difference in the shape of the upper M3 ectoloph or in the wear stage at which the lingual valley
5 closes in the upper premolars; it may be true that these teeth have a more reduced lingual cingulum
6 in *C. mauritanicum*, but this is weak support for species distinction. Choosing between these names
7 for the Kanapoi species is a matter of preference; in age and morphology, it is certainly close to the
8 Laetoli form, but calling it *C. efficax* hides the remarkable stability of the North African lineage and
9 I prefer to keep calling it *C. mauritanicum*, of which I regard *C. efficax* as a junior synonym.

10

11 Genus *Diceros* Gray, 1821

12 *Diceros praecox* (Hooijer and Patterson, 1972)

13 Type: KNM-KP 36 (see below); I refer to this species Early to Middle Pliocene African
14 representatives of *Diceros*.

15

16 KNM-KP 36 (Fig. 1C; Hooijer and Patterson, 1972:Fig. 9A) is the type-specimen of
17 *Ceratotherium praecox* Hooijer and Patterson, 1972. It consists of a large portion of the skull of a
18 relatively old adult, unfortunately in very poor condition and lacking the anterior part, so that few
19 features can be observed. Size is larger than in *D. bicornis*. The bottom of the nasal notch is more
20 posterior than in *D. bicornis*; the ventral orbital border is rounded, as in other Dicerotini. The
21 temporal fossa was certainly long. As far as the preservation allows, it seems that the occipital was
22 broad and intermediate in orientation between those of the modern forms, i.e., less vertical than that
23 of *D. bicornis*, but less stretched caudally than in *C. simum*. This orientation is in agreement with a
24 marked angle between the basisphenoid and basioccipital, again intermediate between those of
25 modern forms. In *C. simum*, the cranial base is almost straight, the long neurocranium being in line
26 with the basicranium; in *D. bicornis* instead, the basicranial angle is even stronger than in KNM-KP
27 36, and the neurocranium is rotated so that the occipital is vertical or even inclined rostro-dorsally
28 with respect to the occlusal plane. The teeth are much worn and very imperfectly preserved. On P⁴-
29 M² (Fig.1C), the protoloph is only slightly curved distally, so that the protocone does not occupy
30 much more than half of the lingual part of the tooth. The crochet is present but small, perhaps
31 because of heavy wear. The poor preservation of the specimen forbids precise measurements, but it

1 was certainly large, with an estimated M² width of c. 73 mm, thus slightly above the maximum
2 recorded by Guérin (1980) for *D. bicornis*.

3 KNM-KP 35 is an incomplete, much worn P². The lophs are transverse, without any crochet
4 or crista. The postfossette is completely enclosed by the metaloph and distal cingulum. There is a
5 continuous lingual cingulum. KNM-KP 30216 (Fig. 1E) is another well preserved, moderately worn
6 P². It has lophs that are almost transverse, a strong crochet but no crista, and a strong cingulum
7 completely circling the lingual part of the tooth. KNM-KP 58726 (Fig. 1F) is still another P², similar
8 to the previous ones, except that the broken crochet might have been slightly smaller. KNM-KP
9 30472 (Fig. 1D) is an upper premolar, probably P³, lacking the mesiobuccal corner. Its main
10 characters are similar to those of KNM-KP 30216; the cingulum is complete all around the lingual
11 part of the tooth. The crochet is stronger than in modern *D. bicornis* or than in Plio-Pleistocene
12 representatives of this genus, such as WT-41576. KNM-KP 57018 is a fragment of a rather
13 brachyodont lower molar.

14 KNM-KP 39 (Harris et al., 2003:Fig.14A) is a complete humerus; I follow Harris et al.
15 (2003) in assigning it to *Diceros* on the basis of size, assuming that *D. praecox* is smaller than
16 *Ceratotherium* (SOM Table 2).

17 In addition, there are some isolated teeth and various fragments that are unidentifiable to
18 genus: KNM-KP 30 are cranial fragments including nasal and occipital pieces; KNM-KP 32556 and
19 KNM-KP 57014 are tooth fragments; KNM-KP 504 is also a tooth fragment, but is very ¹³C
20 depleted (Cerling et al., 2015) and is therefore probably of *Diceros*; KNM-KP 36520 is a
21 mandibular piece with two much worn teeth; KNM-KP 31 is a fragment of mandible with the
22 condyle; KNM-KP 57007 and KNM-KP 59726 are isolated, much worn lower molars; KNM-KP
23 540 is a sesamoid; and KNM-KP 538 is a distal MT III.

24
25 Comparisons and discussion One of the main reasons of interest in the Kanapoi Rhinocerotidae is
26 that they include the type of *Ceratotherium praecox* Hooijer and Patterson, 1972. I had previously
27 shown (Geraads, 2005) that this type specimen belongs in fact to *Diceros*, and this generic
28 assignment has gained general acceptance among researchers working on these rhinos (Giaourtsakis
29 et al., 2009; Hernesniemi et al., 2011). Unfortunately, over the years '*Ceratotherium praecox*' had
30 become synonymous with 'primitive *Ceratotherium*,' leading to much confusion (e.g., Harris, 1983;
31 Hooijer and Churcher, 1985; Guérin, 1987). It is clear, anyway, that there are two lineages in the

1 Pliocene and Pleistocene of Africa, one ending in the modern *C. simum*, the other in *D. bicornis*,
2 although side branches may of course have arisen and gone extinct (SOM Fig. 1). Geraads (2005)
3 regarded the late Miocene Western Mediterranean *Ceratotherium neumayri* (Osborn, 1900),
4 previously known as '*Diceros pachygnathus*' or '*Diceros neumayri*', as the last common ancestor of
5 these lineages, whereas Giaourtsakis et al. (2006, 2009) and Hernesniemi et al. (2011) believed that
6 this species is in fact a side branch, because of some derived postcranial characters that bar it from
7 the ancestry of modern forms, whose last common ancestor would be in fact '*Dicerorhinus*'
8 *primaevus* Arambourg, 1959 from the Vallesian (early late Miocene) of Algeria, first recognized as
9 a Dicerotini by Geraads (1986). Unfortunately, those purportedly specialized postcranial features
10 remain unpublished. Antoine and Saraç (2005) listed some characters of the postcranials that they
11 also assumed to be autapomorphic. A full discussion would be beyond the scope of this paper, and I
12 shall only mention that the absence of a trapezium facet on MC II is in fact shared by both modern
13 forms (Guérin, 1980), that there is no evidence that the fusion of tibia and fibula occurred early in
14 life and that it is based upon a single specimen, and that some of their other features are inconsistent
15 with their descriptions (distal keels on central metapodials said to be acute but described and figured
16 by Giaourtsakis [2009] as smooth; medial calcaneal facet on the astragalus said to be low but
17 described and figured as tall; it is also tall in most Plio-Pleistocene *Ceratotherium*). Therefore, the
18 assumption of Giaourtsakis et al. (2009) that the similarities of *C. neumayri* with later
19 *Ceratotherium* are in fact "early convergences" remains unsubstantiated. Still, the idea of the
20 derivation of both lineages from '*D. primaevus*' is acceptable, although our poor knowledge of the
21 anatomy of this species prevents a full appraisal of its phylogenetic position. In any case,
22 *C. neumayri* is certainly not far removed from this common ancestry, and its cranial anatomy is
23 much better known (Osborn, 1900; Weber, 1904; Arambourg and Piveteau, 1929; Thenius, 1955;
24 Geraads, 1988; Geraads and Koufos, 1990; Antoine and Saraç, 2005; Giaourtsakis et al., 2006,
25 2009; Geraads and Spassov, 2009; Spassov et al., in press), allowing the reconstruction of
26 evolutionary trends in these two lineages. All available evidence shows that its dental morphology is
27 primitive and closer to that of *D. bicornis*; the tooth crown is low, the protoloph is only moderately
28 curved disto-lingually on the molars, and the crista is usually absent and at most weak (SOM Fig. 1).
29 By contrast, the skulls differ from those of *D. bicornis* in being long, with an orbit located more
30 posteriorly. Undistorted ones have a gently concave dorsal profile and an occipital that is essentially
31 vertical, with a nuchal crest whose caudal extension is intermediate between those of the modern

1 species, although there is variation in all these forms. The skull is, on the average, certainly less
2 lengthened than that of *C. simum*, but they share the same overall shape; this is why I prefer to
3 include *C. neumayri* in *Ceratotherium* rather than in *Diceros* (but this is not a central issue). In the
4 *Ceratotherium* lineage, the nuchal crest becomes more stretched backwards, but the most
5 conspicuous changes affect the cheek teeth. From the Late Pliocene to the Pleistocene, they
6 increased their hypsodonty and plagiolophodonty (e.g., Geraads, 2010), so that those of the
7 Pleistocene and modern *C. simum* much differ from those of their ancestors. These changes are
8 obviously adaptations to a grazing diet (and parallel those that occur in the Asian *Rhinoceros*
9 *unicornis* as opposed to the browser *R. sondaicus*).

10 By contrast, the cheek teeth of modern *D. bicornis* are little changed over those of
11 *C. neumayri*, but the orbit is located more anteriorly, the dorsal profile is more concave, and the
12 occipital is vertical, or even inclined forwards in old individuals (although not to the extent of
13 modern *Rhinoceros*). As first analyzed by Zeuner (1934), these differences are linked to a different
14 head posture, that of *C. simum* being held more vertically, in relation with its grazing habits,
15 *D. bicornis* being instead a browser or at most a mixed feeder. There is every reason to believe that
16 this cranial morphology of *D. bicornis* is derived: first, because no late Miocene potential ancestor
17 displays it; and second, because Zeuner (1934) showed that, during the ontogeny of the 'black' rhino,
18 the plane of the occipital changes from vertical to forwardly inclined. Unfortunately, well preserved
19 cranial elements that would document the evolution from *D. praecox* to *D. bicornis* are rare; there is
20 a poorly preserved skull from Laetoli (Guérin, 1987) and some incomplete specimens from Hadar
21 (Geraads, 2005). This evolution involves some decrease in size, at least in most populations,
22 because Pliocene forms are close to, or slightly above, the maximum size of the modern species. The
23 tooth row is located slightly more posteriorly in *D. bicornis*, and this can probably be related to
24 increased cranial flexure. It is clear, anyway, that differences are slight and species assignment of
25 Pliocene specimens is often difficult.

26 Giaourtsakis et al. (2009) described a skull from Kuseralee in the Middle Awash, dated to
27 5.2 Ma, which they ascribed to '*Diceros*' *douariensis* Guérin, 1966 and placed in the ancestry of
28 *Ceratotherium* on the basis of an oblique protoloph on M1 and the presence of a lingual protocone
29 groove on the same tooth. This species was first described from Douaria in Tunisia, a locality whose
30 age is poorly constrained, but a very large giraffid suggests the latest Miocene, thus roughly
31 contemporaneous with Kuseralee. The diagnosis of this species provided by Giaourtsakis et al.

1 (2009) is a mixture of features common to all Dicerotini and to the Kuseralee cranium. In fact, there
2 is no significant difference between the teeth of the Kuseralee cranium, those of '*D.* *douariensis*,
3 and those of *C. neumayri*, as exemplified by the skull and dentitions from Maragha (Thenius, 1955),
4 Pikermi (Geraads, 1988), Samos (NHMB), Akkaşdağı (Antoine and Saraç, 2005), or Kalimantsi
5 (Geraads and Spassov, 2009). Giaourtsakis et al. (2009:455) believed that the Kuseralee cranium is
6 "close to the ancestral stock of the *Ceratotherium* clade" because of its M¹ with oblique protoloph
7 and lingual protocone groove, but the protoloph is certainly not more oblique than on the type
8 specimen of *C. neumayri* (NHMW A4791); the flattened lingual wall of the protocone can hardly be
9 called a groove and the difference with some *C. neumayri* is quite subtle. What is quite clear in the
10 Kuseralee skull is its shape, with its raised neurocranium forming a strong angle with the facial part,
11 resulting in a deeply concave dorsal profile of the neurocranium and a vertical occipital plane. These
12 are all features shared by *D. bicornis* and the Kuseralee cranium definitely belongs to its lineage.
13 However, both the nasal notch and the orbit are located more posteriorly than in *D. bicornis* and
14 more like in *C. neumayri*. Thus, the Kuseralee cranium is a good morphological intermediate
15 between earlier *C. neumayri*, preserving a similar dental morphology and facial pattern, and later
16 *Diceros*, of which it already has the upwardly tilted neurocranium. It does differ in some features
17 from *D. bicornis*, including a slightly larger overall size, but most of those noted by Giaourtsakis et
18 al. (2009) are quite subtle, if not non-existent; it is not true, for instance, that the protoloph is more
19 inclined than in the modern species, but it seems that the lingual protocone wall is indeed more
20 flattened, and overall size is larger. These are differences that are also found in the Kanapoi
21 material, and I can see no reason for not including the Kuseralee cranium in *D. praecox*.

22 It seems that the reluctance of some authors to admit that the *D. bicornis* cranial shape is
23 derived is linked to the change of diet with which it is correlated. In the interpretation favored here,
24 ancestors of the modern African rhinos, with their intermediate cranial morphology, were likely
25 mixed feeders. Later, while the representatives of the *Ceratotherium* lineage became more grazers
26 (an evolutionary trend that is easily accepted), the lineage leading to *D. bicornis*, with its flexed
27 cranium, must have shifted to a more browsing diet. This is an evolution that is less easily
28 conceivable, as it seems to be a reversal to an ancestral condition; however, Cerling et al. (1999)
29 showed that it occurred in elephants. A plot of $\delta^{13}\text{C}$ isotopic values of late Miocene to modern
30 African rhinos (Fig. 3) shows that, for most of the Pliocene, many rhinos, although they were
31 certainly already part of either the *Diceros* or *Ceratotherium* lineage, still had mixed-feeder habits

1 that are no longer found today ($\delta^{13}\text{C}$ between -3 and -7‰). Some of the specimens are certainly of
2 *Ceratotherium* that had not fully shifted to a grazing diet (Harris and Leakey, 2003). Others, such as
3 KNM-LT-28762 and LT-23971 from the Apak Member of the Nachukui Formation, are definitely
4 of *Diceros*, but their $\delta^{13}\text{C}$ (respectively -3.6 ‰ and -2.5‰) are clearly above values of modern
5 *D. bicornis*, showing that their diet certainly incorporated a significant grass component. It also
6 seems that no fossil reached such very low ^{13}C values as some modern *Diceros*, but it remains to be
7 confirmed that this is not just an effect of smaller sample size. At Kanapoi, however, the distinction
8 is clear-cut (Cerling et al., 2015) and we may assume that in this site at least, the rhinos had already
9 adopted their modern dietary preferences, perhaps also testifying to the presence of various habitats,
10 including both grassland/savannas and bushland/woodland, but sample size is far too low for
11 estimating their relative importance.

12

13 *Family Equidae Gray, 1821*

14 Description It seems that the dispersal of hipparionines into the Old World is a virtually
15 instantaneous event at the geological scale, as their first appearance in Africa at >10 Ma (Pickford,
16 2001) might well be contemporaneous with their FAD in Europe. However, in contrast to what
17 occurs in the well-known 'hipparion faunas' of the Western Mediterranean, their fossil
18 documentation in Africa is very patchy, and in many of the famous hominid bearing East African
19 Pliocene and Pleistocene sites, they are mostly represented by incomplete bones and isolated teeth.
20 Kanapoi is no exception, and the whole equid collection, reviewed here, consists of only about 50
21 specimens, among which there are only a few partial tooth rows (tooth measurements: SOM Table
22 3) and a single complete bone. Given the difficulties of equid systematics, even when dealing with
23 far better preserved material, definite conclusions cannot be reached.

24

25 Hipparioninae Gen. et sp. indet.

26

27 Hooijer and Maglio (1974) described and/or figured the following specimens: KNM-KP 42,
28 said to be a set of three lower teeth but what I have seen with this number is an M_3 with an
29 ectostylid reaching about half of the crown height; KNM-KP 43, an upper tooth series P^3-M^3
30 (Hooijer, 1975:Pl. 6, his Fig.1 also illustrated a P^2 with the same accession number; it could well be
31 of the same specimen, but I have not seen this tooth); KNM-KP 44, a mandible with P_3-M_2 and part

1 of M₃; KNM-KP 45, a distal metatarsal; KNM-KP 46, tooth fragments; KNM-KP 47, a poorly
2 preserved upper molar; and KNM-KP 48 (Fig. 2E), a much worn upper molar.

3 According to Hooijer and Maglio (1974:18), the last three specimens "have the characters
4 of *Hipparion turkanense*," and they also tentatively assigned KNM-KP 45 to the same species,
5 while KNM-KP 42, KNM-KP 43, and KNM-KP 44 would belong to *H. primigenium*. In addition,
6 they referred two upper M³s, KNM-KP 490 and KNM-KP 496, to *H. cf. sitifense*, but these
7 accession numbers are erroneous and they probably meant KNM-KP 49, a set of poorly preserved
8 upper molars. I shall mention below the main specimens that were not described by Hooijer and
9 Maglio (1974).

10 KNM-KP 51 (Fig. 2C) is certainly an M², not much worn. The mesostyle is narrow; the
11 central part of the tooth bears several long folds, especially in the distal part of the prefossette; the
12 protocone is flattened lingually; the pli caballin is double; and the hypocone is pinched and almost
13 isolated, obviously because of the early wear stage.

14 KNM-KP 55 (Fig. 2G) is a lower cheek tooth, probably a P₄, not much worn, with a
15 relatively large ectostylid reaching the occlusal level. KNM-KP 56 is probably also a P₄, poorly
16 preserved, with a very small ectostylid.

17 KNM-KP 58 (Fig. 2I) are an associated P₂ and M₂₁; the ectostylid is minute; it reaches the
18 occlusal surface on P₂, but not on M₂₁. On this tooth, both the lingual and buccal flexids are deep
19 and come into contact with each other; the metastylid is angular and pointed.

20 KNM-KP 532 (Fig. 2L) is a partial mandible, with teeth in medium wear, somewhat larger
21 than those of KNM-KP 44. They include P₂, half of P₃, and the series M₁-M₃. The double knot is
22 clearly of caballine type, with a pointed metastylid, and a broad, U-shaped lingual flexid that
23 comes into contact with the buccal flexid on the molars; this lingual flexid is more V-shaped in
24 other specimens, such as KNM-KP 44. The molars have a pli caballinid, stronger on M₂. None of
25 the teeth display an ectostylid; since the teeth are still embedded in bone, nothing is missing on the
26 buccal side of the teeth, the cement layer is rather thin, and we can therefore assume that this stylid
27 was at most extremely small.

28 KNM-KP 30555 (Fig. 2H) are associated P₂₄ and M₃, moderately worn. On P₂₄ the
29 ectostylid is rather large and reaches the occlusal level, whereas it is smaller and is only about 35
30 mm tall on M₃, therefore failing to reach this level. The lingual flexid is V-shaped and the
31 metastylid angular. The hypoconulid of M₃ is divided by a deep lingual groove.

1 KNM-KP 30556 (Fig. 2D) are three successive teeth, probably P^4 - M^2 , very similar in size
2 and morphology to KNM-KP 43 (Hooijer and Maglio, 1974:Pl. 3); the long folds in the central part
3 of the tooth are especially noticeable. Slight differences are that the protocone is more flattened
4 lingually and that the pli caballin is single.

5 KNM-KP 50797 (Fig. 2F) is an M_{21} with a tall, much compressed ectostylid; the double
6 knot is caballine, with a wide lingual flexid.

7 KNM-KP 50822 (Fig. 2J) is an M_2 that is not much worn and is 51 mm tall; a small
8 ectostylid fails to reach the occlusal level, but there is also a long pli caballinid and a small
9 protostylid. The double knot and lingual flexid are similar to those of KNM-KP 50797.

10 KNM-KP 51005 is an associated set of three upper teeth. Two of them, that I identify as M^1
11 and M^2 , are slightly worn, but their occlusal surfaces are blurred; the third one is unworn and I
12 regard it as a P^4 . M^2 is 24 mm long and 54.5 mm high, and thus distinctly less hypsodont than later
13 Pliocene teeth, such as those from Omo (Hooijer, 1975; Eisenmann, 1985; Hooijer and Churcher,
14 1985).

15 KNM-KP 56934 is a mandible fragment with P_2 and P_3 ; there is no evidence of an
16 ectostylid, but the teeth are very little worn and are covered by a thick cement coating, so that it
17 might be concealed in it. There is a long pli caballinid on both teeth and an accessory fold in the
18 lingual flexid, which is quite wide, and the metaconid has a complex shape; these latter features
19 would probably have disappeared with wear.

20 KNM-KP 57003 (Fig. 2K) is a P_3 in medium wear, also with a wide lingual flexid, but the
21 metastylid is more rounded than in the previous specimens. There is no evidence of an ectostylid
22 on the occlusal surface, and the cement layer is too thin to hide it lower down so that it was almost
23 certainly absent.

24 KNM-KP 58730 (Fig. 2B) is a P^{23} similar to the teeth KNM-KP 43 in its long folds in the
25 central part of the tooth and digitate pli caballin; the protocone is also flattened lingually.

26 In summary, the Kanapoi teeth can be characterized by: hypsodonty moderate; premolars
27 distinctly larger than the molars; narrow, lingually flattened protocones; moderately incised
28 hypoglyph; long, numerous folds in the central part of upper cheek teeth; mesostyle narrow; pli
29 caballin varying from simple to complex; ectostylids small and low, rarely reaching the occlusal
30 level of slightly worn teeth; pli caballinid frequent; double knot caballine but with lingual flexid of

1 variable width; and/or buccal flexid rather shallow. It should be stressed that these features are
2 observed on a small number of teeth only.

3 The distal metatarsal KNM-KP 45, already mentioned above, is smaller than the Lothagam
4 specimen (Bernor and Haile-Selassie, 2009:Fig.13.21) or than the Hadar ones (Bernor et al., 2005);
5 the articular keel is more salient than in the Höwenegg reference sample (Bernor et al., 1997).

6 The most complete equid fossil from Kanapoi is a humerus KNM-KP 246 (Fig. 2A) not
7 mentioned by Harris et al. (2003), probably because it was stored with the Suidae. Unfortunately,
8 no other hipparionine humerus has been reported from the East African Pliocene. There is a distal
9 humerus in the Moroccan site of Ahl al Oughlam, close to the Plio-Pleistocene boundary
10 (Eisenmann and Geraads, 2007); it is slightly larger than the Kanapoi one and, in contrast to the
11 latter, the distal articulation is not perpendicular to the long axis of the bone, but slightly slanting
12 disto-laterally.

13
14 Comparisons In their study of the hipparionines from Lothagam, Kanapoi, and Ekora, Hooijer and
15 Maglio (1974) recognized three species at Kanapoi, *Hipparion primigenium* (von Meyer, 1829),
16 *Hipparion turkanense* Hooijer and Maglio, 1973, and *Hipparion cf. sitifense* Pomel, 1897. The first
17 species is mostly known from the Vallesian of Europe (and is now assigned to the genus
18 *Hippotherium*), but Hooijer and Maglio (1974), following Forsten (1968), regarded it as a senior
19 synonym of *Hipparion africanum* Arambourg, 1959 from the early late Miocene of Bou Hanifia in
20 Algeria, and it is mostly with this species that Hooijer and Maglio (1974) compared the Kanapoi
21 form. *H. turkanense* is based upon a complete skull from Lothagam. *H. sitifensis* was described on
22 two isolated upper molars and a calcaneum, so that assignment of any other specimen to the same
23 species is problematic and the name is best regarded as a nomen nudum. Bernor and Harris (2003)
24 used a partial anterior limb from Lothagam, assigned to *Hipparion cf. sitifense* by Hooijer and
25 Maglio (1974), as the type of their new species *Eurygnathohippus feibeli*, but did not discuss the
26 affinities of the Kanapoi specimens.

27 Harris et al. (2003) argued against naming Pliocene forms represented by insufficient
28 material; consequently, they listed the Kanapoi hipparionine material known at that time under
29 *Eurygnathohippus* sp. indet., although they observed that some specimens look either smaller or
30 larger than most others. There is indeed no compelling morphological evidence for more than one
31 taxon and the size of almost all teeth can be accommodated within the range of a single species; the

1 only specimen that is really larger is KNM-KP 53, an upper premolar whose occlusal surface is not
2 readable. Thus, I shall hold the more parsimonious option of recognizing only one species. In the
3 absence of cranial remains (in particular, preorbital area and cranial basis) and complete
4 metapodials, identifying it with a previously named species would be too risky, especially implying
5 biogeographic connections that would not be strongly supported.

6 The Kanapoi hipparion clearly differs from the earlier '*Hipparion turkanense* from
7 Lothagam in its thinner protocone and more complex enamel folding (Hooijer and Maglio, 1974); in
8 addition, Bernor and Harris (2003:Table 9.10) noted that the pli caballin is usually double, whereas
9 it is often single or complex in the Kanapoi sample. Thus, the latter certainly differs from the
10 Lothagam population, but the material is insufficient to reject species identity.

11 Bernor and Haile-Selassie (2009) described material from the Middle Awash that is of latest
12 Miocene to earliest Pliocene age. They compared it to *E. feibeli* from Lothagam but noted some
13 differences (e.g., in robustness of the metapodials, size of an astragalus and phalanx I, shape of the
14 double knot, number of protostylids) and accordingly regarded it as more advanced on the lineage
15 leading to *H. hasumense*, a species defined in the lower part of the Koobi Fora Formation
16 (Eisenmann, 1983). Upper teeth are similar to the Kanapoi ones, and the lower ones share the same
17 small ectostylid as the Kanapoi form (although the figured lower p4 KWA-VP-1/2 is an exception),
18 but the metastylid looks on the average more rounded.

19 The Kanapoi hipparion differs significantly from the recently described *Eurygnathohippus*
20 *woldegabrieli* Bernor et al., 2013 from the slightly older sites of the Aramis region of the Middle
21 Awash, Ethiopia. This species is more hypsodont, on the upper cheek teeth the protocone is longer,
22 and the hypoglyph is extremely deep. By contrast, lower teeth do not look very different; they also
23 have small ectostylids.

24 The Kanapoi form differs from the very incompletely published hipparions from the Hadar
25 Formation in their smaller protocone and/or thinner mesostyles, shallower buccal flexid, and smaller
26 ectostylids. It similarly differs from the poorly known *Hipparion hasumense* from the lower part of
27 the Koobi Fora Formation (Eisenmann, 1983) and perhaps the Laetolil Beds (Armour-Chelu and
28 Bernor, 2011) in its smaller ectostylids, less advanced hypsodonty (Armour-Chelu and Bernor
29 [2011] mention teeth more than 75 mm high), and perhaps (there is some variation in this feature)
30 shallower buccal flexid. Armour-Chelu and Bernor (2011) also mention a strong pli caballinid in

1 this species, but it is virtually absent on the type (Eisenmann, 1983:Pl. 5.11). Only further collecting
2 at Kanapoi and metric and statistical studies on all these samples would allow definite conclusions.

3 Last, the Kanapoi hipparion differs from the c. 2.5 Ma *Hipparion pomeli* Eisenmann and
4 Geraads, 2007 from Ahl al Oughlam in its narrower mesostyle, less complex pli caballin, much
5 smaller ectostylids, and in the orientation of the distal humerus articulation.

6 In the absence of cranial remains and metapodials, species distinction in African hipparions
7 cannot be based upon clear cut features and it is safer not to attempt species identification. Still, and
8 although the Kanapoi material is certainly not a sound basis for revising the phylogeny and
9 taxonomy of African hipparions, I wish to comment again on the use of the name *Eurygnathohippus*
10 van Hoepen, 1930. Bernor et al. (2010:698) diagnose the genus as follows: "...united by the
11 synapomorphy of ectostylids occurring on the permanent mandibular cheek-teeth" and include in it
12 all African hipparionines younger than 6.5 Ma (with the possible exception of the doubtfully valid
13 species *H. sitifensis*). However, it is clear that the ectostylid (whose variations in height and size
14 were first discussed by Eisenmann, 1977) and other structures, such as pli caballinid, ptychostylid,
15 and protostylid (equivalent to the bovid 'goat fold'), increase chewing efficiency and/or reduce rate
16 of wear. They are adaptations to grazing and, as such, are likely to have evolved in parallel in
17 several lineages in response to the expansion of grassland/savanna in the late Cenozoic. Why this
18 particular pillar developed especially in African Pliocene to Pleistocene hipparionines remains
19 unknown, but it likely has to do with a diet consisting mostly of C₄ grasses. In any case, using this
20 single criterion demands inclusion in *Eurygnathohippus* of all specimens (be they African or not)
21 with this structure and exclusion from it of all specimens lacking it (such as several Kanapoi
22 specimens and many other African specimens of early Pliocene age); discarding these specimens as
23 exceptions to the rule simply means that the hypothesis of the monophyly of *Eurygnathohippus* is
24 not falsifiable. It is very likely that many late Pliocene and Pleistocene African forms should indeed
25 be united in a single clade, but the hypothesis that this clade extends back in time to the early
26 Pliocene or even the late Miocene, and includes all African fossils of these ages, remains to be better
27 substantiated.

28 29 **Paleoecological interpretations**

30 Paleoecological interpretations are hard to draw because of the small size of the collection.
31 For instance, it would not be meaningful to calculate the relative abundance of the browser *Diceros*

1 vs. the grazer *Ceratotherium*, but the presence of both genera and the sharp difference in their
2 isotopic values attest to the presence of grassy plains but also of significant arboreal vegetation.

3 The Equidae are also rare, and the lack of metapodials or phalanges prevents the
4 ecomorphological analyses that are usually conducted upon these bones. Thanks to their robustness,
5 teeth are better represented but are too few to provide significant mesowear indices; occlusal
6 surfaces have low relief, in agreement with relatively tall crowns suggesting a mostly grazing diet.

7 Perhaps the most informative aspect of the Kanapoi Perissodactyla is their rarity itself. In the
8 Pliocene, this group had long passed the climax of its diversity and had even sharply declined by
9 comparison with its late Miocene abundance, but it was still common in some African sites younger
10 than Kanapoi, so that this general trend alone does explain its low frequency there. I believe that it
11 speaks against an extensive grass cover, where larger herds of hipparions would have thrived; this
12 interpretation is tentative, but none of the large mammal groups precludes it.

14 **Conclusions**

15 In spite of its small size, the Kanapoi rhino sample is important because it corresponds to a
16 poorly documented time period in the evolution of the lineages leading to the modern forms. Still,
17 only the discovery of well preserved, undistorted skulls could settle the disagreements regarding the
18 evolution of the Rhinocerotidae in Africa, because their rather uniform cranial morphology and the
19 scarcity of complete remains too often leads researchers to over emphasize dental features whose
20 differences between closely related modern forms (*C. simum* vs. *D. bicornis*, but also among the
21 Asian *Rhinoceros*) demonstrate the lability.

22 Pending elucidation of the relationships of these early forms, I think it is safer to leave the
23 Kanapoi hipparionine unidentified to genus; this is perhaps to be preferred to the option of using
24 *Hipparion* as a 'wastebasket' (as done by Eisenmann and Geraads [2007]). In the development of its
25 hypsodonty and ectostylids, the Kanapoi hipparionine fits well into the general trend towards an
26 increasing reliance on grazing in Pliocene African forms (Melcher et al., 2014).

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9
10

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- 32

1 Figure legends

2

3 Figure 1. A-B) *Ceratotherium mauritanicum*. A) Elements of a skull KNM-KP 30187; A1) lateral
4 view of skull; A2) buccal view of P³-P⁴; A3) occlusal view of P³-P⁴. B) Right P⁴ KNM-KP 38. C-F)
5 *Diceros praecox*. C) P⁴-M² of the type specimen KNM-KP 36; D) left P³ KNM-KP 30472; E) left P²
6 KNM-KP 30216; F) right P² KNM-KP 58726. Scale bar = 20 cm for Figure A1, 15 cm for A2 and
7 A3, 10 cm for all others.

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10 Figure 2: Hipparioninae Gen. et sp. indet. A) Right humerus KNM-KP 246, anterior view. B) P²³
11 KNM-KP 58730. C) M² KNM-KP 51 in occlusal (C1) and buccal (C2) views. D) P⁴-M² KNM-KP
12 30556. E) KNM-KP 48, upper molar. F) M₇₁. G) P₄ KNM-KP 55. H) Associated P₇₄ and M₃ KNM-
13 KP 30555 in occlusal (H1) and buccal (H2) views. I) Associated P₂ and M₇₁ KNM-KP 58 in
14 occlusal (I1) and buccal (I2) views. J) M₂ KNM-KP 50822 in occlusal (J1) and buccal (J2) views.
15 K) P₃ KNM-KP 57003. L) Partial mandible with P₂, part of P₃, and M₁-M₃, KNM-KP 532. Scale bar
16 = 15 cm for Figure A, 5 cm for all others.

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18 Figure 3. $\delta^{13}\text{C}$ values of dental enamel of Central and Eastern African fossil rhinos of the Dicerotini
19 tribe. Data (SOM Table 5) from Zazzo et al. (2000), Likius (2002), Semaw et al. (2005), Bedaso et
20 al. (2010, 2013), Kingston (2011), Uno et al. (2011), and Cerling et al. (2015).

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