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Stephanorhinus kirchbergensis (Rhinocerotidae, Mammalia) from the Rhino Cave in Shennongjia, Hubei

TONG HaoWen[1*] & WU XianZhu[2]

[1] *Key Laboratory of Evolutionary Systematics of Vertebrates, Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences, 100044 Beijing, China;*
[2] *Chongqing Normal University, Chongqing 400047, China*

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The Rhino Cave, a Paleolithic site in Shennongjia, is the highest altitude locality of rhinoceros in the Middle-South part of China, and it is also the southernmost and the richest locality in *Stephanorhinus kirchbergensis* fossils which include cranium, mandibles, isolated teeth and postcranials. These materials can be referred to the species *Stephanorhinus kirchbergensis* according to the following characters: incisorless, mandibular symphysis contracted, occiput high, subaural channel closed, with nasal and frontal horns, nasal septum partially ossified, premolars hypsodont and cheekteeth with smooth enamel surface, etc.; except its relatively shorter limb bones. In China, all the Pleistocene non-*Coelodonta* tandem-horned rhinoceroses were assigned to the genus *Dicerorhinus* in the past decades. From today's viewpoint, most of them should be included in the genus *Stephanorhinus*, because *Dicerorhinus* is quite different from *Stephanorhinus* in the following characters: smaller body size, generally unossified nasal septum, subaural channel open and with reduced incisors, etc. This is the first knowledge of *Stephanorhinus kirchbergensis* associated with *Ailuropoda-Stegodon* fauna, the typical Pleistocene mammalian fauna in South China.

***Stephanorhinus kirchbergensis*, Rhino Cave, Shennongjia, Hubei, Late Pleistocene**

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For quite a long time, almost all of the fossils of the Pleistocene rhinoceros from South China were exclusively placed within the species *Rhinoceros sinensis*. The fossil materials of rhino from the Rhino Cave in Shennongjia in Hubei Province were also determined as *Rhinoceros sinensis* in the preliminary excavation report [1]. But the recent study shows that these materials should be included in the species *Stephanorhinus kirchbergensis* which is the common element in the North China Fauna [2]. Both in material quantity and preservation state, the rhino fossils from the Rhino Cave are the best, especially the nearly complete juvenile cranium is rare; although the juvenile cranium was once reported from CKT Loc. 1, but the material is not available nowadays. Additionally, the Rhino Cave in Shennongjia is the highest altitude locality of Quaternary rhinoceros in the Middle-South part of China, and it is also the southernmost occurrence of *Stephanorhinus* in China. Therefore, the significances of the rhino fossils lie not only in systematic paleontology, but also in paleoenvironmental studies.

The pinpoint of the Rhino Cave lies in the west side of Hongping Town in the Shennongjia Forest District, and its geographic coordinates are 31°40′19.9″N, 110°25′11.9″E. The cave was developed in the limestone, and it opens toward southwest. The elevation at the cave entrance is 2102 m above sea level [1].

*Corresponding author (email: tonghaowen@ivpp.ac.cn)

Abbreviations: CKT, Zhoukoudian (=Chou-kou-tien); IVPP, Institute of Vertebrate Paleontology and Paleoanthropology; L, length; Loc, Locality; Max, maximum value; Min, minimum value; SMNH, Shennongjia Museum of Natural History; W, width.

1 Systematic Paleontology

Mammalia Linnaeus, 1758
Perissodactyla Owen, 1848
Rhinocerotidae Owen, 1840
Subfamily Rhinocerotinae Owen, 1845
Tribe Dicerorhinini Loose, 1975
Genus *Stephanorhinus* Kretzoi, 1942

Generic diagnosis. Skull is dolichocephalic; with nasal and frontal horns, and the nasal one relatively bigger; nasal septum partially ossified; the nasal notch and the orbit as well as the palatine notch moved back; vomer not sharply ridged; posterior margins of pterygoid plates sloped; mastoid developed, and the widest part of the occipital is at the level of the mastoid; subaural channel closed; occipital crest inclines backward slightly. Incisorless; premolars highly molarized; without anticrochet in upper cheekteeth. Ascending ramus slopes backward. Radius quite long, which is more than 85% of that of humerus and even with the same length; great trochanter of the femur is robust; metacarpals long; head of the fibula is short [3,4].

Type species. *Stephanorhinus etruscus* (Falconer, 1859–1868)

Included species. *S. kirchbergensis* (Jäeger, 1839), *S. etruscus* (Falconer, 1859–1868), *S. hemitoechus* (Falconer, 1868), *S. hundsheimensis* (Toula, 1902), *S. yunchuchenensis* (Chow, 1963), *S. lantianensis* (Hu et Qi, 1978).

Stephanorhinus kirchbergensis (Jäeger, 1839)

(Figures 1 and 2)

1931. *Rhinoceros choukoutiensis* Wang, p.69–76, pls I–IV [5]

1941. *Rhinoceros mercki* (Jäeger)-Teilhard de Chardin and Pei, p.62–65, text figs. 50–52 [6]

1963. *Dicerorhinus choukoutienensis* (Wang)-Chow, p.62–70, pl. I [7]

1976. *Dicerorhinus kirchbergensis* (Jäeger)-Ji, p. 62, pl. I, fig.5 [8]

1976. *Dicerorhinus mercki* (Jäeger)-Jinniushan, p.122–123, pl. I, figs. 3–5 [9]

1979. *Dicerorhinus choukoutienensis* (Wang)-Chow, p.236–258, pls I–II [10]

1986. *Dicerorhinus kirchbergensis* (Jäeger)-Xu, 229–241, pl. I [11]

1996. *Dicerorhinus mercki* (Jäeger)-Huang, p.183–193, text fig.86, pls XXX–XXXI [12]

1998. *Rhinoceros sinensis* (Owen)-Wu, p.125, pl. I , figs. 8–8 [1]

2002. *Dicerorhinus mercki* (Jäeger)-Tong, p.111–120, text figs. 3-6–3-7, pls 11–12 [2]

Specific diagnosis. Large in size; with high head; plane of the occipital surface is sub-vertical; subaural channel closed; mastoid inflated, and the widest part of the occipital is at the level of the mastoid; mastoid is not fused with the paroccipital process; angle between opisthion+basion and palate is less than 110° [13]; Cheekteeth big and have smooth enamel surface; without anticrochet and metastyle on upper cheekteeth; upper premolar highly molarized and quite hypsodont; molars sub-hypsodont; upper teeth much higher buccally than lingually, and thus extremely ectolophodont [14]. With longer limbs and strongly concave limb joints, which indicate graviportal locomotion.

Materials. Nearly complete skull (cranium and mandible) of a juvenile; maxillary with complete deciduous tooth rows; broken mandibles with deciduous lower teeth. Nasal bone; broken maxillary with P4–M3; broken maxillary with P4–M2; mandibles with complete lower cheek toothrows of adults. Atlas, axis and other cervical vertebrae; broken scapula; complete humerus; complete radius; ulna; carpals; metacarpals; phalanges; basin bones; femur; tibia; fibula; patella; astragalus; calcaneum, metatarsals, etc.

It is necessary to indicate that some of the materials in the museum were not measured in this study, because the exhibit box was unopenable.

Repository. Shennongjia Museum of Natural History and the local government office for cultural relics administration at Shennongjia.

Locality. Rhino Cave (or Xiniudong) at Hongping Town, Shennongjia Forest District, Hubei Province.

Geological age. Late Pleistocene [1].

1.1 Descriptions on the juvenile cranium (measurements see Table 1)

Conditions of preservation. The cranium is nearly complete, except the following parts: tip of nasal, the premaxillary, muzzle part of maxillary, right jugal and the upper right part of the occiput.

(i) Dorsal view (Figure 1A3). **Nasal.** The nasal bone is becoming narrower toward the tip; the sutures are not fused yet, including the suture between two portions of the nasal bone and the naso-frontal one. At the proximal end of the nasal bone, there exists a V-shaped cut in which the anterior process of the frontal bone was hosted. The naso-frontal contact lies at the level of the anterior border of the orbit. The ventral surface is flat, without the septum. The posterior portion of the nasal is like a roll tile, and its side wings meet the maxillary and lacrimal respectively.

Frontal. All the sutures, including frontal, naso-frontal, fronto-parietal and lacrimo-frontal ones, are not fused yet. The frontal bone is complete, which is composed of the left and right sides; the supra-orbit part which is just near the naso-frontal suture is the widest, and it getting narrowed backward; at the frontier of frontal bone, there exists a sharp process which is invaded into the nasal bone; the fronto-parietal suture coincides with the narrowest part of the cranium. The top of the frontal bone is very flat, like a platform. The forming of the rugosity of the horn boss is not formed yet. The supra-orbit process is not prominent.

Parietal. A unique piece of bone; the surrounding sutures are not fused yet, including the parieto-squamosal, frontoparietal and the parieto-interparietal ones; the anterior boundary is a little concave in which the frontal protruded;

in the rear part there is a funnel-shaped concave which contains the front part of interparietal. The least distance between the temporal ridges lie at the middle part of the parietal.

Interparietal. The interparietal is developed and with long interparietal process which is hosted in the funnel-like concave in the parietal bone; the suture between interparietal and occipital is fused completely; but the parieto-interparietal suture is not fused yet.

(ii) Lateral view (Figure 1A4). The lateral profile is almost straight, with slight concave in front of the frontal horn; the posterior half is like a roll tile and in contact with the maxillary and lacrimal respectively; the nasal bone meets the maxillary at the middle point of the nasal notch.

All the sutures, including naso-maxillary, lacrimo-maxillary and the jugo-maxillary ones, are not fused yet. In the uppermost part, there is a narrow process which is wedged between the nasal and lacrimal bones; nasal bone and the maxillary construct the nasal notch which is deep and high; zygomatic process of maxillary begins from the level above M1 and in front of the anterior border of the orbit.

Lacrimal bone is oval-shaped; the longer axis is almost vertical; the upper anterior border meets the nasal bone, which is a primitive character according to Geraads [15]. The lacrimal tubercle or preorbital process is moderately developed.

The anterior portion of the frontal is slightly convex, which hosts the frontal horn; around the fronto-parietal suture, there exists a shallow saddle.

Postglenoid process is robust; temporal ridge extends along with the occipital crest downward and divided into two branches above the external auditory meatus, the upper branch joints the zygomatic process of squamosal, and the lower branch fused with the mastoid process of temporal bone; the anterior portion of mastoid is in contact with the postglenoid process, and the lower posterior portion joints the paroccipital; the expanded part of the mastoid is at the same level as the occipital condyles. The occiput is nearly vertical, but the apex of the occipital crest extends slightly upward and backward. In the sphenoid region, the posterior margins of pterygoid plates are sloped.

Mastoid is the extension of the temporal bone toward the posttympanic area, which is also called the posttympanic process. The anterior part of the mastoid meets the postglenoid process under the external auditory meatus; in the juvenile stage, the suture between them is not fused, but in adulthood, they fused completely.

(iii) Occipital view (Figure 1A2). The right upper portion is broken; but its outline is still obvious enough. The temporal bone extends to the nuchal area and meets the upper occipital bone and the lateral parts of occipital bone respectively. The lateral parts of occipital bone extend downward outside of the occipital condyles to form the paroccipitals.

Occipital bone. Though the right upper portion is broken, the outline of the occiput is detectable, which is in trapezoid, i.e. the lower width is larger than the upper width, and its broadest part lies at the level of mastoid; the occiput is high. The occiput is composed of four parts: upper occipital bone and two lateral parts of occipital bone as well as the basal occipital. The sutures are not completely fused yet, including the temporo-lateral occipital, temporo-upper occipital and upper occipito-lateral occipital; but the suture between the interparietal and upper occipital is fused completely. The foramen magnum is large and with its transverse diameter larger than vertical diameter.

(iv) Palatal view (Figure 1A5). The palatal surface is trench-like, with the bottom very flat and a tiny mid-ridge extending along the longitudinal axis; the two sides of the trench lift and serve as one side of the alveoli. The maxillo-palatine suture is serrated, and there exist several foramina along the suture; the posterior edge of palatine or palatine notch lies at the level of M1/M2; the root of the zygomatic arch originates from M1. Basal occipital is short; basisphenoid bone is long; the choana between the pterygoid processes is broad; the basisphenoid is rod-shaped. The foramina such as foramen lacerum, hypoglossal foramen and caudal alar foramen, are obvious. The maximum zygomatic width lies at the level of the minimum width of the braincase. The distance between the two postglenoid processes is quite large, which is 162.5 mm in juvenile. The counterpart dimensions in adult *Dicerorhinus sumatrensis* is only 113 mm (based on specimen C/O.34), and in juvenile *Rhinoceros unicornis* is only 93 mm (based on specimen OV 1046).

(v) Anterior view (Figure 1A1). The nasal cavity is quite large and reversed trapezoid in outline; infra-orbit foramen is big, and located much near the nasal cavity; that's why it's difficult to view it from the lateral view.

1.2 Descriptions on other elements from the skull

Isolated nasal bone. Among the materials, there is an adult nasal bone, which also has some part of the frontal bone attached (specimen No.243). In dorsal view, the naso-frontal suture almost can not be detected, its outline is the same as in the juvenile in the foregoing descriptions; the width of the nasal at both ends is nearly the same, and the tip is slightly narrowed; nearby the nasal tip, there exists a rugosity area which represents the nasal horn boss; in the frontal area, the boss of the frontal horn is not so rough. In lateral view, the top profile is flat, but with a slight convex near the nasal tip, which corresponds with the nasal horn boss, in front of which the nasal bone bends downward, and connects with premaxillary through the nasal septum. In the frontal area, there exists a very gentle bulge, which should be the location of the frontal horn boss. On the ventral surface, the trace of the ossified septum is prominent, which covers two thirds of the depth of the nasal notch and is getting weaker from the nasal tip backward (Figure 1D1). The dimensions of the specimen No. 243 is as follows: anterior width 86 mm, mid-line length 177 mm, maximum length 230 mm.

There is bone fragment (specimen No. 343) represents the anterior cranial fossa, on which the cribriform plate and the crista galli were preserved.

Broken juvenile maxillary with complete deciduous tooth rows (specimen No. 256); DP2 and DP3 have come into use, but DP1s are not worn yet, and the DP4s are still in eruption. All the sutures are not fused yet, including the median palatine and the maxillo-palatine sutures. The palatal widths at DP1, DP2, DP3 and DP4 are 46.1, 50.8, 56.7 and 63.4 mm respectively (Figure 1 C).

A broken maxillary with left DP1-4 (specimen No. 246), all the teeth are worn to some extent (Figure 1 B).

Left maxillary of an adult with P4-M3 (displayed in SMNH) (Figure 2 A) and a broken left maxillary with P4-M2 (specimen No. 257) (Figure 2 B).

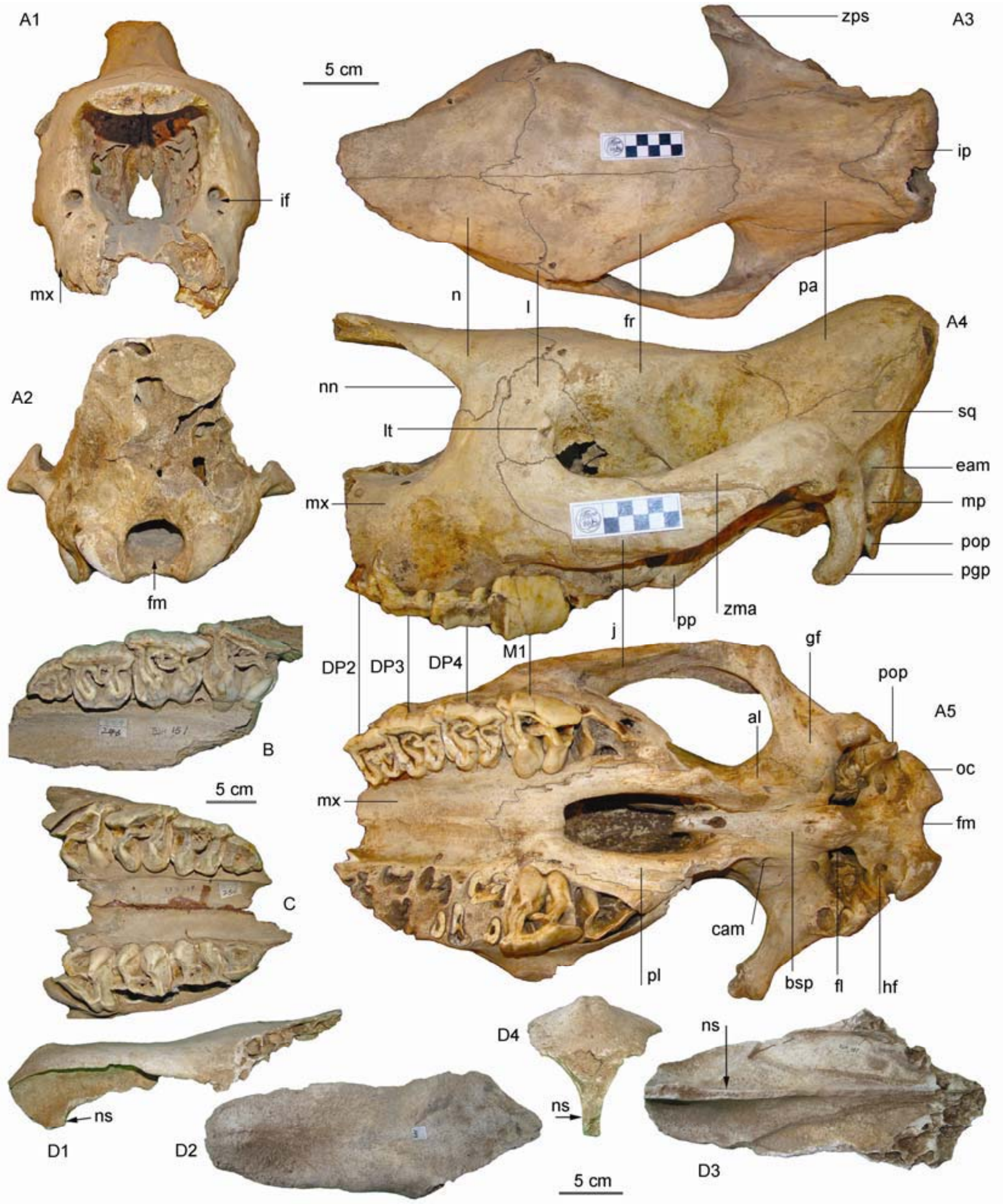

Figure 1 *Stephanorhinus kirchbergensis* from the Rhino Cave in Shennongjia. A, Juvenile cranium (No.H36); B, left juvenile maxillary (No.246), occlusal view; C, juvenile maxillary (256), palatine view; D, nasal bone (No.243). A1, D4, anterior views; A2, posterior view; A3, D2, dorsal views; A4, D1, lateral views; A5, D3, ventral views.

Abbreviations: al, alisphenoid; bsp, basisphenoid; cam, caudal alar foramen; eam, external auditory meatus; fl, foramen lacerum; fm, foramen magnum; fr, frontal; gf, glenoid fossa; hf, hypoglossal foramen; if, infraorbital foramen; ip, interparietal; j, jugal; l, lacrimal; lt, lacrimal tubercle; mp, mastoid process; mx, maxillary; n, nasal; nn, nasal notch; ns, nasal septum; oc, occipital condyle; pa, parietal; pgp, postglenoid process; pl, palatine; pop, paroccipital process; pp, pterygoid plate; sq, squamosal; zma, zygomatic arch; zps, zygomatic process of squamosal.

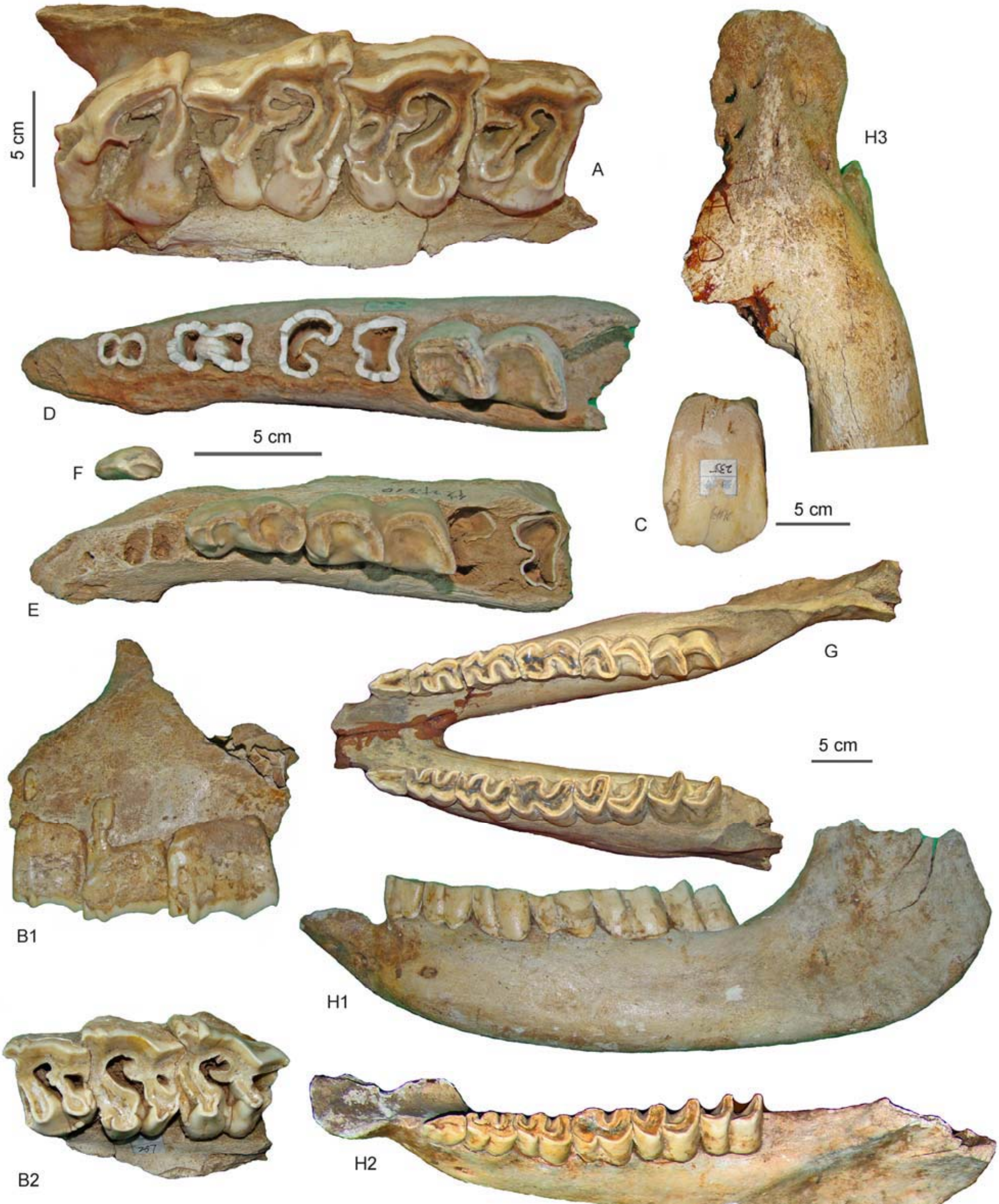

Figure 2 Maxillae and mandibles of *Stephanorhinus kirchbergensis* from the Rhino Cave in Shennongjia. A, Right maxillary with P4–M3; B, Left maxillary with P4–M2 (No.257); C, Left P4 (No.235); D, right mandible with dp4; E, right mandible with dp2–dp3; F, right dp1; G, mandible; H, left mandible with the mandibular symphysis (No.142); H3, details of the symphysis. A, B2, D–G, H2, crown views; B1, C, H1, buccal views; H3, ventral view.

Table 1 Measurements of the cranium of *Stephanorhinus kirchbergensis* (Unit: mm)

Dimensions	Rhino Cave
Length occipital crest-rhinion	?515
Distance orbit-nasal notch	80
Breadth occipital crest	125
Maximum occipital breadth	192
Maximum (zygomatic) breadth of the cranium	325
Distance foramen magnum-occipital crest	151
Palatinal breadth between P4–M1	71
Foramen magnum breadth	48.8
Occipital condyle breadth	137.7
Nasal breadth	170
Maximum frontal breadth	204
Frontal length	225
Parietal length	88.5
Interparietal length	81.7

There are four pieces of mandible, two of which are displayed in SMNH, two others are preserved in the local government office for cultural relics administration at Shennongjia. Among all the mandibles, three of them with the complete cheek toothrows (Figure 2G–H). All the mandibles with their mandibular bodies well preserved, but the ascending rami are broken away, and the mandibular symphyses are also broken to some extent. These mandibles are the best fossil materials of *Stephanorhinus kirchbergensis* in China. The mandibular symphysis is constricted at the distal end, and without lower incisors, which is one of the most important characters of *Stephanorhinus*. The inferior border of the mandibular body is nearly straight, with a slight lift from m2 toward the muzzle, and the symphysis part is prominently lifted. On the top surface of the symphysis, there exists a shallow trench along the longitudinal axis. In ventral view, there are some nutrient foramina can be observed on the ventral surface of the symphysis (Figure 2 H3); the posterior edge of the symphysis is nearly vertical (for measurements see Table 2).

Table 2 Measurements of the mandible of *Stephanorhinus kirchbergensis* (Unit: mm)

Dimensions		Rhino Cave	West Europe [16]
Length of mandibular symphysis	Min	106.4	109
	Max	127.2	137
	Mean	116.8(2)*	118.3(4)
Distal width of mandibular symphysis	Min	–	–
	Max	–	–
	Mean	58.1	–
Minimum width of mandibular symphysis	Min	–	–
	Max	–	–
	Mean	57.2	–
Mandibular body depth at p4	Min	–	86
	Max	–	114
	Mean	81.7	97.1(18)
Mandibular body depth at m1	Min	81.6	90
	Max	101.8	117
	Mean	92.4(3)	102.9(15)
Mandibular body depth at m2	Min	92.9	93
	Max	104.1	125
	Mean	98.5	108.6(16)
Mandibular body depth at m3	Min	89.3	100
	Max	107.7	125
	Mean	95.8(3)	115.8(10)

* Sample size.

1.3 Descriptions on the teeth

(i) Upper teeth (for measurements see Tables 3 and 4; Figure 3a). DP1 is triangular in occlusal view. Ectolophe developed, and its profile is not straight, but arc-like; protolophe reduced and strongly oblique, and connects with the ectolophe and the metalophe respectively, which makes the valley closed and form a large trigon basin; metalophe moderately developed. No cingulum.

DP2 is trapezoid in occlusal view, buccal length larger than the lingual length; maximum width lies at the metalophe. Profile of the ectolophe is oscillatory wave-like. Both protolophe and the metalophe developed. Parastyle developed. Crochet and crista are robust and meet together to form the medifossette. At the anterior cingulum and the entrance of the medisinus, there exist some tubercles; anterior and posterior cingula developed; there exists a faint lingual cingulum at the entrance of the medisinus.

DP3 is trapezoid in occlusal view, buccal length larger than the lingual length; maximum width lies at the protolophe. Profile of the ectolophe is straight. Parastyle and paracone rib developed; the protocone is constricted. Both protolophe and the metalophe developed, crochet developed, but the crista reduced. Postfossette big. Anterior cingulum developed; posterior cingulum shortened; no lingual cingulum.

DP4 is very similar to DP3 in morphology, but much larger in size (Figure 3a). Parastyle and paracone rib developed. Crochet as well as the posterior cingulum are more developed; crochet almost connects to the protolophe; crista reduced. Protocone is seriously constricted. The medisinus is much broader.

P4's outline is in rectangle in occlusal view, and the width is larger than length. Hypsodont (Figure 2C). Parastyle developed; paracone fold prominent, but doesn't reach far downward. Crochet not developed, without crista. Medisinus narrow; postfossette large and deep. Anterior cingulum developed, posterior and lingual cingula obvious.

M1 is similar to P4, but slightly larger. Crochet developed. Protocone is seriously constricted. Cingulum is not developed.

M2's length/width ratio increased; anterior width is remarkably larger than posterior width. Protocone is constricted; parastyle and the paracone fold developed. Crista

Table 3 Measurements of the upper deciduous teeth of *Stephanorhinus kirchbergensis* (in: mm)

Dimensions		Rhino Cave			Tangshan, Nanjing [2]			CKT Loc.1 [5]			CKT Loc.13 [6]	West Europe [16]		
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Min	Max	Mean
DP1	L	31.8	32.9	32.4(2)*	28	29	29.5(2)	27.5	27.5	27.5(2)	35	26	32	29(3)
	W	26	27.9	27(2)	28	28	28(2)	24	25	24.5(2)	32	23	29	25.3(3)
DP2	L	44	47.3	45.7(2)	38	39	38.5(2)	36.5	–	–	41	34	39.5	36.7(7)
	W	42.6	47.9	45.3(2)	40	42	41(2)	39.5	–	–	40	31	43	37.6(8)
DP3	L	50.6	55.8	53.2(2)	47	48	47.5(2)	43.5	–	–	51	41.5	50.5	45.9(10)
	W	48.2	52	50.1(2)	50	52	51(2)	49	–	–	53	42	54.5	46.9(11)
DP4	L	56.6	60	58.3(2)	48	52	50(2)	47	49.5	48.3(2)	53	48	57	52.8(5)
	W	52.6	54.5	53.6(2)	54	54	54(2)	48.5	53.5	51(2)	56	51	57.5	53.2(6)
DP1–4 length		172.8	183	177.9(2)	175	177	176(2)	–	–	147(1)	150	–	–	151.3(1) [17]

* Sample size.

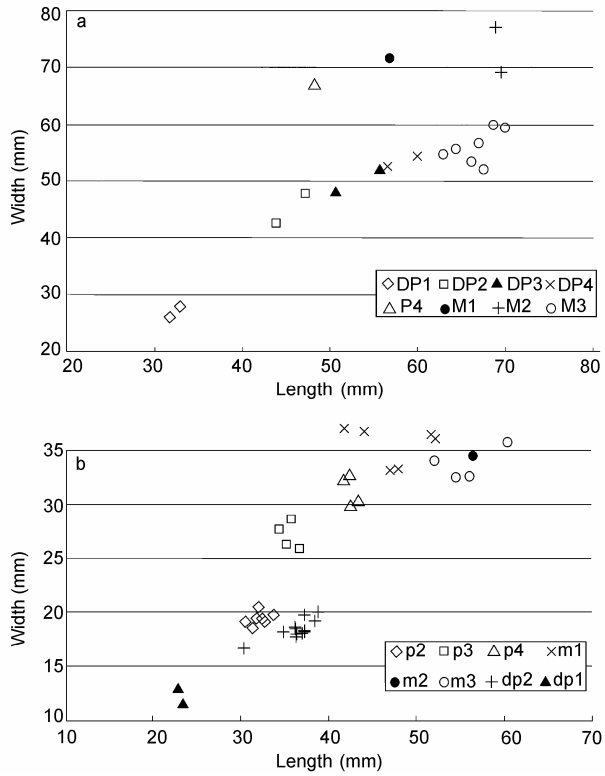

Figure 3 Bivariate scatter plot of measurements of the teeth of *Stephanorhinus kirchbergensis.* a, Upper cheekteeth; b, Lower cheekteeth.

robust. Medisinus broad. Anterior cingulum developed.

M3's outline is in triangular in occlusal view. Protocone expanded, and the protocone constriction is not obvious. Crochet reduced. Metalophe disappeared; occasionally the vestigial metalophe can be observed (Figure 2A). Medisinus broad. Anterior cingulum developed.

(ii) Lower teeth (for measurements see Tables 4 and 5; Figure 3b). The dp1 is simply structured, posterior lobe not developed. Paraconid, protoconid and metaconid connected into a lophe which is nearly straight. The anterior valley is not formed; posterior valley is narrow and shallow, and its orientation has a very small angle with the longitudinal axis; the entrance of the posterior valley is very backwardly located (Figure 2F). With two roots.

The dp2 is two times as big as dp1. With three lobes, the additional lobe is formed by the parastylid and its lingual valley; from anterior to posterior, the valleys are getting larger; the additional valley is formed by parastylid and paraconid; the anterior valley is composed of paraconid, protoconid and metaconid; the posterior valley is constru-cted by the metaconid, hypoconid and entoconid. At the entrance of the anterior valley, there exist some small tubercles; the posterior valley is very narrow (Figure 2E). With two roots.

The dp3 is very similar to dp2 in morphology, but obviously larger. On the lingual side of the parastylid, there exists a gulf or "additional valley", but it's much smaller than in dp2; anterior and posterior valleys are broad. With two root.

The dp4 is the same size or slightly smaller than dp3; very similar to molars in morphology, but not so hypsodont. Anterior and posterior valleys are broad. With two roots.

The p2 is simply structured; anterior lobe is narrow and the anterior valley is not prominent. The posterior valleys are variable. With two roots.

The p3 is obviously larger than p2; the anterior width is slightly smaller than the posterior width. Anterior and posterior valleys narrow. With two roots.

The p4 is larger than p3; anterior width is nearly the same as the posterior width. Posterior valley is much broader than anterior valley. External syncline is deep. With two roots.

The m1 is larger than p4; anterior width is the same as the posterior width. With two roots.

The m2 is very similar to m1 both in size and morphology, but the posterior valley is more broader. With two roots.

The m3 is very similar to m2 both in size and morphology, but both of the anterior and posterior valleys are broad. With two roots.

In the lower deciduous teeth, both dp2 and dp3 have the paraconid rib, and it's more developed in dp2; this character

Table 4 Measurements of the permanent teeth of *Stephanorhinus kirchbergensis* (in: mm)

Dimensions		Rhino Cave			Anping [11]			CTK Loc.1 [10]			West Europe [16]		
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
P2	L	–	–	–	32.5	36.8	–	30	36	33.8(7)	36.5	41	338.3(4)
	W	–	–	–	40.1	41.8	–	39	43	41.6(7)	41	44.5	42.7(6)
P3	L	–	–	–	38.2	43.2	–	38	39	38.6(5)	45.5	49	47.1(4)
	W	–	–	–	55.9	60.2	–	57	61	59.3(5)	50	63	57.3(7)
P4	L	48.3	–	–	44.2	51	–	44	50	46.3(7)	50	53	51.9(4)
	W	67.1	–	–	60.8	66.3	–	64	69	66.7(7)	56	69.5	63.6(7)
M1	L	56.9	–	–	47.2	54.7	–	56	62	54.3(6)	52	63.5	58.3(5)
	W	71.6	–	–	61.2	67.2	–	60	74	69.5(6)	60	71.5	67.2(5)
M2	L	68.9	69.6	69.3(2)*	53.4	62.7	–	50	60	55(6)	61.5	67	64.8(4)
	W	69.4	77.1	73.3(2)	66	70.9	–	64	71	67.1(6)	62	72.5	67.6(7)
M3	L	63	70	66.9(8)	60.5	67.2	–	60	67	63.2(9)	63	65	63.9(4)
	W	52.1	66.6	57.4(8)	60.2	63.5	–	59	67	62.4(9)	59.5	68.5	63.4(6)
p2	L	30.5	33.5	32.1(7)	29.1	32.7	–	26	32	29(7)	31	34	32.1(6)
	W	18.7	20.5	19.4(7)	18.5	21.8	–	17	23	19.5(7)	20	21.5	20.9(7)
p3	L	34.5	36.8	35.6(4)	32.6	41.1	–	33	38	36.4(5)	35	46	40(13)
	W	25.9	28.6	27.2(4)	26.5	28.4	–	21	29	24.2(5)	27	35.5	30.2(13)
p4	L	42	43.4	42.6(4)	37.9	42.8	–	40	49	43(5)	38	51	44.8(19)
	W	30	32.7	31.3(4)	29.6	33.7	–	30	36	33.2(5)	28.5	38.5	33.9(21)
m1	L	41.8	47.9	45.3(4)	44.1	51.1	–	40	45	42.5(6)	43	59	51.2(17)
	W	33.1	37	35(4)	30.8	37.1	–	29	33	31.3(6)	33	42	37.2(17)
m2	L	51.8	56.5	54.2(4)	49.5	54.7	–	38	53	44.2(6)	53	63	57(16)
	W	34.6	36.3	35.4(4)	32.1	36.3	–	29	34	30.7(6)	32	40	36.6(19)
m3	L	52.1	60.4	55.8(4)	52.1	55.8	–	47	57	53.4(5)	50	64	58.4(14)
	W	32.6	35.7	33.7(4)	31.7	32.8	–	30	38	34(5)	31	39	34.3(13)

* Sample size.

Table 5 Measurements of the lower deciduous teeth of *Stephanorhinus kirchbergensis* (in: mm)

Dimensions		Rhino Cave			West Europe [16]			Taubach [17]			CTK Loc.13 [6]		
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
dp1	L	23	23.4	23.2(2)*	17.5	23	20.3(2)	16.6	21.8	19.8(4)	21	–	–
	W	11.6	13	12.3(2)	–	–	14(1)	8.7	12.1	11.1(4)	13	–	–
dp2	L	30.5	38.8	36.5(14)	28	38	33.1(7)	27.8	32.9	31(4)	35	–	–
	W	16.7	20	18.4(14)	16.5	21.5	19.3(9)	15.2	19.3	18.1(4)	21	–	–
dp3	L	49.2	–	–	38	44.5	42.2(13)	39.2	43.9	42(4)	44	–	–
	W	25.1	–	–	21	28.5	23.4(15)	20.8	24.1	23(4)	26	–	–
dp4	L	49.5	52	–	42	51	45.6(12)	45.1	48.3	34.7(3)	47	–	–
	W	27.1	27.4	–	21	31	26.6(12)	25	29.1	26.7(4)	29	–	–
dp1–dp4 length		182	201	191.5(2)	–	–	–	131.7	146.2	138.7(3)	–	–	–

* Sample size.

only observed in *Stephanorhinus kirchbergensis* and in *Dicerorhinus sumatrensis* [18]. The cingulum in the lower teeth is not developed. The p2–m3 length is 265 mm, the m1–m3 length is 151.5 mm.

1.4 Postcranial bones

Among the postcranials, the followings are the well preserved: humerus, radius, ulna, metacarpal, femur, tibia, fibula, astragalus, metatarsal, etc. But only some of them were measured. Based on their dimensions (see Table 6), it can be seen that the limb bones, especially the radius and Mc III, of *Stephanorhinus kirchbergensis* from the Rhino Cave are relatively shorter than those from other localities.

2 Comparisons and discussion

2.1 Fossil identification

The rhino fossils from the Rhino Cave can be referred to the dicerorhine rhinoceros based on the following characters in the juvenile skull: the nasal notch and the orbit as well as the palatine notch moved back; vomer not sharply ridged; posterior margins of pterygoid plates sloped rather than vertical; angle between opisthion+basion and palate is less than

Table 6 Measurements of the postcranial skeletons of *Stephanorhinus kirchbergensis* (in: mm)

Dimensions		Rhino Cave	Anping [11]	CTK Loc.1[5,10]	Tangshan, Najing [12]	Taubach [17]	West Europe [16]
Anteroposterior diameter of scapula glenoid	Min	92.8	–	–	–	124.3	90
	Max	96.7	–	–	–	150.8	101
	Mean	94.8(2)*	–	–	–	136.1(10)	96.3(6)
Length of radius	Min	370	–	425	–	421.5	408
	Max	380	–	431	–	455.5	455.5
	Mean	376.7(3)	457	428(3)	>442	438.5(2)	421.8(5)
Length of Mc III	Min	188.7	–	205	–	–	206
	Max	202.2	–	219	–	–	250.5
	Mean	195.5(2)	–	212	–	204.2	225.2(13)
Length of femur	Min	335	–	–	–	–	502
	Max	340	–	–	–	–	573
	Mean	337.5(2)	538	–	>418	522.1	531.3(3)
Length of tibia	Min	350	–	–	–	355	404
	Max	390	–	–	–	384.8	457
	Mean	370(2)	415	425	433	370(2)	429(3)
Length of Mt III	Min	–	–	–	–	–	198
	Max	–	–	–	–	–	222
	Mean	171.7	–	–	–	>194.6	209.1(10)

* Sample size.

110°; cheekteeth big and quite hypsodont, etc. Additionally, the following characters can be evidences to put these materials in *Stephanorhinus* rather than in *Dicerorhinus*, such as their big size, partially ossified nasal septum, closed subaural channel, etc. These materials can be further referred to the species *Stephanorhinus kirchbergensis* according to the following characters: incisorless in the mandible, cheekteeth big and have smooth enamel surface, upper premolars highly molarized and quite hypsodont, but M3 prominently reduced.

2.2 Discussions on the nomenclatures at generic and specific levels

In the early stage, the Pleistocene dicerorhine rhinoceros was also included with the genus *Rhinoceros*. Later on all the two-horned rhinos were removed to the genus *Diceorhinus* (or *Didermocerus*), this stage lasted for quite a long time; during this period, almost all of the dicerorhine rhinos, from the Miocene to Recent, were placed within this genus. In order to distinguish from the genus *Dicerorhinus*, another generic name, *Stephanorhinus*, was proposed in the 1940s for the species with such characters as incisorless, nasal septum developed, subaural channel closed, etc. [4,19]. It means that in the early bibliographies, the generic name *Dicerorhinus* included both *Diceorhinus* (*sensu* stricto) and *Stephanorhinus*. Although the species *kirchbergensis* was transferred to the genus *Stephanorhinus* in Europe, its common name is still Merck's rhinoceros. It is worth mentioning that the generic name, *Stephanorhinus*, is not completely accepted by all the scholars, and the usage of *Dicerorhinus mercki* is still pertained, but a subgeneric rank, *Dicerorhinus* (*Brandtorhinus*), was established for those elements that are incisorless and with developed nasal septum [16].

Concerning the specific name, many synonyms were once used [20]. But the most frequently used are *Dicerorhinus mercki*, *Dicerorhinus kirchbergensis* and *Dicerorhinus choukoutienensis*, which was discussed in some other paper [11].

Concerning the etymology of the generic and specific names, the author was recently told by Dr. R.-F. Kahlke that the generic name *Stephanorhinus* was named after the King Stephen I of Hungary; and the specific name was derived from the name of a town which is called Kirchberg in Southwest Germany.

2.3 Comparison with *Dicerorhinus sumatrensis*

Compared with *Dicerorhinus sumatrensis*, the latter is much smaller; nasal septum rarely ossified; subaural channel is open; with upper and lower incisors; cheekteeth are smaller and less hypsodont [18].

2.4 Comparison with other fossil dicerorhines ever recovered in China

All the crania of the fossil dicerorhines ever recovered in China are incisorless, and the subaural channel is closed, therefore it is reasonable to transfer them to the genus *Stephanorhinus*.

Although the studies on *Stephanorhinus kirchbergensis* have experienced more than one and a half centuries, the knowledge about this species is still not enough because of the lack of fossil materials. Concerning the causation of the scarcity of the fossil record of this species, there are several different hypotheses [13,20]. In China, the situation is much better [2], the important localities ever reported are as follows: CKT Loc.1 and 13, Nanjing, and Anping in Liaoning, etc. Compared with the materials from CKT, the deciduous teeth and the upper permanent teeth from the Rhino Cave are relatively larger, but the lower permanent teeth are smaller. The p2–m3 lengths are 265 mm and 292 mm for Rhino Cave and CKT respectively.

In morphology, the DP1 from the Rhino Cave is different from that of the CKT and Nanjing, the former's protolophe joints ectolophe and metalophe respectively, which makes the medisinus enclosed; but in the latter, the protolophe is almost parallel to the metalophe, and the medisinus is broadly open.

Additionally, the other co-generic species are *Stephanorhinus yunchuchenensis* (Chow, 1963) [21] and *Stephanorhinus lantianensis* (Hu et Qi, 1978) [22]; but these two species are mono-locality.

Dicerorhinus yunchuchenensis (Chow, 1963), a species of mono-type and mono-localitiy, whose type specimen is an almost complete cranium (some part of the occipital crest broken away). Its characters can keep it an independent species under the genus *Stephanorhinus*. Its peculiarity is the expanded nasal bone, and the relatively smaller and less hypsodont cheekteeth. All these characters are very similar with that of *Stephanorhinus etruscus* (Falconer, 1868) in Europe, except its larger size of the cranium. Considering its scarcity in fossil record, it is difficult to go further in the comparisons and discussions of phylogenetic relationships.

Stephanorhinus lantianensis was found in Gongwangling, an early human site, in Lantian, Shaanxi Province. It is also a mono-locality species. The type specimen is an almost complete cranium (the jugals were broken away). It is similar to other co-generic species, except its smaller size, narrowed nasal tip and the Π-shaped lophe structures of the upper cheekteeth, etc. It is a pity that the only available specimen is an old individual, whose teeth are seriously worn, it is impossible to make more comparisons.

In conclusion, the valid species of the Quaternary dicerorhines from China are as follows: *Stephanorhinus yunchuchenensis, Stephanorhinus lantianensis, Stephanorhinus kirchbergensis* and *Dicerorhinus sumatrensis*.

2.5 Comparison with the European dicerorhines of Quaternary age

Some specific studies have been conducted on the comparisons of dental characters among the four species under the genus *Stephanorhinus* in Europe [23], the result shows that in *Stephanorhinus hundsheimensis* and *Stephanorhinus kirchbergensis*, P2 and P3 are developed, but M3 reduced; additionally, the comparisons and statistical work also covered the following aspects: crochet, crista, anticrochet, medifossette, paracone fold and protocone constriction in the upper cheekteeth; the forms and the entrance levels of the lingual valleys and the buccal syncline in the lower cheekteeth. The result shows some differences to the previous studies, such as the paracone fold and protocone constriction, which is not prominent in *Stephanorhinus kirchbergensis*. This conclusion does not coincide with the Rhino Cave materials in this study either. Concerning the developed P2–P3 and reduced M3, it is also verified in this study. But the present authors think that the reduction of M3 is not necessarily a specific character for *Stephanorhinus kirchbergensis*.

Odontometric data show that the *Stephanorhinus kirchbergensis* from the Rhino Cave and Tangshan in Nanjing is larger than those from Europe, which can be explained by two possibilities, one is the measuring method which affected the result, because in Europe, the dimensions were taken at the tooth collar, but in China it means the maximum dimensions of the crown; the second possibility is that the Chinese *Stephanorhinus kirchbergensis* is really larger.

The contact between the posttympanic process and the paroccipital process is a little different from the standard proposed by Loose who thinks that in *Stephanorhinus kirchbergensis*, the two bones do not fuse together completely, but in *Stephanorhinus etruscus* they form together a pyramid [13]. In the Rhino Cave materials, the situation is variable, in the juvenile, the two bones are not fused, but in an adult specimen, they fused together completely.

In addition, the fusion of the sutures in *Stephanorhinus kirchbergensis* is also peculiar, in the juvenile cranium (No. H36), although the M1s have come into use, the sutures are not fused yet; in the cranium of a more younger juvenile of *Rhinoceros unicornis* (IVPP OV.1046) whose M1s are not erupted yet, but it is difficult to observe the fronto-parietal suture.

2.6 Discussions on the phylogenetic relationships

In some aspects, *Stephanorhinus* is considered to be more closer to *Rhinoceros* than to *Dicerorhinus*, the following characters will support such a proposal: the firm fusion of postglenoid and posttympanic, the great mastoid inflation, and the strong molarization of the premolars (with development of crochets, medifossettes and closed median valleys); but *Stephanorhinus* is different from *Rhinoceros* in the following characters: vomer is not sharply ridged, the posterior margins of pterygoid plates are sloped instead of vertical [3]. The present authors think that in the horn number, cranium morphology and the longer facial portion, *Stephanorhinus* is closer to *Dicerorhinus* than to *Rhinoceros*.

There also exist some similarities between *Stephanorhinus* and *Coelodonta*, such as both of them have two horns, dolichocephalic skull, nasal septum completely ossified or partially ossified, facial part is long, occipital crests incline backward, incisorless and cheekteeth hypsodont, etc., which shows that *Stephanorhinus* is relatively closer to *Coelo-*

donta than to *Rhinoceros*. On the other hand, both *Stephanorhinus* and *Coelodonta* were originated in Palearctic Region. That's why Groves once group *Stephanorhinus* with *Coelodonta* together [3]. The present authors also agree with his proposal.

Europe is the evolutionary center for *Stephanorhinus*, but it is strange enough that there is no fossil record of *Stephanorhinus kirchbergensis* older than Middle Pleistocene [13,16]; therefore its origin is still a mystery. Although the knowledge about its evolutionary tendency is limited, some students proposed that *Stephanorhinus kirchbergensis* got its body size increased during evolution [14]. Lacombat proposed that the development of P2–P3 and the reduction of M3 are archaic characters [23].

2.7 Paleoenvironmental adaptations of *Stephanorhinus kirchbergensis*

Stephanorhinus kirchbergensis was proposed as the biggest dicerorhine [16], with long limbs and a high head posture, the ectolophodont dentition, hypsodont premolars and sub-hypsodont molars in combination with the high head suggest a predominantly browsing mode of feeding. But the strongly concave limb joints suggest graviportal locomotion in the closed forests [13,24,25]. That's why this rhino was also called woodland or forest rhinoceros. The inferences on the paleoenvironmental adaptations of *Stephanorhinus kirchbergensis* coincides quite well with the environment around the Rhino Cave in Shennongjia. But still some other proposed that "*Stephanorhinus kirchbergensis* seems to have been a grazing square-lipped rhinoceros like the present day *Ceratotherium simum*" [26]. The present authors think that *Stephanorhinus kirchbergensis* is, at most, a mixed feeder, i.e. it could be a browser and a grazer. Because its molars are not high enough, although the premolars are hypsodont.

Stephanorhinus kirchbergensis usually associated with the Palearctic fauna assemblage in North China, even if it once occurred to the south of the Yangtze River at the Nanjing Man Site, it still co-existed with the boreal elements. But at the Rhino Cave in Shennongjia, *Stephanorhinus kirchbergensis* associated with the *Ailuropoda-Stegodon* fauna, the typical Pleistocene mammalian fauna in South China whose major elements including the following elements: *Hystrix*, *Atherurus*, *Rhizomys*, *Ailuropoda melanoleuca*, *Stegodon*, *Megatapirus*, *Cervus unicolor*, *Capricornis*, *Bubalus,* etc. [1]. Though *Stephanorhinus kirchbergensis* associated with the South China fauna at the Rhino Cave, it doesn't mean that it must reflect a warmer climate, because the elevation of the locality is more than 2000 m above sea level. According to the modern life zones in the mountains of Shennongjia area, the altitudes above 1500 m correspond with the temperate deciduous and coniferous forests [27], which are the common biota in North China. Previous study shows that *Stephanorhinus kirchbergensis* only occurred during the interglacial periods in Europe, such as the Holsteinian and Eemian interglacials [13]. In China, it also usually appeared in the warm temperate zone. But how could it reach such an altitude as more than 2000 m is still a mystery, because none of the 5 extant rhinoceros can live in such a high mountain.

3 Conclusions

In fossil materials, the Rhino Cave is the richest after Zhoukoudian site, especially the nearly complete juvenile cranium and the adult mandibles with complete tooth rows are very rare. These materials are identified as *Stephanorhinus kirchbergensis* based on the following characters: with nasal and frontal horns; nasal septum partially ossified; subaural channel closed; occipital crest inclines backward slightly; without upper and lower incisors; cheekteeth big and with smooth enamel surface; upper premolar highly molarized and quite hypsodont; molars sub-hypsodont etc. The majority of the Pleistocene dicerorhine rhinoceros ever recovered in China should be referred to *Stephanorhinus* rather than *Dicerorhinus* because of the following characters: big size; nasal septum partially ossified; subaural channel closed; incisorless and the hypsodont premolars. The Rhino Cave represents the highest altitude locality of rhinoceros in the Middle-South part of China, which is of very important significance in the study of paleoenvironment. The *Stephanorhinus kirchbergensis* from the Rhino Cave has relatively shorter limbs; it can be attributed to the mountainous forest environment.

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