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Rhinoceros specimens included in anatomical and morphological studies by Professor Alexander J. E. Cave (Perissodactyla: Rhinocerotidae)

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Abstract. Alexander James Edward Cave (1900–2001) was a superb anatomist who extensively improved our knowledge of rhinoceros anatomy and osteology; he also published several studies on the osteology of other groups of mammals and one conservation-focused study about numbers of *Ceratotherium cottoni* in Uganda. Our contribution contains an identification of the rhinoceros specimens examined by A. J. E. Cave, his complete bibliography related to rhinoceroses, and two recommendations in accord to his legacy. All Cave's morphological and genetic studies should specify the exact geographic origin of the wild rhinoceroses, if known, and some unambiguous reference numbers in the case of collections and/or captive-based specimens. Cataloguing of extinct and near-extinct extant rhinoceroses in world collections, future preservation of the collection material and its anatomical/morphological documentation for the last remnants of *Ceratotherium cottoni*, *Dicerorhinus sumatrensis*, as well as *Rhinoceros sondaicus* and localized wild-based specimens of *Diceros bicornis* is highly recommended.

Key words. Rhinocerotidae, morphology, anatomy, comparative studies, captivity.

INTRODUCTION

Our knowledge of rhinoceros morphology and anatomy and the evolution of their morphological traits has been established by many generations of superb morphologists, anatomists, palaeontologists, and evolutionary biologists, as reviewed exhaustively by Rookmaaker (1983), and partly also by Groves (1983), Prothero & Schoch (1989), and Moodley & Robovský (in press). Significant improvement in our knowledge, especially of the anatomy of rhinoceroses, was associated with the life-long effort by Professor Alexander James Edward Cave (1900–2001); see Hume (1967) and Walls (2001) for his biographic data; his partial bibliography is available in Walls (2001). He was affiliated over the course of time with the University of Leeds, University College London, Royal College of Surgeons London, Medical College of St. Bartholomew's Hospital London and, after his retirement in 1967, with the Zoological Society of London (Hume 1967, Walls 2001). He contributed mostly to the soft tissue anatomy of rhinos, of nearly all species (see below), but also to the osteology of all extant rhinoceros species (e.g. Cave 1959, 1965, 1985), and the morphology of several other groups of mammals (Cave 1965, 1979b). His rhinoceros studies include detailed descriptions of particular organs or structures

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and comparisons with most of the recognized species and with species of some other relevant mammalian groups. His studies compared the results with all relevant studies on the topic, always with respect to his predecessors.

Concerning taxon sampling, A. J. E. Cave specified conspicuously the examined specimens under the conventionally accepted taxonomy. Since rhinoceros experts emphasize the intraspecific diversity in rhinoceroses (see e.g., Groves & Grubb 2011), and since some experts have recognized captivity-induced changes in the morphology of rhinoceroses (see e.g., Groves 1982, Taylor et al. 2014, partly reviewed by Moodley & Robovský in press), we attempt to review Cave's rhinoceros specimens with respect to available information on their history, geographic origin, and taxonomic affiliation. A reason for this review is also the fact that A. J. E. Cave specified the examined individuals in detail in many of his papers, but only briefly in some others. Experts focusing on some particular issues of rhinoceros morphology/anatomy and unfamiliar with his entire scientific output could miss some interesting aspects if they were to read the papers with only brief notes on examined individuals. We therefore offer an identification of the rhinoceros individuals throughout Cave's papers. Simultaneously, this contribution presents, completed and revised, Cave's bibliography on rhinoceroses (see References).

MATERIAL AND METHODS

We compiled data on rhinoceros specimens examined for anatomy by Alexander James Edward Cave (AJEC) based on presumably all his papers, which include rhinoceros examinations (as available in the Rhino Resource Center, see RRC 2022) with respect to species, sex, name of the individual, age, date of death/examination, (institutional) source of the examined material, geographic origin, and reference/inventory number of the individual/specimen. Compiled data are available in Table 1, ordered by the original species names, reference numbers, and sex.

We tried to synonymize the specimens with lists of rhinoceros individuals kept in captivity compiled by Rookmaaker (1998), the Species360 database (formerly International Species Information System; Species360 2022) and the EEP Annual Studbook Report for Eastern Black Rhinoceros (Biggle & Pilgrim 2011). For the successfully identified specimens, we added the International Studbook Numbers for captive rhinoceroses via 'Animal' search (Species360 2022, Rookmaaker 1998, Biggle & Pilgrim 2011). Where applicable, we mention the collection inventory numbers and particular rhinoceros specimens stored by institutions based on Rookmaaker (1998), Groves (1982), Robovský et al. (2010), and online collection catalogues/databases, specifically SurgiCat (2022), Collection Online (OUMNH 2022), and Data Portal – Natural History Museum, London (NHM 2022).

Since AJEC published several papers using rhinoceros osteological material (Cave 1964a, 1965, 1985), we also compiled the list of these specimens with respect to collection inventory numbers, collection specifications, and origin of the specimens, when available, in Table 2. When we found the data on geographic origin (using, e.g. Flower & Garson 1884, Hopwood 1939, Pocock 1944, 1945, 1946, Cave 1947, Zukowsky 1965, Groves 1967, Groves 1972, Loose 1975, Rookmaaker 1977, Groves 1982, Miles & Grigson 1990, Rookmaaker 1998, collection databases mentioned above, and the JR survey in the Natural History Museum London in 2011), we specified infraspecific taxonomy in additional notes in accordance with Groves & Grubb (2011). Table 2 is organized according to the original species names, institutions, and inventory numbers.

Additional note. Taking into account the long professional career of AJEC, some institutions changed their names over time, which gave rise to some significant variability in AJEC's papers. The names of institutions that kept rhinoceros specimens follow Rookmaaker (1998), the names of natural history collections follow Miles & Grigson (1990) and Sabaj (2020). We also specify the revised taxonomy based on the known geographic origin of the rhinoceros specimens, following the taxonomy suggested by Groves & Grubb (2011).

When data (predominantly regarding the estimated ages of examined rhinoceroses or date of examination) were not concordant, we preferred to specify all variants. Exceptions, however, were made regarding the variability of names related to the Zoological Society of London (ZSL), for example in relation to the menagerie of ZSL, London Zoo, or sometimes also in relation to Whipsnade Park. These variants we unified based on rhinoceros location according to Rookmaaker (1998).

RESULTS AND DISCUSSION

Professor Alexander J. E. Cave contributed much to our knowledge of the anatomy and morphology of extant rhinoceros species due to his taxonomically extensive and detailed studies that used macroscopic and often histological examinations as well. He focused on organ systems neglected at that time (e.g. aortic arch branching, epipharyngeal bursa, cardiac receptor system, faucial and laryngopharyngeal tonsils, lingual intrinsic musculature, major intrinsic pancreatic ducts, lymph node structures, pedal scent gland, postcava structure, preputial skin and glands,

Fig. 1. Adult male of *Ceratotherium cottoni* named Ben at the London Zoo on 1 January 1968. Photo credit: Keystone Press/Alamy Stock Photo.

Table 1. List of rhinoceros specimens examined by Alexander J. E. Cave; AM – anatomical material; BMNH – Natural History Museum, London, U.K.; NMB – Naturhistorisches Museum Basel, Switzerland; NMP – National Museum, Prague, Czech Republic; RCSHC – Royal College of Surgeons Museum, Hunterian Museum, U.K., ZSL – Zoological Society London, U.K; ZMUC – Natural History Museum of Denmark,

ID	ref. no.	examination date	origin	sex	name; (studbook) name, zoo, arrival, death
Ceratotherium simum					
1	R 20	1964	London and Whipsnade	♂	perh. Mphugane; ♂ (st. 1532), Natal; Whipsnade 31 Jul 1962 to 31 Jan 1964 (†)
2	R 76	1976	London	♀	perh. whi17, Myrtle or Mpundu (but only Mpundu died in 1976: ♀ Mpundu (st. 107), Natal; Whipsnade 5 Aug 1970 to 14 Jan 1976 (†)
3	R 162	1964	London	♀	Bebe; ♀ (st. 290), Uganda; London, 25 Jul 1955 to 19 May 1964(†)
4		living obs. 1968	London	♂	prob. Ben; ♂ (st. 19), Uganda; London, 25 July 1955 to 27 Aug 1986 († 25 Jun 1990, Dvůr Králové)
5		31 Jan 1964	Whipsnade	♂	prob. R 20, see above
6		bef. 23 Jun 1987	?	♂	same as R 20?
7		living obs. 1962	Paraa, Uganda	♀	inapplicable; observed in wild: Paraa, Uganda
8		1964	London	♀	perh. R 162, see above
9		1964	London	♀	Perh. R 162, see above
10		living obs. 1968	London	♀	prob. Mashobeni; ♀ (st. 20), Natal; Whipsnade 31 Jul 1962, London; 14 Oct 1964 to 17 Oct 1986 († 16 Dec 1995, Glasgow)
11		before Jun 1958 (paper publication)	H. E. Williams Arua	?	inapplicable; obtained in wild: West Nile Dist., Uganda
Diceros bicornis					
12	R 19	1960	London and Whipsnade	♀	none; ♀ [no name] (st. 613), East Africa; Whipsnade 14 Jun 1960 to 28 Dec 1960 (†)
13	R 24	1962	Whipsnade	♂	none; ♂ [no name] (st. 614), East Africa; Whipsnade 14 Jun 1960 to 15 Nov 1962 (†)
14	R 27	1963 (? erroneous)	London	♀	Lorna; ♀ (st. 551), Kenya; London 1 Oct 1947 to 22 Mar 1964 (†)
15	R 68	1968	Kenya	?	inapplicable; obtained in wild of Kenya
16		15 Jan 1974	London	♂	Paul; ♂ (st. 16), East Africa; London 15 Jul 1966 to 18 December 1973 (†)
17		1962	Whipsnade	♂	prob. R 24, see above
18		† 16 Nov 1962 (should be 15 Nov)	Whipsnade	♂	prob. R 24, see above
19		living obs. 1968	London	♂	Perh. Paul, see above
20		bef. 8 Oct 1968	?	♂	?

University of Copenhagen, Denmark; n – number, perh. – perhaps, prob. – probably, ♀ – female, ♂ – male, ? – unspecified/unknown, † – death, L – spirit preparations in the Physiological Series, Royal College of Surgeons Museum, U.K. Inserted information from sources other than Cave's papers are underlined

ID	age	included in	note
Ceratotherium simum			
1	young (3 years)	Cave (1964b, 1966, 1969, 1974b, 1975, 1976a, c, 1977, 1979b, 1980, 1987), Cave & Aumonier (1965)	AM ZD 1999.327–328 (BMNH)
2	adult (10 years)	Cave (1977, 1979b, 1980)	no female fits exactly with the age of 10 years
3	adult (11 or 11–12 years)	Cave (1974b, 1976a, c, 1977, 1979b, 1980, 1982, 1987)	*Ceratotherium cottoni*; not *Diceros bicornis* as in Cave 1979a; skull C.58.18 (BMNH)
4	18 years or ca. 18 years	Cave (1969)	*Ceratotherium cottoni*; skeleton NMP 93510
5	young	Cave & Aumonier (1964a)	
6	juvenile	Cave (1988)	*Ceratotherium* spp.
7	2½ years	Cave (1969)	*Ceratotherium cottoni*
8	10 years	Cave & Aumonier (1966), Cave (1969)	
9	subadult or adult	Cave (1979a)	
10	10–11 years	Cave (1969)	
11	immature or adult	Cave (1958), Cave & Allbrook (1958, 1959), Aumonier & Cave (1960, 1964a)	*Ceratotherium cottoni*; skull C.58.5, AM ZD 1999.326 and ZD 1999.330 (BMNH)
Diceros bicornis			
12	young (2 years, ca. 2 years, 2–3 years or ca. 2–3 years)	Cave (1964c, 1974b, 1976ac, 1977, 1979a, b, 1980, 1981a, 1987)	skeleton BMNH 1961.1.31.1 and AM ZD 1999.329 (BMNH)
13	4 years	Cave (1964b, c, 1969, 1974b, 1987), Cave & Aumonier (1965), Cave & Rookmaaker (1977)	AM ZD 1999.324 (BMNH)
14	adult (18 years)	Cave (1974b, 1987)	AM ZD 1999.325 (BMNH)
15	foetus	Cave (1974b)	AM ZD 1999.323 (BMNH)
16	adult	Cave (1974a)	
17	4 years	Cave (1969, 1981a)	
18	young	Cave & Aumonier (1963a, 1964c)	
19	8 years	Cave (1969)	the age given is not a precise fit
20	3 years	Cave (1969), Cave & Rookmaaker (1977)	prob. neither R 24, nor any captive London or Whipsnade individual

Table 1. (continued)

ID	ref. no.	examination date	origin	sex	name; (studbook) name, zoo, arrival, death
21		bef. June 1961	?	♂	?
22		1960	Whipsnade	♀	prob. R 19, see above
23		bef. 14 Apr 1981	London	♀	prob. R 19, see above
24		bef. 10 Dec. 1974	London	♀	perh. R 19, see above
25		1964	London	♀	prob. R 27, see above
26		living obs. 1968	London	♀	prob. June; ♀ (st. 17), East Africa; Whipsnade 15 Jul 1966 to 11 Oct 1991 († 28 Dec 1991, Port Lympne)
27		1960	Whipsnade	♀	?
28		bef. 12 Sep. 1961	Whipsnade	♀	prob. R 19, see above
29		bef. May 1963	?	?	?
Didermocerus sumatrensis					
30	R 62	1961 and 1962	Basel	♀	Betina (not Bettinga as in Cave 1987), ♀ Sumatra; Basel 2 Jul 1959 to 8 Sep 1961(†)
31	R 72	1972	Copenhagen	♀	Subur; ♀ Subur, Sumatra; Copenhagen 4 Dec 1959 to 24 Feb 1972 (†)
Rhinoceros unicornis					
32	L331.1 L333.1	1932	London	♂	none; ♂ [no name] (st. 377) India; London 20 May 1834 to 19 Sep 1849 (†)
33	L332.1	1905	London	♂	Jim; ♂ (st. 289), Assam; London 25 Jul 1864 to 12 Dec 1904 (†)
34	R 21	1961 and 1964	Whipsnade	♂	Mohan; ♂ (st. 13), Assam; Whipsnade 7 Aug 1947 to 7 Mar 1961 (†)
35	R 41	Nov 1941	London	♂	Felix; ♂ (st. 383), Nepal; London 13 Dec 1924 to 21 Nov 1941 (†)
36	R 45	March 1945	London and Whipsnade	♂	Hush; ♂ (st. 384) Nepal; London 29 Apr 1933, Whipsnade 6 Jun 1935 to 15 Mar 1945 (†)
37	R 75	May 1975	Whipsnade	♂	Manik (not Malik); ♂ (st. 20), zoo born; Whipsnade 18 Aug 1960 to 25 Apr 1975 (†)
38		liv. obs. Aug 1960	Whipsnade	♂	prob. R 75 [Manik was just born in Aug 1960, first birth in Whipsnade], see above
39		bef. 12 Sep 1961	Whipsnade	♂	R 21 or R 45, see above
40		liv. obs. Aug 1960	Whipsnade	♀	prob. Mohini; ♀ (st. 8), Assam; Whipsnade 18 Jul 1952 to 26 Apr 1976 († 25 Apr 1985, Amsterdam)

ID	age	included in	note
21	1 year	Cave (1961)	prob. neither ZSL nor Whipsnade individual
22	2 years	Cave (1961, 1969, 1979a, 1981a, 1988)	
23	young (3 years)	Cave (1981a, 1982), Cave & Rookmaaker (1977)	
24	2–3 years	Cave (1975)	♂ in material, ♀ in text (Cave 1975)
25	18–20 years or 20 years	Cave (1969), Cave & Rookmaaker (1977)	
26	6–7 years	Cave (1969, 1981a)	the age given is not a precise fit
27	foetus or advanced foetus	Cave (1961, 1969), Cave & Rookmaaker (1977)	no individual fits the specified data
28	young	Cave & Aumonier (1962a), Cave (1981a)	
29	young	Cave (1963a)	perh. R 19, Cave, however, also compared some non-captive specimens
Didermocerus sumatrensis			
30	immature to adult (11–12 or 12 or 13 years) or old age	Cave & Aumonier (1962b, 1963b, 1966, Cave 1964c, 1975, 1976a, c, 1981ab, 1987, 1988)	*D. s. sumatrensis*; remains preserved, NMB 10259, AM ZD 1999.322 and ZD 1999.344–358 (BMNH)
31	adult (13–15 years)	Cave & Wingstrand (1972), Cave (1973, 1974b, 1976a, c, 1979b, 1988)	*D. s. sumatrensis*; remains preserved, ZMUC 3791
Rhinoceros unicornis			
32	20	Cave (1953a, 1976a, c)	both specimens related (see RCSHC); skeleton BMNH 51.11.10.2; famous through the dissection by R. Owen
33	40+	Cave (1953a, 1976a, c)	
34	adult (18 years or ca. 18 years)	Cave (1961, 1962, 1964c, 1969, 1974b, 1976a, c, 1977, 1979b, 1980, 1981a, 1982, 1987), Cave & Aumonier (1966)	† 7 Mar 1961 (not 8 as in Cave 1964c); skeleton BMNH 1961.5.10.1, AM ZD 1999.318–319 (BMNH)
35	adult (20 years or ca. 20 or 21 years)	Cave (1953a, b, 1961, 1962, 1969, 1975, 1976a, b, 1977, 1980, 1981a, 1987)	skull BMNH 1950.10.18.4
36	adult (15 years / ca. 15 years)	Cave (1953a, b, 1961, 1962, 1964b, 1969, 1974b, 1975, 1976a, c, 1977, 1980, 1981a, 1987)	skull BMNH 1951.10.18.4 (but see Table 2)
37	adult (15 years)	Cave (1975, 1976a, b, c, 1978, 1979b, 1981a, 1987)	
38	infant / 3 months	Cave (1969)	offspring of the female ID 40; the date of does not fit precisely 3 months
39	adult	Cave & Aumonier (1962a, 1964b)	
40	10–11 years	Cave (1969)	

salivary glands, thymus gland, thyroid and parathyroid glands, tongue, and visceral histology – Cave 1962, 1964c, 1974a, 1975, 1976a, 1977, 1978, 1979a, 1980, 1981b, 1982, 1987, 1988, Cave & Aumonier 1963d, 1964a, 1965) and some peculiar morphological structures (e.g., foramen ovale, temporo-pterygoid ligament, traction epiphyses – Cave 1959, 1965, 1979b). He was also able to improve the knowledge of basic hair distribution and skin histology in rhinoceroses (e.g., Cave & Allbrook 1958, Cave 1969). In effect, he established an excellent platform for further deepening of our knowledge, due to comprehensive descriptions and associated figures presented in his studies.

His attention to particular specimens in his studies is also inspiring. The recommended practice of making data fully transparent or at least of specifying collection specimens or accession numbers (e.g., GenBank) is the best way to verify and upgrade the previous observations. In many cases, the association of DNA voucher specimens with some morphological/phenotype and location data is highly recommended to minimize misidentifications and maximize the potential to assess the evolutionary differentiation of examined taxa (e.g., Groves 2006).

From this point of view, the majority of AJEC's studies include data on examined individuals with respect to sex, age, collection, geographic origin, and other useful data. Specifically, only three studies of rhinoceroses lack such specifications – Cave (1957, 1959, 1963b), but not due to omission. The first study reviews Owen's (1852, 1868) observation of muscles (M. depressor palpabrae inferioris and M. nictitator), the second offers a short generalization of differences in structure of the foramen ovale in all extant rhinoceros species based on extensive sampling of (unspecified) collection specimens, and the third study estimates total numbers of *Ceratotherium cottoni* in Uganda. Some of AJEC's studies include all sets of detailed information about examined rhinoceros individuals, but some only a part of them. Our impression based on all his studies indicates that he tried to specify details when he had them and if the mention of them was important in respect of observed variability. In some structures that exhibit a higher conservatism in examined species and specimens, he generalized the observation without noting particular specimens more closely, and vice versa.

Our attempt to identify particular specimens across all published studies (Table 1) was quite successful due to the complete sets of specified information or some combination of them (for example, even Cave 1976c was associable due to the specified number of thyroid lobes in particular rhinoceros specimens using Cave 1976a). Of the forty specimens mentioned in various forms, the origins of one juvenile white rhinoceros male, two young males, a female foetus and a young unsexed *Diceros bicornis* individual remain unknown. The origin of a further adult female of *Ceratotherium* spp. and an adult male of *Rhinoceros unicornis* remain uncertain, but we were able to present some candidates that were found in specified institutions at those times.

Certain variations in the mentioned information could be easily explained by typing errors (e.g., in the names of animals), but not in the case of various ages of the same individuals, in particular in two specimens. An immature wild-killed individual of *Ceratotherium cottoni* was once misspecified as an adult (Cave & Aumonier 1964a), and an adult female of *Dicerorhinus sumatrensis* kept at the Basel Zoo was once misspecified as immature (Cave 1981a). The source of this variability remains unknown and could have been caused by the conflicting associated notes that were preferred by the author for particular studies.

The revised taxonomy in Table 1 shows that AJEC examined both white rhinoceros species, *Ceratotherium simum* and *C. cottoni*. The latter species is therefore a fairly well-documented taxon, as is *Dicerorhinus sumatrensis sumatrensis*, based on two females from central Sumatra, and as the representatives of the Nepal and India populations of *Rhinoceros unicornis* (for

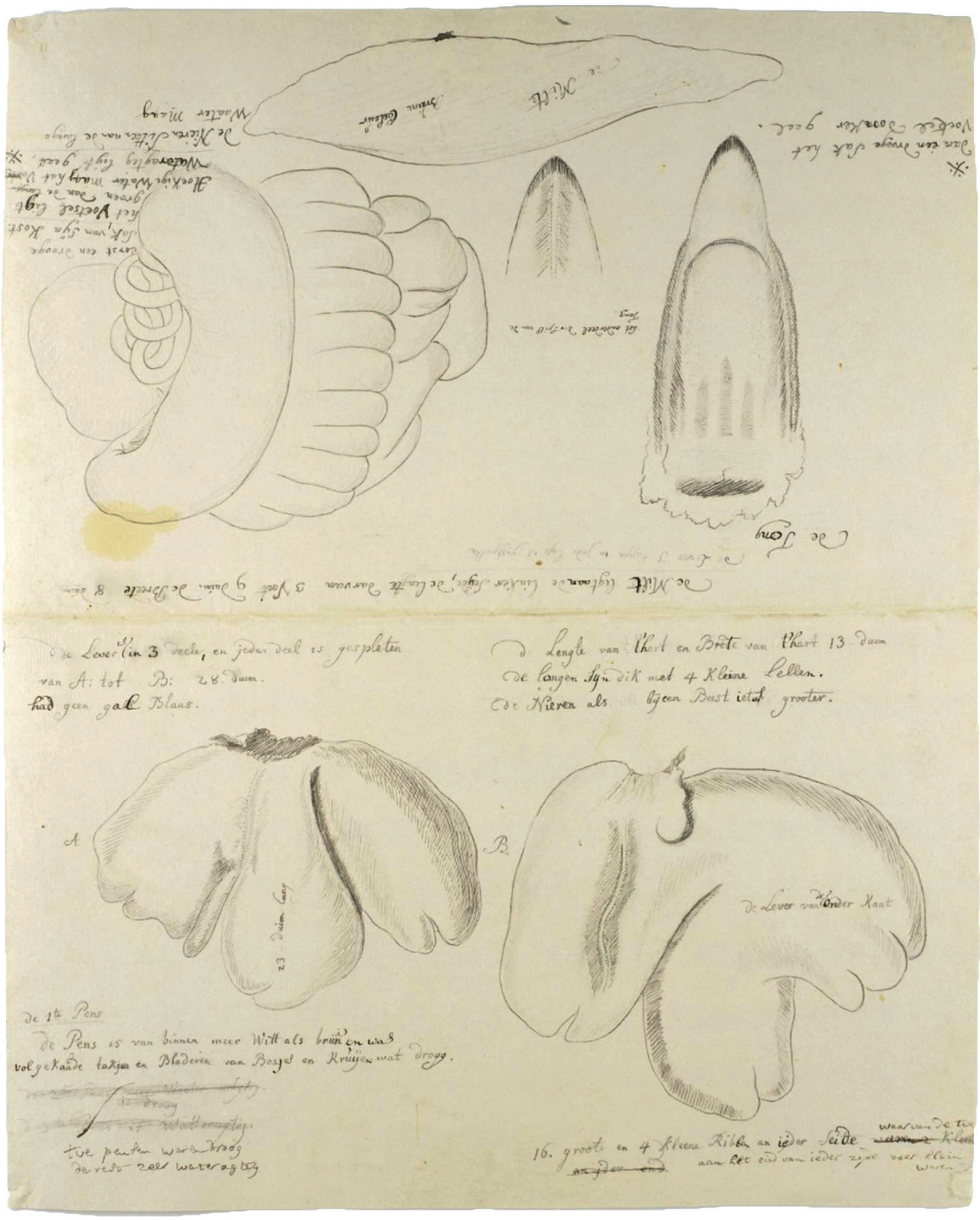

Fig. 2. Anatomical drawings made by the Dutch army officer Robert Jacob Gordon (1743–1795) of *Diceros bicornis bicornis* which he killed on 2 November 1778 at the Gamka River, Eastern Cape, South Africa. Photo credit: Rijksmuseum, Amsterdam, Gordon Atlas GA208.

Table 2. List of rhinoceros osteological specimens examined by Alexander J. E. Cave (1964a, 1965, 1985); BMNH – Natural History Museum London, U.K.; MM – Manchester Museum, University of Manchester, U.K.; OUM – Oxford University Museum of Natural History, U.K.; OC – Osteological Catalogue; OS – Osteological Series; RCSHC – Royal College of Surgeons of England Museum, London, U.K.; ? – unspecified/unknown. Inserted information from sources other than Cave's papers are underlined

collection no.	institution	origin	note
Ceratotherium simum			
B.M.1948.1.28.1	BMNH	South Africa	skull
B.M.1948.1.28.2	BMNH	Lado Enclave, Uganda	*Ceratotherium cottoni*; skull
C.58.5	BMNH	Arua, West Nile District, Uganda	*Ceratotherium cottoni*; skull (see Table 1)
C.58.7	BMNH	?	skull
C.58.8	BMNH	?	skull
C.58.9	BMNH	?	skull
C.58.18	BMNH	Uganda	*Ceratotherium cottoni*; skull, Bebe (see Table 1)
ZC-08218 (OC 1564)	OUM	South Africa, type locality Chué Spring, Makuba Range, South Africa	a left maxillary first molar; Animal A; paralectotype
ZC-08219 (OC1565)	OUM	South Africa, type locality Chué Spring, Makuba Range, South Africa	a right maxillary fourth premolar; Animal A; paralectotype
ZC-08220 (OC 1567)	OUM	South Africa, type locality Chué Spring, Makuba Range, South Africa	a left maxillary forth premolar; Animal A; paralectotype
ZC-08221 (OC 1568)	OUM	South Africa, type locality Chué Spring, Makuba Range, South Africa	a right maxillary second molar; Animal A; paralectotype
ZC-08222 (OC 1566)	OUM	South Africa, type locality Chué Spring, Makuba Range, South Africa	a left maxillary second molar; Animal B; paralectotype
ZC-08223 (OC 1569)	OUM	South Africa, type locality Chué Spring, Makuba Range, South Africa	a mandibular left third molar; Animal B; paralectotype
ZC-08224 (OC 1570)	OUM	South Africa, type locality Chué Spring, Makuba Range, South Africa	a mandibular right first molar; Animal B; paralectotype
ZC-08225 (OC 1571)	OUM	South Africa, type locality Chué Spring, Makuba Range, South Africa	a mandibular left first molar; Animal B; paralectotype
Diceros bicornis			
B.M.23.10.20.18	BMNH	Jubaland, Northern Guasso Nyiro, in South Somalia, or maybe in NE Kenya	*Diceros bicornis michaeli*; skull
B.M.33.5.5.1	BMNH	Handeni District, Tanganyika, now Tanzania	*Diceros bicornis minor*; skull
B.M.99.6.29.11	BMNH	Zomba, Brit. Central Africa/southern Nyasaland, now Malawi	*Diceros bicornis minor*; skull

collection no.	institution	origin	note
C.58.11	BMNH	?	skull
U.70	BMNH	?	skull
Didermoceros sumatrensis			
B.M.1461b	BMNH	Sumatra	*Dicerorhinus sumatrensis sumatrensis*; skull
B.M.1879.3.11.1	BMNH	Sagaliut, Sandakan district, Sabah, Borneo	*Dicerorhinus sumatrensis harrissoni*; skull
B.M.1886.12.20.8	BMNH	Sandakan, Borneo	*Dicerorhinus sumatrensis harrissoni*; skull
B.M.1948.1.14.1	BMNH	?	*Dicerorhinus sumatrensis*; skull
B.M.1949.2.1.1	BMNH	?	*Dicerorhinus sumatrensis*; skull
B.M.1952.4.1.2	BMNH	Sumatra	*Dicerorhinus sumatrensis sumatrensis*; skull
Rhinoceros sondaicus			
?	MM	?	old male; from captivity; the advanced periodontal disease in the upper and lower jaws; pathological change on the cranium undersurface and in each temporomandibular joint
B.M.1902.12.18.1	BMNH	Java	*Rhinoceros sondaicus sondaicus*; skull
OS 2133 (RCSHC/CO 2133)	RCSHC	?	cranium; supernumerary incisors
Rhinoceros unicornis			
B.M.1870.3.10.18	BMNH	India	skull
B.M.1903.2.13.1	BMNH	Cooch Behar (Maharaja), West Bengal, India	skull
B.M.1950.10.18.4	BMNH	Nepal	skull, Felix (see Table 1)
B.M.1950.10.18.5	BMNH	Nepal?	skull, Hush according to the BMNH, see Table 1, but Groves (1982) specified BM 1951.10.8.4 for this individual
B.M.1951.11.30.2	BMNH	Nepal Terai = Nepal	skull
B.M.1952.4.1.1	BMNH	Bhotan Terai, West Bengal, India	skull
B.M.1962.7.6.7	BMNH	?	skull
OS 2124	RCSHC	Nepal Terai = Nepal	cranium; supernumerary incisors
OS 2125 (RCSOM/G 64.4)	RCSHC	Nepal Terai = Nepal	cranium; supernumerary incisors

a review of the intraspecific variation in this species, see Moodley & Robovský, in press). We were unable to specify infraspecific taxonomy for *Diceros bicornis* due to lack of precise localities. The specification of the origin from East Africa/Kenya is not very helpful, since three subspecies of this species (*D. b. ladoensis*, *D. b. michaeli*, *D. b. minor*) are reported there (Groves & Grubb 2011). Taking into account the taxa examined and the limited number of rhinoceros individuals, we could recommend some improvements to our knowledge about the morphological diversification of extant rhinoceroses (see below).

AJEC himself recognized the high conservatism in some organ systems and morphological structures (see e.g., Cave & Aumonier 1964a, Cave 1973, 1988, partly also Cave 1974a, 1976a) or great individual variability in examined specimens in some other organs (e.g., partly Cave 1959, 1965, 1976a, 1979a, 1987). From this point of view, these anatomical parameters examined in AJEC's work seem to be the most promising for potential further documentation: aortic arch branching (Cave 1987), cardiac receptor system (Cave 1981b), epidermal structures and occurrence and distribution of body hair (Cave & Allbrook 1958, Cave 1969), (para)thyroid glands (Cave & Aumonier 1963d, 1966, Cave 1976a), postcava structure (Cave 1975), preputial skin and glands (Cave & Aumonier 1965, Cave 1966), processus glandis (Cave 1964b), relationships of the foramina ovale et lacerum (Cave 1985), salivary glands (Cave 1982), tongue (Cave 1977), and visceral histology (Cave & Aumonier 1963d).

It should be remembered that AJEC covered many aspects of rhinoceros anatomy and morphology, but not all. Some other anatomical parameters could therefore be found, for example, in Loose (1975), Groves (1983), Rookmaaker (1983), Prothero & Schoch (1989), Moodley & Robovský (in press), etc.

Concerning the collection specimens, we were able to revise some original taxon specifications (see Table 2), and we also noticed some imperfections in the literature. For example, the cranium of *Rhinoceros javanicus* with supernumerary incisors is correctly labeled (2133) in Cave (1985), but not in Miles & Grigson (1990); see SurgiCat (2022). The attempt to add a geographic location to osteological specimens from the Natural History Museum, London, was complicated by the absence of a list of specimens in Lydekker (1916). Although these lists were present in most groups, the reason for this omission remains unknown.

Regarding the origin of rhinoceros specimens, AJEC regularly acknowledged donors as persons or institution. The majority of anatomical specimens were associated with the Zoological Society London (ZSL) and its associated institutions such as the London Zoo and Whipsnade Zoo, as a donation of the Council of the Zoological Society. Specifically, he acknowledged E. H. Tong, Director of the Whipsnade Zoo (e.g. Cave & Aumonier 1962a, 1963c, 1964), V. J. A. Manton, Deputy Director of Whipsnade Zoological Park (Cave & Aumonier 1964a), R. N. Fiennes and Mr. Martin Sr. (Cave 1962), the Society's veterinarian officers David M. Jones and V. J. A. Manton (Cave & Aumonier 1965), the Society's pathologist Ian Keymer (e.g. Cave 1962, 1976b, 1978,1979a, b, 1981b, 1987), and Head Keeper W. G. Crompton in the case of living animals (Cave 1969).

It is worth mentioning that the ZSL has a long and impressive tradition of scientific assessment of carcasses of animals after their demises at the menagerie/zoo. It could be demonstrated, for example, by the trinity of eminent anatomists working in close collaboration with the ZSL: Richard Owen (Cave 1961, Felger & Zeiger 2010), Alfred Henry Garrod (responsible for our knowledge about anatomy of exterminated *Dicerorhinus sumatrensis lasiotis* and *Rhinoceros sondaicus inermis*; see e.g., Forbes 1881), and Reginald Innes Pocock (Gippoliti et al. 2018).

The examination of a rare *Dicerorhinus sumatrensis* was made possible by the courtesy of Magnus DEGERBØL, Copenhagen Natural History Museum, K. G. WINGSTRAND, University of Copenhagen (e.g. CAVE 1979a), and L. FORCART, Basel Natural History Museum and S. LINDT, Institute of Animal Pathology at the University of Bern (e.g. CAVE & AUMONIER 1963d, CAVE 1981a, 1987). The immature *Ceratotherium cottoni*, injured by native poachers, was shot by official order in the West Nile District of Uganda. Dr. H. E. WILLIAMS of Arua, secured and

With warmest regards AJE Cave

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Observations on the rhinoceros cardiac receptor system

A. J. E. CAVE
Zoological Society of London

(*Accepted 10 February 1981*)

To my fellow rhinocerologist - with kindest regards - AJE Cave

J. Zool., Lond. (*A*) (1985) **207,** 527–535

An unrecorded specimen of the Javan rhinoceros (*Rhinoceros sondaicus*)

A. J. E. CAVE
Zoological Society of London, Regent's Park, London NW1 4RY

(*Accepted 12 March 1985*)

With kindest regards. Probably my last rhinoceros paper. AJE Cave

J. Zool., Lond. (1987) **213,** 253–261

The pattern of aortic arch branching in the Rhinocerotidae

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(*Accepted 9 April 1987*)

Fig. 3. Three of CAVE's inscriptions on reprints provided to Kees ROOKMAAKER.

fixed specimens of the animal's skin, nuchal eminence, liver, kidney, gut wall, neck musculature and lymph nodes (e.g. Aumonier & Cave 1960). The gift of a *Diceros bicornis* foetus from Kenya was associated with the courtesy of W. R. Cook, Veterinary School of the University of Glasgow (Cave 1974a).

AJEC himself donated very valuable rhinoceros material to the collection of the Natural History Museum London (BMNH). Specifically, several skulls (BMNH 1967.8.31.1, 1967.8.31.2, 1967.8.31.3, 1967.8.31.4, 1967.8.31.5, 1967.8.31.6, 1967.8.31.7) and skull with skeleton (BMNH 75.2384) of *Ceratotherium cottoni* from the West Nile District, Uganda were donated to this institution (JR, pers. obs.). Regarding the skull with skeleton (BMNH 75.2384), AJEC was specified as the donor, and H. E. Williams was specified as the collector. Furthermore, according to the NHM (2022), AJEC donated the anatomical material of rhinoceroses accumulated by him to this institution in 1999. The publicly available list includes four items of *Rhinoceros unicornis* (R 73 – Catalogue Number ZD 1999.320, R 44b – ZD 1999.321; incl. R 21 from Table 1), 15 items of *Dicerorhinus sumatrensis* (incl. R 62 from Table 1), five items of *Diceros bicornis* (ZD 1999.358; incl. R 19, R 24, R 27 and R 68 from Table 1), and four items of *Ceratotherium* spp. (incl. R 20 and immature *C. cottoni* from Uganda collected in 1958 (58.5) from Table 1 and Table 2).

Concerning the authorship, AJEC was the sole author of the majority of his studies, and 13 papers were co-authored; namely, nine with F. J. Aumonier, two with D. B. Allbrook, one with K. G. Wingstrand, and one with Kees Rookmaaker, the second author of this contribution. Frederic John Aumonier (1911–2003) was the colleague of AJEC in the Departments of Anatomy and Physiology of the Medical College of St. Bartholomew's Hospital London and focused on the histological examinations of the viscera, lymph nodes, preputial and parathyroid glands (see, e.g., Cave & Aumonier 1963d, 1964b, 1965, 1966). David Benjamin Allbrook (1923–2016), of the Anatomy Department, Makerere Medical College, Kampala, Uganda, blocked and processed the field material of immature *Ceratotherium cottoni* secured by H. E. Williams of Arua (Aumonier & Cave 1960). Karl Georg Wingstrand (1919–1992) from the University of Copenhagen made possible the examination of the female of *Dicerorhinus sumatrensis* held in the Copenhagen Zoo (Cave 1979a), and Leendert Cornelis (Kees) Rookmaaker (b. 1953) is an expert focused on historical, bibliographical and taxonomic assessments of rhinoceroses (e.g. Ganslosser 1997) and Chief Editor of the Rhino Resource Center since 2004.

Finally, we would like to specify two lessons from the legacy of AJEC. First, all anatomical, morphological, and genetic studies should specify sampled individuals with respect to geographic origin, in as much detail as possible in the case of wild specimens, and some unmistakable reference number (e.g., a collection ID of the specimen and/or an international studbook number for a captive specimen). Second, some taxa remain unexamined with respect to their anatomy and detailed morphology. Collection samples of extinct or nearly extinct extant rhinoceros taxa (*Rhinoceros sondaicus annamiticus*, *R. s. inermis*, *Dicerorhinus sumatrensis harrissoni*, *D. s. lasiotis*, *Diceros bicornis chobiensis*, *D. b. brucii*, *D. b. longipes*, and *Ceratotherium cottoni*) are of enormous scientific value, and some future catalogues and investigations of such material are highly desirable – as in the case of *Ceratotherium cottoni* – for example, the osteological atlas compiled by Colyn (1980), *D. b. bicornis* – Rookmaaker & Groves (1978), or *R. s. inermis* – Rookmaaker (1997). Future preservation of material and anatomical/morphological documentation of the two last known females of *Ceratotherium cottoni*, the last remnants of *Dicerorhinus sumatrensis harrissoni*, and localized wild specimens of *Diceros bicornis* (i.e., *D. b. chobiensis*, *D. b. minor*, *D. b. occidentalis*, *D. b. michaeli*, *D. b. ladoensis* – see Groves

& Grubb 2011, and *D. b. rowumae* – see Moodley & Robovský, in press) is one way responsibly to deepen our current knowledge of anatomical and other morphological parameters of extant rhinoceroses.

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This paper is dedicated to Hynek Burda, the excellent zoologist, morphologist, and a highly regarded colleague, who also shares our delight in the rhinos.

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