The skull of *Stephanorhinus hemitoechus* (Mammalia, Rhinocerotidae) from the Middle Pleistocene of Campagna Romana (Rome, central Italy): biochronological and paleobiogeographic implications

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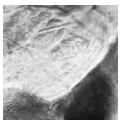

A fragmentary rhinoceros skull from the "Campagna Romana" was analysed. The results of morphometrical and morphological analysis identify the skull as *Stephanorhinus hemitoechus*. The petrography and geochemistry of the volcanoclastic sediments containing the rhinoceros skull indicate that its geographic provenance is the northern area of Rome (between the Tiber River and the southern area of the Sabatini Volcanic District). The textural and geochemical features of white pumice indicate that the volcanoclastic sediments were deposited at *ca* 500 ka during the MIS13. A revision of the earliest records of *S. hemitoechus* in Europe reveals that the skull from Campagna Romana is the earliest record of the species. The time and spatial collocation of this occurrence postdate the diffusion of *S. hemitoechus* in the Mediterranean Basin, most likely due to the favourable climate. Successively, the species becomes common in the rest of western and northern Europe and reached its maximal geographic extension during MIS5. • Key words: *Stephanorhinus hemitoechus*, paleobiogeography, biochronology, Middle Pleistocene, Campagna Romana, Sabatini Volcanic District.

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The area surrounding the city of Rome (Central Italy) is the result of complex geological processes, which were particularly intense during the Quaternary. For this reason, the stratigraphic successions of the so-called "Campagna Romana" have been well known since the beginning of the 20th century for the peculiarity of their volcanic rocks and the richness of fossil mammal assemblages. Due to the intense urbanisation of Rome between the end of the 19th century and the beginning of the 20th century, a large number of vertebrate fossil remains were collected from the Campagna Romana (among others Meli 1896a, b; Ponzi 1867, 1878; Portis 1893). The fossil remains were mainly referred to the Middle Pleistocene and were found in alluvial deposits of the Tiber River and its tributaries (Di Stefano *et al*. 1998, Petronio *et al.* 2011). These deposits are frequently constituted by volcanoclastic materials and are interlayered by volcanic deposits of the Sabatini or Colli Albani Volcanic Districts (Caloi *et al.* 1998). The chronological successions of these volcanic districts have been reconstructed by petrographic, geochemical and radiometric data. Thus, in central Italy, the Pleistocene volcanic deposits are a useful tool to establish a regional chronostratigraphic framework within which deposits with mammal remains can be placed. Indeed, the volcanic deposits mark the chronological limits of several faunal assemblages, such as Fontana Ranuccio (Middle Pleistocene, Anagni Basin) and Cerveteri (Middle Pleistocene, Rome; Biddittu *et al.* 1984, Capasso Barbato *et al.* 1983, Mancini *et al.* 2006).

At the beginning of the 20th century, a rhinoceros skull was recovered in an undefined location in Campagna Romana. This skull, which is preserved in the Museum of Paleontology at the Sapienza University of Rome (MPUR), was filled and covered with volcanoclastic material, which was partially enclosed in the bone cavities. The aim of the present paper is to define the stratigraphic origin and chronological position of the above-mentioned skull.

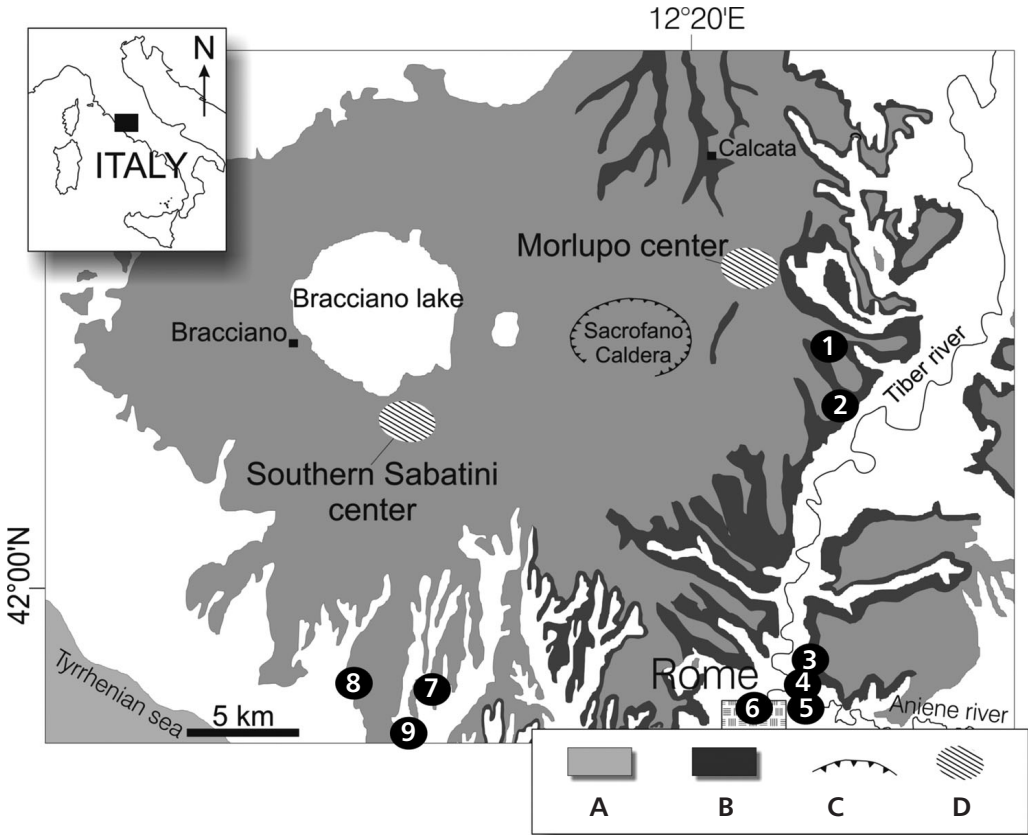

Figure 1. Sketch map of the Quaternary Sabatini Volcanic District (SVD), Roman Province, and localization of some large-mammal fossil sites. Legend: A – SVD volcanism; B – outcrop area of the oldest (?547 ± 5 ka) eruption products; C – caldera rim; D – inferred source areas during the Morlupo (*ca* 800–500 ka) and Southern Sabatini (*ca* 500–400 ka) activity periods. The volcano-tectonic depression hosting Bracciano Lake and the Sacrofano Caldera are also shown. 1 – Riano; 2 – Capena; 3 – Cava Redicicoli; 4 – Prati Fiscali, Monte Sacro; 5 – Sedia del Diavolo, Saccopastore, Casal dei Pazzi; 6 – Cava Nera Molinario, Tor di Quinto, Ponte Molle (= Ponte Milvio); 7 – La Polledrara; 8 – Torre in Pietra; 9 – Collina Barbattini, Castel di Guido.

Finally, a palaeontological analysis of the skull identifies it as a late Middle-Late Pleistocene European species. The records of the species during the Middle Pleistocene are revisited in light of the chronological interval related to the analysis of the volcanic material.

Abbreviations. – Marine Isotopic Stage – MIS; Sabatini Volcanic District – SVD.

Institutional abbreviations. – MPUR – Museum of Paleontology, Sapienza University of Rome, Italy; MCAUR – Museum of Comparative Anatomy, Sapienza University of Rome, Italy; MPP – Museum of Paleontology, University of Parma, Parma; MPAVC – Paleontological and Archaeological Museum "Virginio Caccia", San Colombano al Lambro, Milan; IGF – Natural History Museum of Florence, Geological and Paleontological Section, Florence; BNHM – British National History Museum, London; IQW – Institute für Quartärpaläontologie, Weimar; SMNK – Staatliches Museum für Naturkunde, Karlsruhe; SMNS – Staatliches Museum für Naturkunde, Stuttgart; MNHM – Museum NaturHistorisches, Mainz.

Geological setting and selecting vertebrate-bearing sites of Campagna Romana

The so-called "Campagna Romana" is a relatively large, flat zone around Rome (central Italy) crossed by the Tiber River and bounded at the southwest by the Tyrrhenian Sea, at the east by the Pre-Apennine, at the north by the Sabatini Volcanic District (SVD) and at south-southeast by the Colli Albani Volcanic District (Di Stefano *et al.* 1998; Petronio & Sardella 1999; Petronio *et al.* 2011; Sottili *et al.* 2010, 2011, and references therein). The rocks outcropping in the Campagna Romana are represented by Plio-Pleistocene sedimentary sequences partly covered by the volcanic products of the above-mentioned volcanic districts. In particular, the sedimentary rocks located in the right bank of the Tiber are covered or interfingered with the middle-distal pyroclastic products of the Sabatini Volcanic District. It is noteworthy that the majority of fossil vertebrates have been sampled in this part of the "Campagna Romana". The rocks of the Sabatini Volcanic District extend over an area of ~1800 km^2 (Fig. 1) and are derived from

Table 1. SVD volcanic products used for comparison with the pumice in the skull MPUR/1522.

Eruptive Unit	Label	Composition	Age
First Ash-fall Deposits	FAD	Phonolite Low SiO_2	582 ± 1 ka
Lower Tufo Giallo della Via Tiberina	LTGVT	Phonolite Low SiO_2	561 ± 1 ka
Upper Tufo Giallo della Via Tiberina	UTGVT	Phonolite Low SiO_2	548 ± 3 ka
Grotta Rossa Pyroclastic Sequence	GRPS	Phonolite Low SiO_2	514 ± 5 ka
Fall A	Fall A	Phonolite High SiO_2	<514 ka >485 ka
Fall B	Fall B	Trachyte	485 ka
Tufo Rossoa Scorie Nere Sabatino	TRSNS fall	Phonolite High SiO_2	450 ka
Tufo Rossoa Scorie Nere Sabatino	TRSNS flow	Trachyte	
Fall E	Fall E	Trachyte	420 ka
Tufo Giallo di Sacrofano	TGS	Phonolite Low SiO_2	285 ± 1 ka
Tufo di Bracciano	TBR	Trachyte	190 ka
Tufo di Baccano	TBA	Phonolite Low SiO_2	85 ka

a wide spectrum of ultrapotassic magma compositions (*e.g.*, Masotta *et al.* 2010, Sottili *et al.* 2011). The available volcanologic and geochronologic data (*e.g.*, Sottili *et al.* 2010) show that the SVD volcanism included a variety of eruption types during three main periods of activity: 1) the oldest period (*ca* 0.800–0.510 Ma) took place from the Morlupo source area, located in the eastern SVD sector, and emplaced voluminous pyroclastic successions (including the major Tufo Giallo della Via Tiberina pyroclastic succession; Table 1); 2) the intermediate period emplaced several Plinian fall deposits and the main Tufo Rosso a Scorie Nere from the southern Sabatini source area (*ca* 0.510–0.420 Ma) as well as the Tufo di Bracciano (*ca* 0.310 Ma) and the Tufo Giallo di Sacrofano (0.285 ± 0.01 Ma) caldera-forming eruptions from the present day Lake Bracciano depression and the Sacrofano Caldera; 3) the most recent period of activity (at least until *ca* 90 ka) was sourced around the Bracciano and Sacrofano calderas in the central-northern SVD area and was characterised by dominant hydromagmatic and subordinate strombolian/effusive activities from either scattered or clustered monogenetic centres. The SVD volcanic succession results correlate with the unconformity-bounded-stratigraphic units recently defined for the sedimentary terrains of coastal-marine to continental environments (*i.e.*, Sottili *et al.* 2010). Consequently, the volcanoclastic sediments occurring in the right bank of the Tiber River are well constrained by the stratigraphic and geochronological data of the SVD deposits.

Table 2. Selecting specimens of rhinoceros skulls considered in the morphological analysis.

Species	**Location**	**Label**
S. hemitoechus	MPAVC	sn
S. hemitoechus	IGF	1105
S. hemitoechus	IGF	1109
S. hemitoechus	IGF	10792
S. hemitoechus	MPUR	V2832
S. hemitoechus	BNHM	45 205
S. hemitoechus	SMNS	16295-1929
S. hundsheimensis	MPP	sn
S. hundsheimensis	IQW	1965-2 513 (Suss. 9 615)
S. hundsheimensis	IGF	1931V
S. hundsheimensis	MPUR	1956 sn
S. hundsheimensis	MNHM	PW 1945-172
S. hundsheimensis	MNHM	PW 1977-13
S. hundsheimensis	MNHM	PW 1963-156
S. hundsheimensis	MNHM	PW 1956-62
S. hundsheimensis	MNHM	PW 1958-764
'*D.*' *kirchbergensis*	SMNK	PAL 4254
'*D.*' *kirchbergensis*	SMNS	6516.4.2.66.4
'*D.*' *kirchbergensis*	SMNS	6616.2.11.89.13
'*D.*' *kirchbergensis*	SMNS	6616.17.10.83.8
'*D.*' *kirchbergensis*	SMNS	6617.2.12.67.3 PW
'*D.*' *kirchbergensis*	MNHN	1949-238

The Campagna Romana is rich in fossil mammal assemblages corresponding to the late Early Pleistocene and Middle Pleistocene.

The earliest assemblages have been recovered in the sites of Capena, Cava Redicicoli and in the "*Helicella* clays" of Ponte Galeria (= *sensu* Conato *et al.* 1980 and Petronio & Sardella 1999; Fig. 1). They are represented by *Bison degiulii* and *Axis eurygonos* (Capena), by *Bison schoetensacki*, *Mammuthus meridionalis*, *Equus altidens*, *Stephanorhinus hundsheimensis* and other taxa (Cava Redicicoli) and by *Prolagurus pannonicus* and *Predicrostonyx* sp. ("*Helicella* clays" of Ponte Galeria; Kotsakis *et al.* 1992, Capasso Barbato *et al.* 1998, Di Stefano *et al.* 1998, Petronio & Sardella 1999, Milli *et al.* 2004, Petronio *et al.* 2011).

A faunal assemblage chronological referable to a time span between 0.800 and 0.700 Ma is reported in the "beach and shoreface gravels and sands" of Ponte Galeria (= *sensu* Conato *et al.* 1980 and Petronio & Sardella 1999). It represents the "classic fauna" of Ponte Galeria and among the other taxa, "*Hemibos*" *galerianus*, *Crocuta crocuta*, *Praemegaceros verticornis*, and *Mammuthus trogontherii* are recorded (Petronio & Sardella 1999, Petronio *et al.* 2011).

More recent faunal assemblages, referable to a time span between 0.650 and 0.500 Ma, are represented by several taxa, including *Macaca sylvanus*, *Lynx pardina spelaea*, *Meles meles*, *Equus altidens*, *Equus süssenbornensis*, *Sus scrofa priscus, Hippopotamus antiquus*, *Axis eurygonos*, *Cervus elaphus acoronatus* and *Bison schoetensacki* (Petronio & Sardella 2001, Mancini *et al.* 2008). They are reported in several localities of the Campagna Romana as GRA Km 2 and Ponte Molle (= Ponte Milvio) (Di Stefano *et al.* 1998, Capasso Barbato *et al.* 1998; Fig. 1).

From pyroclastic deposits outcropping at Fontignano and Cava Nera Molinario (dated to approximately 0.450 Ma), fossils referable to *Bos primigenius* and *Cervus elaphus eostephanoceros* are reported (Di Stefano *et al.* 1998).

Furthermore, the northern and eastern areas of Campagna Romana provide different faunal assemblages ascribed to late Middle Pleistocene, which have been reported in the following selected localities: Castel di Guido, Riano, Malagrotta, Torre in Pietra, Cava Rinaldi (upper levels) and Collina Barbattini, Monte Sacro, Sedia del Diavolo (Capasso Barbato & Minieri 1987, Caloi *et al.* 1998, Di Stefano *et al.* 1998, Petronio *et al.* 2011; Fig. 1). On the whole, these sites can be referred to a time span between MIS10 and MIS6 and the occurrences of *Canis lupus*, *Megaloceros giganteus* and *Ursus spelaeus* were reported (Gliozzi *et al.* 1997).

Materials and methods

In the past centuries, all remains of European Pleistocene rhinoceroses not ascribed to the genus *Coelodonta* were referred to the genus *Rhinoceros* and later to the genus *Dicerorhinus*. Guérin (1980) ascribed them to the genus *Dicerorhinus* and the species *jeanvireti*, *etruscus*, *hemitoechus* and *kirchbergensis* (= *mercki*) to the new subgenus *Brandtorhinus*; later, this last was elevated to the genus rank (Guérin 1989). Fortelius *et al.* (1993) referred the European Pleistocene rhinoceros species *jeanvireti*, *etruscus*, *hundsheimensis*, *hemitoechus* and *kirchbergensis* to the genus *Stephanorhinus* Kretzoi, 1942. This viewpoint was followed by several authors (Cerdeño 1993, 1995a, b, 1998; Lacombat 2005). However, Deng *et al.* (2011) recently referred the species *kirchbergensis* to '*Dihoplus*', together with the Miocene species *ringstroemi* and *pikermiensis* and the Pliocene *megarhinus*. According to these results, morphologic characteristics distinctive of the genus *Stephanorhinus*, such as a partially ossified nasal septum and loss of functional incisors, evolved twice in the Pleistocene. Moreover, an early acquisition of the nasal septum and loss of incisors occurred even in the Miocene elasmothere *Ninxiatherium* (Chen 1977, Cerdeño 1995a, Deng 2008), which implies that these characteristics are independent acquisitions within different evolutionary lineages.

The morphological characteristics considered in the present paper are those listed by several authors, including Loose (1975), Guérin (1980) and Lacombat (2005). For the morphological comparison of the skull, different specimens from Middle and Late Pleistocene European sites are taken into account (Table 2). Other considered skulls are those reported by Falconer (1868), Azzaroli (1962), Borsuk-Bialynicka & Jakubowski (1972), Loose (1975), Guérin (1980), Lacombat (2005), Van der Made (2010), Pandolfi (2011), and references therein. The morphometric methodology is based on the works of Guérin (1980) and Lacombat (2005), and the results are compared with those reported by Guérin (1980) for *S. hemitoechus*, by Lacombat (2005) for *S. hundsheimensis* and by Loose (1975) and Van der Made (2010) for '*D.*' *kirchbergensis*. Simpson ratio diagrams were made using data on extant *Diceros bicornis* (skull 111/360 preserved in the MCAUR) as a reference.

The volcanoclastic matrix occurring in the internal and external parts of the skull was gently removed from the bone using a thin blade. The sediment was split at the binocular, and different components (*e.g.*, minerals, rock fragments) were mounted on the stabs. Morphoscopic structures were observed at the Dipartimento di Scienze della Terra, Sapienza-Università di Roma, using a FEI Quanta 400 SEM. The composition of phases occurring in the selected pumice clast were determined at CNR-IGAG (Roma, Italy) using a CAMECA SX50 electron microprobe equipped with five wavelength-dispersive spectrometers (WDS) employing a 15 kV accelerating voltage, a 5 nA beam current, and a 0–10 μm beam diameter. Natural and synthetic standards as well as the ZAF correction scheme were used.

The skull from Campagna Romana (MPUR/1522)

Paleontological description and comparisons

Only the neurocranial portion (with occipital, parietal, temporal and part of the zygomatic bones) of the considered skull (MPUR/1522) is preserved (Fig. 2).

In the dorsal view, the parietal crests are well evident, despite the presence of volcanic sediment. The posterior edge of the occiput is linear (with a central depression due to damage). In the lateral view, the occipital crest overhangs the occipital condyles; the occipital face has a linear edge, and in the otic region, the postglenoid process is well developed with a concave anterior edge. In the occipital view, the occipital face has a trapezoidal shape and is relatively high; the maximal width in this view is at the level of mastoid processes; and the dorsal profile of the occipital crest is relatively linear.

On the whole, the morphological characteristics of the considered skull can be recognised in *S. hemitoechus* (Fig. 3). In particular, the occipital crest overhangs the occipital condyles in all the considered specimens and in the types of the species from Minchin Hole and Northampton (described by Falconer 1868). Moreover, a liner profiles of the occipital crest (in dorsal view) and of the occipital face (in lateral view) can be recognized in the Falconer's specimens and in the considered skulls (see also Azzaroli 1962 and Guérin 1980).

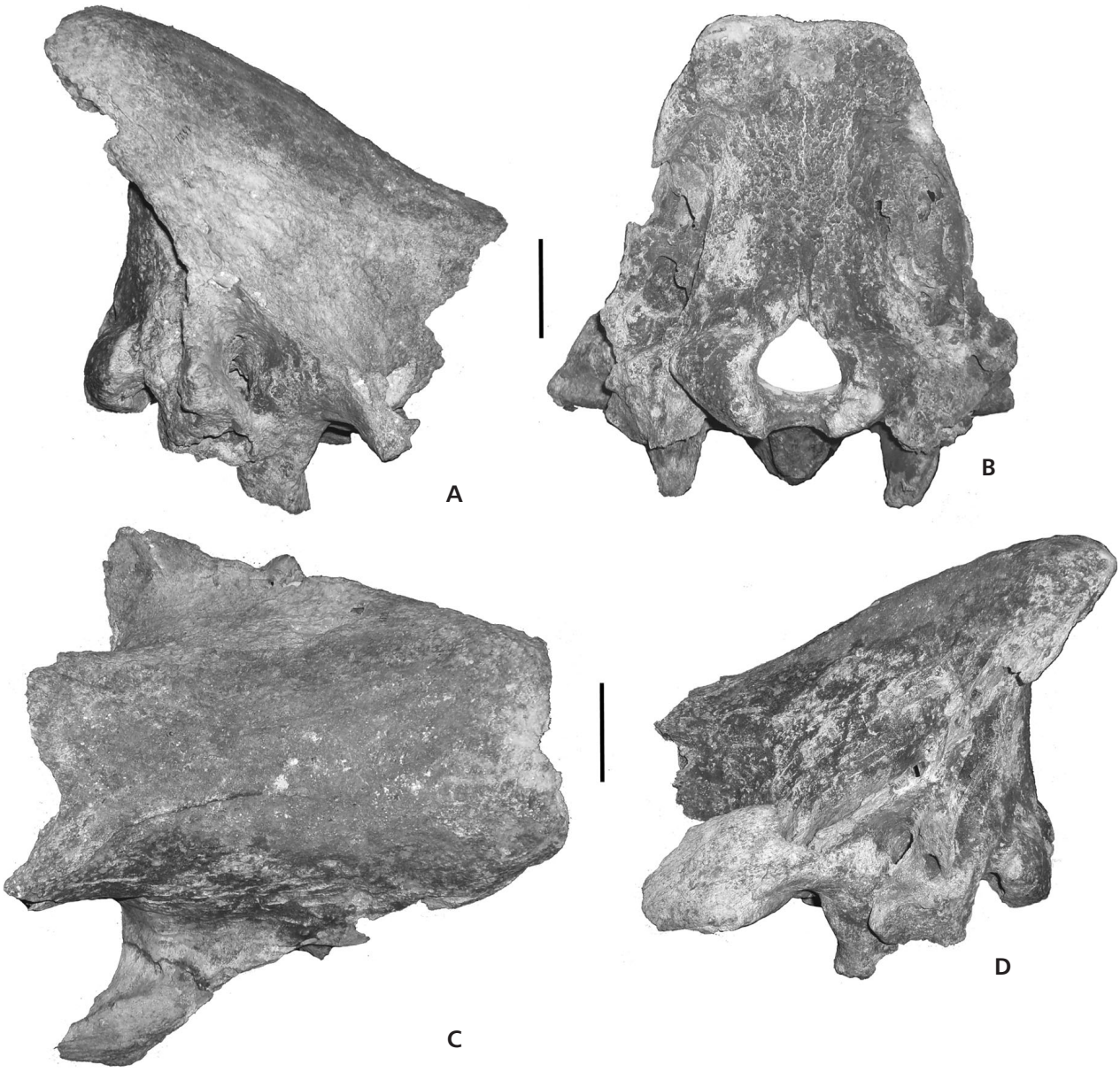

Figure 2. Skull MPUR/1522 from Campagna Romana. • A – right side view; B – view of the occipital face; C – dorsal view; D – left side view. Scale bar = 5 cm.

Indeed, in '*D.*' *kirchbergensis* the occiput is narrow, with a broad V-shaped or concave posterior edge. Furthermore, in all the specimens the occipital crest is less developed posteriorly than the occipital condyles. Finally, in *S. hundsheimensis*, the occipital crest is slightly prominent posteriorly (but it does not overhangs the occipital condyles) and, in dorsal view, has a slight concave or concave posterior edge. Furthermore, a convex upper profile of the occipital crest can be observed in the occipital view.

The dimensional characteristics of the considered skull are close to the mean values reported by Guérin (1980) for *S. hemitoechus* (Table 3). '*D.*' *kirchbergensis* has greater values of DTO, DTAM, DTCPmin and DTOC than those of the skull from Campagna Romana (Table 3). Furthermore, the values of the diameters of the occipital region are lower than those reported for *S. hundsheimensis* from Isernia La Pineta (Table 3) (Lacombat 2005). The ratio between the transverse diameter of the occipital crest and the mastoid processes is close to that reported for *S. hemitoechus* but is quite different for those of the other Middle Pleistocene species. For '*D.*' *kirchbergensis* and *S. hundsheimensis*, the values of DTO/DTam are above 0.59. Finally, the Simpson diagram shows that, proportionally, the skull MPUR/1522 is closer to *S. hemitoechus* than to the other species (Fig. 4).

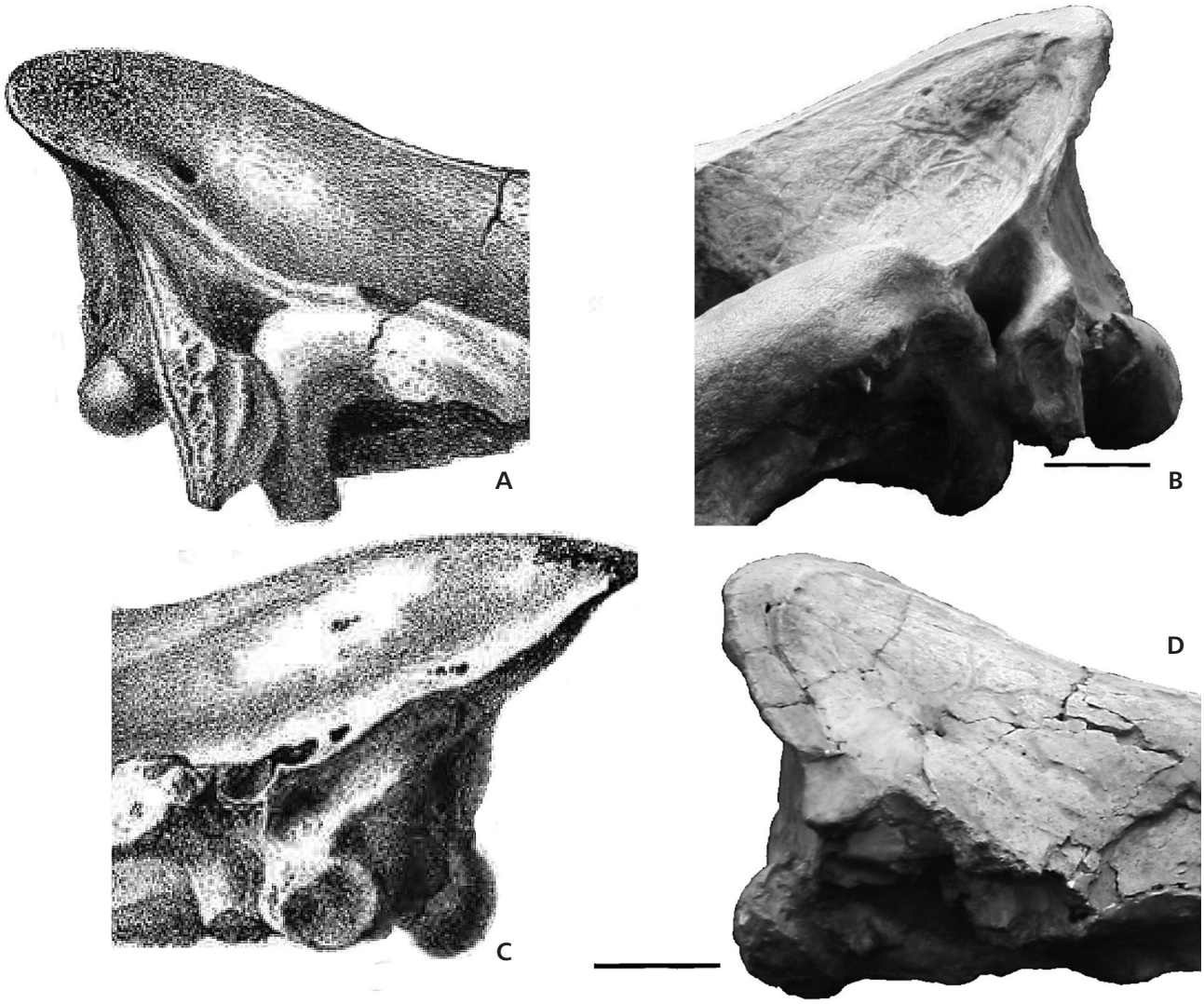

Figure 3. Skulls of *S. hemitoechus* from Northampton (A) and Minchin Hole (B) (from Falconer 1868; not in scale) and of '*D.*' *kirchbergensis* (SMNK PAL 4254) and *S. hundsheimensis* (IQW 1965–2513, Suss. 9615). Lateral view of the occipital region. Scale bar = 5 cm.

Table 3. Comparative dimensions of the skull MPUR/1522 and the Middle Pleistocene species *S. hundsheimensis*, '*D.*' *kirchbergensis* and *S. hemitoechus*. DTO = transverse diameter of the occipital crest; DTAM = transverse diameter of the mastoid apophysis; DTCPmin = minimum values of the transverse diameter of the parietal crests; DTZAmax = maximum values of the transverse diameter of the zygomatic arches; HOF = height of the occipital face; DTFM = transverse diameter of the foramen magnum; DTOC = transverse diameter of the occipital condyles; HFM = height of the foramen magnum.

Skull		DTO	DTAM	DTCPmin	DTZAmax	HOF	DTFM	DTOC	HFM
Campagna Romana	1522	139	247	40	ca 316	165	46	135	42.3
	min	101	220	18	295	141	37	111.5	
S. hemitoechus	med	130.97	247.53	46.25	328.25	158.56	52.9	138.71	
	max	160	288	70	380	186	61.5	155	
	min	156	264	52	364		46	140.5	30.5
'*D.*' *kirchbergensis*	med	167.51	276.2	68.48	381.7	143.1	50.92	148.5	38.16
	max	204	292.8	118.5	391		58	154	45
	min	152.3	252.9			122.7	39.8	124.6	29.4
S. hundsheimensis	med	172.93	258	60.3	313.7	126.43	45.18	132.62	38.18
	max	187.2	275			130	48.9	142	57.1

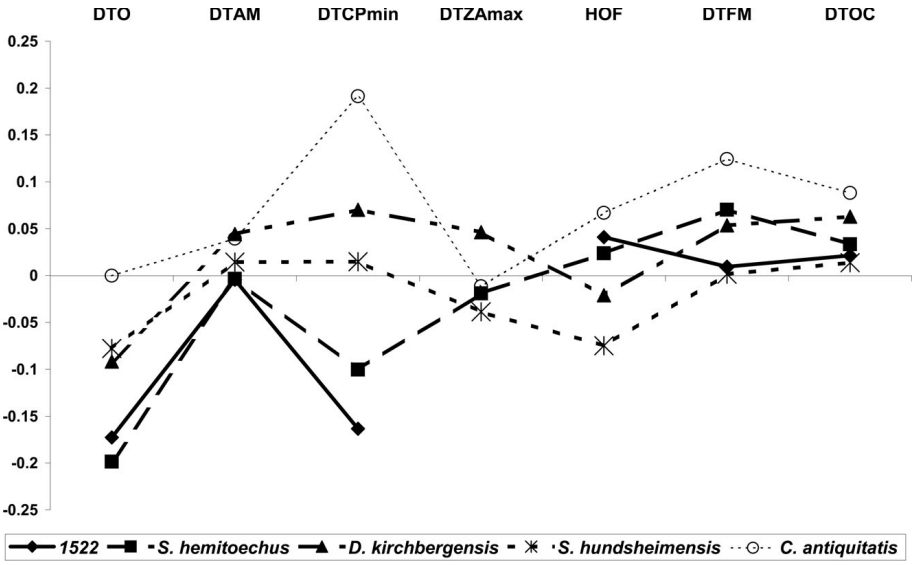

Figure 4. Ratio diagram of the skull MPUR/1522 and the Middle Pleistocene species *S. hundsheimensis*, '*D.*' *kirchbergensis*, *S. hemitoechus* and *Coelodonta antiquitatis*. For abbreviations see Table 3.

Origin of volcanoclastic matrix

The XRD data and SEM observations indicate that the sediment attached to the rhinoceros skull is almost entirely composed of pyroclastic components (*i.e.*, lithic clasts, juvenile lapilli, ash particles and minerals). In particular, white pumice lapilli, characterised by a fresh appearance (*i.e.*, without macroscopic evidence of weathering) was found in the sediment occurring in the internal part of the rhinoceros skull. This pumice lapilli was specifically analysed with the aim to compare its textural and geochemical features with those of primary volcanic components occurring in the well-constrained pyroclastic deposits of Sabatini Volcanic District.

The white pumice has an aphyric texture (degree of porphyricity <1 vol.%), a vitrophyric groundmass (glass ≥50 vol.%) and moderate vesicularity (up to 50 vol.% in thin section), and it contains rare sanidine, clinopyroxene, plagioclase and oxide phenocrysts (∅ > 50 μm). The sanidine is submillimetre sized and round shaped, while the clinopyroxene is submillimetre sized, euhedral to subhedral and occurs as glomerocrysts associated with plagioclase and oxides. The glass occurring in the groundmass shows a phonolitic composition in the TAS diagram (Fig. 5) and is characterised by low CaO, MgO and Al_2O_3 (Fig. 5). The clinopyroxene shows a Si-poor and Ti- and Fe-rich composition, while the plagioclase presents a Na-poor bytownite composition. The petrography and geochemistry of the white pumice recovered in the interior part of the rhinoceros skull is typical of juveniles found in the large explosive eruptions of the SVD. The most important SVD activity period in terms of large explosive eruptions took place at *ca* 0.800–0.400 Ma in the Morlupo and southern Sabatini sectors, which are part of the Campagna Romana zone (Sottili *et al.* 2010, 2011; Masotta *et al.* 2010). In particular, the white pumice shows textural and chemical features similar to those of Fall A, which is positioned between the Grottarossa Pyroclastic Sequence (GPPS) and the Fall B eruptive units, which are dated to 0.514 ± 0.05 Ma and 0.488 ± 0.02 Ma, respectively (Fig. 5). This eruptive unit is part of the Biedano Synthem belonging to the Aureliano-Pontino Supersynthem, and its stratigraphic position matches stage 13 of the $\delta^{18}O$ curve and sea level fluctuations (Sottili *et al.* 2010). Therefore, the textural and geochemical features of the white pumice indicate that the volcanoclastic sediments containing the rhinoceros skull were deposited at *ca* 0.500 Ma during a high stand of the sea level.

Discussion

The morphological and morphometric results allow skull MPUR/1522 from Campagna Romana to be ascribed to *S. hemitoechus* whose origin remains unclear. Cerdeño (1993) and Kahlke & Kaiser (in press) suppose an Asian origin, while Guérin (1980) proposed a direct European lineage of *S. etruscus-S. hemitoechus*.

The earliest occurrence of *S. hemitoechus* in Europe is relatively controversial. Fortelius *et al.* (1993) reported the occurrence of the species at Mosbach 2 in association with *S. hundsheimensis* and at Petralona, Visogliano and Caune de L'Arago. Moreover, Gliozzi *et al.* (1997) cited the appearance of the species in the Early-Middle Pleistocene transition.

However, the presence of remains attributable to *S. hemitoechus* in the levels of Mosbach 2 is highly doubtful. Concerning this point, Guérin (1980) wrote, "…qui ont cru le reconnaître à Mosbach mais se sont à mon avis trompé sur ce point". Recently, only the presence of *S. hundsheimensis* and '*D.*' *kirchbergensis* was reported at Mosbach 2 (von Koenigswald *et al.* 2007).

The occurrence of *S. hemitoechus* at Visogliano, referable to MIS12, is unfounded. The maxilla with molars

reported by Bartolomei *et al.* (1977) and ascribed to *Rhinoceros mercki*, show morphological and morphometrical characteristics closer to '*D.*' *kirchbergensis*. Indeed, the molars have waved vestibular profiles with non-marked folds, and the morphometric values are greater than those of the molars of *S. hemitoechus*.

The fossil remains from Petralona are of uncertain temporal attribution. Three different mammal assemblages are recognised in the mentioned site, and the rhinoceros remains come from the upper levels, being chronologically younger than or close to 0.400 Ma (Fortelius & Poulianos 1978, Crégut-Bonnoure & Tsoukala 2005, Koufos & Tsoukala 2007, Baryshnikov & Tsoukala 2010, Kahlke *et al.* 2010).

Finally, the occurrence of *S. hemitoechus* at the site of Caune de L'Arago, confirmed by Guérin (1980) and Lacombat (2005), is referable to approximately 0.450 Ma, MIS12 (Moigne *et al.* 2006). In agreement with Fortelius *et al.* (1993), the latter seems to be, at present, the most ancient record of the species in Europe.

However, Gliozzi *et al.* (1997) reported the occurrence of *S. hemitoechus* in the Italian peninsula during the Slivia Faunal Unit (approximately 0.900–0.800 Ma) basing on the remains recovered in the Slivia local fauna. These remains were referred by Ambrosetti *et al.* (1979) to intermediate forms between *S. etruscus* and *S. hemitoechus*, very close to the specimens of Voigstedt and Süssenborn, actually ascribed to *S. hundsheimensis* (Lacombat 2005). Indeed, the morphological traits of the teeth discovered at Slivia (strong lingual and mesial cingula on the upper premolar, profile of the vestibular wall slight wavy with thin and lightly prominent paracone fold, broad V-shaped posterior valley in the lower molar) are closer to *S. hundsheimensis* than *S. hemitoechus*.

Furthermore, even the remains reported by Cigala Fulgosi (1976) from the alluvial deposits of Torrente Stirone (Parma; 0.800–0.700 Ma) and by Petronio (1988) from the gravel and sand layer of Cava di Breccia di Ponte Galeria (Rome; approximately 0.800–0.700 Ma), ascribed to *Dicerorhinus hemitoechus*, can be referred to *S. hundsheimensis*.

The skull from Torrente Stirone shows many features close to *S. hundsheimensis*; in lateral view, the posterior border of the nasal notch is situated above the P4/, the anterior border of the orbital cavity is situated above the M2/, the base of the nasal horn is well developed, the occipital condiles are located more posteriorly than the occipital crest and the inferior border of occipital face is very oblique. In dorsal view, the occipital crest has a central concavity and the parietal crests are not marked.

In the Cava di Breccia di Ponte Galeria mandible (recovered in the gravel and sand layer), the posterior margin of the mandibular symphysis is located at the level of P/2–P/3 boundary, the horizontal ramus is relatively low and its lower border is slightly convex; furthermore, the angle between the horizontal and vertical ramus is of about 130°, the lower P2 has only the posterior lingual valley and is relatively large and the lower molars have a U-shaped lingual valleys. All these characteristics can be recognized in *S. hundsheimensis* (see Lacombat 2005).

Remains attributable to *S. hemitoechus* have mainly been reported in Italy at several sites (*e.g.*, Malagrotta and Torre in Pietra) and are chronologically related to MIS10–8 (Capasso Barbato & Petronio 1981; Caloi & Palombo 1978, 1979; Di Stefano *et al.* 1998; Di Canzio *et al.* 2003; Pandolfi & Petronio 2011; Pandolfi 2011).

In agreement with the results of the present paper, the earliest occurrence of *S. hemitoechus* in Italy and Europe can be referred to approximately 0.500 Ma. According to recent data about the Italian and European faunal assemblages, *S. hemitoechus* seems to replace *S. hundsheimensis* during the Middle Pleistocene. Nevertheless, *S. hundsheimensis* disappears from the Peninsula before MIS13. The last occurrences of *S. hundsheimensis* in Italy are recorded in the faunal assemblages chronologically related to MIS16–15 (Sala & Fortelius 1993, Coltorti *et al.* 2005, Petronio *et al.* 2011). In central and northern Europe, the last records of *S. hundsheimensis* are reported in sites earliest or close to MIS13 as Hundsheim (MIS15 or 13), Mauer (lower sands, MIS15) and Boxgrove (MIS13) (Toula 1902; Schreiber 2005, Breda *et al*. 2010, Kahlke *et al*. 2010, Wagner *et al*. 2010).

Remains of *S. hemitoechus* have been reported at several sites in western Europe (see Guérin 1980, Fortelius *et al.* 1993, Lacombat 2005). In Spain and Portugal, the species is the only one of the genus present during the Middle and Late Pleistocene (Cerdeño 1990, Cardoso 1993, Marks *et al.* 2002, Lacombat 2005, Van der Made 2010). The appearance of the species in the Iberian Peninsula is referable to approximately 0.400 Ma at Ambrona (Cerdeño 1990, Sesé & Toto 2005), while the occurrence of the species at Cullar de Baza-1 (early Middle Pleistocene; Kahlke *et al.* 2010) seems to be highly doubtful, and rhinoceros remains from the above-mentioned site are ascribed to other species by other authors (see Cerdeño 1989, 1993; Agustí *et al.* 2000). In central and northern Europe, *S. hemitoechus* is sometimes reported in association with '*D.*' *kirchbergensis* and/or *C. antiquitatis* (sites of La Fage and Neumack-Nord; Guérin 1973, 1980; Schreve 1996; Van der Made 2010). *S. hemitoechus* was first recorded in Great Britain during MIS11 together with '*D.*' *kirchbergensis* (Boyn Hill and Orsett Heath sites; Schreve 1996, Bridgland *et al.* 2004). Furthermore, the two species are coeval at the site of Bilzingsleben (Germany) and are chronologically related to MIS11 (Van der Made 2000, Bridgland *et al.* 2004), most likely representing the first occurrence of *S. hemitoechus* in Germany. The deposits of Račiněves (Czech Republic), in which *S. hemitoechus* and '*D.*' *kirchbergensis* are recorded (Tyráček *et al.* 2001, 2004), correspond to the same chronological time span.

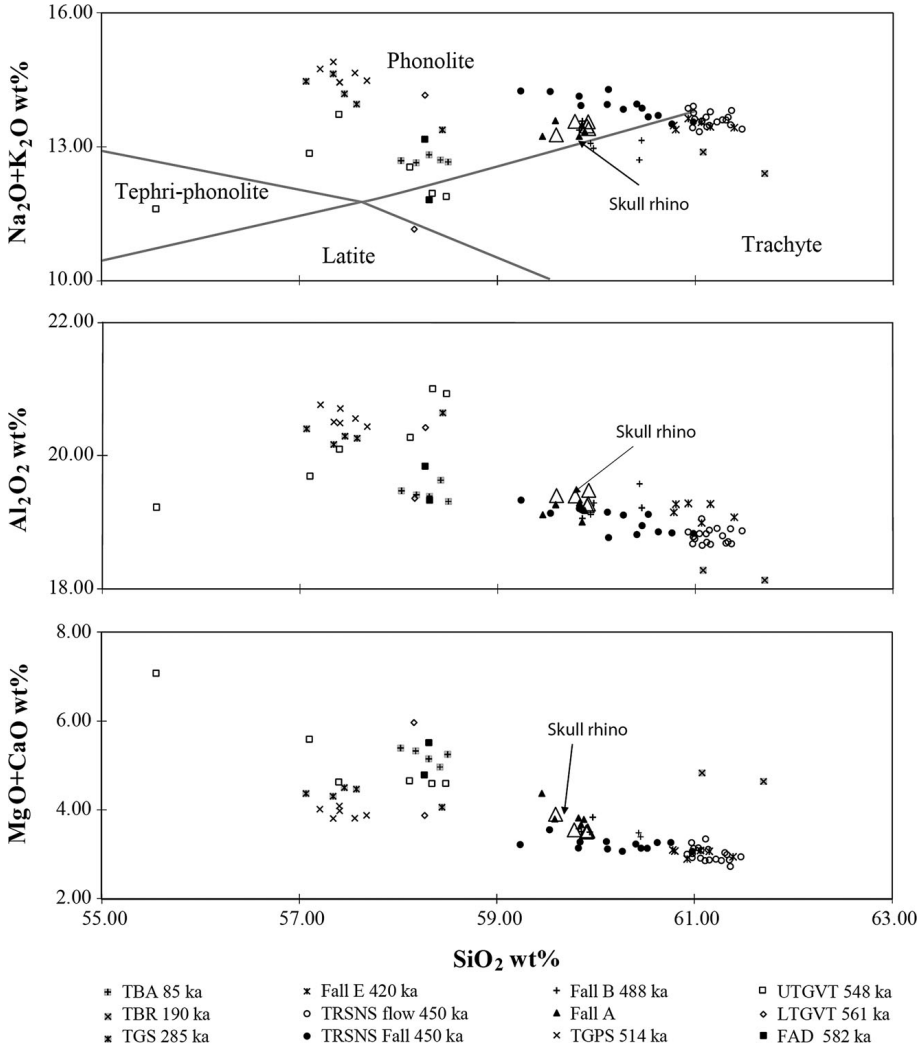

Figure 5. Chemical composition of SVD glasses reported in the TAS, Al_2O_3 *vs* SiO_2 and CaO+MgO *vs* SiO_2 diagrams; noteworthy, the glasses occurring in the skull MPUR/1522 show the chemical composition similar those of Fall A glasses (0.514 > Ma > 0.488).

The presence of the species in Asia seems to be highly doubtful. According to Guérin (1980), rhinoceros remains from Binagady (Late Pleistocene, Azerbaidjan) seem to be very close to *Dicerorhinus hemitoechus* (= *Stephanorhinus hemitoechus*) (Baryshnikov 2002).

Other remains reported in European Russia by Pavlova (1925) and later by Gromova (1935) as *Rhinoceros* aff. *hemitoechus* appear very doubtful. In any case, this remain appears unavailable at present (Billia pers. com.) and any sure systematic attribution cannot be obtained from the figure of Pavlova (1925). *S. hemitoechus* has been reported in Late Pleistocene sites of North Africa (Morocco and Algeria) and in the Middle East (Guérin 1980, Geraads 1982); furthermore, according to Guérin (1980), *Rhinoceros subinermis* Pomel, 1895 is synonymous with *D. hemitoechus*.

In agreement with the records of the species in the Mediterranean Basin and in the rest of Europe, the diffusion of *S. hemitoechus* can be related to the diffusion of the Mediterranean-type habitat during the interglacial periods, with the presence of abrasive herbaceous elements. This is even in accordance with the dental and skeletal features of the species (Fortelius 1982, Fortelius *et al.* 1993, Mazza 1993, Hernesniemi *et al.* 2011). Moreover, the appearance of *S. hemitoechus* during MIS13 is concomitant with an increase of herbaceous elements due to the climatic trend towards an arid period (Russo Ermolli *et al.* 2010, Bertini 2000).

The last occurrence of *S. hemitoechus* is usually reported during the last glaciation (Guérin 1980, Petronio *et al.* 2011). In particular, the species disappears before the last glacial maximum in central Europe, is documented up to MIS3 (Ingarano site, Petronio *et al.* 2011) in Italy and is recorded until the end of the Late Pleistocene in Spain (site of La Ventana; Sánchez *et al.* 2003). Nevertheless, in spite of the relatively well-constrained temporal and regional distribution, the origin of *S. hemitoechus* remains unclear because neither the European (from *S. hundsheimensis*) nor Asian origins can be excluded. Therefore, a careful revision of Plio-Pleistocene Eurasian rhinoceroses will be essential to explain the species origin.

Conclusions

The Campagna Romana, due to its richness of fossiliferous sites and the presence of detailed chronostratigraphy, is an exceptional archive of useful information for the study and understanding of the paleobiogeography and paleoenvironment during the Pleistocene. In the present paper, we report the results of an integrated approach between paleontologists and volcanologists to the study of a fossil rhinoceros skull occurring in the Campagna Romana. This skull, ascribed to *S. hemitoechus*, is referred to approximately 0.500 Ma and represents the earliest occurrence of the species in Europe. Because of its adaptation to an abrasive diet, *S. hemitoechus* most likely found the Mediterranean Basin to be a favourable climate for its diffusion. Successively, during the interglacial stages, the species become common in the rest of western and northern Europe and it reached its maximal geographic extension during MIS5.

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