



New Hipparionine (Perissodactyla) Fossils from Potwar Plateau of Pakistan

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ABSTRACT

New dental material of hipparionines from the Middle Siwalik deposits of district Attock, Potwar Plateau, Punjab, Pakistan has been described. The fossiliferous sites, Dhok Mila of Nagri Formation (early Late Miocene) and Kaulial Kas of Dhok Pathan Formation (Late Miocene – Early Pliocene) are located in district Attock, Punjab, Pakistan. The recovered material comprises isolated premolars and molars. The identified species of hipparionines include *Hipparion* sp. small, *Cormohipparion* sp., *Sivalhippus* cf. *nagriensis*, and *Sivalhippus* cf. *theobaldi*. These specimens provide additional information about the recorded species and contribute to recent work of Perissodactyla from the Middle Siwalik Hills of Pakistan.

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Authors' Contribution

MAK presented the concept and designed the study. MH collected data. NR, MJ and MSK analyzed and interpreted the data. MH and NR prepared the draft of the manuscript.

Key words

Hipparionine, *Sivalhippus*, Dhok Pathan, Perissodactyla fossils.

INTRODUCTION

During the course of Early Miocene through Late Pliocene, prehistoric rivers accumulated the deposits in the form of Siwalik formations of northern Pakistan (Barry *et al.*, 1985; Flynn *et al.*, 1990; Badgley and Behrensmeyer, 1995). The Mio-Pliocene strata have traditionally been divided into Kamlial, Chinji, Nagri, and Dhok Pathan formations. In all of these formations, exposures typically consist of gently tilted strata that form shallow strike-valleys and higher ridges as the surface expression of the large structural synclinorium underlying the Potwar Plateau. The valleys are formed by more simply eroded floodplain siltstones and mudstones, while the edges or ridges are formed by laterally extensive channel sandstones (Willis and Behrensmeyer, 1994).

The Khaur region, located in the north-central Potwar includes Kaulial Kas, Malhuwala, Dinga, Ganda, Ratha and Dhok Mila (Barry *et al.*, 1980). The Kaulial Kas, in particular, was a focal area for pinning down the level of first appearance of a big bovid. The surveyed portion of the Kaulial Kas section consists of about 2100 m (6930 feet) spanning the time interval from 10.9 to about 7.1 Ma and is one of the few areas in the northern Potwar where the later part of this interval is well enough exposed to produce a reasonable fossil record. In both the Khaur and

Chinji areas this approach also was used to define the “*Hipparion*” appearance level, and the resulting data support the assertion that equids do not occur lower than this level (Barry *et al.*, 2002; Wolf *et al.*, 2013).

The hipparionine material has been recovered from the Dhok Mila village of the Nagri Formation (early Late Miocene) and the Kaulial village of the Dhok Pathan Formation of the Middle Siwalik Subgroup (Fig. 1). These villages are situated in the Attock district, Punjab, Pakistan, comprising the outcrops of Late Miocene – Early Pliocene, date to 10.1-3.4 Ma (Barry *et al.*, 2002). The sediments exhibit an excellent development of cyclic deposition of clay, shale and sandstones (Pilbeam *et al.*, 1977). The clays are orange-brown in color (Pilbeam *et al.*, 1977; Barry *et al.*, 2002).

We present here in situ hipparionine fossils from Late Miocene – Early Pliocene localities of the Siwalik Group and provide evidence of the presence of four species of the Siwalik hipparionine.

MATERIALS AND METHODS

Various field visits were made for the fossil collection. The hipparionine fossils were collected carefully from the fossilized locations of the Kulial Kas. The identifiable fossils from the gross collection were catalogued and nominated for the taxonomic study. The fossils were thoroughly washed and cleaned in the laboratory with the help of fine needles and brushes and prepared for the study.

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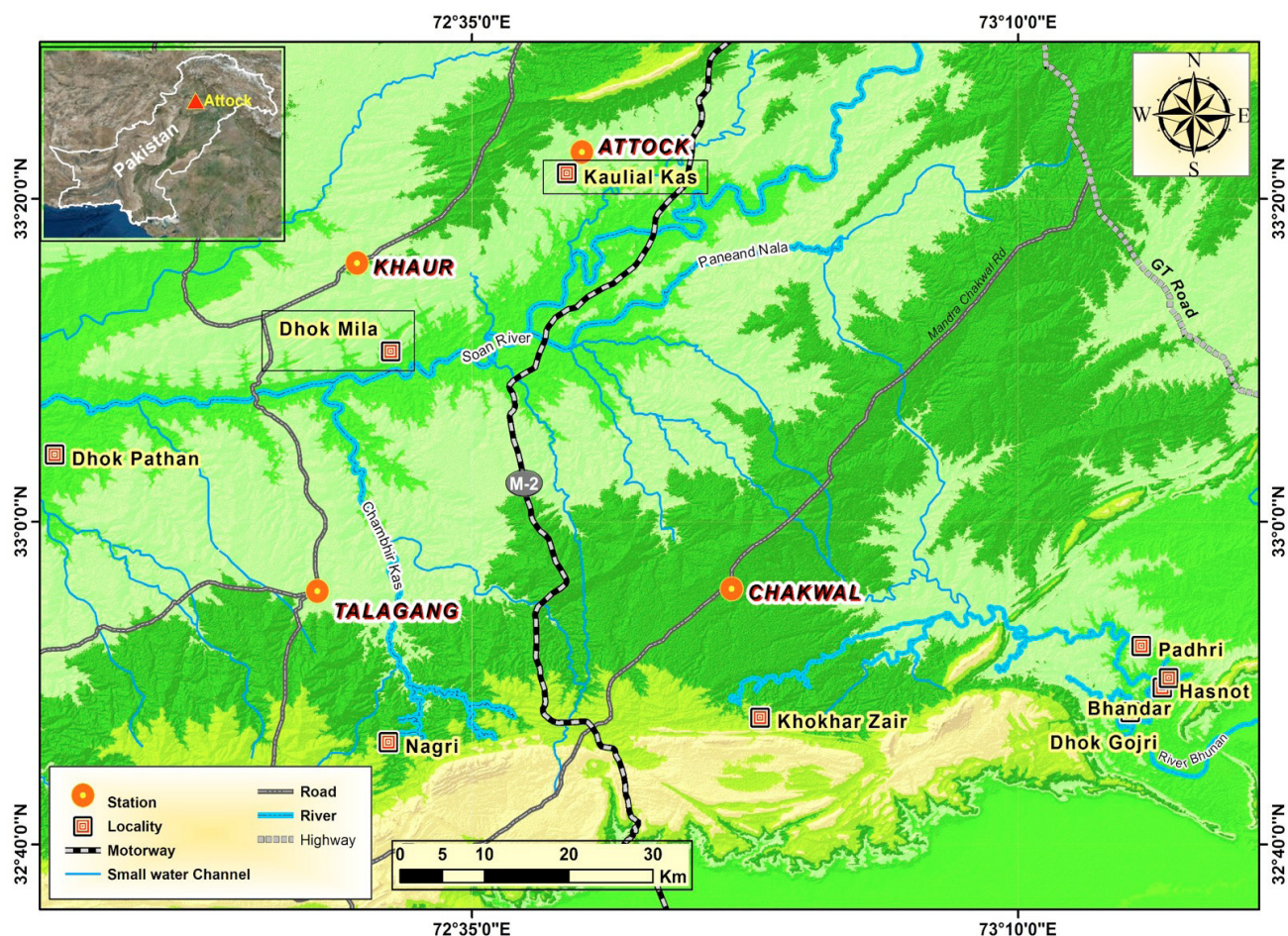


Fig. 1. Map of the Potwar Plateau, Northern Pakistan; the studied localities are encircled.

Damaged parts of the fossils were assembled with some kinds of gums (resins) such as elfy, elite, fixin, araldite and magic stone. The specimens inventory number consists of a yearly catalogue number and serially catalogue number, so numbers on the specimen represent the collection year and the serial number of that year (e.g. PUPC 15/38). Upper case letters stand for upper dentition and lower case letters for lower dentition. The measurements were taken from occlusal surface of the teeth, including the cement and separately from the teeth belonging to different stages of wear.

Systematic Paleontology

Family Equidae Gray, 1821

Subfamily Equinae Steinmann and Doderlein, 1890

Genus *Hipparion* De Christol, 1832

Hipparion sp. small

New material: PUPC 16/283, partial left m3; PUPC 16/296, partial right m3.

Description

Both m3 are partially broken, having lost their hypoconulid (Fig. 2B). The molars are robust and slightly curved being concave anteriorly. The first lobe is higher than the second one. The molars are furnished by cement sparsely. The protoconid unites with metaconid, both being curved inward. Double knot structure is present.

Comparison and discussion

The most remarkable aspect of these molars that they are small in size. Probably, the molars do not support the earlier recorded species from the Siwaliks (Hussain, 1971; MacFadden and Woodburne, 1982; Bernor and Hussain, 1985; Bernor *et al.*, 1996, 2010; Wolf *et al.*, 2013). However, the material is insufficient for a conclusive taxonomic evaluation. The small size of the molars (Table I) can be referred to *Hipparion* sp. small from the Kulial Kas of the Siwaliks. The specific allocation of these small specimens is unclear owing to the poor data.

Table I.- The comparative measurements of the cheek teeth of *Hipparion* sp. small, *Cormohipparion* sp., *Sivalhippus nagriensis* and *Sivalhippus theobaldi*.

Taxa	Number	Position	Height	Length	Width	W/L
<i>Hipparion</i> sp. small	PUPC 16/283*	lm3	38.05	22.64	11.69	0.52
	PUPC 16/296*	rm3	45.16	29.93	9.330	0.31
	YGSP15462	rm3	-	25.60	11.50	0.45
	YGSP5816	lm3	-	25.50	11.70	0.46
	YGSP15462	rm3	-	25.60	11.50	0.45
	YGSP48416	lm3	-	28.80	12.00	0.42
<i>Cormohipparion</i> sp.	PUPC 16/280*	rM	47.42	27.94	-	-
	PUPC 16/351*	rM3	45.72	23.72	23.49	0.99
	PUPC 16/297*	lm	31.24	23.43	12.56	0.54
	PUPC 16/281*	rm1	45.60	24.51	12.92	0.53
	PUPC 16/293*	lm2	38.23	24.81	12.36	0.50
	PUPC 16/285*	rm3	36.92	29.82	11.56	0.39
	YGSP20151	rM3	-	21.30	14.50	0.68
	YGSP15998	lm3	-	-	18.80	-
	YGSP16620	rM3	-	22.20	15.20	0.68
	YGSP27728	rm2	-	21.30	12.20	0.57
	YGSP46336	rm3	-	26.00	11.60	0.45
<i>Sivalhippus nagriensis</i>	PUPC 16/276*	lp2	39.45	35.78	25.36	0.71
	PUPC 16/273*	rM1	33.47	28.05	25.84	0.92
	PUPC 16/287*	rM1	44.92	26.30	27.36	1.04
	PUPC 16/282*	rp3	49.59	17.90	20.38	1.14
	PUPC 16/290*	lp4	44.51	27.51	17.67	0.64
	PUPC 16/295*	lp4	51.85	26.33	16.88	0.64
	YGSP46510	lp2	-	35.30	25.40	0.72
	YGSP16743	lp2	-	36.10	24.60	0.68
	YGSP14757	rP2	-	35.80	25.20	0.70
	YGSP14847	lm1	-	24.50	25.50	1.04
	YGSP15786	lm1	-	25.80	22.90	0.89
	YGSP5733	lm1	-	25.70	24.70	0.96
	YGSP49548	lp3	-	28.80	15.50	0.54
	YGSP46719	rp3	-	27.60	17.30	0.63
	YGSP50677	lp4	-	25.80	16.10	0.62
	YGSP16384	lp4	-	27.30	15.60	0.57
	YGSP8910	rp4	-	28.80	16.40	0.57
<i>Sivalhippus theobaldi</i>	PUPC 16/275*	lp2	24.76	29.10	23.61	0.81
	PUPC 16/289*	rP4	59.17	29.25	26.66	0.91
	PUPC 16/278*	rP4	49.51	30.12	-	0.94
	PUPC 16/272*	rP4	52.89	28.60	28.60	1.00
	PUPC 16/288*	lp4	45.68	29.94	27.74	0.93
	PUPC 16/279*	lm1	49.21	24.50	-	1.07
	PUPC 16/277*	rM1	45.57	27.46	26.38	0.96
	PUPC 16/274*	rM2	32.78	25.04	28.82	1.15
	PUPC 16/294*	rM3	27.64	23.36	25.58	1.10
	PUPC 83/284	P2	22.00	39.50	21.50	0.54
	PUPC 83/498	P2	20.00	40.00	22.00	0.55
	AMNH 19857	P2	-	32.00	26.50	0.83
	AMNH19466	P2	-	38.50	26.00	0.68
	GSI C 153	P2	-	38.50	26.00	0.68
		P3	-	30.30	25.20	0.83
		P4	-	30.00	24.00	0.80
	AMNH 98728	P2	-	37.80	27.20	0.72
		P3	-	32.10	29.20	0.91
		P4	-	27.00	25.50	0.94
		M1	-	25.80	26.40	1.02
		M2	-	26.60	24.60	0.92
		M3	-	25.60	20.50	0.80

Taxa	Number	Position	Height	Length	Width	W/L
<i>Sivalhippus theobaldi</i>	AMNH 19466	M1	-	26.00	26.00	1.00
		M2	-	26.50	26.00	0.98
		M3	-	24.00	22.00	0.92
	AMNH 19857	M1	-	21.00	25.00	1.19
		M2	-	21.00	25.00	1.19
		M3	-	25.00	23.00	0.92

*The studied specimens. Referred data are taken from Colbert (1935), Ghaffar (2005), Khan *et al.*, (2012) and Wolf *et al.* (2013).



Fig. 2. The representative cheek teeth of the Siwalik hipparionine from the Middle Siwalik of Attock, Punjab, Pakistan. *Hipparion* sp. small: **A**, PUPC 16/283, l m3; **B**, PUPC 16/296, rm3. *Cormohipparion* sp.; **C**, PUPC 16/351, rM3; **D**, PUPC 16/281, rm1; **E**, PUPC 16/293, lm2; **F**, PUPC 16/285, rm3. *Sivalhippus nagriensis*; **G**, PUPC 16/276, lP2; **H**, PUPC 16/273, rM1; **I**, PUPC 16/282, rp3; **J**, PUPC 16/290, lp4. *Sivalhippus theobaldi*; **K**, PUPC 16/275, lP2; **L**, PUPC 16/272, rP4; **M**, PUPC 16/288, lP4; **N**, PUPC 16/277, rM1; **O**, PUPC 16/274, rM2; **P**, PUPC 16/294, rM3. Scale bar 10mm.

Genus *Cormohipparion* Skinner and Macfadden, 1977*Cormohipparion* sp.

New material: PUPC 16/280, partial right upper molar; PUPC 16/351, partial right M3; PUPC 16/297, partial left lower molar; PUPC 16/281, right m1; PUPC 16/293, partial left m2; PUPC 16/285, partial right m3.

Description

The protocone is elongate oval shaped in the upper molars (Fig. 2C). The plications are complex, especially opposing borders of the pre- and postfossettes. The plicabalin is bifid and in some specimens it is trifid. The molars represent partial cementation. The parastyle is heavy, the mesostyle is high and the metastyle is incipient. The hypoconal groove is narrow and much incised in the upper molars.

The lower molars represent double knot occlusally (Fig. 2D, E, F). The protostylid, mesostylid and metastylid are prominent. The metaflexid is broad marginally and narrow centrally. The entoflexid is longer and narrower than the metaflexid. The entoflexid is bifurcated in some molars. At the base of the hypoconid there is an indication of hypoplasia in PUPC 16/293. The molars are covered with cement labio-lingually.

Comparison and discussion

The upper cheek teeth reflect primitive features in having the deep incision of hypoglyph/hypoconal groove (until late wear) and the lower cheek teeth show primitive characters in having the round shape of the metaconid-metastylid and V-shaped linguaflexid. The size and morphology (Table I, Fig. 2C, D, E, F) of these teeth compare favorably with Sinap *Cormohipparion sinapensis* (Bernor et al., 2003). The advanced features include increasing crown height and shortening of the protocone with distinct lingual flattening associate them with the Bou Hanifia hipparion, "*Cormohipparion*" *africanum*, dated to 10.5 Ma (Bernor and White, 2009). However, the Siwalik material is limited, we cannot confirm these teeth to a particular species of the Old World *Cormohipparion* in the Siwaliks.

Sivalhippus Lydekker, 1887*Sivalhippus nagriensis* Hussain, 1971

New material: PUPC 16/276, partial left P2; PUPC 16/273, right M1; PUPC 16/287, partial right M1; PUPC 16/282, right p3; PUPC 16/290, left p4; PUPC 16/295, partial left p4.

Description

The parastyle is pointed and elongated whereas accessory rib is faint in the P2 (Fig. 2G, H). The protocone is ovate: flat lingually and rounded labially. The plications are simple and prominent. The plicabalin is bifid. The prefossette is larger than the postfossette, having complex plications at its posterior border. The styles are prominent: parastyle heavy, mesostyle high and metastyle thin. The hypoglyph is open and less incised. The pli-protoconule is well-developed.

The parastylid is large and flanked in the lower premolar (Fig. 2I, J). The protostylid is united with the protoconid. The protoconid is slightly smaller than the hypoconid, which has crenulated border. The preflexid is much smaller and wider than the postflexid, which is narrow and have serrated border. A well-developed incised spur is present at the posterior border of the preflexid. The ectoflexid is much incised, isthmus is prominent. The hypocouldid is small in the m3. The cement is abundant labio-lingually.

Comparison and discussion

The specimens represent the characters of the Siwalik early hipparionine *Sivalhippus nagriensis*: anterostyle elongated in P2, increasing crown height of maxillary teeth with multiple plications on the posterior border of prefossette and the anterior border of postfossettes, bifid to trifid plicaballins, oval protocone flattened lingually and rounded labially, and hypoglyph deeply incised (Hussain, 1971; MacFadden and Woodburne, 1982; Bernor and Hussain, 1985; Wolf et al., 2013).

Hussain (1971) noted the general uniformity of the hipparionine specimens from the Nagri Formation of the Siwalik Group and applied the nomen *Cormohipparion* cf. *nagriensis*. Bernor and Hussain (1985) suggested that the holotype of *S. nagriensis* (BSPG 1956 II H15, given as BSM-H15, a single right M1 or M2) was too incomplete to be safely grouped with other. They recommended that this material be referred to *Cormohipparion* (*Sivalhippus*) sp. until more complete material could be retrieved from the type locality. Later on, many specimens were collected from the type locality, having dimension and morphology comparable to the holotype of *S. nagriensis*. Wolf et al. (2013) believe that most of the earlier Siwalik hipparionine material, collected from the type locality, can be confidently tied to the holotype, and we thus refer these specimens to *Sivalhippus nagriensis* (Table I, Fig. 2G, H, I, J). Morphologically, *Sivalhippus nagriensis* is similar to North American hipparions of the *Cormohipparion occidentale* complex (Woodburne, 2007) as well as several early Old World hipparions referred to as *Cormohipparion* (Bernor et al., 2003, 2010).

Sivalhippus theobaldi Lydekker, 1877

New material: PUPC 16/275, partial left P2; PUPC 16/289, partial right P4; PUPC 16/278, partial right P4; PUPC 16/272, right P4; PUPC 16/288, left P4; PUPC 16/279, partial upper M; PUPC 16/277, partial right M1; PUPC 16/274, partial right M2; PUPC 16/294, right M3.

Description

The anterostyle and accessory rib are broken in the P2 (Fig. 2K, L, M, N, O, P). The protocone is elongated and pointed anteriorly. The plications are not much complicated except the posterior border of the prefossette. The hypoglyph is less incised. The protocone is flattened lingually and rounded labially in the P4. The mesostyle is the highest one. The protocone is flat lingually and rounded labially in the molars. The plicabalin is trifid and simple. The protoconule is eye shaped. The prefossette is smaller than the post fossette. The anterior and posterior borders of the prefossette whereas the anterior border of the postfossette are plicated. The pliprotconule, pliprotoloph, plipostfossette and plihypoloph are prominent. The hypoglyph is well incised. An islet is present near the distal border of the hypoglyph.

Comparison and discussion

The protocone is flattened as compared to oval shape in *Hipparion* (Wolf *et al.*, 2013). The pillar like isolated protocone of the studied specimens in the Siwaliks supports their inclusion in the genus *Sivalhippus*. *Sivalhippus theobaldi* is characterized in having the visible enamel foldings, less complex plications and large size. The difference of *Sivalhippus theobaldi* with other hipparionines includes the greater size of molars (Table I), which are more oblong and less square shape. The hypocone extends back to the posterior border of the teeth; a character represents *Sivalhippus theobaldi*. The enamel plications are relatively simple in *Sivalhippus theobaldi* (Lydekker, 1882; Colbert, 1935; Bernor *et al.*, 1996).

The morphology (Fig. 2K, L, M, N, O, P) of the studied specimens reveals all the features of species *Sivalhippus theobaldi* as described by Lydekker (1882), Colbert (1935) and Ghaffar (2005). This species is characterized by the isolated, compressed and pillar like protocone and the molars are large. The enamel bordering of the fossettes are relatively simple. As indicated by measurements (Table I), the specimens are extremely hypsodont and show less complicated plications. According to Colbert (1935), it is heavy and large species. Therefore, the sample can be assigned to *Sivalhippus theobaldi*.

Sivalhippus theobaldi is a rare taxon in the Siwalik sequence. It is a difficult taxon to identify because the teeth are only slightly larger than *S. nagriensis* and *S. perimensis*

when worn, and its relatively low maximum crown height is also not readily apparent in later wear stages. *Sivalhippus theobaldi* was reported by previous authors to be of Dhok Pathan age, the first certain stratigraphic occurrence demonstrated in the YGSP collection is between 9.290 and 9.159 Ma, the taxon is also present up to ca. 7.8 Ma. The latter appearance is more consistent with the assumed provenience of the holotype of *S. theobaldi* and the specimen AMNH 98728 near the Dhok Pathan Rest house (MacFadden and Woodburne, 1982). Morphologically, *Sivalhippus theobaldi* is certainly closest to *S. nagriensis*, and in fact is likely derived from that species (Wolf *et al.*, 2013).

GENERAL DISCUSSION

The earliest occurrence of the Siwalik hipparionines that can be determined with some certainty, the local *Hipparion* Datum, ca. 10.7 or 10.8 Ma (Woodburne *et al.*, 1981; Bernor *et al.*, 1996; Woodburne *et al.*, 1996; Gradstein *et al.*, 2004; Woodburne, 2007). It is thus somewhat younger than the *Hipparion* Datum in Central Europe, Austria, has been calibrated up to 11.2 Ma (Daxner-Hoock and Bernor, 2009). Beside the Australian material, Snap *Cormohipparion sinapensis*, the earliest hipparionine from Turkey (Bernor *et al.*, 2003), has been demonstrated to compare closely with North American *Cormohipparion*. North African *C. africanum* (Bou Hanifia, 10.5 Ma), while advanced in cheek tooth crown height, also has skull and postcranial features recalling North American *Connohipparion* (Bernor and White, 2009; Bernor *et al.*, 2010).

The cranial and postcranial material of the Harvard collection suggests that between ca. 10.7 and 10.2 Ma *Sivalhippus nagriensis* evolved from the initial population of Siwalik *Cormohipparion* (possibly initially co-existing with the more plesiomorphic taxon) by increasing general body size, crown height, and plicaballin complexity and changing protocone shape. While retaining certain plesiomorphic characteristic, such as a dorsoventrally extensive, medially deep and posteriorly pocketed POF and deeply incised ectoflexid on the mandibular premolar teeth. For approximately 1 Ma, *Sivalhippus nagriensis* appears to have been generally the only hipparionine of the Siwalik Hill's region, with the exception of the rare presence of the extremely small horse described here as *Hipparion* sp. small. This, latter taxon, while not represented by material sufficient for a conclusive taxonomic evaluation, was probably not endemic. Wolf *et al.* (2013) supported earlier observations for the Nagri Formation by Hussain (1971), MacFadden and Woodburne (1982) and Bernor and Hussain (1985) concerning the predominantly

monospecific Siwalik hipparionine population during this time period (with the exception of *Hipparions* sp. small).

The *Sivalhippus* lineage is distinguished at its origin from other early Old World lineages in particular by the early onset of maximum crown height of more than 65 mm. Mandibular cheek teeth remain rather primitive in *Sivalhippus nagriensis*. In comparison to contemporaneous Central European members of the *Hippotherium* lineage, mandibular cheek teeth differ in having less complex pre- and postflexid margins (Bernor *et al.*, 1996). The metapodial of *S. nagriensis* may have been somewhat stouter and less elongate. But this is difficult to judge given the incomplete nature of all available early Siwalik metapodials. *Cormohipparion sinapensis* is a small and plesiomorphic early Old World hipparionine, but clearly has more slender limb (Bernor *et al.*, 2003) than *Hippotherium primigenium* and *Sivalhippus nagriensis*. More derived somewhat younger hipparionine from Sinap contemporaneous with *Sivalhippus nagriensis* show various derived features distinct from *S. nagriensis*. *Hipparion kecigibi* shows slender, short metapodials.

By at least 9.290 Ma the appearance of massive but not very high-crowned teeth indicate the presence of *Sivalhippus theobaldi* in the Siwaliks. This is earlier than expected in view of the presumed stratigraphic provenience near the Dhok Pathan Rest house as mentioned by MacFadden and Woodburne (1982) and Hussain and Bernor (1984). Despite the massive increase in size of *Sivalhippus theobaldi* retains a basal facial morphology with a dorsoventrally extensive preorbital fossa throughout its occurrence. *Sivalhippus theobaldi* was apparently rare in the Siwalik Hills, it seems, to have sympatrically coexisted with first *Sivalhippus nagriensis* and later the more derived *Sivalhippus perimensis* and the immigrant clade *Cremohipparion antelopinum* (Eisenmann *et al.*, 1988; Eisenmann, 1994; Bernor *et al.*, 2010).

CONCLUSIONS

Four hipparionine species are documented at first time from Dhok Mila and Kaulial Kas of the Attock district, Punjab, Pakistan. The fossiliferous site Dhok Mila is of the Nagri Formation (early Late Miocene) and Kaulial Kas is of Dhok Pathan Formation (Late Miocene – Early Pliocene). The new material described from Attock confirms the existence of the various sized hipparionine in the Late Miocene – Early Pliocene of the Potwar Plateau in Pakistan.

Statement of conflict of interest

Authors have declared no conflict of interest.

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