



Enamel Hypoplasia Analysis of Middle Miocene Mammals from Chabbar Syedan, Punjab, Pakistan

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ABSTRACT

The present article is the first ever report on occurrence of enamel hypoplasia (EH) in extinct mammals of Chabbar Syedan. Three types of EH were observed: single linear hypoplasia, multiple linear hypoplasia and pitting enamel hypoplasia. Single linear hypoplasia is the most common type of EH observed in Chabbar Syedan mammals. The low occurrence (only 8%) of EH provide a clue for stable community and favorable paleoenvironmental conditions in studied site during the Middle Miocene. The paleoecology of the Chabbar Syedan area through a system of comparative analogy is also briefly discussed.

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Authors' Contribution

MKN performed research and drafted manuscript. MAK provided literature and supervised the research work.

Key words

Enamel hypoplasia, Paleoenvironment, Chinji Formation, Miocene, Siwaliks.

INTRODUCTION

Chabbar Syedan is a fossil site situated at the base of the Bakralla ridge in the district Jhelum (Fig. 1). It is known for the mammalian fauna, mainly of Middle Miocene age. The first noticeable account of this site is found in Sarwar (1977) who reported a specimen of *Protanancus chinjiensis* from this site. However, after Sarwar (1977) the site was mostly neglected till 2015, although Pickford (1988) has reported a specimen of *Conohyus sindiensis* from this site. Aftab *et al.* (2015) highlighted the site by documenting the formerly recovered upper third premolar of *Giraffokeryx punjabiensis* and the quest for the mammalian fauna from this site was started again. These three mammalian species just mentioned, are characteristic of the Chinji Formation fauna, and hence, the Chabbar Syedan mammalian fauna can be comparable to Chinji fauna.

The lithological features of the outcrops yielding the remains during the field surveys occurred in 2015-19, show typical Chinji Formation characteristics including the bright red or brick colored predominant mudstone and subordinate gray colored sandstone and dark to light red

colored conglomerates and pseudoconglomerates (Fig. 2). The sediments of Chinji Formation were deposited during the Middle Miocene, that ranges in age from 11.2 to 14.2 Ma (Johnson *et al.*, 1985; Badgley and Gingerich, 1988). Extended account of lithology and estimated age of this area can be found in Aftab *et al.* (2015), Abbas *et al.* (2016) and Nawaz *et al.* (2019).

EH is the reduction of tooth enamel consequential from interruptions in the enamel deposition by ameloblasts for the period of crown growth (Yaeger, 1980; Ensor and Irish, 1995). During tooth development, enamel does not alter, and because of chronological development, it develops stress marks (for instance pits, linear grooves *etc.*). Owing to developmental stress, enamel creates ideal records of genetic conditions and dietary interactions throughout the development stage of an extinct animals' life which indirectly reveals the environmental conditions existing during that time (Goodman and Rose, 1990; Ogden *et al.*, 2007; Guatelli-Steinberg *et al.*, 2014). The fossilized tooth with EH is shown in Figure 3.

EH has broadly been studied in extant as well as extinct mammals, as in recent times, it has drawn concentration of the paleontologists as a reliable clue for indigenous paleoecological situation and on a local scale

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Abbreviations

PUPC, Punjab University Paleontological Collection; EH, enamel hypoplasia; LEH, linear enamel hypoplasia; PEH, pitting and grooves enamel hypoplasia; P, upper premolar; M, upper molar; p, lower premolar; m, lower molar; i, lower incisor.

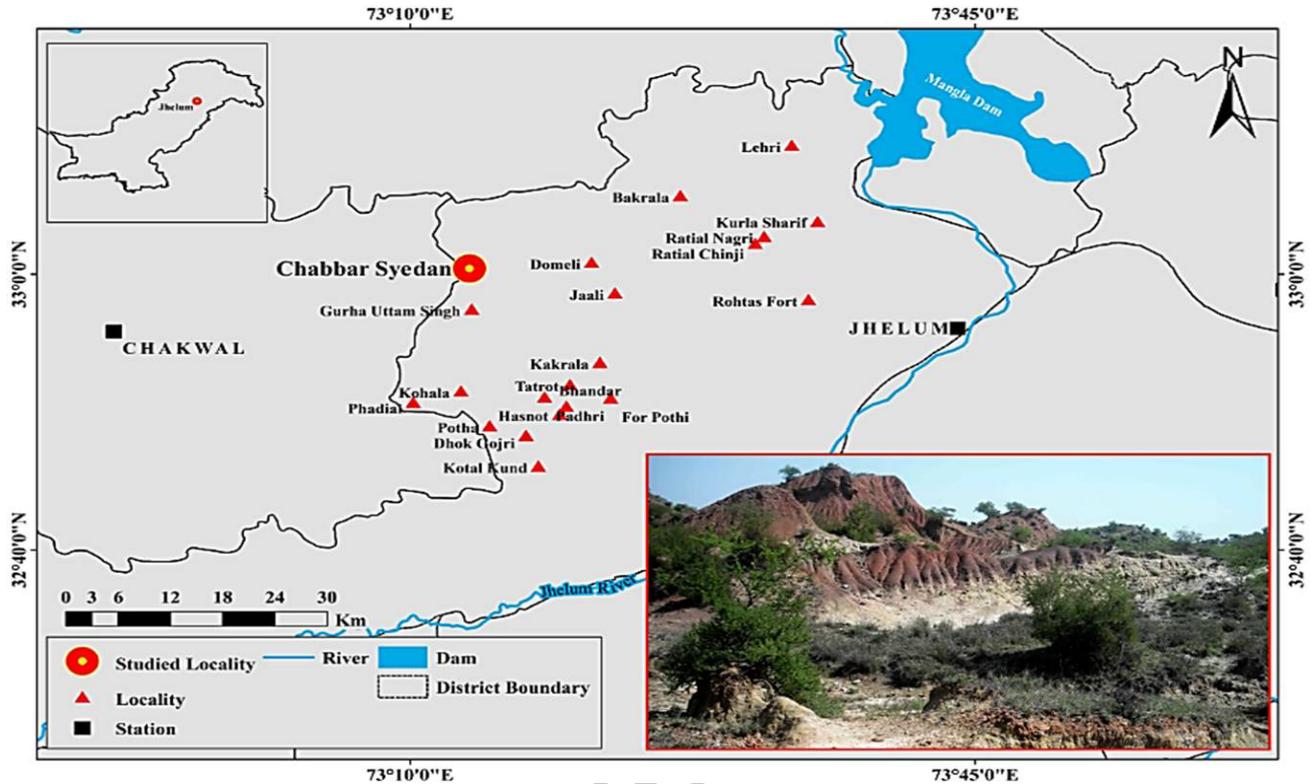


Fig. 1. Location of the collection area “Chabbar Syedan” site in Jhelum district with outcrops exposed in the vicinity of the village.

paleoenvironmental transformation (Mead, 1999; Franz-Ondendaal et al., 2004). EH represents three main types: linear enamel hypoplasia (LEH), semicircular enamel hypoplasia (SEH), pits and grooves enamel hypoplasia (PEH) (FDI, 1982). LEH is further divided into single LEH and multiple LEH. In single LEH, only one horizontal groove or line visible on tooth's surface and in multiple LEH, two or more horizontal grooves or lines visible on tooth's surface. SEH is a tooth depression in semi-circular form in horizontal direction (Goodman and Rose, 1990; Skinner and Goodman, 1992). Pitting enamel hypoplasia (PEH) can take various forms and ranges from minor rounded pinpricks to large asymmetrical depressions, these can be single or multiple, some arrange into rows whereas others dispersed arbitrarily (Goodman and Rose, 1990; Witzel et al., 2006; Ogden, 2007). Some researchers only documented LEH while others include all defects (Goodman et al., 1984; Ogilvie et al., 1989; Miszkiewicz, 2015; Smith et al., 2016). Area with enamel lost can be examined macroscopically whereas pits as well as grooves can mostly be analyzed with the aid of microscope. Usually, genetic conditions, physiological, nutritional or environmental stress bring about EH that is faced during the teeth development of an animal (Goodman and Rose, 1990). The affected teeth, along with the distance of EH

mark on crown from neck, express the time and duration of the stress event. The width of EH indicates the stress time span; its severity can be recorded from the depth of EH mark (Goodman et al., 1980).

As stated above that the EH analysis can be employed as a reliable basis for the presumption of ecological interactions as well as climatic fluctuations of the past to summarize the paleoenvironment of a region so, EH analysis is useful to evaluate the existence and non-existence of ecological stresses for the Middle Miocene mammals recently collected from the Chabbar Syedan. The present work is the very first effort to analyse EH in the extinct mammals of the Chabbar Syedan site.

MATERIALS AND METHODS

The material was collected by the first author. The entire Chabbar Syedan collection is used for EH analysis except horn-cores, symphyseal fragments and tusks. A total of 130 specimens were used for EH analysis, including 4 maxilla fragments, 14 mandible fragments, 45 isolated premolars, 56 isolated molars, 4 isolated incisors, 4 isolated canines, 3 serially arranged teeth. These specimens belong to 11 families and 23 species (Table I). The family-wise detail of the dentition type used for EH analysis is provided in Table II.

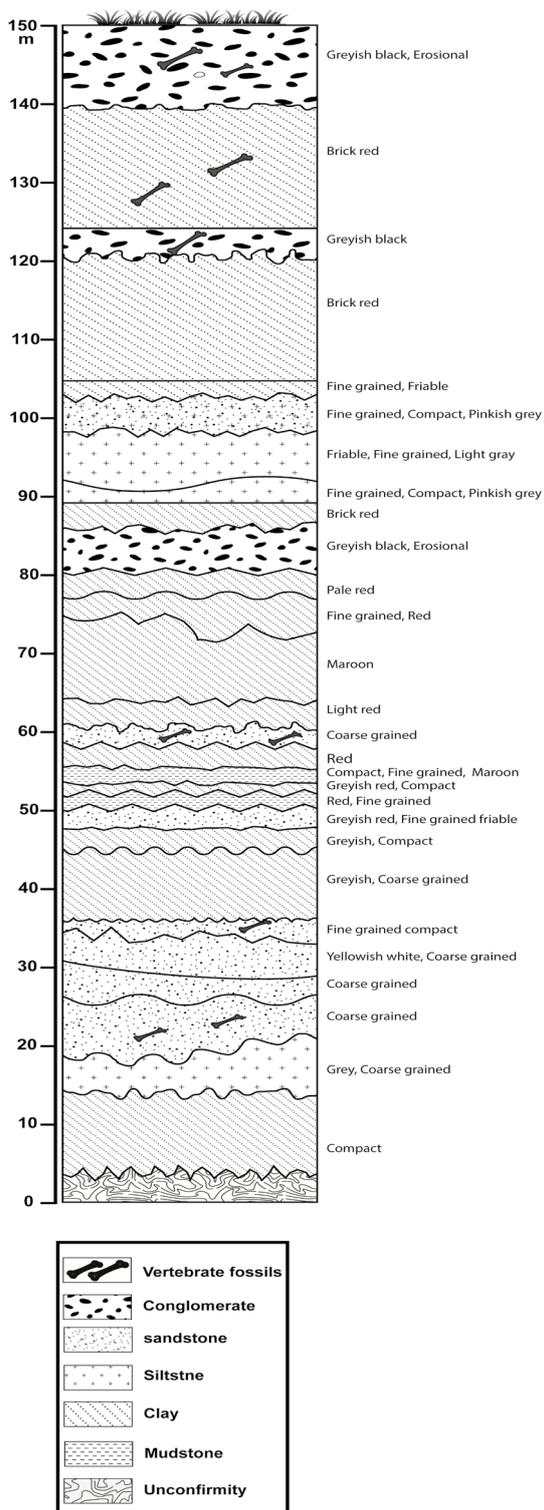


Fig. 2. Lithological column of the surveyed area in the Chabbar Syedan, Potwar Plateau, Pakistan. The area represents the Chinji Formation of the Lower Siwaliks and other formations are missing from the surveyed area.

Table I.- The mammalian taxa investigated for EH analysis from the Chabbar Syedan Middle Miocene of Pakistan.

S. No.	Families (No. of species)	Taxa
1	Bovidae (5)	<i>Miotragocerus gluten</i> <i>Helicopotax praecox</i> <i>Sivaceros gradiens</i> <i>Eotragus</i> sp. <i>Gazella</i> sp.
2	Giraffidae (3)	<i>Giraffokeryx punjabiensis</i> <i>Giraffa priscilla</i> cf. <i>Progiraffa exigua</i>
3	Tragulidae (4)	<i>Dorcatherium minus</i> <i>Dorcatherium majus</i> <i>Siamotragulus akbari</i> sp. nov. <i>Siamotragulus</i> sp. nov.
4	Anthracotheriidae (1)	<i>Merycopotamus nanus</i>
5	Suidae (3)	<i>Listriodon pentapotamiaie</i> <i>Conohyus sindiensis</i> <i>Propotamochoerus</i> sp.
6	Rhinocerotidae (1)	<i>Brachypotherium</i> sp.
7	Mustelidae (1)	<i>Vishnuonyx chinjiensis</i>
8	Percrocutidae (1)	cf. <i>Percrocuta</i> sp.
9	Deinotheriidae (2)	<i>Deinotherium pentapotamiaie</i> <i>Deinotherium indicum</i>
10	Amebelodontidae (1)	<i>Protanancus chinjiensis</i>
11	Gomphotheriidae (1)	<i>Gomphotherium</i> cf. <i>browni</i>
Total analyzed species		23

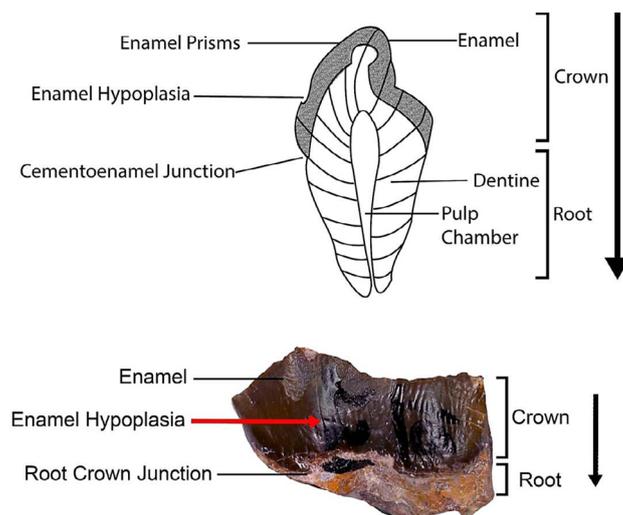


Fig. 3. **A**, the hypothetical tooth diagram representing enamel development (Goodman and Rose, 1990; Franz-Odenaal *et al.*, 2004); **B**, The process of enamel formation revealed in the studied giraffid molar; arrow direction pointed towards the EH (tip to base).

Each tooth was examined macroscopically and if required, by using 10x hand lens, the type and the position along with the number of defects were noted down. Every fossil was reliably studied no less than three times for the existence or nonexistence of EH with the intention of higher accuracy of the results. Other researchers have also verified the existence of these marks. EH marks diagrammatically represented by various authors have also been compared with the marks appeared on the teeth in the present study (Fig. 4).

The categorization of EH is in accordance with Federation Dentaire International (1982). In the current study, the observed EH can be categorized into single LEH, multiple LEH and PEH. EH elevation from cervical

zone of tooth had also been calculated. The terms and methodology of Mead (1999) and Franz-Odenaal *et al.* (2004) related with macroscopic EH analysis is considered for this study. To demonstrate EH marks, the teeth with EH were accurately taken into picture.

The scale (mm) has been used to take all measurements. The digital caliper was used for measuring the location of EH mark on the tooth crown. The results of measurements rounded off to whole number in order to make possible photographic representation of these measurements for location of EH on the crown of affected teeth. The height of EH mark on the tooth crown is measured from the root-crown junction with the help of Vernier caliper in mm (Table III).

Table II.- The used dentition for EH analysis, recovered from the Middle Miocene of Chabbar Syedan, Punjab, Pakistan.

Families	Maxilla fragment	Mandible fragment	Serially arranged tooth	Deciduous	Incisor	Canine	Premolar	Molar
Bovidae	03	06	-	-	-	-	13	20
Giraffidae	-	01	-	01	-	-	13	10
Tragulidae	-	04	01	-	-	-	01	11
Anthracotheriidae	-	-	-	-	-	-	01	01
Suidae	-	02	01	02	02	02	06	09
Rhinocerotidae	01	-	-	01	01	01	01	01
Mustelidae	-	-	01	-	-	-	-	-
Percrocutidae	-	-	-	-	-	01	01	-
Deinotheriidae	-	-	-	-	-	-	01	04
Amebelodontidae	-	01	-	01	-	-	03	-
Gomphotheriidae	-	-	-	-	-	-	01	-

Table III.- Detail of EH occurrence in Chabbar Syedan mammalian fauna.

Species	Specimen	Enamel hypoplasia		
		Position	Cusp	Type and height from the neck
<i>Miotragocerus gluten</i>	PUPC 16/174	M2	Hypocone	One LEH at 03 mm above the neck
	PUPC 16/175	M2	Protocone	One LEH at 05 mm above the neck
	PUPC 17/195	M3	Hypocone	One LEH at 05 mm above the neck
<i>Gazella sp.</i>	PUPC 16/320	M2	Protocone	PEH at 05 mm above the neck
	PUPC 19/72	M2	Hypocone	Two LEH at 04 and 06 mm above the neck
<i>Giraffa priscilla</i>	PUPC 16/221	P4	Entoconid	One LEH at 02 mm above the neck
<i>Dorcatherium minus</i>	PUPC 17/193	M2	Hypocone	One LEH at 07 mm above the neck
<i>Listriodon pentapotamiae</i>	PUPC 19/71	i2	Labial side	One LEH at 10 mm above the neck
	PUPC 18/57	P4	Postprotocrista	One LEH at 03 mm above the neck
<i>Deinotherium pentapotamiae</i>	PUPC 17/177	M2	Paracone and Metacone	Three LEH at 08, 17 and 20 mm above the neck
<i>Protanancus chinjiensis</i>	PUPC 18/246	P4	tritolophid	PEH at 25 mm above the neck

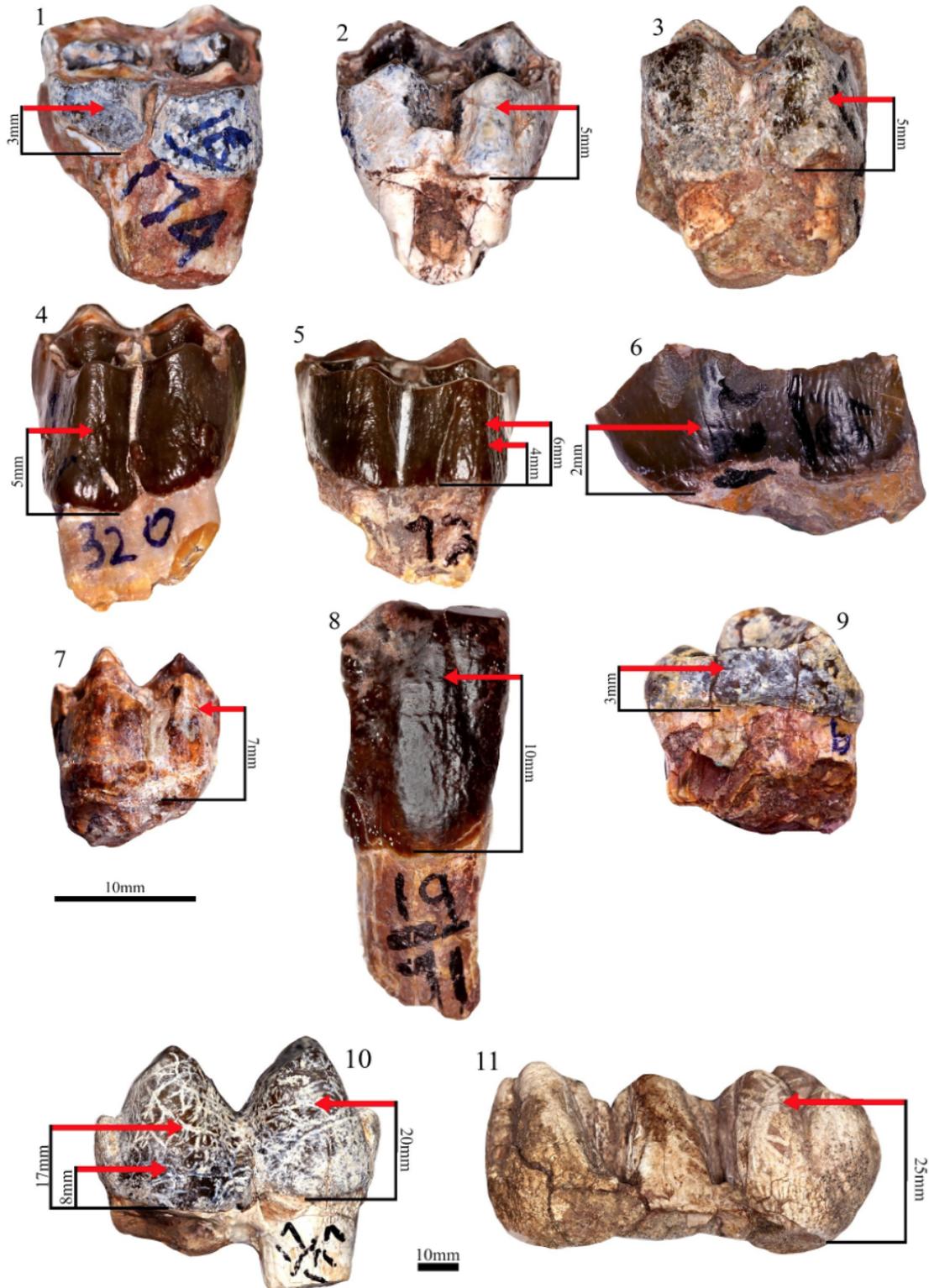


Fig. 4. EH in mammalian species of Chabbar Syedan: 1-3, *Miotragocerus gluten*; 4-5, *Gazella* sp.; 6, *Giraffa priscilla*; 7, *Dorcatherium minus*; 8-9, *Listriodon pentapotamiae*; 10, *Deinotherium pentapotamiae*; 11, *Protanuncus chinjiensis*.

RESULTS

The EH was reported in 7 out of 23 species only, and these species belongs to 6 families. Overall, out of the 130 studied teeth, 11 (8%) shows EH: three of *Miotragocerus gluten*, two of *Gazella* sp., two of *Listriodon pentapotamie*, one each of *Giraffa priscilla*, *Dorcatherium minus*, *Deinotherium pentapotamie* and *Protanancus chinjiensis* (Table III). The percentage of EH occurrence within each of these six families is: Bovidae 12% (5 out of 42), Giraffidae 4% (1 out of 25), Tragulidae 6% (1 out of 17), Suidae 8% (2 out of 24), Deinotheriidae 20% (1 out of 5) and Amebelodontidae 20% (1 out of 5). These results summarized in Table IV show that the proboscideans and bovids might be confronted with slightly higher ecological stresses such as interspecific competitions and food shortage, probably due to their population density.

Table IV.- EH occurrence among six families of Chabbar Syedan mammals.

Family	Total No. of specimens representing family	Total No. of specimens with EH	EH Percentage (%) out of the total No. of specimens representing family
Bovidae	42	5	12
Giraffidae	25	1	4
Tragulidae	17	1	6
Suidae	24	2	8
Deinotheriidae	5	1	20
Amebelodontidae	5	1	20

The occurrence of EH in premolars is three out of 41 (7%), for molars this value is seven out of 56 (12%), for incisor it is one out of three (33%). The LEH (either single or multiple) and PEH have been observed in the present study (Table III). The maximum marks of EH observed on a single tooth are three in number. The histogram results suggest that amid EH types, the single LEH is the most occurring type of EH in Chabbar Syedan mammals (Fig. 5), which also provide a clue for a relatively stable environment.

DISCUSSION

EH provides tremendous source of comparative investigation to show the effects of different nutritional as well as ecological stressors in various mammalian taxa (Khan, 2017). The Middle Miocene Siwalik paleoclimate

is characterized by warm and humid conditions with dense forests domination (Raza *et al.*, 1984; Heissig, 2003). In the Siwalik Middle Miocene (16-12 Ma) no EH were documented in well sampled lineages of rhinos, and validate stable ecological conditions (Roohi *et al.*, 2015; Ahmed *et al.*, 2020). Early Middle Miocene episode of the global warming triggered the temperature rise. Small ruminants were highly dependent on temperature and tropical conditions (Rössner, 2007). Tragulids population density reaches highest at about 11.5 Ma and declined during the Late Miocene due to different ecological conditions (Barry *et al.*, 1991; Badgley *et al.*, 2008).

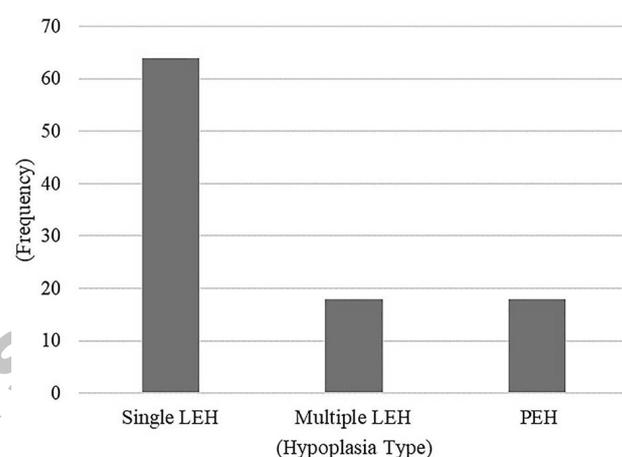


Fig. 5. Histogram showing frequencies (%) of hypoplasia types (single LEH, multiple LEH and PEH) in the observed teeth samples.

Three types of hypoplasia were observed in the studied teeth: single linear hypoplasia (LEH), multiple LEH and pitting enamel hypoplasia (PEH). LEH is the most common type of EH in Chabbar Syedan mammals, as shown in Figure 5. In current EH analysis, the dominance of single LEH, compared to multiple LEH and PEH, might indicates less stressful conditions for browsing mammals in the Chabbar Syedan area (Fig. 5). A relatively high occurrence of single linear enamel hypoplasia suggests stable climatic conditions during the Middle Miocene (Lovell and Whyte, 1999; Guatelli-Steinberg, 2015; Towle and Irish, 2019). The certain types of weathering marks like penetration of root or corrosion can be erroneously attributed to, and/or mixed with LEH, however, both types differ from each other in extent and nature of the marks, EH being more prominent in loss of enamel during the development not the breakage of enamel after postmortem or burial.

The recovered Middle Miocene mammals from Chabbar Syedan site, show a considerably low EH

occurrence. Among eleven studied families, EH observed in only six families. Giraffidae, Tragulidae and Suidae depict low EH occurrence that might be due to their exploitation of various dietary habitats. However, Deinotheriidae, Amelodontidae and Bovidae show slightly higher EH occurrence, that might be due to stress that was imposed by interspecific competition or slight limitations of food resources. The low EH occurrence (9%) in the Siwalik tragulids during the Middle Miocene, compared to the high EH occurrence (48%) during the Late Miocene-Early Pliocene, suggests that the Middle Miocene habitats were beneficial for browsing mammals (Ahmed *et al.*, 2020). The diversity of the mammalian groups provide clue for their compatibility with the Middle Miocene habitats and the existence of a warm, stable and advantageous conditions in the Chabbar Syedan site of northern Pakistan.

CONCLUSIONS

This is the first report on EH of the Middle Miocene mammals (bovids, suids, proboscideans, giraffids and tragulids) from the Chabbar Syedan site. It was speculated that this fauna, faced low level of environmental stress. Although, the direct inference of positive or stressful conditions based only on EH is not straightforward, because the manifestations of EH can have a range of different causes. Moreover, the low occurrence of EH might indicates favorable ecological conditions for browsing mammals in the Middle Miocene (Chinji Formation) of the Chabbar Syedan.

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Statement of conflict of interest

The authors have declared no conflict of interests.

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