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Philip D. Gingerich, Director

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MACHOCYON ABBASI, A NEW EARLY EOCENE QUETTACYONID (MAMMALIA, CONDYLARTHRA) FROM THE MIDDLE GHAZIJ FORMATION OF MACH AND DAGHARI COAL FIELDS, BALUCHISTAN (PAKISTAN)

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Abstract — *Quettacyon parachai* and a new genus and species of quettacyonid condylarth, *Machocyon abbasi*, are described from the coal-bearing middle Ghazij Formation (s.s.) of Mach coal field in Baluchistan. *Machocyon* is similar to *Quettacyon* but differs in being significantly larger, in having more crowded lower premolars, and in having the talonid of M_2 broader than the trigonid. New quettacyonid specimens referred to *Machocyon abbasi* are also described from the middle Ghazij of Daghari coal field. Middle Ghazij mammals are the older of two distinct land-mammal faunas known from Baluchistan. Both faunas lie above lower Ghazij shales containing planktonic foraminifera of P6 age (in the Sor Range) and below Drug limestone containing planktonic foraminifera of P9 age (in eastern Baluchistan and western Punjab). This means that the mammal-bearing middle Ghazij is probably middle early Eocene, calibrated at about 52±1 Ma.

INTRODUCTION

The Ghazij Formation is a sequence of marine and continental clastic strata, coal-bearing in the middle part, that is widely distributed in the axial belt of the Sulaiman part of the lower Indus Basin, Baluchistan. Ghazij sediments were deposited in a foreland basin that developed in the Neo-Tethys ocean off the northwestern margin of the Indo-Pakistan subcontinent during early Eocene time, before tectonic suturing of the subcontinent to the rest of Asia. The distribution of sedimentary facies and paleocurrent directions both indicate derivation from the north and west, from an offshore source (Jones et al., 1960; Waheed and Wells, 1990; Pivnik and Wells, 1996; Warwick et al., 1998). This source is envisioned as a faulted chain of Ghazij Islands (Gingerich et al., 1997), possibly related to obduction of Tethyan sea floor forming what are now known as

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Bela-Waziristan ophiolites (Allemann, 1979; Ahmad and Abbas, 1979; and Bannert et al., 1992). Ghazij deposition had a complex history that can only be clarified with better temporal control on the geographic distribution of stratigraphic facies and sedimentary environments. Fortunately, Ghazij sediments contain fossil land mammals (Gingerich et al., 1997, 1998; Ginsburg et al., 1999). Mammals generally evolve rapidly and disperse widely, and better knowledge of these promises to improve our understanding of the timing and environment of deposition of economically-important Ghazij coal, and the biogeographic history of early Cenozoic mammals.

The Ghazij Formation of Oldham (1890) and Williams (1959) is conventionally divided into three parts (e.g., Jones et al., 1960): (1) a lower green shale unit with marine fossils and minor lenticular sandstones indicating that it was deposited offshore in Tethys beyond the transport of coarse clastics; (2) a middle green shale unit with interbedded lignitic coals and tabular sandstones interpreted as having been deposited in a paludal environment in a lagoonal setting; and (3) an upper variegated green, brown, red, purple, and yellow mudstone and shale unit, with cross-bedded lenticular sandstones, and conglomerate in places. Color bands in the upper unit are interpreted as paleosols developed on overbank muds, while coarser clastics are interpreted as alluvial fanglomerates and channel sands deposited in a fluvial environment. The lower, middle, and upper units differ lithologically, and are sometimes divided into two formations (e.g., Shaheed Ghat and Toi formations), or the name Ghazij is sometimes used as a formation or group representing all sediments deposited during early Eocene time (Shah, 1990, 1991; Kazmi and Jan, 1997). However, the Ghazij Formation (sensu stricto), as used here, is part of a single shallowing-upward marine-to-continental genetic sequence, and, in the absence of compelling evidence requiring revision, we retain long-established stratigraphic nomenclature in the area of our study (e.g., Jones et al., 1960; Reinemund et al., 1985).

The purpose of this report is to place on record several new mammalian fossils extending the geographic range of the middle Ghazij fauna, and augmenting the diversity of known middle Ghazij land-mammals. Constraints on the age of the middle Ghazij fauna are also considered.

INSTITUTIONAL ABBREVIATIONS

GSP-UM — Geological Survey of Pakistan-University of Michigan collection, Quetta (Pakistan)
UM — University of Michigan Museum of Paleontology, Ann Arbor (U.S.A.)

QUETTACYONIDS FROM MACH AND DAGHARI

Quettacyon parachai was first described from the Sor Range 20 km east-southeast of Quetta (Gingerich et al., 1997; Fig. 1). New quettacyonid specimens described here come from the Mach and Daghari coal fields. Mach is located some 50 km southeast of Quetta, in the north central part of Baluchistan, and Daghari is located some 35 km east-southeast of Quetta (Fig. 1). Three areas are mined near Mach: (1) Satra, north of Mach; (2) Bor, south and southeast of Mach; and (3) Gishtari, west and southwest of Mach (Fig. 2). Both Mach fossils described here came from the Gishtari area.

Order CONDYLARTHRA
Family Quettacyonidae Gingerich et al., 1997

Included genera. — Four genera and species of quettacyonids are known: *Quettacyon parachai* Gingerich et al., 1997; *Sororocyon usmanii* Gingerich et al., 1998; *Obashtakaia aeruginis* Gingerich et al., 1998; and *Machocyon abbasi* new genus and species.

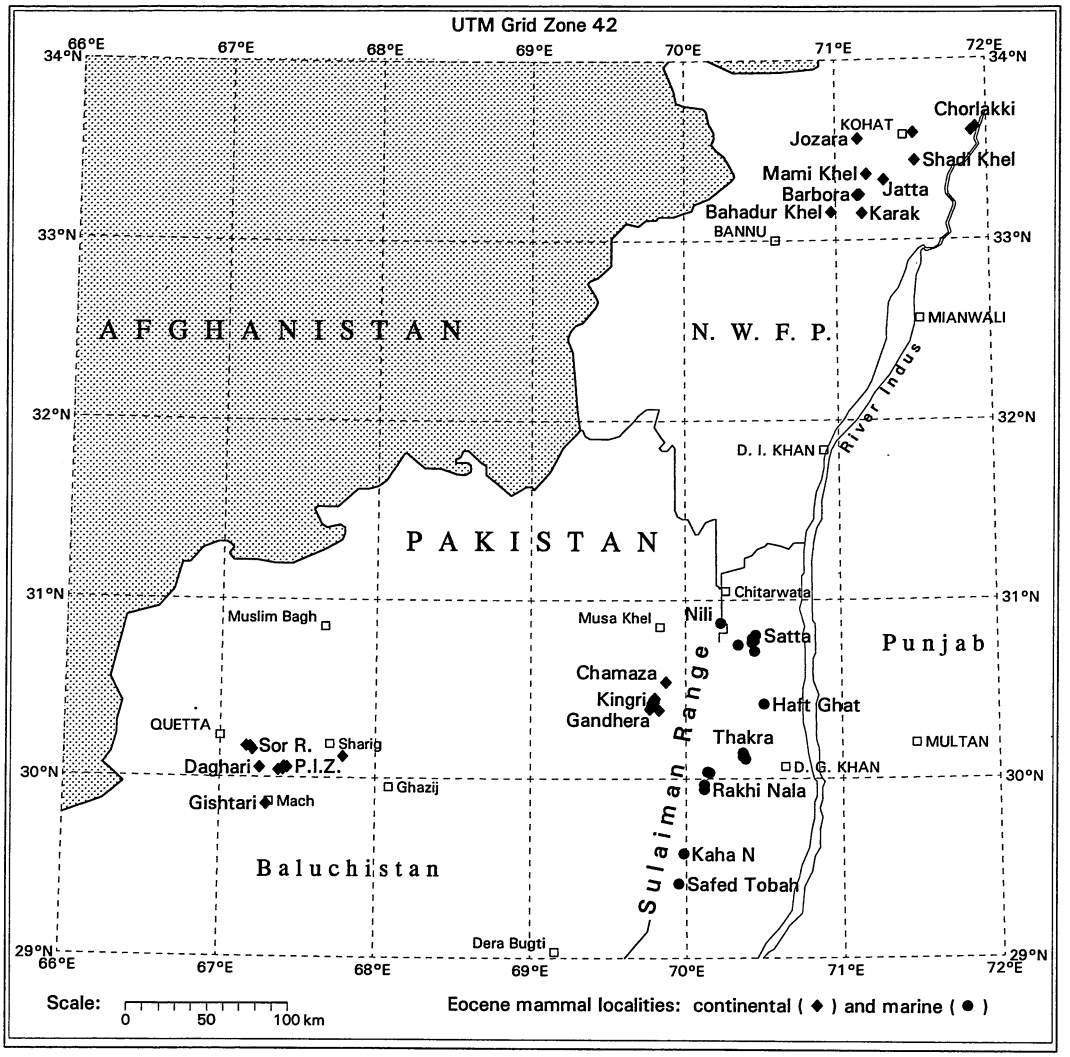

FIG. 1 — Map showing the locations of Mach and Daghari coal fields relative to the city of Quetta, to the Sor Range coal field, and to the Sharig-Nakus coal field yielding middle and upper Ghazij Formation specimens described previously (Gingerich et al., 1997, 1998; Ginsburg et al., 1999). Other Pakistan continental and marine Eocene mammal localities in Universal Transverse Mercator grid zone 42 are shown for reference.

Discussion. — *Quettacyon* was first placed in Quettacyoninae by Gingerich et al. (1997), and this was regarded as a subfamily of Arctocyonidae. Quettacyoninae was elevated to family status by Gingerich et al. (1998) because canine teeth of *Sororocyon* are unlike those of Arctocyonidae, and to acknowledge newly-documented South Asian diversity.

Quettacyon parachai Gingerich et al., 1997
Fig. 3

Holotype. — GSP-UM 4000, a right dentary with P_4-M_3 from Tariq Habib coal mine in the Sor Range coal field east of east-southeast of Quetta.

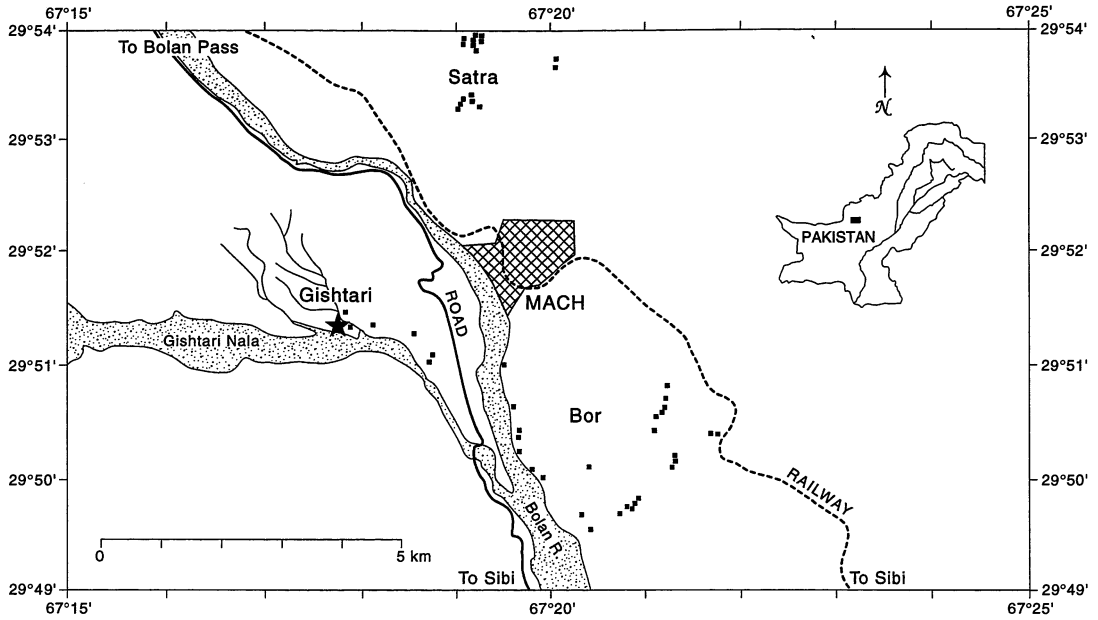

FIG. 2 — Map showing three coal mining areas of Mach coal field: Satra in the north, Bor in the southeast, and Gishtari in the southwest. Mach fossils described here came from the Gishtari area. The type locality of *Machocyon abbasi* in Pundelgoat, just north of Gishtari Nala, is shown as a star.

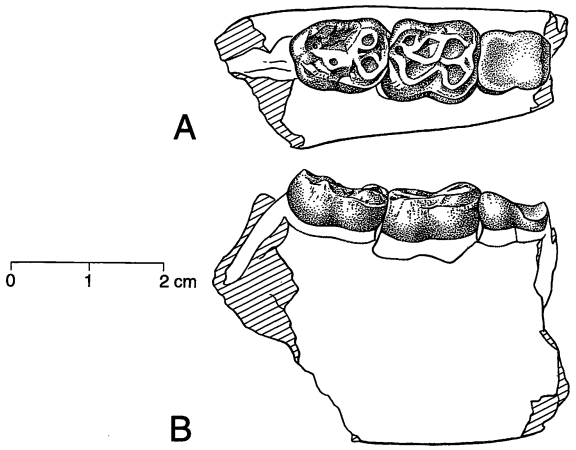

FIG. 3 — Referred specimen of *Quettacyon parachai*, GSP-UM 4021, from the Gishtari area of Mach coal field (precise locality and stratigraphic level unknown). Right dentary with M_{1-3} in (A) occlusal, and (B) right lateral views.

Referred specimen. — GSP-UM 4021, right dentary with M_{1-3} (Fig. 3) from the Gishtari area of Mach coal field southeast of Quetta.

Age and distribution. — *Quettacyon parachai* is known from the type locality in the Sor Range coal field some 20 km east-southeast of Quetta, and the referred specimen comes from the Mach

TABLE 1 — Measurements of the holotype and referred dentaries of *Quettacyon parachai* from Sor Range and Mach coal fields, respectively, and the holotype of *Machocyon abbasi* from Mach coal field. Abbreviations: *CrL*, anteroposterior crown length; *CrW*, buccolingual crown width; *TriW*, buccolingual trigonid width; *TalW*, buccolingual talonid width; *MndD*, mandibular depth. All measurements are in mm. Asterisks indicate estimates.

	Quettacyon parachai GSP-UM 4000 (holotype) Sor Range				*Quettacyon parachai* GSP-UM 4021 Mach (Gishtari)				*Machocyon abbasi* GSP-UM 4208 Mach (Gishtari)			
	CrL	CrW-TriW	TalW	MndD	CrL	CrW-TriW	TalW	MndD	CrL	CrW-TriW	TalW	MndD
Maxillary dentition												
C^1	—	—	—	—	—	—	—	—	14.1	12.1	—	—
Mandibular dentition												
P_2	—	—	—	—	—	—	—	—	10.1	6.9	—	38.4
P_3	—	—	—	—	—	—	—	—	13.8	10.5	—	36.0
P_4	10.4	8.2	—	20.8	—	—	—	—	13.8	10.8	—	34.1
M_1	9.4*	8.0*	8.3	22.1	9.8	8.0	8.6	26.1	12.1	9.8	10.5	36.9
M_2	11.1	9.9	9.7	22.8	11.3	11.1	11.0	26.1	14.2	12.5	12.7	39.2
M_3	12.0	9.0	7.9	23.5	12.6	10.0	9.2	—	16.2	12.0	11.0	43.0

coal field some 50 km southeast of Quetta, in Baluchistan Province, Pakistan (Fig. 1). Both localities are in the coal-bearing middle part of the Ghazij Formation, which is middle Ypresian in age, early Eocene (planktonic foraminiferal zones P6-P7; see Fig. 12 and discussion below).

Diagnosis. — *Quettacyon parachai* differs from other quettacyonids in having a longer, narrower crown on P_4, with a diastema between P_3 and P_4 (there is no interproximal facet on the anterior surface of the crown of P_4), and in having smaller, narrower, higher-crowned lower molars. All other genera and species have a more massive P_4 with P_3 and P_4 closely appressed. Molars of *Q. parachai* and *Machocyon abbasi* are similar in shape, but *Quettacyon* is smaller and has the talonid of M_2 narrower than the trigonid.

Referred specimen. — GSP-UM 4021, right dentary with M_{1-3} from the Gishtari area of Mach coal field southeast of Quetta.

Description. — The new *Quettacyon* specimen is a right dentary with M_{1-3} (Fig. 3). It has fresh breaks in front of M_1 and behind M_3, indicating that it was once more complete. The molars have cusps and crests developed and positioned very much like those of the holotype GSP-UM 4000, but teeth of the new specimen are more worn. Molar lengths are similar to those of GSP-UM 4000, while molar widths are greater (Table 1). M_1 is heavily worn, and it appears that the medial side of the tooth was broken in life, subjecting the crown to unusual wear. M_{2-3} are a little more worn than these teeth in the holotype, with perforation of the enamel connecting most cusps on M_2. Larger size could indicate that a different species is represented, but we conservatively retain the new specimen in *Quettacyon parachai*.

Discussion. — The new specimen was reported and made available for study by Mr. Mian Abbas Ali, engineer and former inspector of mines (now managing partner of Mian Enterprises in Quetta), who received the specimen from a nephew employed in a supervisory position in the Mach coal field. The new specimen is said to have come from the Gishtari coal bed in the Gishtari area, but there are several coal beds being mined in this area (Warwick et al., 1994) and records are inadequate to confirm which coal it came from. The new specimen has been assigned number GSP-UM 4021, although the original has been retained by Mr. Mian Abbas Ali.

FIG. 4 — Photograph showing the Aziz Brothers mine (arrow), lease #20, in middle Ghazij strata, Pundelgoat, Gishtari area of the Mach coal field. Large dry stream bed at left is Gishtari Nala. View is to the west.

Machocyon abbasi, new genus and species
Figs. 6-8; 9A; 10C-E, G-I, K-M, and P-Q

Holotype. — GSP-UM 4208, associated left C^1 (Fig. 8A), left P_4, and right dentary with alveoli for C_1 and P_1 and intact crowns of P_2-M_3 (Fig. 7A-B).

Type locality. — Shisha coal in Aziz Brothers Mining Company lease #20 (Figs. 4-5), incline #1, Pundelgoat, Gishtari area of Mach coal field, some 50 km southeast of Quetta, in Baluchistan Province, Pakistan. Coordinates of the *Machocyon abbasi* type locality are 29°51.38' N latitude and 67°17.83' E longitude (Survey of Pakistan 15' topographic map 34 O/5).

Referred specimens. — Daghari specimens of *Machocyon abbasi* include GSP-UM 4385, crown of left P^4 (Fig. 8B-C); 4386, left maxilla with M^{1-2} (Fig. 8D-E); 4387, crown of left M^1 (Fig. 9C); 4388, partial crown of left M^2 (Fig. 9D); 4390, partial crown of right P^4 (Fig. 9F); 4391, crown of right M^1 (Fig. 9G); 4392, crown of right M^1 (Fig. 9H); 4393, crown of right M^3 (Fig. 9I); 4395, right dentary with M_{2-3} (Fig. 8F-G); 4396-4397, right dentary with partial crown of P_3 and right dentary with M_2 and partial crown of M_3, respectively—possibly associated (Fig. 9P-Q); 4398, crown of right P_3 (Fig. 9K); 4399, talonid of right M_2 (Fig. 9L); 4400, trigonid of right M_3 (Fig. 9M); and 4401, midshaft of right humerus (Fig. 10A).

Age and distribution. — *Machocyon abbasi* is known from the type locality, and from 400 feet down Hole #2 of the Aziz Coal Company mine in Daghari coal field, some 35 km east-southeast of Quetta (coordinates of the mine are not yet available; Daghari is shown in Fig. 1). Both localities

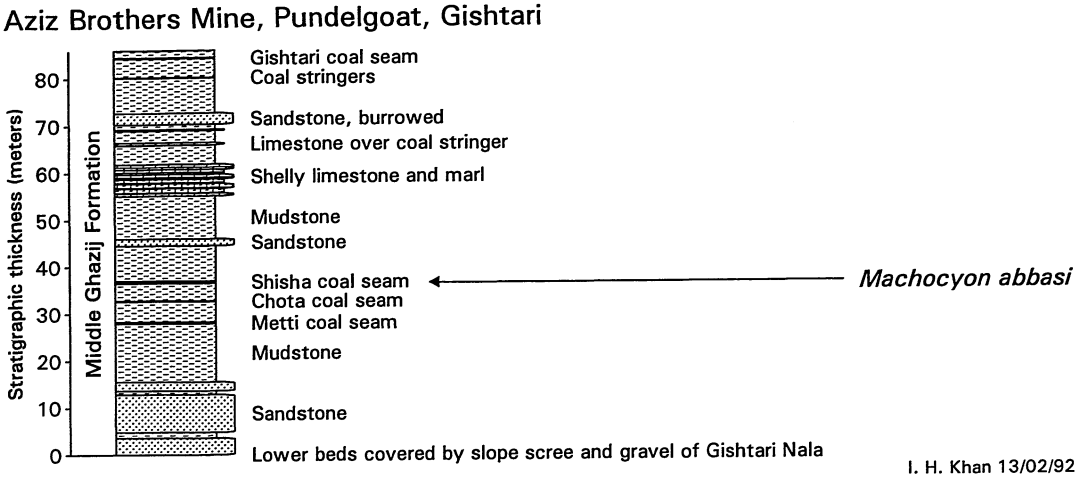

FIG. 5 — Stratigraphic section of the Aziz Brothers mine, lease #20, in the middle part of the Ghazij Formation, Pundelgoat, Gishtari area of the Mach coal field. Four distinct coal seams are present in this section, and the holotype of *Machocyon abbasi* came from the Shisha seam.

are in the coal-bearing middle part of the Ghazij Formation, which is middle Ypresian in age, early Eocene (planktonic foraminiferal zones P6-P7; see Fig. 12 and discussion below).

Diagnosis. — *Machocyon abbasi* is the largest quettacyonid known to date. It has the relatively narrow, high-crowned lower molars of *Quettacyon parachai*, but differs in having more massive premolars and no diastema between P_3 and P_4. The talonid of M_2 is broader than the trigonid in *Machocyon* (Fig. 11). *Machocyon* further differs from *Sororocyon* in lacking the crest connecting the hypoconid and entoconid found in the latter. Further differs from *Obashtakaia* in lacking a medial cusp on the talonid of P_4.

Etymology. — Genus is named for Mach coal field; root *kyon*, Gr. (masc.), dog, parallels that of other quettacyonids and arctocyonids. Species is named for Mr. Syed Abbas, formerly raising contractor at Aziz Brothers Mining Company, Mach, and now owner of the Royal Coal Company mine in the Sor Range. Mr. Syed Abbas found the type specimen of *Machocyon abbasi* on the spoil pile of the Aziz Brothers mine, Mach, in 1982.

Description. — The holotype is the principal specimen of *Machocyon abbasi* known to date. We first describe it and then describe referred specimens. The type dentary was found attached to a bed of marl ('*met*') several centimeters thick embedded in glassy vitreous coal, confirming that it came from the *Shisha* ('glassy') coal seam. It was still embedded in coal and marl when presented to us for study (Fig. 6). The associated upper canine and isolated premolar were found at the same time, suggesting that this specimen too was once substantially more complete.

The right dentary of the holotype of *M. abbasi* is the most complete quettacyonid specimen described to date (Fig. 7). The mandibular symphysis is well preserved on the medial side of the horizontal ramus. It is massive and extends back to a position below P_3. Left and right dentaries were not co-ossified in life. An alveolus for C_1 is preserved, and this appears to have housed a canine with a laterally compressed root (but apparent compression may have been caused by compaction during burial). There is an alveolus for a single-rooted P_1. All of the rest of the cheek teeth are double-rooted.

The crown of P_2 is relatively small and narrow, with a substantial apical cusp (protoconid), now worn, and conspicuous crests running anteriorly and posteriorly from this. The posterior crest has

FIG. 6 — *Machocyon abbasi* holotype, GSP-UM 4208, in matrix as found on the spoil pile of the Aziz Brothers Mining Company, lease #20, in the Pundelgoat area of Gishtari Nala, Mach coal field, Baluchistan. Matrix is shown in cross-section, with a 3 cm layer of black coal at the bottom, a 3-4 cm layer of khaki-colored marl or *met* in the middle, and a thin layer of black coal with the specimen at the top (original top of the block is indeterminate — it may be upside down as shown here). The ascending ramus of the dentary, lateral side up, covers approximately 7 cm of the right top surface of the block shown here. A remnant of the medial part of the mandibular condyle caused the conspicuous depression of bedding in the marl during postdepositional burial and compaction. Coal attached to the specimen has a vitreous luster, confirming that the fossil came from the *Shisha* or 'glassy' coal seam in this area. Scale is in cm.

a slight swelling where the talonid cusp (hypoconid) is developed on following premolars. P_3 and P_4 are much larger than P_2 and very similar to each other. Both have massive apical cusps (protoconids) perforated by wear to expose a circular, slightly-cupped dentinal surface. Both have substantial talonid cusps (hypoconids), each with a smaller circular, cupped exposure of dentine. P_3 differs from P_4 in having a slightly narrower anterior crown and in lacking an interproximal facet on the anterior surface of the crown.

The crown of M_1 is relatively small and narrow compared to the preceding premolars and following molars. The trigonid is completely worn away leaving a relatively large rectangular surface of dentine surrounded by a rim of enamel. Talonid cusps are also heavily worn, but there is a labial crescent of dentine exposure representing what was once a substantial hypoconid, and there is a smaller lingual crescent of dentine exposure representing what appear to have been twinned hypoconulid and entoconid cusps. The hypoconid is positioned well in toward the midline of the tooth, and there is a substantial labial cingulid surrounding it laterally and posteriorly.

The crown of M_2 is well preserved, with wear perforating the enamel on the protoconid, metaconid, hypoconid, and hypoconulid. The tooth as a whole is relatively high-crowned, like M_2 of *Quettacyon parachai*, but the trigonid is a little higher than the talonid. The two principal trigonid cusps, the protoconid and metaconid are confluent at their bases, and in addition have both anterior and posterior crests connecting them. Each trigonid crest thus encloses a small anterior or posterior trigonid fovea. There is a small cuspule on the anterior crest near the metaconid that represents what remains of a paraconid. The hypoconid is the lowest cusp on the crown of M_2,

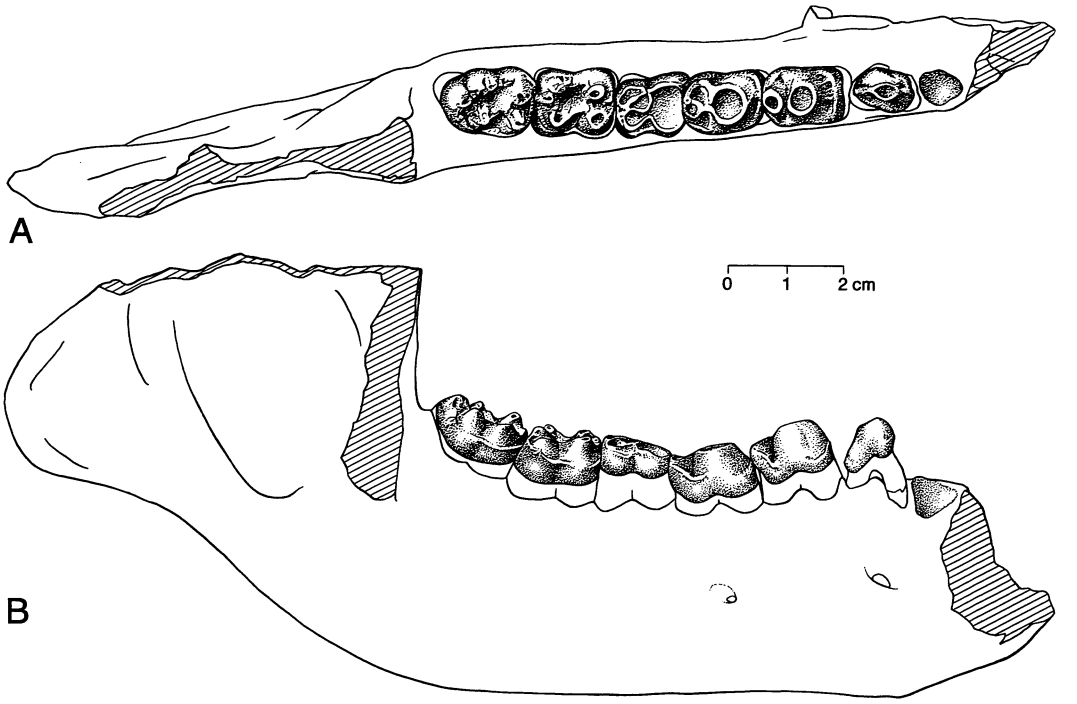

FIG. 7 — *Machocyon abbasi* holotype, GSP-UM 4208, right dentary with P_2-M_3 after preparation, in (A) occlusal, and (B) lateral views. Note massive symphysis, which was unfused in life; the relatively narrow space remaining for a canine alveolus, suggesting that the lower canine may have been mediolaterally compressed; the large P_3 and P_4 with heavy wear on the apical cusp; and the elevated position of the mandibular angle.

while the hypoconulid and entoconid, twinned near the lingual side of the tooth, are somewhat higher. The cristid obliqua on the talonid runs forward and slightly medially from the hypoconid to join the posterior crest connecting trigonid cusps. Low crests connect the hypoconid to the hypoconulid and the entoconid to the back of the metaconid, thus enclosing a narrow talonid basin. There is a distinct labial cingulid that becomes faint where it surrounds the hypoconid but it is again distinct posteriorly. On M_2 the talonid, when measured, is slightly wider than the trigonid, but this difference is difficult to see without measurement.

The crown of M_3 is similar to that of M_2 with the notable difference that the talonid is longer and narrower, and the hypoconulid is positioned more posteriorly. The lateral surface of the dentary has mental foramina below P_2 and below P_4. The ascending ramus of the dentary rises vertically just behind M_3. The ventral border of the posterior part of the horizontal ramus rises at an angle of about 35 to 40° before flaring into a broad and flat mandibular angle. The mandibular condyle was positioned above the mandibular angle, well above the level of the tooth row. The masseteric fossa on the posterior border of the ascending ramus appears relatively shallow as preserved, but this is probably misleading as the lateral surface of the posterior border of the masseteric fossa is missing. In other quettacyonid specimens this border forms a prominent flange of bone projecting above a deep masseteric fossa.

Two additional teeth are preserved with the holotype of *Machocyon abbasi*. One is an isolated left P_4 that is a mirror image of P_4 in the type right dentary. The other is a left C^1 with much of the root and crown preserved (Fig. 8A). The root is much more massive than the crown. It is posteriorly-angled relative to the crown, but the root itself is relatively straight. The root is oval in cross-

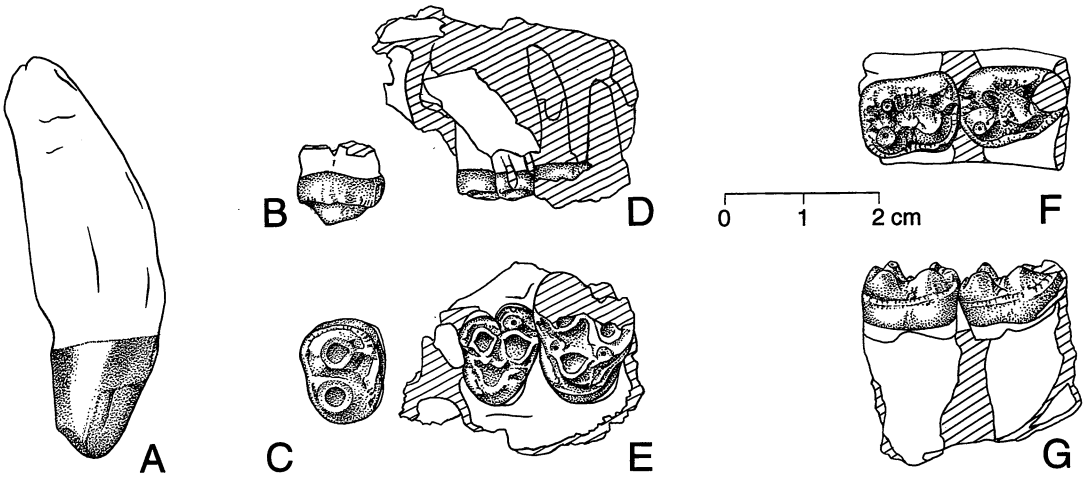

FIG. 8 — *Machocyon abbasi*. A, left canine of holotype, GSP-UM 4208 from Mach coal field, in medial view. B-C, left P^4, GSP-UM 4385 from Daghari coal field, in lateral and occlusal views. D-E, left maxilla with M^1-M^2, GSP-UM 4386 from Daghari coal field, in lateral and occlusal views. F-G, left dentary with M_2-M_3, GSP-UM 4395, from Daghari coal field, in occlusal and lateral views. Note the large size of C^1, oval in cross-section, with wear on the anteromedial surface of the crown due to occlusion with a lower canine, and wear on the posteromedial surface of the crown and root thought to result from abrasion while stripping plant material. Note also the large crushing crown of P^4, the small size of M^1 relative to M^2, and the distinct metastyle lateral to the metacone on M^1 (a metastyle was probably present on M^2 too, but the metastylar area of M^2 is broken). Paraconids are more strongly developed on M_2 and M_3 of GSP-UM 4395, shown here, than they are on these teeth in the holotype.

section, measuring about 19.2 × 13.4 mm in greater and lesser diameters, respectively. The lateral surface of the crown of C^1 has a band of crenulated enamel separating the base from the lower crown, but otherwise the enamel surface is relatively smooth. The medial surface is more complex, with a slight anteromedial fovea surrounded by wear from occlusion with C_1, and a large medial and posteromedial area of abraded wear above the dentinoenamel junction that appears to have been caused by stripping vegetation. This abrasion extends around the posterior part of the root and is expressed as a concavity in both medial and lateral views.

Referred specimens. — Specimens from the Aziz Coal Company mine in Daghari add information about variation in characteristics known in the holotype, and some new information about teeth not preserved in the type. These were found together 400 feet down Hole #2 during excavation of a gallery that is faulted with no coal seam. All were presented to us in a bag of broken jaws, teeth and bones. Some pieces fit together and have been reassembled, but most appear to represent different individuals and in some cases a species other than *Machocyon abbasi*. All are described together here because they were found together, most represent *M. abbasi*, and there is uncertainty about attribution of the few teeth and bones that do not belong to *Machocyon*.

GSP-UM 4389 is a left or right canine root (Fig. 9E) similar in size and proportions to that associated with the type.

GSP-UM 4385 is an isolated P^4 (Fig. 8B-C) with two cusps, a large buccal paracone and a slightly smaller lingual protocone. Both have large perforations in the enamel of the crown exposing circular areas of dentine. There are weak crests running anteriorly and posteriorly from the paracone, and a continuous cingulum surrounds all but the lingual margin of the crown.

GSP-UM 4386 is a maxillary fragment with $M^{1\text{-}2}$ (Fig. 8D-E). This is the first maxilla of a quettacyonid to be described and shows M^1 to be notably smaller than M^2. The crown of M^1 is worn but shows the essential features (see also GSP-UM 4387, and 4391-4392; Figs. 10C, and G-H, respectively). The crown is tritubercular, with prominent protocone, paracone, and metacone.

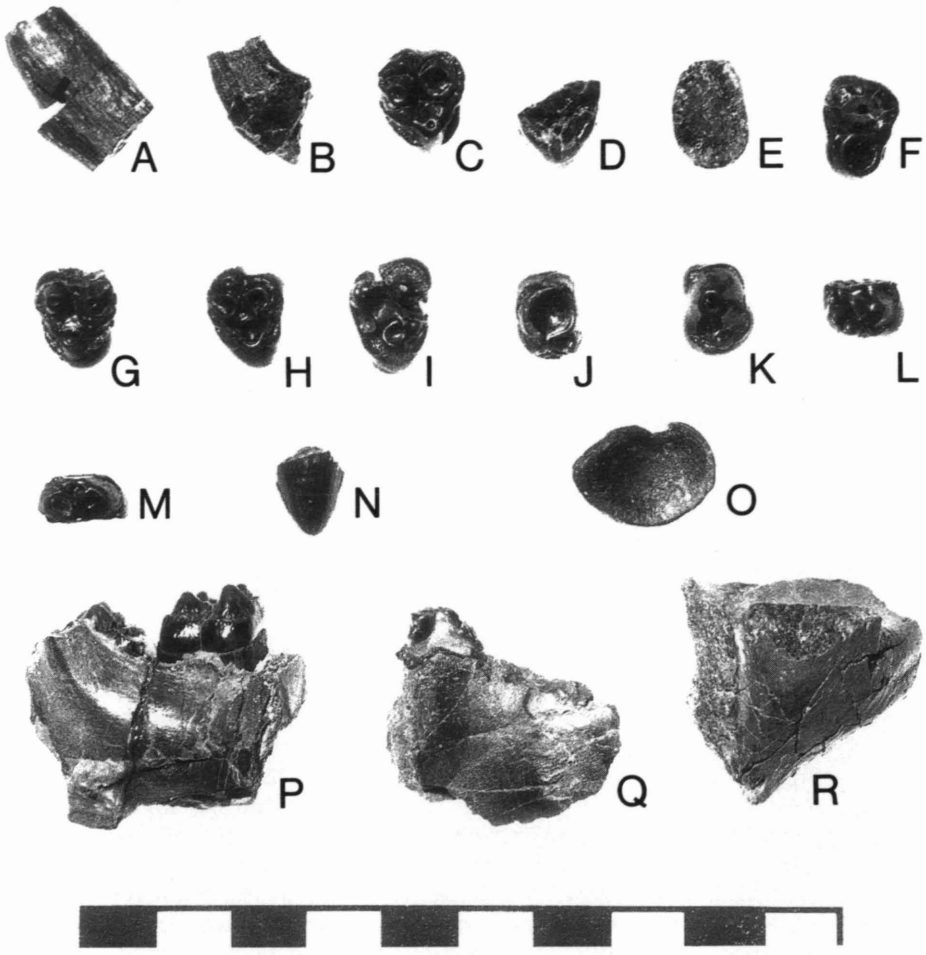

FIG. 9 — Teeth and bones from the Aziz Coal Mine in Daghari coal field. A, GSP-UM 4383, left C_1 root and partial crown, possibly *Machocyon abbasi*, lateral view. B, GSP-UM 4384, right C_1 partial crown, possibly *Quettacyon parachai*, medial view. C, GSP-UM 4387, left M^1 crown lacking metastyle, *M. abbasi*, occlusal view. D, GSP-UM 4388, left M^2 partial crown, *M. abbasi*, occlusal view. E, GSP-UM 4389, left or right C^1 root, *M. abbasi*, cross-section. F, GSP-UM 4390, right P^4 crown, possibly *M. abbasi*, occlusal view. G, GSP-UM 4391, right M^1 crown, *M. abbasi*, occlusal view. H, GSP-UM 4392, right M^1 crown, *M. abbasi*, occlusal view. I, GSP-UM 4393, right M^3 crown, *M. abbasi*, occlusal view. J, GSP-UM 4394, left P_4 partial crown, possibly *M. abbasi*, occlusal view. K, GSP-UM 4398, right P_3, *M. abbasi*, occlusal view. L, GSP-UM 4399, right M_2 talonid, *M. abbasi*, occlusal view. M, GSP-UM 4400, right M_3 trigonid, *M. abbasi*, occlusal view. N, GSP-UM 4404, crocodilian tooth, lateral view. O, GSP-UM 4402, radial head, possibly *Q. parachai*, proximal view. P, GSP-UM 4397, right dentary with M_2, M_3 erupting, *M. abbasi*, lateral view. Q, GSP-UM 4396, right dentary P_3 (?), *M. abbasi* (possibly same individual as GSP-UM 4397), lateral view. R, GSP-UM 4403, left squamosal fragment, possibly *M. abbasi*, ventral view.

There is some indication of a weakly developed paraconule between the protocone and paracone in some specimens, and a well developed metaconule is consistently present between the protocone and metacone. The buccal cingulum is well developed surrounding both the paracone and metacone and distinctively inflected between them. There is a conspicuous metastyle or metastylar cusp developed on the buccal cingulum positioned laterally and just slightly anteriorly relative to the

metacone. Anterior and posterior cingula flank the protocone. These are variably but weakly connected lingually to the protocone.

M^2 is best preserved in GSP-UM 4386 (Fig. 8D-E; see also GSP-UM 4388, Fig. 9D). This tooth is much larger than M^1 in the same maxilla and probably resembled it closely (however no M^2 is known preserving the buccal margin of the crown). Conules, particularly the paraconule, appear to be a little better developed on M^2 than they are on M^1.

The only known M^3 of *M. abbasi* is an isolated tooth, GSP-UM 4393 (Fig. 9I), with a worn crown. It is generally similar to M^1 and M^2, but differs in lacking a metastyle and in having a smaller metacone that is more lingually positioned on the crown.

Two lower canines of very different form are present in the Daghari collection. The first lower canine, GSP-UM 4383 (Fig. 9A) possibly representing *M. abbasi*, has a narrow band of thin smooth enamel on the lateral side representing the base of the crown. The crown and root appear to have been straight. The root is large but mediolaterally compressed, unlike the roots of the upper canines in the type (GSP-UM 4208; Fig. 8A) and referred specimen (GSP-UM 4389; Fig. 9E). The second lower canine, GSP-UM 4384; Fig. 9B), possibly representing *Quettacyon parachai*, differs in being smaller, in having a more curved crown and root, and in having more crenulated enamel with a distinct crest running up the lingual side of the crown. The latter canine is typical of some carnivorous early Eocene mammals like, for example, oxyaenids.

GSP-UM 4398 (Fig. 9K) is a P_3, as is, possibly, GSP-UM 4396 (Fig. 9Q) — the latter may be dP_3. The crown of GSP-UM 4398 is similar to that of P_3 in the holotype, but it is smaller and a little narrower anteriorly. There is no interproximal wear facet for P_2 on the front of the tooth, but there is a distinct interproximal facet for P_4 on the back.

GSP-UM 4394 (Fig. 9J) is a worn crown of P_4 that is smaller than P_4 in the holotype, but referred to this species because it has both anterior and posterior interproximal facets for contact with adjacent teeth.

The only M_1 known is that in the holotype. M_2 and M_3 are present in two additional specimens, GSP-UM 4395 (Fig. 8F-G) and GSP-UM 4397 (Fig. 9P). Both have M_2 a little smaller than that in the holotype but are otherwise very similar. The M_2 paraconid of GSP-UM 4395 is more strongly developed than the M_2 paraconid of the holotype, while that of GSP 4397 is intermediate. M_3 in GSP-UM 4395 is similar to M_3 of the holotype, but cuspules are more evident on all of the crests. The crown of M_3 in GSP-UM 4397 is damaged, but also clearly not yet fully erupted. If GSP-UM 4396 and 4397 are parts of the same individual (both are juveniles), then identification of the tooth in the former as P_3 or dP_3 has implications for the pattern of dental development and life history in *Machocyon* — these can only be investigated when better specimens are available.

One fragmentary cranial bone was found in the Daghari collection in addition to the maxilla described above. GSP-UM 4403 is a left squamosal fragment (Fig. 9R) preserving much of a cylindrical glenoid fossa, part of the postglenoid process, and the base of the left zygomatic arch. There is no postglenoid foramen.

Some fragmentary postcranial remains were found in the Daghari collection. The two identifiable specimens are GSP-UM 4401, the midshaft of a right humerus, and GSP-UM 4402, the head of a radius. GSP-UM 4401 (Fig. 10A), identified as *M. abbasi*, is larger and a little less complete but otherwise similar to the upper Ghazij humeral midshaft GSP-UM 4011 (Fig. 10B) that Gingerich et al. (1998, p. 11) referred to *Sororyctes ghaznavii* (this humerus is now regarded as belonging to *Obashtakaia aeruginis*, based on a new partial skeleton from Pir Ismael Ziarat). Both have the supinator crest rising from the lateral side of the midshaft at approximately the same level as the distalmost extension of the deltopectoral crest, and both of these crests were clearly very strongly developed. GSP-UM 4401 preserves a part of the entepicondylar foramen, which is also present in GSP-UM 4011. Both humeri are similar to those of European Paleocene *Arctocyon primaevus* (e.g., Russell, 1964, p. 162), but the supinator and deltopectoral crests and the entepicondyle of the latter are more strongly developed. Supinator and deltopectoral crests and the entepicondyle are much less developed in primitive cursors of similar size like *Phenacodus* (e.g., UM 94050 and 95020). GSP-UM 4401 measures 22.7 mm in minimum anteroposterior diameter below the

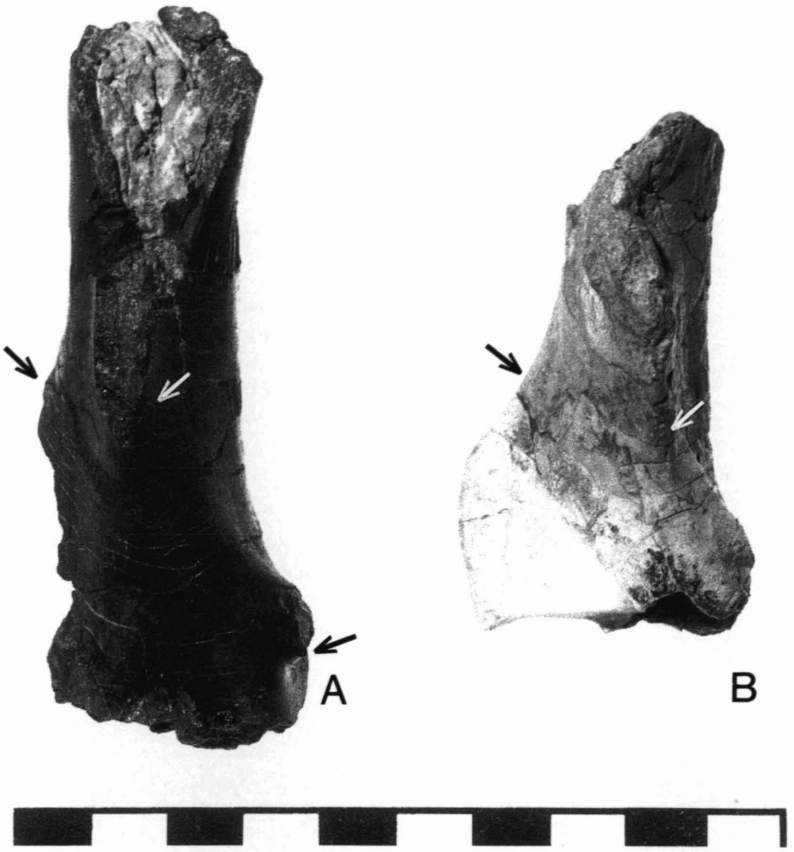

FIG. 10 — *Machocyon abbasi* humerus compared to that of *Obashtakaia aeruginis* (previously referred to *Sororyctes ghaznavii* by Gingerich et al., 1998). A, midshaft of right humerus of *Machocyon abbasi*, GSP-UM 4401, in anterior view. B, midshaft of right humerus of *Obashtakaia aeruginis*, GSP-UM 4011, in anterior view. Note that both have the apex of the flaring supinator crest on the lateral side of the humerus (black arrows) at the same level as the base of the deltopectoral crest on the midline of the shaft (white arrows). A portion of the entepicondylar foramen is present on the medial side of the shaft in the *Machocyon* humerus (black arrow). Scale is in cm.

deltopectoral crest and above the entepicondylar foramen; 22.4 mm in minimum transverse diameter above the supinator crest and above the base of the deltopectoral crest; and 23.5 mm in anteroposterior diameter at the level of the entepicondylar foramen. For comparison, these diameters are 18.6, 20.0, and 18.3 mm, respectively, in GSP-UM 4011.

The radial head GSP-UM 4402 (Fig. 9O) appears to be too small to articulate with a humerus the size of GSP-UM 4401 (again comparing to *Phenacodus* UM 94050), and it is thus tentatively referred to *Quettacyon parachai*. The ulnar border of the radial head is smoothly curved (unlike either *Arctocyon* or especially *Phenacodus*), which permitted considerable supination and pronation of the forearm. Remaining unidentifiable postcranial bone fragments from Daghari are included as a lot in GSP-UM 4405.

Measurements of the holotype of *Machocyon abbasi* are listed in Table 1, and measurements of Daghari specimens are listed in Table 2.

TABLE 2 — Inventory of vertebrate specimens reported from the Aziz Coal Company mine, Daghari coal field. Abbreviations: *CrL*, crown length; *CrW1*, crown width measured over the paracone for upper molars, or trigonid width for lower molars; *CrW2*, crown width measured over the metastyle (M^1 and M^2) or metacone (M^3) for upper molars, or talonid width for lower molars. All measurements in mm. Asterisks indicate estimates.

GSP-UM	Description	CrL	CrW1	CrW2	Remarks	Text-figure
4383	Left C_1 crown-root	—	9.1	—	Root cross-section 13.8 × 8.6	Fig. 9A
4384	Right C_1 crown	12.4	8.5	—	Base of crown, tip broken	Fig. 9B
4385	Left P^4 crown	11.4	15.2	—	—	Fig. 8B-C
4386	Left max. M^{1-2}	10.2	12.5	13.2	M^1 measurements	Fig. 8D-E
		13.8	17.9	—	M^2 measurements, metastylid broken	
4387	Left M^1 crown	11.1	14.0	—	Metastylid broken	Fig. 9C
4388	Left M^2	—	—	—	Lingual half of crown	Fig. 9D
4389	L or R canine root	—	—	—	Root cross-section 14.9 × 10.4	Fig. 9E
4390	Right P^4 crown	10.2	14.2	—	—	Fig. 9F
4391	Right M^1 crown	11.8	14.3	14.9	—	Fig. 9G
4392	Right M^1 crown	10.6	12.8	14.0	—	Fig. 9H
4393	Right M^3 crown	11.6	15.1	14.3	—	Fig. 9I
4394	Left P_4 crown	12.0*	8.6	—	Posterior margin broken	Fig. 9J
4395	Left dent. M_{2-3}	13.0	10.7	11.0	M_2 measurements	Fig. 8F-G
		14.0	10.7	9.4	M_3 measurements	
4396	Right dent. P_3 (?)	11.6*	7.8*	—	Possibly same individual as 4397	Fig. 9P
4397	Right dent. M_{2-3}	12.6*	10.8	11.2	M_2 measurements, poss. part of 4396	Fig. 9Q
		—	10.0	9.0	M_3 measurements	
4398	Right P_3	12.5	9.9	—	—	Fig. 9K
4399	Right M_2 talonid	—	—	11.4	—	Fig. 9L
4400	Right M_3 trigonid	—	11.8	—	—	Fig. 9M
4401	R humerus midshaft	—	—	—	Midshaft ca. 22.7 × 22.4 (see text)	Fig. 10A
4402	Head of radius	—	—	—	Head ca. 19.2 × 13.8	Fig. 9O
4403	Squamosal fragment	—	—	—	—	Fig. 9R
4404	Crocodilian tooth	—	—	—	Tooth measures ca. 9.0 × 7.0 at base	Fig. 9N
4405	Miscellaneous bones	—	—	—	—	—

Discussion. — The type specimen of *Machocyon abbasi* has been assigned specimen number GSP-UM 4208, although the original has been retained by Mr. Syed Abbas. A cast of the type and originals of all other specimens are available for study at the Geological Survey of Pakistan, Quetta (GSP-UM collection), and casts of all specimens are available at the University of Michigan (UM collection).

Taking all of the middle Ghazij quettacyonid specimens together, we regard *Machocyon abbasi* as a similar but larger relative of *Quettacyon parachai*. Size variation at the best represented tooth position, M_2, clearly exceeds the amount expected for linear measurements in a single species (Fig. 11). Linear measurements of central cheek teeth generally have a range of about 0.2 units on a natural-logarithmic scale. At the same time, larger and smaller teeth differ in trigonid and talonid proportions. Trigonid and talonid widths are all less than crown lengths, but smaller teeth have trigonid widths greater than talonid widths, while larger teeth have talonid widths greater than trigonid widths. The former are included in *Quettacyon parachai* and the latter are included in *Machocyon abbasi* (Fig. 11).

The mandible and dentition of the type and most complete specimen of *Machocyon abbasi*, GSP-UM 4208 (Figs. 7, 8A), shows it to have had a powerfully-built jaw with blunt crushing wear on premolars and anterior molars. The upper canine is a robust tooth with distinctive abrasive wear interpreted as resulting from stripping of vegetation, and the crested form of the molars is

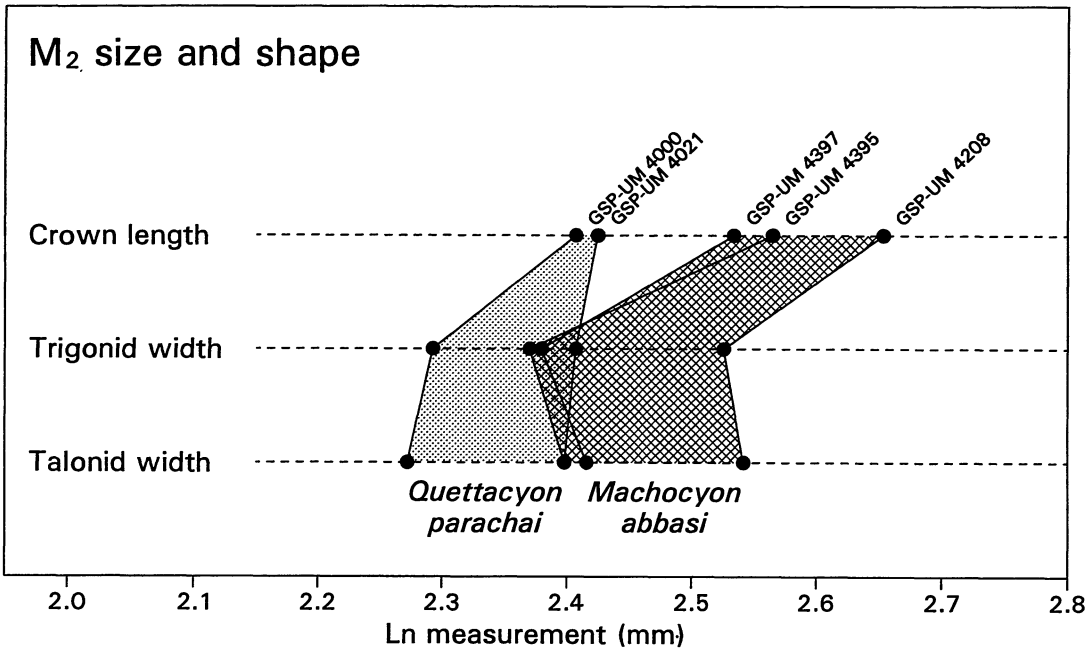

FIG. 11 — Graphic representation of M_2 size and shape distinguishing *Quettacyon parachai* and *Machocyon abbasi*. Here teeth of the same size for a given measurement will overlap, while teeth of the same shape for a series of measurements will plot as parallel lines (that overlap if they are the same size). Two groups are evident: (1) a group of smaller specimens with trigonid width intermediate between talonid width and crown length (stippling), and (2) a group of larger specimens with trigonid width less than both talonid width and crown length (cross-hatching). The former group includes the type of *Quettacyon parachai* (GSP-UM 4000), and the latter group includes the type of *Machocyon abbasi* (GSP-UM 4208).

consistent with bear-like herbivory or omnivory. The humerus from Daghari shows evidence of powerful deltopectoral and supinator crests. Previously, quettacyonid humerus GSP-UM 4011 was interpreted as belonging to a digging mammal (Gingerich, 1998, p. 10), and we infer that *Machocyon* was also a powerful digger.

MIDDLE GHAZIJ MAMMALS

Mammals described to date from the coal-bearing middle part of the Ghazij Formation are all land mammals. Two are quettacyonid Condylarthra: *Quettacyon parachai* described by Gingerich et al. (1997), and *Machocyon abbasi* described here. A third species, *Nakusia sharigensis*, was identified by Ginsburg et al. (1999) as an anthracobunid in the infraorder Anthracobunia, order 'Uranotheria.' All three, as described, belong to endemic South Asian families. This suggests separation and even isolation from contemporary faunas on other continents, but raises important questions as well. Does this endemicity reflect evolution on isolated Ghazij Islands? Does it reflect evolution on a separated Indo-Pakistan subcontinent? Can such a small sample provide an adequate basis for paleofaunal and paleogeographic inference? The answer to the latter is certainly negative, but the first two questions illustrate how important each new addition to the middle Ghazij fauna will be.

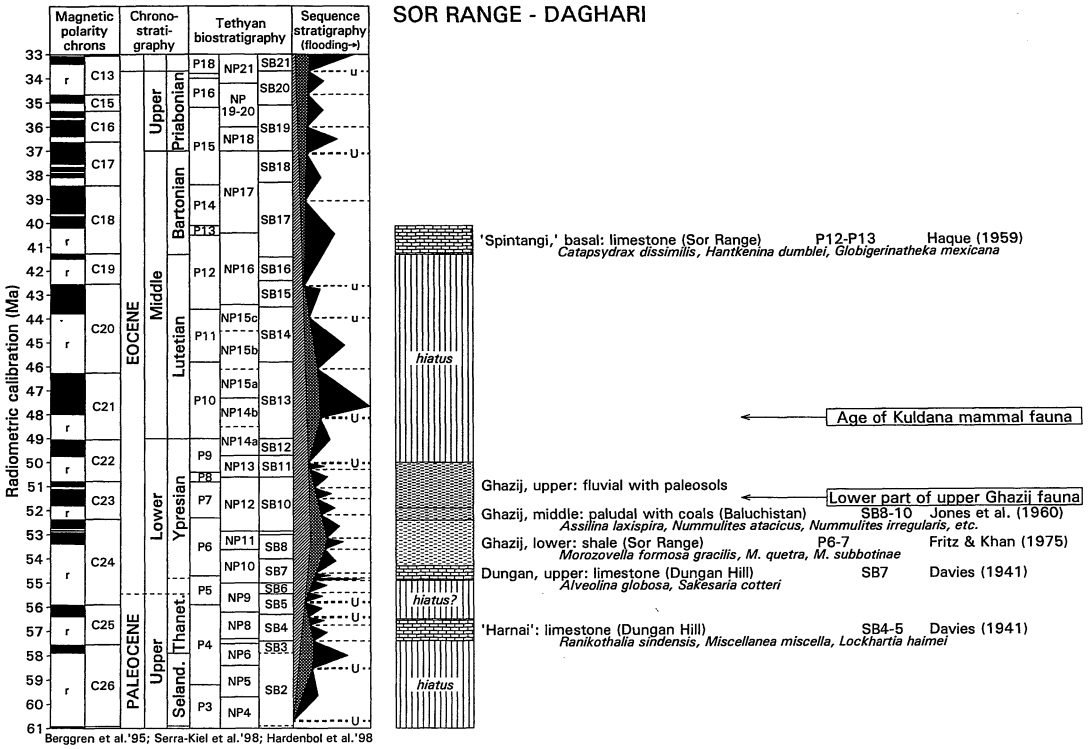

FIG. 12 — Temporal correlation chart for Paleocene-Eocene formations of Sor Range-Daghari, showing constraints on the age of middle Ghazij Formation mammals described here. Left side of chart shows global magnetic polarity and chronostratigraphy, Tethyan biostratigraphy, and global sea level stratigraphy. Right side of chart shows lithology and associated planktonic foraminiferal (P) or shallow benthic (SB) ages, with literature references and lists of index species. Boxes show ages of other Pakistan Eocene mammalian faunas for comparison. The time scale and planktonic zones shown here are from Berggren et al. (1995). Shallow benthic zones and correlation are from Serra-Kiel et al. (1998), and sea level stratigraphy is from Hardenbol et al. (1998).

AGE OF THE MIDDLE GHAZIJ FAUNA

Jones et al. (1960) reported shallow benthic foraminifera of zones SB8-10 from the lower and middle Ghazij Formation in different parts of Baluchistan. More importantly, Fritz and Khan (1975) reported planktonic foraminifera of zones P6-7 from the lower Ghazij of the Sor Range. This is consistent with description of SB4-5 and SB7 forams from the underlying Dungan Formation (Davies, 1941). Taken together, these records indicate that the middle part of the Ghazij Formation of the Sor Range is not likely to be older than middle Ypresian or middle early Eocene (index taxa are listed in Fig. 12).

The age of the thick continental mammal-bearing upper part of the Ghazij Formation of the Sor Range (Gingerich et al., 1998) is imprecisely known, but it is constrained by the age of the Drug Limestone overlying it in eastern Baluchistan, which has yielded P9 foraminifera across the provincial boundary in western Punjab (Afzal, 1996; Fig. 12). Hence the age of *Quettacyon parachai* described by Gingerich et al. (1997) and the age of *Q. parachai* and *Machocyon abbasi* described here are also unlikely to be younger than middle Ypresian or middle early Eocene. The middle Ypresian age of the middle Ghazij specimens described here corresponds to a radiometric calibration of about 52 ± 1 Ma on the time scale of Berggren et al. (1995). Haque (1959) reported P12-13 or early Bartonian planktonic foraminifera from the upper part of the Ghazij Formation in

the Sor Range. However the upper Ghazij is continental, and the foraminifera must have come from the base of the overlying marine Kirthar or 'Spintangi' limestone (the contact is difficult to recognize because it is often buried in scree), which means that there is a hiatus of some 8 m.y. between the Ghazij and 'Spintangi' or Kirthar formations (Fig. 12).

The middle Ghazij mammalian fauna is the oldest known from the Cenozoic of South Asia, and it is probably some 4 m.y. older than classic Kuldana and Kalakot faunas of Pakistan and India. For example, the Kuldana Formation at Chorlakki (Fig. 1) has yielded *Pakicetus* and a diversity of other early-to-middle Eocene mammals (Gingerich et al., 1983; Russell and Gingerich, 1987; Thewissen et al., 1987), all, where comparable, more modern than those described here. The Chorlakki locality is in the Panoba section of eastern Kohat, where it is constrained below by the SB12-16 age of the Shekhan limestone with *Orbitolites complanatus* (Weiss, 1993) and above by the Lutetian transgression of the Kohat limestone. The Kalakot fauna, with mammals again more modern than those described here, has long been regarded as being early middle Eocene in age in India (Sahni and Jolly, 1993).

As Eocene mammalian faunas from South Asia become better known, they will of course themselves contribute to understanding ages of strata that yield them.

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