Journal of The Palaeontological Society of India
Vol. 48, 2003, pp. 103-113
ISSN 0552-9603

A LATE EOCENE *JUXIA* (PERISSODACTYLA, HYRACODONTIDAE) FROM LIYAN MOLASSE, EASTERN LADAKH, INDIA

B. N. TIWARI

WADIA INSTITUTE OF HIMALAYAN GEOLOGY, 33, GENERAL MAHADEO SINGH ROAD, DEHRA DUN - 248 001, INDIA
FAX NUMBER: 91-135-2625212
E-MAIL: BNTIWARI56@REDIFFMAIL.COM

ABSTRACT

The discovery of a nearly complete skull of *Juxia* Chow and Chiu, 1964 (Perissodactyla: Rhinocerotoidea: Hyracodontidae) from the high altitude (> 5000 m) molasse of the Liyan Formation in eastern Ladakh, is documented. The specimen was recovered from the horizon, 40 m above the base of the molasse and documents the oldest fossil mammal from the Ladakh region. The skull has taxonomic affinities with *Juxia sharamurense* of China on the basis of morphological characters and it is inferred to suggest late Eocene age for lower horizons of the Liyan Formation. Its occurrence in a bed with a temperate fan palm, *Trachycarpus ladakhensis*, indicates that the Liyan Formation was deposited at a much lower altitude (~3000 to 3500 m below the present day altitude), and the area was accessible to immigrating forms from central Asia. Because of faunal elements of the late Eocene (present study) and early Miocene ages from lower horizons of the Liyan and Kargil formations respectively, a period of non-deposition is suggested between the two formations of the Ladakh Molasse Group.

INTRODUCTION

During the field investigation of the Ladakh Molasse Group in the fall of 1992, a rhinocerotoid skull was discovered from the Liyan Formation exposed near Liyan Gompa in the Nyoma region of eastern Ladakh (fig. 1). Preparation and comparative study of the skull followed an initial report (Tiwari, Nanda and Kumar, 1993). It is now referred to a late Eocene hyracodontid, *Juxia sharamurense* Chow and Chiu, 1964 until now known only from China. The species provides a temporal and biogeographic perspective for the Liyan Molasse. All the earlier records of mammalian fossils from the Ladakh Molasse Group are from the Kargil Formation exposed around Kargil (Dixit, Kachroo, Rai and Sharma, 1971; Nanda and Sahni, 1990,1998; Kumar, Nanda and Tiwari, 1996).

All records of *Juxia,* except for the present one from eastern Ladakh, are confined to China (Dashzeveg, 1991) and this record is the westernmost occurrence of the genus (fig. 2).

STRATIGRAPHY OF THE LADAKH MOLASSE

Tewari (1964) identified horizons of 'Ladakh Molasse' along the southern flank of the Ladakh Granitoids in the Kargil region and separated them from the 'Indus Flysch' (= Indus Formation, see Thakur and Virdi, 1979). Subsequently, other workers studied the molasse in different areas and assigned different formal and informal local names, for example, the Kargil Formation in the Kargil area (Shah, Sharma, Gergan and Tara, 1976), the Indus Molasse and the Hemis Conglomerate in the Kargil - Upshi area (Frank, Gansser and Trommsdroff, 1977), the Karu Formation in the Hemis area (Pal, Srivastava and Mathur, 1978), the Liyan Formation in the Liyan Gompa area (Ravi Shankar, Padhi, Prakash, Thussu and Das, 1982), the Indus Group in the entire region (Srikantia and Razdan, 1980,1985), the Wakka Chu Formation in the Kargil area (Brookfield and Andrews-Speed, 1984) and the Indus Clastics in the Kargil - Leh region (Garzanti and Van Haver, 1988).

Following Nanda and Sahni (1990), the term 'Ladakh Molasse Group' has been used here for all molasse horizons of Ladakh, including the northern and southern (= central and southern) belts identified by earlier workers (for details, see Frank *et al.*, 1977 and Ravi Shankar *et al.*, 1982). The Ladakh Molasse Group, extending from Kargil in the west to Hanle in the east, has been provisionally divided into two formations of regional extent - the Liyan and Kargil formations. The Liyan Formation – a name proposed for the molasse sections in the Liyan Gompa area by Ravi Shankar *et al.* (1982, p.163) – includes rather

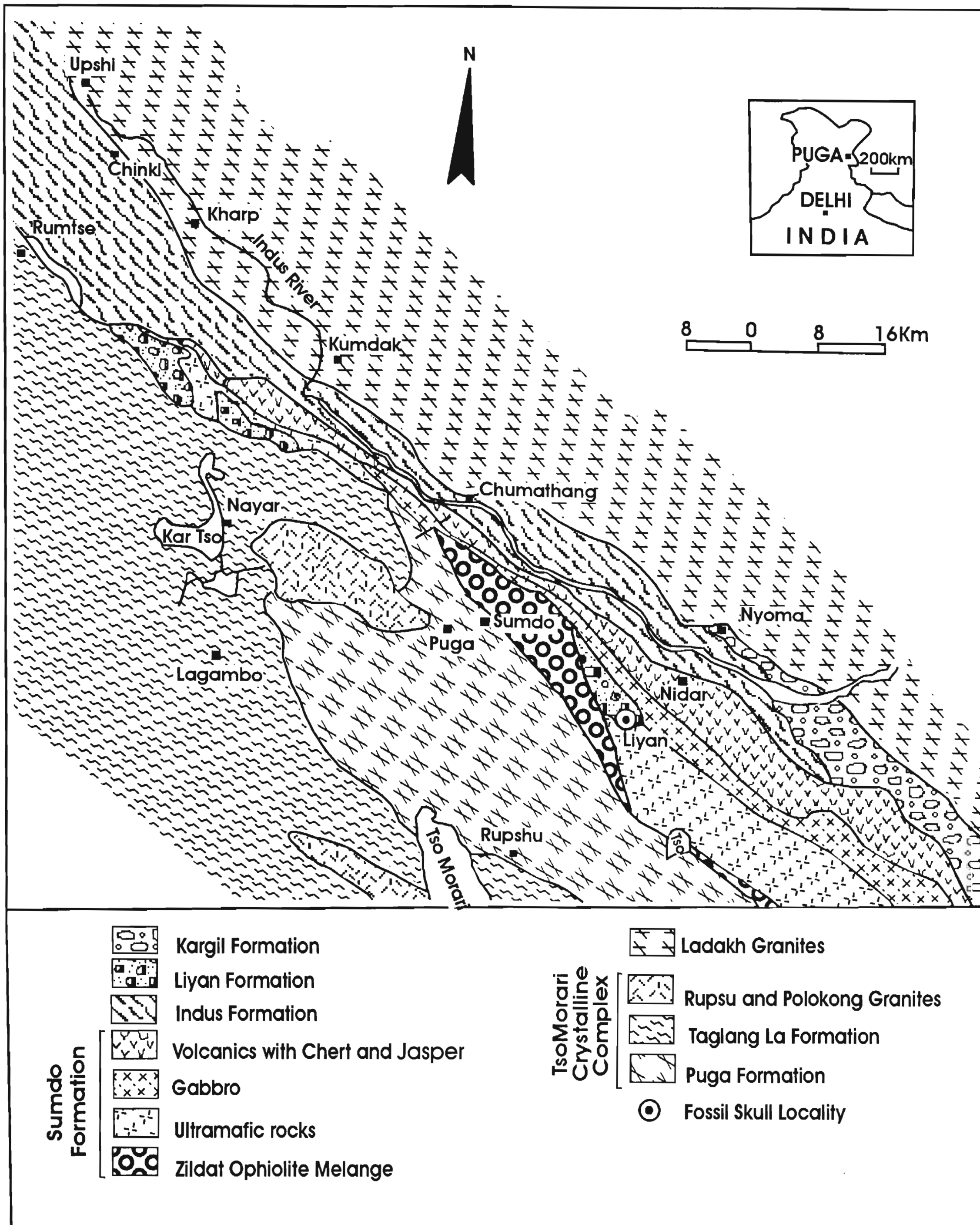


Fig. 1. Geological map of the Indus Suture Zone of eastern Ladakh (after Thakur and Misra, 1984; in part) showing the Liyan Formation and *Juxia* locality.

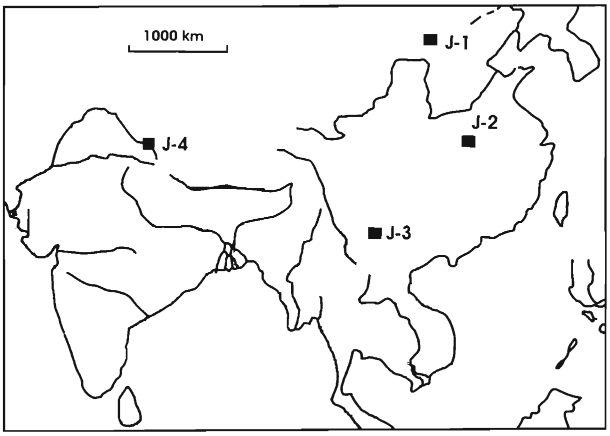


Fig. 2. Global distribution of *Juxia* (*sensu* Dashzeveg, 1991) localities, J-1, Ula Usu, Baron Sog Mesa, Inner Mongolia, China (type locality), J-2, Wucheng Basin, Henan, China J-3, Lunnan Basin, Yunnan, China, J-4, Liyan Basin, Eastern Ladakh, India.

all the southern molasse horizons that occur above the volcanosedimentary Sumdo Formation. The Kargil Formation consists mostly of the northern molasse horizons that unconformably overlie the southern flank of Ladakh Granitoids and/or the Indus Formation. In view of this revised scheme, the earlier classifications of the Ladakh Molasse Group by Bhandari *et al.* (1977) and Srikantia and Razdan (1980, 1985) now represent further subdivisions of the Kargil Formation.

In the light of present discovery of a late Eocene form from the lower beds of the Liyan Formation and the presence of early Miocene rodents (Kumar *et al.*, 1996) in the lower horizons of the Kargil Formation, it is obvious that the Kargil Formation is younger than the Liyan Formation and not homotaxial as conceived by Ravi Shankar *et al.* (1982, p.160, table 1). This classification is consistent with the suggestion of Tewari (1964, p. 51-53, fig.4) who proposed a two-fold division of the Ladakh molasse on the basis of lithology with a 'tremendous hiatus and a considerable time gap' between them. An integrated view of the currently available vertebrate palaeontological data (Nanda and Sahni, 1990,1998; Kumar *et al.* 1996; and present data) substantiates field observations in the Kargil area by Tewari (1964).

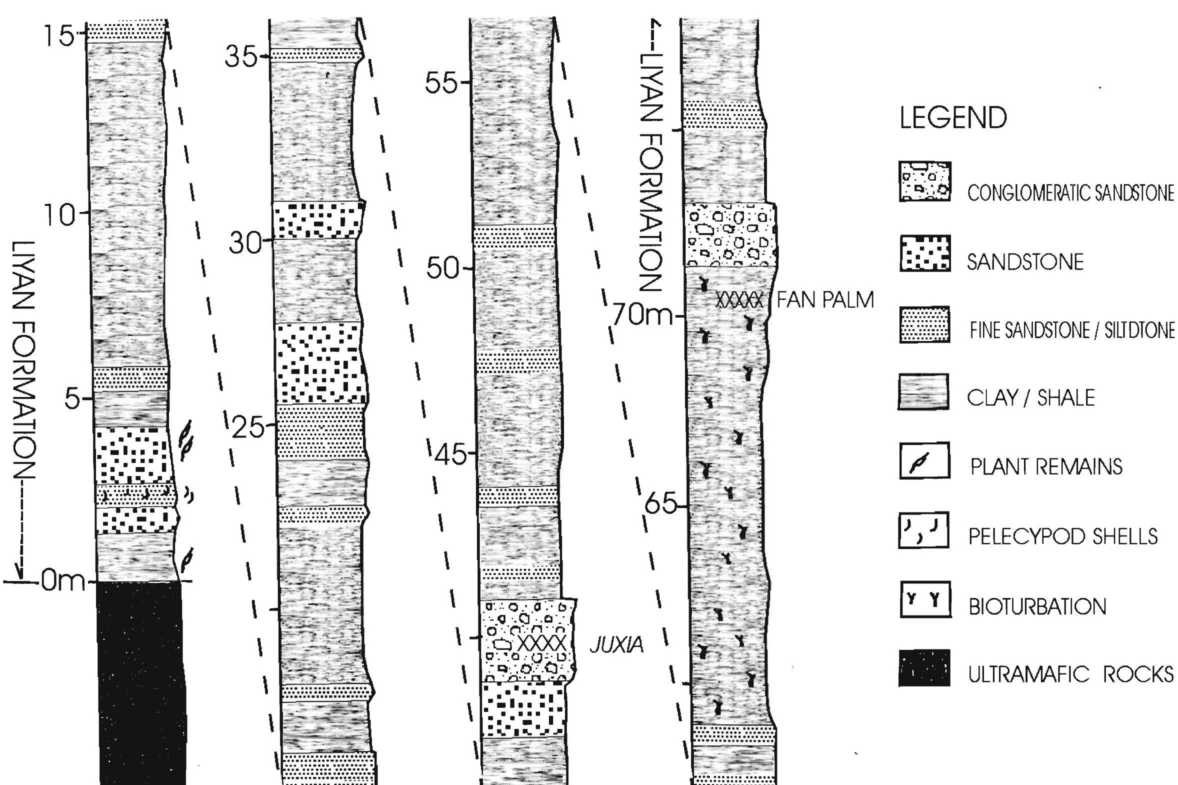


Fig. 3. Measured Gompa Section showing *Juxia*-yielding horizon in the Liyan Formation.

Similarly, Brookfield and Andrews-Speed (1991) have identified the late Eocene and Oligo-Miocene phases of the deposition of the Ladakh Molasse Group. The molasse strata of the Liyan and the Kargil formations strike E-W but in most sections they dip towards the north and the south respectively, that is, towards each other.

The Liyan Formation consists of conglomerates, grits, sandstones and shales of grey and green colours. A thick conglomerate sequence, comprising the boulders of limestone, gneiss, schist and phyllite, constitues the top of the formation. The Liyan Formation rests unconformably on the Sumdo Formation (= Zildat Ophiolite Melange + Nidar Ophiolite, Thakur and Virdi, 1979; = Sangeluma Group, Srikantia and Razdan, 1980) and is probably succeeded by horizons of the Kargil Formation only in a section near Lalu Village in the Kargil region (Tewari, 1964, p. 42,46, fig.2 and 4). Except for the westernmost exposures (= Hemis Conglomerate of Frank *et al.*, 1977), the outcrops of the Liyan Formation occur as outliers.

Liyan Gompa Section

From west to east in the Liyan - Nyoma area of eastern Ladakh (fig. 1) various lithologic units of Indus Suture Zone are juxtaposed. Excepting the basal unconformable contacts of the molasse horizons, all other contacts are tectonic in nature.

A team comprising A. C. Nanda, Kishor Kumar and the author measured a 120-m thick section at the skull site, starting from the contact between the molasse and the underlying ultrabasic rocks. The section is located about 800 m north of the Liyan Gompa (N 78°32' 17": E 33°06'06") and is exposed in a dry riverbed. Beds in the section strike E-W and dip at 25 degrees towards the north. Prominent lithologies in the measured lower section (fig. 3), in decreasing abundance, are greenish shale, fine sandstone/siltstone, sandstone and conglomerate. The lateral extension of conglomerates is very limited. Fine-grained sandstones and bioturbated shales with fragmentary plant remains and pelecypod shells were also observed. Leaf impressions of the fan palm *Trachycarpus ladakhensis* were also collected at about 70 m above the base of the molasse (fig. 3).

The skull was found in the lower part of first conglomeratic sandstone bed approximately 40 m above the base of the molasse (fig. 3). This conglomeratic horizon is yellowish-grey to brownish in colour with a thickness that varies from 2 to 4 m. The skull locality (N 78°32' 24": E 33°06' 24") is also about 800 m towards the north of the Liyan Gompa. The skull-yielding lithologic unit forms a ledge between the shales below and above it.

PREVIOUS PALAEONTOLOGICAL STUDIES

The earliest record of fossils (fresh water bivalves and gastropods) from the Ladakh Molasse Group was made by Stoliczka about 150 years ago (see Mathur, 1983). Since recognition of the Ladakh Molasse Group by Tewari (1964), workers describing its fossil biota are: Dixit *et al.* (1971), Tewari and Dixit (1971), Bhandari, Venkatchala and Singh (1977), Savage, Dixit and Murty (1977), Mathur (1983), Guleria, Thakur, Virdi and Lakhanpal (1983), Lakhanpal, Prakash, Thussu and Guleria (1984), Sahni, Srikantia, Ganesan and Wangdus (1984), Nanda and Sahni (1990,1998), and Kumar *et al.* (1996).

The report of the anthracothere *Hyoboops* from the Kargil Formation initiated vertebrate palaeontological studies in the Ladakh Molasse Group (Dixit *et al.*, 1971; Savage *et al.*, 1977). Later, fish teeth and molluscs were described from the Kargil Formation exposed in the Nyoma area (Sahni *et al.*, 1984). A mammalian assemblage comprising of ctenodactyloid rodents and artiodactyls of tragulid and gelocid families of Oligo-Miocene age was recovered from the Wakka Chu Section exposing the basal horizons of the Kargil Formation (Nanda and Sahni, 1990, 1998). However, a study of ctenodactyloid rodents collected subsequently from the same horizons of the section indicates an early Miocene

EXPLANATION OF PLATE I →

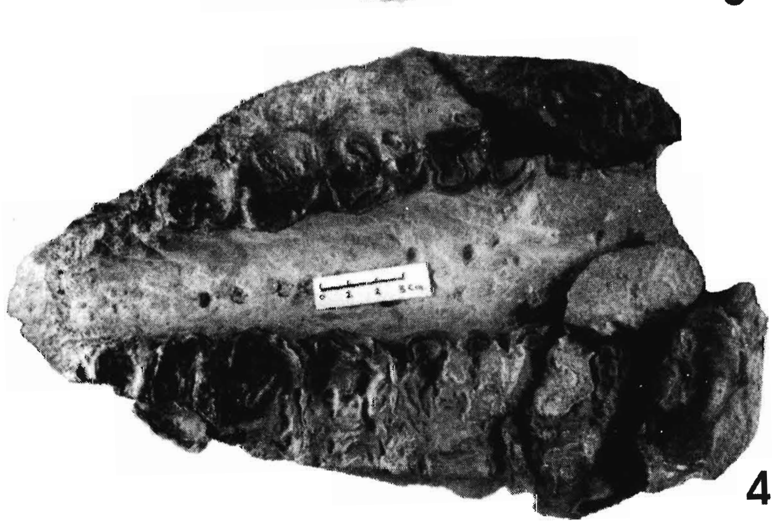
1-4: Dorsal (Fig. 1), left lateral (Fig. 2), ventral (Fig. 3) views and close-up of cheek teeth (Fig. 4) of the skull (WIF/A 1063) of *Juxia sharamurense* Chow and Chiu from the Liyan Formation.

Plate I

1

2

3



4

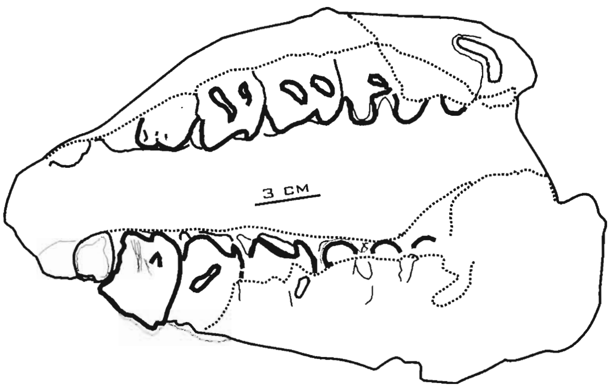


Fig. 4. Line drawing of the cheek teeth of the Skull (WIF/A 1063).

age (Kumar *et al.*, 1996). Vertebrate fossils were not known earlier from the Liyan Formation. Guleria *et al.* (1983) and Lakhanpal *et al.* (1984) described temperate floral elements, *Prunus* and *Trachycarpus* from the Tajurma and Liyan Gompa sections respectively.

The skull of *Juxia sharamurense* (bearing catalog no. WIF/A 1063) is in the repository of the Museum of the Wadia Institute of Himalayan Geology, Dehra Dun, India.

SYSTEMATIC PALAEONTOLOGY

Class **Mammalia** Linnaeus, 1758

Order **Perissodactyla** Owen, 1848

Superfamily **Rhinocerotoidea** Owen, 1845

Family **Hyracodontidae** Cope, 1879

Subfamily **Indricotheriinae** Borissiak, 1923

Genus ***Juxia*** Chow and Chiu, 1964

Type Species: *Juxia sharamurense* Chow and Chiu, 1964

Included Species: Only the type species *Juxia sharamurense* Chow and Chiu, 1964.

Distribution: Middle to late Eocene of China and Ladakh, India.

Revised Diagnosis: *Juxia* is a small indricotheriine distinguished from other indricotheres by the following combination of characters: size small; skull dolichocephalic with an elongate braincase relatively high nuchal region having a wide, rounded notch at the middle; sagittal crest present; deep nasal incision up to above P3; premaxillaries horizontal (not downturned); all incisors present, but I1 and i1 somewhat larger than the other incisors; canines and first premolars present; P2 to P4 molariform; degree of closure of the trigon basin increasing from P2 to P4; and M3 metacone absent.

Remarks: Lucas and Sobus (1989) and Dashzeveg (1991) recently reviewed the indricotheres and found that *Juxia* differs from related species of *Forstercooperia* in having more molariform premolars, giving P2 to P4 a rectangular outline and a deeper nasal incision extending back to above P3. Chow, Chang and Ding (1974), Lucas, Schoch and Manning (1981, p 828), Lucas and Sobus (1989, p 364) and Dashzeveg (1991, p. 60) showed that *Juxia* is distinguishable from other indricotheriine genera, and that it cannot be placed in synonymy with *Forstercooperia* as opined by Radinsky (1967).

Dashzeveg (1991) recognized six genera of indricotheres: *Forstercooperia, Armania, Juxia, Urtinotherium, Paraceratherium*, and *Indricotherium.* Persistent development of the maxillo-labialis musculature in indricotheres seems to be related to the enlargement of I1 / i1; loss of I2-3 / i2-3, C1 / c1 and P1 / p1; deepening of the nasal incision to above P4, and down turning of the premaxillaries in advanced forms (for example, *Paraceratherium*; Lucas and Sobus, 1989). The nasal incision which extends back to above P3 in *J. sharamurense*, reveals its intermediate position in indricotheriine phylogeny.

Dashzeveg's (1991, p.49) argument that *Juxia* includes only *J. sharamurense*, *sensu stricto*, and that *Eotrigonias borissiaki* and *Forstercooperia ergiliinensis* are not synonymous has been followed here.

Juxia sharamurense Chow and Chiu, 1964

(Pl. I, figs. 1-4; fig. 4)

Referred Material: An almost complete skull (WIF/A 1063), with poorly preserved dentition.

Locality and Horizon: From 800 m north of the Liyan Gompa, eastern Ladakh, northwestern Himalaya; lower beds (a conglomeratic sandstone 40 m above the base) of the Liyan Formation (figs. 1 and 3).

Description: The skull (WIF/A 1063) represents a mature adult individual of the taxon. It is fairly well preserved and complete except for premaxillaries, buccal margins of the cheek teeth, parts of the zygomatic archs, and rear and base of the cranium. Preservation of the specimen is not uniform; the anterior half of the skull is better preserved than the posterior while the details have been lost around orbital region. The basicranial region is badly damaged and reveals little. The skull is slightly distorted and has been prepared for anatomical details and comparative study.

Dorsal Aspect: The skull bears no horn boss on the nasals (Pl. I, fig. 1). The long, gently tapering, and down-bending nasals and slender cranial rostrum together impart an elongate (dolicocephalic) appearance to the skull in dorsal view. Total length of the skull, as preserved, is 580 mm. Anterior to the centrally placed post – orbital processes, the lateral margins on the antero - dorsal surface converge gradually. The frontal area is broad. From the partial left zygomatic arch, it can be seen that zygomatic arch is apparently slightly convex upward. The supratemporal crests converge in straight lines from the rear margins of the post - orbital processes and meet at the midline to give rise to a low and narrow sagittal crest. A wide rounded notch interrupts the nuchal crest at the middle. The braincase is not expanded. The nasal/frontal suture lies in a shallow linear depression. The skull is widest (200 mm) above the orbits.

Lateral Aspect : The profile of the skull in lateral view is elongate; highest at the nuchal crest and lowest at the anterior tip of down-bending nasals (Pl. I, fig. 2). A very shallow saddle above the orbital region divides the slightly convex dorsal profile of the muzzle with gradually up-trending profile of the brain-case region. The orbit is at about the middle of the total length of the skull. Owing to the poor preservation of the orbital region, it is not possible to recognize foramina. The nasal incision is conspicuous, and extends back to above the anterior of P3.

Ventral Aspect : The skull has narrow palate, with almost straight and parallel rows of cheek teeth (Pl. I, fig. 3 & 4; fig. 4). Owing to missing premaxillaries, the upper anterior dentition of the Liyan specimen is unknown, but the cheek teeth resemble those of the indricotherine hyracodontids. The preserved part of the basicranial region in WIF/A 1063 closely resembles that of the type specimen (in the collection of Institute of Vertebrate Palaeontology and Palaeoanthropology, Beijing, IVPP Cat. No. 2891) of *Juxia sharamurense* described by Chow and Chiu (1964).

Upper Teeth : The upper cheek teeth appear far more advanced than those of all the species of *Forstercooperia* do. The worn crowns, with labial edges nearly obliterated, exhibit some morphological resemblance between the premolars and molars, excepting dP1, in lateral as well as occlusal views (Pl. I, figs. 3 & 4; fig. 4). This is due to the unusually high degree of molarization of the premolars.

The dP1 is heavily worn and lacks occlusal relief. The lingual enamel wall is rounded suggesting that there was only lingual cusp.

P2 through P4 have a crenulated lingual borders and exhibit more advanced characters than those of even the most advanced species of *Forstercooperia*. The presence of a shallow trigon basin on their lingual side causes their outline to be rectangular. However the size of the trigon basin *increases* from P2 to P4. Molarization (Heissig, 1989: fig. 21.1:p. 400) increases from P2 to P4, these teeth range from paramolariform to semimolariform.

M1 through M3 are morphologically similar to other hyracodontid / rhinocerotid taxa. A characteristic feature of the molars of hyracodontids and rhinocerotids lies in the absence of a metacone in M3, giving it a triangular occlusal outline. A deep and penetrating trigon basin, described by some workers as transverse medial valley separates the protocone and hypocone in the molars. Presence of anterocrochet on the beat-up M2's is an important feature – an observation that questions its identification as hyracodontid taxa.

Measurements: Characteristic measurements (in mm.) of the skull (WIF/A 1063) of *Juxia sharamurense* from the Liyan Formation are

Maximum length of the skull, nasalcrest tip to nuchal (approx.)	580
Skull width, at anterior margin of the orbit	188

Maximum skull width, across central orbital region	200
Height of the skull at M1	153
Palatal width, from right to left M2 parastyle	140
Maximum width of nasals	75

Discussion: The deep nasal incision, molarization of P2 to P4, and lack of horn boss in the Liyan skull lead in short-listing the rhinocerotoid forms of comparable size for comparative study. *Juxia is* one such hyracodontid taxon diagnosed on the basis of dolicocephalic skull with deep nasal incision and molariform P2 to P4.

Dentition	Length	Width
P1-P4	105	---
M1-M3	119	---
P1	20	23
P2	28	42
P3	32	46(e)*
P4	33	51(e)
M1	38	52(e)
M2	48(e)	47(e)
M3	48(e)	60(e)

* (e) = estimated

However, presence of anterocrochet in M2's of Liyan *Juxia,* an indricothere, does not go well with its identification as a hyracodontid. May be indricotheres were earlier rightly classified as rhinocerotids (Heissig, 1989) which are known to have anterocrochet in upper molars.

Higher degree of molarization of P2 to P4 and larger size of the cheek teeth of Liyan skull than that of the holotype of *Juxia from* the middle Eocene Shara Murun Formation allow to infer that it is a more advanced form and is therefore possibly younger relatively. The late Eocene spell of deposition of the Ladakh Molasse Group, envisaged by Brookfield and Andrews-Speed (1991), makes it more reasonable to propose late Eocene age for more advanced *Juxia* from the Liyan section. The late Eocene age for *Juxia* from the Liyan section seems justified even against the argument of dental morphology, that it is a direct evolute of the middle Eocene rhinocerotoid taxon *Forstercooperia jigniensis* described by Sahni and Khare (1973) from the Subathu Group of the Lesser Himalaya. However, it must be added here that Lucas *et al.* (1981) removed it from *Forstercooperia* and indicated that the taxonomic position of *F. jigniensis* is as yet undecided. Further, the North American specimens earlier attributed to *Forstercooperia* are now referred to *Uintaceras* and it is proposed that entire evolution of indricotheriine hyracodontids was restricted to Eurasia (Holbrook and Lucas, 1997).

Comparisons: For identification of WIF/A 1063, besides *Juxia,* many other comparable rhinocerotid and hyracodontid taxa, namely, *Forstercooperia, Armania, Subhyracodon,* and *Diceratherium* were studied and found to be distinct from it, as given below, on the basis of certain key parameters. However, detailed comparative studies reveal that morphological features particularly the nasal incision up to above the anterior of P3 and skull measurements suggest that it is referable to the only species of *Juxia*, that is, *Juxia sharamurense* Chow and Chiu, 1964. In particular, the Liyan specimen compares closely with the holotype of *Juxia sharamurense.*

Forstercooperia, a hyracodontid taxon, is morphologically similar to the Liyan form but can be distinguished on the basis of its non-molariform premolars and less deep nasal incision than in the present material WIF/A 1063. *Armania* is characterised by reduced facial part of the skull with front edge of the orbit at the level of P2 – features which distinguish it from Liyan form having long facial part with approximately front edge of the orbit at the level of M1. The Liyan taxon is morphologically distinct from *Subhyracodon*, a rhinocerotid, because of its deeper nasal incision. Besides the strong lingual cingulam in premolars of *Subhyracodon* which differentiates it from the Liyan taxon, the dorsally flat (from nasal to occiput) skull of *Subhyracodon* differs from *Juxia*'s skull with down bending and rising nasal and occiput regions respectively (Russell, 1982). Similarly, because of incomparable nasal retraction and presence of cingulum on the upper cheek teeth *Diceratherium*, too, is morphologically distinguishable from the Liyan *Juxia* .

The holotype of *Juxia sharamurense* Chow and

Chiu, 1964 was recovered from the middle Eocene sediments of the Shara Murun Formation at the Ula Ushu Locality, Baron Sog Mesa of Inner Mongolia, China. The other two *Juxia* localities in China, given in a table of the global distribution of indricotheres by Lucas and Sobus (1989: table 19) are in the Lunnan Basin, Yunnan and the Wucheng Basin, Henan. These three localities are all within a radius of 2500 km from the Liyan locality and are approximately in ENE, ESE and E directions from it respectively (fig. 2). Following Dashzeveg (1991), the Mongolian and Russian localities listed by Lucas and Sobus (1989) are not included in *Juxia* here.

DISCUSSION AND CONCLUSIONS

The vertebrate fauna from the Ladakh Molasse Group, though not prolific, has biostratigraphic, palaeogeographic and palaeobiogeographic significance. As indicated above, the hyracodontid skull, from the outlier of the Liyan Formation near Liyan Gompa, is possibly late Eocene in age which incidentally could also be the age of its lower horizons. This age determination seems to provide a temporal constraint for the geological models explaining the regional geodynamic evolution of the area which, in turn, is crucial to understanding the evolutionary history of the Himalaya. As presently known, the *Juxia* documents the oldest mammal-bearing stratigraphic level of the Ladakh Molasse Group. The earlier records of the anthracothere (*Hyoboops* : Savage *et al.*, 1977), artiodactyles (*Lophiomeryx* and *Iberomeryx* : Nanda and Sahni, 1990), and ctenodactyloid rodents (Kumar *et al.*, 1996; Nanda and Sahni, 1998) are from the higher stratigraphic levels.

The age range of the Ladakh Molasse Group has been a subject of speculation because of lack of reliable time markers (Tewari, 1964; Bhandari *et al.*, 1977; Thakur and Virdi, 1979; Srikantia and Razdan, 1985; Ravi Shankar *et al.*, 1982; and Brookfield and Andrews-Speed, 1984). As suggested by Brookfield and Andrews-Speed (1991, p. 279), the deposition of the Ladakh Molasse Group possibly ocurred in two phases, the late Eocene and Oligocane to Miocene. With the report of *Hyoboops* from the Baru Section in Kargil and ctenodactylid rodent assemblage from the Wakka Chu Section, near Kargil, the age range of the Kargil Formation of the Ladakh Molasse Group appears to be Oligo-Miocene (Nanda and Sahni, 1990, 1998; Kumar *et al.*, 1996).

Trachycarpus, a temperate fan palm, from the Liyan Formation was assigned the Miocene age by Lakhanpal *et al.* (1984), though its report came from the Eocene of Kazakhastan, Ukraine and Germany. The other warm- temperate floral element, *Prunus,* from the Liyan Formation, was reported by Guleria *et al.* (1983) and was similarly assigned a Miocene age. Since these floral elements are long ranging and are not suitable for deducing age of the enclosing sediments, the late Eocene age based on the occurrence of *Juxia* seems justified in the present case.

The presence of central Asiatic elements of the late Eocene and Oligo-Miocene ages in the Liyan and the Kargil formations indicates absence of physical barriers towards north of the basin. This allowed the small (for example, rodents and artiodactyls) to large (for example, *Juxia*) mammals to immigrate to the Ladakh region. As is indicated by the presence of temperate floral elements in the Liyan Formation (Guleria *et al.*, 1983; Lakhanpal *et al.*, 1984), the basin was apparently at a much lower altitude (~ 1200 to 2000 m above the present-day mean sea level). Evidently, following the withdrawal of the Neotethys from the region, the central Asiatic temperate flora reached the Indus Suture and thrived there. The basin thus had acquired the basic biomass for supporting the immigrating herbivores from the surrounding temperate regions. This inference is supported by the occurrence together of *Juxia sharamurense* and *Trachycarpus ladakhensis* and some macerated plant material in the lower horizons of the Liyan Formation.

The discovery of *Juxia sharamurense* from the Liyan Formation, in the current faunal perspective, allows to make following conclusions :

- Deposition of the Liyan Molasse started as early as middle to late Eocene and occurred at a much lower altitude (~ 3000 to 3500 m below its present-day altitude).
- The Oligo-Miocene spell of trans-Himalayan mammalian immigration was preceded by

invasion of the late Eocene forms (fauna and flora) from the central Asia region.

- Lower horizons of the Liyan and Kargil formations of the Ladakh Molasse Group are known to yield the late Eocene and early Miocene mammalian faunal elements respectively and, therefore, are possibly separated by an interlude.

ACKNOWLEDGMENTS

I am thankful to Dr. N.S. Virdi, ex-Director, Wadia Institute of Himalayan Geology, Dehra Dun for the facilities and to Dr. Sunil Bajpai, IIT, Roorkee for relevant literature and comments on the draft. Special thanks are due to Drs A. C. Nanda and Kishor Kumar for their help in the field. Drs. Donald Prothero, Earl Manning, J.G.M. Thewissen (all from USA), V.P. Mishra, (Lucknow) and an anonymous reviewer reviewed the manuscript and offered valuable suggestions for its improvement.

REFERENCES

Bhandari, L.L., Venkatachala, B.S. and Singh, P. 1977. Stratigraphy, palynology and palaeontology of Ladakh Molasse Group in the Kargil area. p. 127-133. In: *Proceedings of IV Colloquium on Indian Micropalaeontology and Stratigraphy*, 1974 – 75. (Eds. Venkatchala B.S. and Sastri, V.V.), Dehra Dun.

Brookfield, M.E. and Andrews–Speed, C.P. 1984. Sedimentation in a high altitude intermontane basin - The Wakka Chu Molasse (Mid. - Tertiary, Northwestern India). *Bull. Ind. Geol. Assoc.*, **17** : 175-193.

Brookfield, M.E. and Andrews – Speed, C.P. 1991. Ladakh Mesozoic to Tertiary Arc Basins and their problems; pp. 261-283. In : *Sedimentary basins of India, Tectonic context*.(Eds. Tandon, S.K., Pant, C.C. and Casshyap, S.M.) Gyanodaya Prakashan, Nainital, India.

Chow, M. and Chiu, C. 1964. An Eocene giant rhinoceros. *Vert. Palasiatica,* **8**: 264-267. (Chinese, with English summary).

Chow, M. M., Chang, Y. and Ding, S. 1974. Some early Tertiary Perrisodactyla (sic) from Lunan Basin. E. Yunnan. *Vert. Palasiatica*, **12** (4) :262-273 (in Chinese, with English summary).

Dashzeveg, D. 1991. Hyracodontids and rhinocerotids (Mammalia, Perissodactyla, Rhinocerotoidea) from the Palaeogene of Mongolia. *Palaeovertebrata*, **21** (1-2) : 1-84.

Dixit, P.C., Kachroo, R.K., Rai, H. and Sharma, N.L. 1971. Discovery of vertebrate fossils from the Kargil Basin, Ladakh (Jammu and Kashmir). *Curr. Sci.* **40**: 633-34.

Frank, W., Gansser, A. and Trommsdroff, V. 1977. Geological observations in the Ladakh area (Himalayas) : A preliminary report. *Schweizerischen Mineralogische und Petrologische Mitteilungen,* **57**: 89-113.

Garzanti, E. and Van Haver, T. 1988. The Indus clastics: forearc basin sedimentation in the Ladakh Himalaya (India). *Sed. Geol.* **59** : 237-249.

Guleria, J.S., Thakur, V.C., Virdi, N.S. and Lakhanpal, R.N. 1983. A fossil wood of *Prunus* from the Kargil (= Liyan) Formation of Ladakh. p. 187-193. In : *Geology of Indus Suture Zone of Ladakh*, (Eds. Thakur, V.C. and Sharma, K.K.), Wadia Institute of Himalayan Geology, Dehra Dun.

Heissig, K. 1989. The Rhinocerotidae, p. 399-417. In : *The evolution of Perissodactyla*. (Eds. Prothero, D.R. and Schoch, R.M.), Oxford University Press, N.Y.

Holbrook, L.T. and Lucas, S.G. 1997. A new species of Rhinocerotoid from the Eocene of Utah and the status of North American "*Forstercooperia*". *Jour. Vert. Pal.* **17**(2): 384-396.

Kumar, K., Nanda, A.C. and Tiwari, B.N. 1996. Rodents from the Oligo-Miocene Kargil Formation, Ladakh. India : biochronologic and palaeobiogeographic implications. *N. Jb. Geol. Palaont Abh. Stuttgart,* **202** (3) : 383-407.

Lakhanpal, R.N., Prakash, G Thussu, J.L. and Guleria, J.S. 1984. A fossil fan palm from the Liyan Formation of Ladakh (Jammu and Kashmir). *Palaeobotanist,* **31** (3): 201-207.

Lucas, S.G. and Sobus. J.C. 1989. The systematics of Indricotheres. pp. 358-378. In : *The evolution of Perissodactyla,* (Eds. Prothero, D.R. and Schoch, R.M.), Oxford University Press, N.Y.

Lucas, S.G., Schoch, R.M. and Manning, E. 1981. The systematics of *Forstercooperia*, a middle to late Eocene hyracodontid (Perissodactyla : Rhinocerotoidea) from Asia and Western North America. *Jour. Pal.*, **55** (4): 826-841.

Mathur, N.S. 1983. Age of the Kargil Formation, Ladakh Himalaya. pp. 145-150. In : *Geology of Indus Suture Zone of Ladakh*,(Eds. Thakur, V.C. and Sharma, K.K.) Wadia Institute of Himalayan Geology, Dehra Dun.

Nanda, A.C. and Sahni, A. 1990. Oligocene vertebrates from the Ladakh Molasse Group, Ladakh Himalaya : Palaeobiogeographic implications. *Jour. Him. Geol.*,**1**: 1-10.

Nanda, A.C. and Sahni, A. 1998. Ctenodactylid rodent assemblage from Kargil Formation, Ladakh Molasse Group, Ladakh Himalaya : age and palaeobiogeographic implications for the Indian Subcontinent in the Oligo-Miocene. *Geobios*. **31**, **4**: 533-544.

Pal, D., Srivastava, R.A.K. and Mathur, N.S. 1978. Tectonic framework of the miogeosynclinal sedimentation in Ladakh Himalaya : a critical analysis. *Him. Geol.*, **8** : 500-523.

Radinsky, L.B. 1967. A review of the rhinocerotoid family Hyracodontidae (Perissodactyla). *Am. Mus. Nat. Hist., Bulletin.* **136**(1): 1-45.

Ravi Shankar, Padhi, R.N., Prakash, G., Thussu, J.L. and Das, R.M. 1982. The evolution of Indus Basin, Ladakh, India. *Misc. Pub. Geol. Surv. India*, **41** (III) : 157-172.

Russell, L.S. 1982 Tertiary mammals of Saskatchewan Part VI: The Oligocene rhinoceroses, *Life Sciences Contributions, Royal Ontario Museum Number* 133: 1-58.

Sahni, A. and Khare, S.K. 1973. Additional Eocene mammals from the Subathu Formation of Jammu and Kashmir. *Jour. Pal. Soc. India*, **17** : 31-49.

Sahni, A., Srikantia, S.V., Ganesan, T.M. and Wangdus, C. 1984. Tertiary fishes and molluscs from the Kuksho

Formation of Indus Group. near Nyoma, Ladakh, *Jour. Geol. Soc. India*. **25** : 744-747.

Savage, R.J.G., Dixit, P.C. and Murty, D.V.N. 1977. On an anthracothere upper molar from Ladakh Kashmir. *Jour. Pal. Soc. India*, **20**: 219-223.

Shah, S.K., Sharma, M.L. Gergan, J.T. and Tara, C.S. 1976. Stratigraphy and structure of the western part of the Indus Suture Belt, Ladakh. Northwest Himalaya. *Him. Geol.*, **6**: 534 - 556.

Srikantia, S.V. and Razdan, M.L. 1980. Geology of part of Central Ladakh Himalaya with particular reference of Indus Suture Zone. *Jour. Geol. Soc. India*, **21** (11) : 523-545.

Srikantia, S.V. and Razdan, M.L. 1985. The Indus Tectonic Zone of the Ladakh Himalaya : its geology, tectonics and ophiolite occurrence. *Rec. Geol. Surv. India* . **115**(2) : 61-92.

Tewari, A.P. 1964. On the Upper Tertiary deposits of Ladakh Himalayas and correlation of various geotectonic units of Ladakh with those of the Kumaun - Tibet region. *Proc XXII Int. Geol. Congress*, **11** : 37-58.

Tewari, B.S. and Dixit P.C. 1971. A new terrestrial gastropod from freshwater beds of Kargil, Ladakh, J & K State. *Bull. Ind. Geol. Asso.* **4** (3-4) : 61-67.

Thakur, V.C. and Misra D.K. 1984. Tectonic framework of the Indus and Shyok suture zones in eastern Ladakh, Northwest Himalaya. *Tectonophysics* **101** : 207-220.

Thakur, V.C. and Virdi, N.S. 1979. Lithostratigraphy, structural framework, deformation and metamorphism in the SE region of Ladakh, Kashmir Himalaya, India. *Him. Geol.*, **9**: 63-78.

Tiwari, B.N., Nanda, A.C. and Kumar, K. 1993. Occurrence of a rhinocerotid skull from high altitude molasse of Liyan, near Nyoma, Ladakh. Abstract Volume of the Seminar on Himalayan Geology at Wadia Institute of Himalayan Geology, Dehra Dun, March, 1993 : 57.

Manuscript Accepted August 2003