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Upper Cretaceous (Maastrichtian) charophyte gyrogonites from the Lameta Formation of Jabalpur, Central India: palaeobiogeographic and palaeoecological implications

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ABSTRACT:

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A charophyte gyrogonite assemblage consisting of *Platychara* cf. *sahnii, Nemegtichara grambastii* and *Microchara* sp. is reported herein from two localities (Bara Simla Hill and Chui Hill sections) of the Lameta Formation at Jabalpur. The Lameta Formation locally underlying the Deccan traps has been shown to be pedogenically modified alluvial plain deposits containing one of the most extensive dinosaur nesting sites in the world. They are associated with dinosaur bones and freshwater ostracod assemblages that suggest a Late Cretaceous (Maastrichtian) age. This is the first detailed systematic account of charophyte gyrogonites from the Lameta Formation. This charophyte assemblage is compatible with the biostratigraphic attribution provided by the ostracods. From a biogeographic viewpoint, it exhibits considerable similarity to other infratrappean assemblages of the Nand, Dongargaon, and Dhamni-Pavna sections (Maharashtra), and some intertrappean assemblages of Kora in Gujarat, Rangapur in Andhra Pradesh and Gurmatkal in South India. Globally, the genus *Microchara* is well distributed throughout Eurasia, whereas the genus *Platychara* occurs richly in the Upper Cretaceous deposits of Europe, Asia, America and Africa. However, at the specific level, *Platychara* cf. *sahnii* shows close affinities with charophytes from the Maastrichtian of Iran whilst *Nemegtichara grambastii* shows distinct affinities with two species of Early Palaeogene deposits of China and Mongolia. The presence of charophyte gyrogonites in the Lameta sediments is attributed to local lacustrine and palustrine conditions within a flood plain environment.

Key words: Charophyta; Palaeobotany; Palaeogeography; Biogeography; Cretaceous-Palaeogene boundary.

INTRODUCTION

Upper Cretaceous Charophyta are well known from North and South America (Musacchio 1973; Peck and Forester 1979; Jaillard *et al*. 1993), Europe (e.g. Grambast 1971, 1975; Feist and Colombo, 1983; Feist and Freytet 1983; Massieux *et al*. 1987; Masriera and Ullastre 1988; Feist *et al*. 2005; Villalba-Breva and Martín-Closas 2012; Villalba-Breva *et al.* 2012) and Africa (Mebrouck *et al*. 2009; Chassagne-

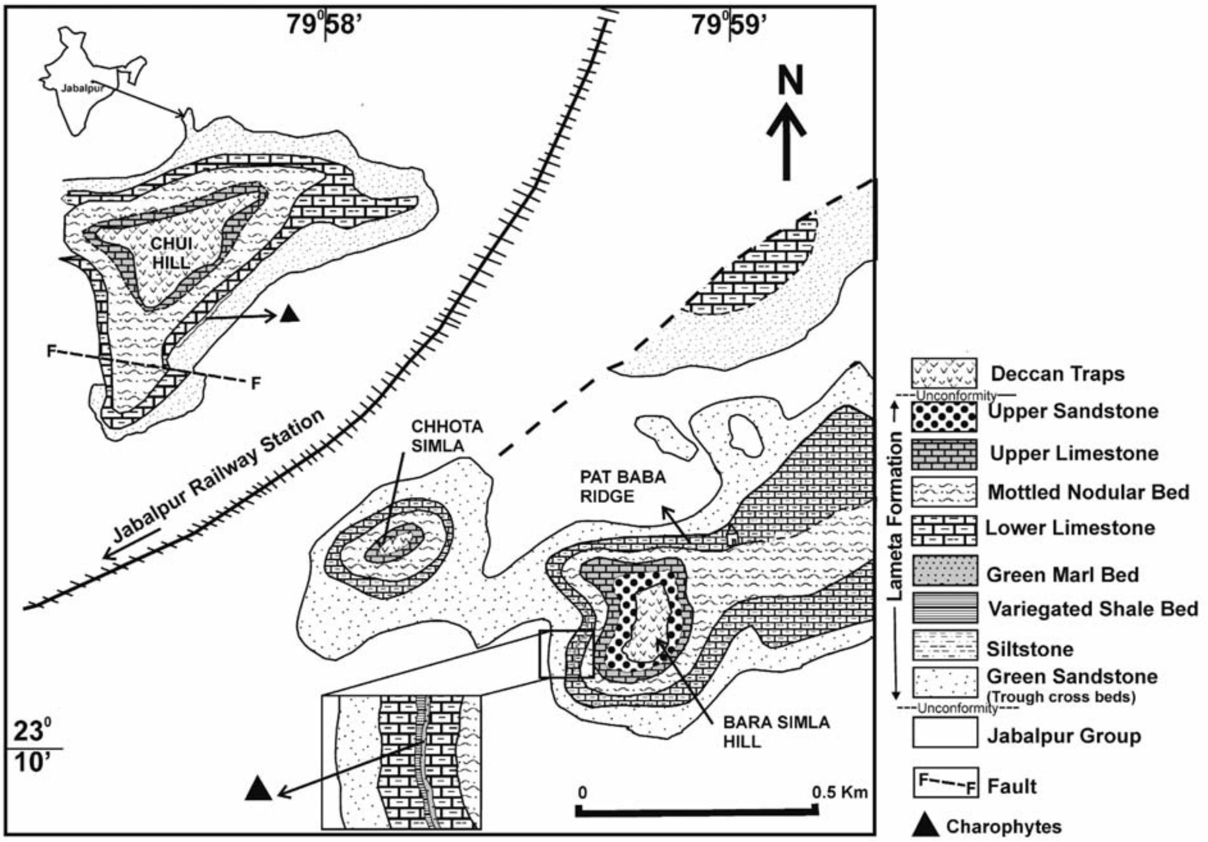
Manoukian *et al*. 2013). Diverse and rich assemblages are also documented from Asia, especially China (Wang Zhen 1978a; Karczewska and Ziembinska-Tworzydlo 1983; Liu 1987; Liu and Wu 1987; Van Itterbeeck *et al*. 2005). The Indian record of Late Cretaceous charophytes is not very rich, and only a few charophyte taxa are known from Upper Cretaceous intertrappean horizons (Bhatia and Mannikeri 1976; Bhatia and Rana 1984; Bhatia *et al*. 1990 a, b; Srinivasan *et al*. 1994). Fossil Charophyta have played an important role in defining the biostratigraphy of non-marine Upper Cretaceous deposits, especially for the Cretaceous-Palaeogene boundary (Feist-Castel 1977; Feist 1979; Massieux *et al*. 1981; Feist and Colombo 1983; Feist and Freytet 1983; Bhatia and Rana 1984; Lepicard *et al*. 1985; Weitong 1985; Riveline *et al*. 1996; Villalba-Breva and Martín-Closas 2012; Villalba-Breva *et al.* 2012). The fossil record from the Lameta Formation (= infratrappeans) of Jabalpur has great significance. Sahni and Tripathi (1990) have published an account of all microvertebrate occurrences from the Lameta Formation in the light of their age implications. Considerable work has been done on megavertebrates such as dinosaurs, fossil seeds and ostracods of these beds (e.g. Sahni *et al*. 1994, 1999; Loyal *et al*. 1996; Khosla and Sahni 1995, 2000; Khosla 2001; Vianey-Liaud *et al*. 2003; Khosla *et al*. 2011 and Wilson *et al*. 2011). It is, however, surprising that the charophytes have not received much attention from micropalaeontologists. Apart from the palaeontological assemblages, much attention has been given to the stratigraphy of beds associated with the Deccan trap (infra- and intertrappean beds) of Jabalpur and nearby areas (Brookfield and Sahni 1987; Tandon *et al*. 1990; Sahni and Khosla 1994 a-c; Khosla and Sahni 2000, 2003; Khosla *et al*. 2004, 2009; Keller *et al*. 2009 a, b, 2010). In order to fill in the lacunae the author took up the study of Upper Cretaceous Charophyta from the Lameta Formation of Jabalpur. The study of charophytes is useful in working out global events, biostratigraphy and palaeobiogeography (Martín-Closas and Serra-Kiel 1986; Villalba-Breva and Martín-Closas 2012; Villalba-Breva *et al.* 2012; Chassagne-Manoukian *et al*. 2013).

The palaeoenvironments of the Lameta Formation at Jabalpur remained in controversy for several years. Presently, there are two interpretations. Brookfield and Sahni (1987) and Fernández and Khosla (2014) interpreted Lameta Formation as pedogenically modified alluvial plain sediments laid down in semi-arid climates whereas Singh (1981) opposed to this view point and considered the Lameta Formation as shallow intertidal marine deposits. On the other hand, the presence of freshwater and terrestrial faunas, such as the dinosaur skeletal material and nests within the Lower Limestone, freshwater gastropods, ostracods and charophytes in the siltstone and green marl beds, and sedimentological studies (Sahni and Khosla 1994 a) would indicate that these sedimentary horizons are mainly fluvio-lacustrine (Khosla and Sahni 2003; Khosla and Verma 2014). Charophytes also contribute in clarifying the non-marine nature of these deposits.

GEOLOGICAL SETTING

The Lameta Formation crops out discontinuously in east-west and central peninsular India (Tandon *et al*. 1990; Khosla and Sahni 2000). The Lameta Formation at Jabalpur is about 32 m thick (Khosla and Sahni 1995) and is exposed in the Chui Hill, Bara Simla Hill and Chhota Simla Hill sections, where it overlies Precambrian rocks. The Lameta Formation is overlain by rocks of the Deccan volcanic suite (Text-fig. 1). The two sections, Chui Hill and Bara Simla Hill, have been selected for the charophyte study as the productive horizon at Chhota Simla Hill is not traceable. The Lameta Formation at Chui Hill is 27 m thick. The total thickness of the Lameta Formation at Bara Simla Hill is 32 m. Lithologically both sections consist of Green Sandstone, Lower Limestone, Mottled Nodular Bed, Upper Limestone and Upper Sandstone (*sensu* Matley 1921). The Green Sandstone in both sections rests sharply on the Jurassic–Early Cretaceous Jabalpur Group, which comprises the Jabalpur Sandstone and Jabalpur Clays of the Gondwana Supergroup (Matley 1921).

The Green Sandstone is the most basal unit in the Chui Hill and Bara Simla Hill areas and shows a gradational contact with the overlying Lower Limestone. The unit exhibits two distinct sub-units. The lower part of the Green Sandstone has small channels filled with pebbles and is more friable, medium- to coarse-grained, and presents large scale trough cross-beds (sets of 1 m) with azimuths predominantly oriented southwest. The topmost part of the unit consists of consists of roughly bedded, low angle and horizontal cross-stratification. Apart from cross beds, this unit shows channel lag deposits consisting of large intrabasinal clasts like sandstone, clays, calcrete nodules and channel scours. Small extrabasinal material such as jasper and chert clasts are also present (Singh 1981; Brookfield and Sahni 1987; Tandon *et al*. 1990). At Chui Hill the charophyte-yielding bed is a grey siltstone (Text-fig. 2 A), which overlies the 8 m thick

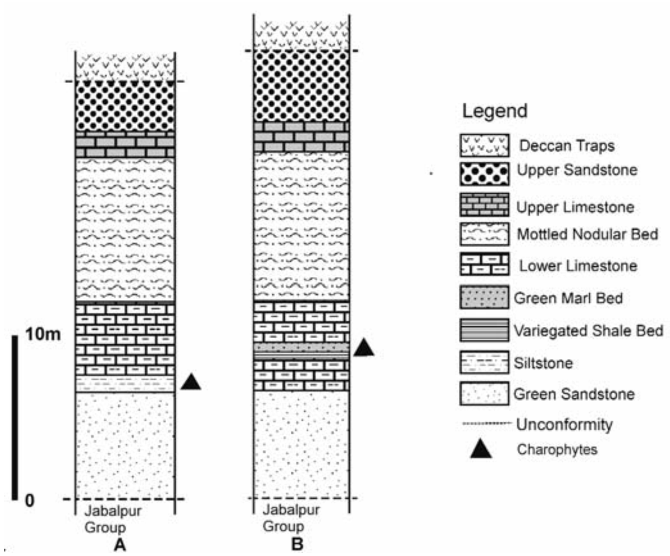


Text-fig. 1. Geological map of the Jabalpur Cantonment area, Madhya Pradesh, showing the charophyte-bearing levels (map modified after Matley 1921). Enlarged views of the inset map (not to scale) showing the presence of the variegated shale and the charophyte-bearing green marl bed, which are intercalated within the Lower Limestone

trough cross-bedded Green Sandstone marking the base of the Lameta Formation at Jabalpur. The Green Sandstone is further overlain by the Lower Limestone, which is a dinosaur egg-rich unit also known as the Lameta Limestone. The Lower Limestone has a white, light grey, creamish or bluish colour. Jasper, chert and quartz grains are dispersed throughout the unit. The upper part of the Lower Limestone often contains irregular stringers and nodules of chert and silcrete cappings. At Bara Simla Hill the charophyte-bearing layer is represented by a green marl bed, which is intercalated within the dinosaur egg- and eggshell- rich Lower Limestone (Text-fig. 2 B). The Mottled Nodular Bed overlies the Lower Limestone. This unit consists of marl, siltstone and mudstone and is characterized by purple-red and green mottles. It is rich in carbonate nodules and shows intense bioturbation and rhizoconcretionary structures. The Upper Limestone exposed at Jabalpur is a rather variable unit of the Lameta succession. The upper part of Mottled Nodular Bed which enters sandy-calcareous facies and become hard and compact is considered as Upper Limestone (Matley 1921; Singh 1981). Clasts of jasper, chert and quartz are also present (Singh 1981; Brookfield and Sahni 1987). In the Jabalpur cantonment area the topmost part of the Upper Limestone is overlain by the Upper Sandstone. Pedogenic modification and calcretization of the sediments is a frequently noticeable feature of the Lameta Formation.

MATERIAL AND METHODS

This study is based on samples collected from two localities at Jabalpur, Madhya Pradesh. The first of the two localities (i.e. Chui Hill Quarry Section, Lat 23° 10¢ N: 79° 58¢ E) is an isolated trap-capped hill and is situated about 1 km NE of Jabalpur Railway Station. The second charophyte-yielding locality is the Bara Simla Hill Section (23° 10¢ N: 79° 59¢ E), located about 1.5 km SE of Chui Hill (Text-fig. 1). The samples were collected from the aforementioned green marl and grey siltstone beds at Jabalpur. The rocks were crushed into small pieces and immersed in kerosene oil for 24 hours to allow complete disaggregation and later sieved with sieves with mesh apertures



Text-fig. 2. Stratigraphic successions of the Lameta Formation at Chui Hill (A) and Bara Simla Hill (B), showing the charophyte-bearing levels

of 1.0, 0.5 and 0.2 mm, the residue being then oven dried. The dried residue was scanned under a stereoscopic binocular microscope for charophytes. Gyrogonites were picked up under the microscope and measured at 40 x magnification. In some samples, charophytes were associated with ostracods, molluscs and microvertebrates. The present study relates to a collection of charophytes (over 60 specimens) (Text-figs 1, 2).

The gyrogonites were distorted during diagenesis and most of them are not suitable for biometrics. However, 12 undeformed gyrogonites were selected, measured and photographed with a scanning electron microscope at Panjab University, Chandigarh and Wadia Institute of Himalayan Geology, Dehradun, India. The assemblage is sufficiently interesting and of stratigraphic significance to warrant recording it in the present publication. Abbreviations are LPA: Length polar axis; LED: Length equatorial index; ISI: Isopolarity index; No: Number; VPL/KH/BSH and CH: Vertebrate Palaeontology Laboratory, Khosla, Bara Simla Hill, Chui Hill. All dimensions are given in micrometres (μm).

SYSTEMATIC PALAEONTOLOGY

Division Charophyta Migula, 1897
Class Charophyceae Smith, 1938
Order Charales Lindley, 1836
Family Characeae Richard ex C. Agardh, 1824
Subfamily Charoideae Al. Braun in Migula, 1897

Genus *Platychara* Grambast, 1962
Platychara cf. *sahnii* Rao and Rao, 1939 (Bhatia and Mannikeri, 1976)
(Pl. 1, Figs 1–4)

1939. *Chara sahnii* n.sp.; Rao and Rao 1939, p. 10, pl. 1, fig. 12, pl.3, fig. 5.
1976. *Platychara sahnii*, Bhatia and Mannikeri, p. 76–77, figs 8–13.
1994. *Platychara sahnii*, Srinivasan, Bajpai and Sahni, p. 564, pl. 1, figs 13–16.

MATERIAL: Three moderately preserved specimens.

HORIZON AND LOCALITY: Green marl bed within the Lower Limestone horizon of the Lameta Formation at Bara Simla Hill, Jabalpur, Madhya Pradesh.

DESCRIPTION: The gyrogonites are oblate and subglobular in shape. The apical part is somewhat rounded and shows an apical rosette about 400 μm in diameter. The lime spirals (80–100 μm wide) are concave to flat and 5–6 convolutions are visible in lateral view. The gyrogonite tapers to the base, with a distinct protruding basal column and the greatest diameter above mid-height.

Dimensions (μm)	**LPA**	**LED**	**ISI**
(No. VPL/KH/ 3001)	660	610	108
(No. VPL/KH/ 3002)	700	660	106
(No.VPL/KH/ 3003)	440	420	104
Mean	600	563	106

REMARKS: This species was originally described as *Chara sahnii* by Rao and Rao (1939) from the intertrappean beds of Rajahmundry. Later, Bhatia and Mannikeri (1976) revised the type specimens and transferred them to the genus *Platychara* as the species *Platychara sahnii*. The present specimens compare closely with *Platychara sahnii* (Bhatia and Mannikeri 1976) described from the Deccan intertrappean beds of Gitti Khadan, Nagpur, Central India in overall shape, lime spirals and number of convolutions but differ from the latter in being much larger and having less swollen apical cells. They differ also from *P. raoi* (Rao and Rao 1939) in being 440–700 µm larger in size, in displaying a more oblate-subglobular shape and a pointed basal structure.

Genus *Nemegtichara* Karczewska and Ziembinska-Tworzydlo, 1972

Nemegtichara grambastii Bhatia, Riveline and Rana, 1990a
(Pl. 1, Figs 5–7)

1990 a. *Nemegtichara grambastii* n. sp.; Bhatia, Riveline and Rana, pp. 318–320, pl. 1, figs 6–9.
1990 b. *Nemegtichara grambastii* n.sp.; Bhatia *et al*. pp. 118, pl. 1, fig. 12.
1994. *Nemegtichara grambastii* Srinivasan, Bajpai and Sahni, p. 564–566, pl. 2, figs 8–10.

MATERIAL: Two moderately preserved gyrogonites.

HORIZON AND LOCALITY: Green marl bed within the Lower Limestone horizon of the Lameta Formation at Bara Simla Hill, Jabalpur, Madhya Pradesh.

DESCRIPTION: The gyrogonites are ovoid in shape. The apex is rounded and slightly protruding in the centre. The lime spirals are 8–10 in number as visible in lateral view, convex and smooth, 50–90 µm high and separated by intercellular ridges. They show a slight periapical narrowing. The base tapers progressively. The basal pore is small, pentagonal in shape and 20–100 µm wide.

DIMENSIONS (µm)	**LPA**	**LED**	**ISI**
(No.VPL/KH/ 3005)	580	420	138
(No.VPL/KH/ 3006)	510	360	141
Mean	545	390	139

REMARKS: The present forms are similar in shape and convolution numbers to *Nemegtichara grambastii* described by Bhatia *et al*. (1990 a) from the Upper Cretaceous intertrappean beds of Rangapur, Andhra Pradesh. They are slightly smaller in size but overall they are regarded as representing the same species. The present specimens are also comparable to two species, namely *Nemegtichara prima* and *N. quarta* described by Karczewska and Ziembinska-Tworzydlo (1972) from the Tertiary "White Beds" of the Nemegt Basin, Mongolia. However, the Jabalpur specimens are smaller in size in comparison to the above-mentioned Chinese and Mongolian species.

Genus *Microchara* Grambast, 1959
Microchara sp.
(Pl. 1, Figs 8–12)

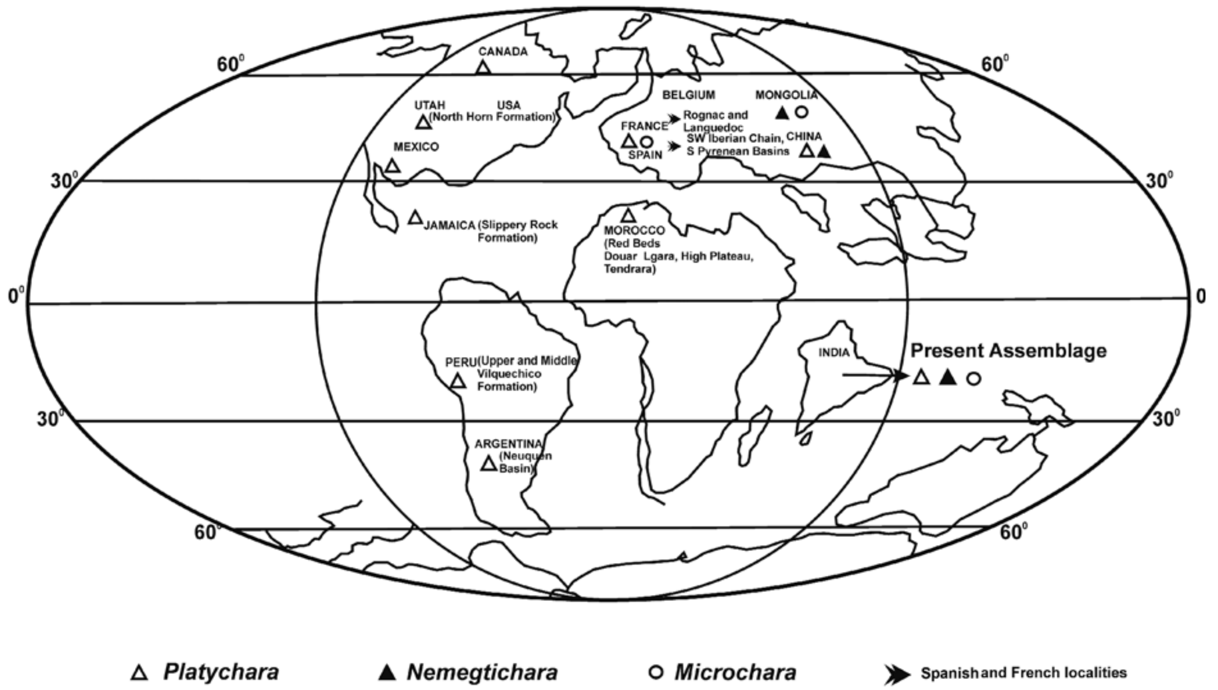
MATERIAL: Seven moderately preserved specimens.

HORIZON AND LOCALITY: Green marl bed within the Lower Limestone horizon of the Lameta Formation at Bara Simla Hill and the siltstone bed at the base of the Lower Limestone horizon at Chui Hill, Jabalpur, Madhya Pradesh.

DESCRIPTION: The gyrogonites are small, varying in size, subprolate, elliptical to conical in shape. They are longer than wide. The apical part is rounded or slightly blunt. The lime spirals are concave and 40 µm wide. They form 8–10 convolutions that are separated by sharp and distinct intercellular ridges. The gyrogonite tapers progressively to the base, which is pointed and bears a small and rounded basal pore.

DIMENSIONS (µm)	**LPA**	**LED**	**ISI**
(No.VPL/KH/ 3007)	640	460	139
(No.VPL/KH/ 3008)	420	320	131
(No.VPL/KH/ 3009)	716	577	124
(No.VPL/KH/ 3010)	599	442	135
(No.VPL/KH/ 3011)	520	440	118
(No.VPL/KH/ 3012)	620	450	137
(No. VPL/KH/3013)	590	437	135
Mean	586	446	131

REMARKS: Morphologically, the present specimens closely resemble *Microchara sausari* recorded earlier from the intertrappean beds of Takli and Asifabad (Bhatia *et al*. 1990 a, b). However, due to the poor preservation and low number of gyrogonites, it is not presently possible to designate the species.



Text-fig. 3. Palaeogeographic distributions of Jabalpur charophyte taxa during the Late Cretaceous (map modified from Srinivasan *et al*. 1994)

DISCUSSION

Palaeobiogeographical implications

The genus *Microchara* sp. includes most of the specimens in the assemblage recovered from the Lameta Formation at Jabalpur and has been recorded from the same formation in the Dongargaon and Dhamni-Pavna sections in Maharashtra (Mohabey *et al*. 1993). The genus is also known from the Gurmatkal (South India) intertrappean beds (Srinivasan *et al*. 1994). Outside India, the genus is abundant in Europe, e.g. in the Campanian and Maastrichtian of Rognac and in some localities from the Languedoc, France (Grambast 1971; Feist and Freytet 1983; Lepicard *et al*. 1985; Massieux *et al*. 1987); in the Campanian–Maastrichtian boundary succession of the Iberian Chain (Grambast and Gutierrez 1977); and in the Southern Pyrenees, Catalonia (Spain), in Late Campanian–earliest Maastrichtian deposits of the Àger, Tremp, Coll de Nargó and Vallcebre basins (Feist and Colombo 1983; Masriera and Ullastre 1988; Villalba-Breva and Martín-Closas 2012; Villalba-Breva *et al.* 2012). The genus has also been documented from the Upper Cretaceous of China, at Shalamulum, Inner Mongolia, and in the Junggar Basin, Xinjiang (Liu 1987; Liu and Wu 1987); from Cretaceous–Palaeocene sequences of China (Bilotte and Massieux 1988) and the Upper Cretaceous of Mongolia and Europe (Karczewska and Ziembinska-Tworzydlo 1983; Grambast and Gutiérrez 1977; Feist and Colombo 1983; Masriera and Ullastre 1988; Villalba-Breva and Martín-Closas 2012; Villalba-Breva *et al.* 2012). In conclusion, the genus *Microchara* appears to be widely distributed throughout Eurasia.

Platychara cf. *sahnii* is a rare species in the present assemblage. The genus *Platychara* is, however, widely distributed and abundant almost worldwide (Text-fig. 3). It is known from the Upper Cretaceous lacustrine deposits of Europe (Bignot and Grambast, 1969; Massieux *et al*. 1985; Feist and Colombo 1983; Feist *et al*. 2005; Villalba-Breva and Martín-Closas 2012), North and South America (Musacchio 1973; Peck and Forester 1979; Kumar and Grambast 1984; Jaillard *et al*. 1993), and northern Africa (Morocco; Mebrouck *et al*. 2009; Chassagne-Manoukian *et al*. 2013). In Asia, it was recorded from a number of localities, mainly from China (Van Itterbeeck *et al*. 2005) and India (Bhatia and Rana 1984; Bhatia *et al*. 1990 a; Srinivasan *et al*. 1994). The species *Gyrogona hubeiensis* Wang Zhen (1978a) recorded from China (Grambast-Fessard 1980; Weitong 1985) also probably belongs to *Platychara*. In Argentina and Alberta the genus is known to range into the Palaeocene (Mussachio 1973; Peck and Forester 1979).

The species *Platychara sahnii* appears to be endemic to the Indian peninsula (Bhatia and Rana 1984; Bhatia *et al*. 1990 a; Srinivasan *et al*. 1994), where it is widely reported from the intertrappean beds of Kachchh (Gujarat), Gurmatkal (South India), Nagpur (Maharashtra) and Asifabad, Andhra Pradesh (Bhatia and Rana 1984; Bhatia *et al*. 1990 a; Srinivasan *et al*. 1994). It has also been listed from the Lameta Formation of Nand (Mohabey *et al*. 1993). With the exception of Gurmatkal, the species is associated with dinosaur remains in all these localities. The record of *P. sahnii* from the Maastrichtian of Iran (Colin *et al*. 2012), requires confirmation (no description or illustration was provided).

Nemegtichara grambastii was known previously from the intertrappean beds of Rangapur, Mamoni (Bhatia *et al*. 1990 a, b) and Gurmatkal (Srinivasan *et al*. 1994), and was listed from the Lameta Formation of Nand-Dongargaon in Maharashtra (Mohabey *et al*. 1993). The genus, however, is also known from outside India; it was reported from the Upper Cretaceous, with possible extension into the Palaeogene, of China (Wang Zhen 1978 a, b; Huang 1979; 1985; Wang Zhen *et al*. 1983; Wang Zhen and Wang Ke-Yong 1985) and Mongolia (Karczewska and Ziembinska-Tworzydlo 1972, 1983).

In conclusion, the charophytes from Jabalpur, especially *Nemegtichara*, show affinities with species of the Late Cretaceous and Early Palaeogene of China and Mongolia.

The charophyte flora of the Deccan volcano-sedimentary sequences has enabled various workers to assume its palaeobiogeographic affinities and to draw conclusions on the possible position of the Indian plate in Late Cretaceous times in the context of the Plate tectonic hypothesis (Srinivasan *et al*. 1994; Bhatia *et al*. 1996; Khosla and Sahni 2003; Khosla and Verma 2014). The palaeobiogeographic significance of the biotic assemblages of the infra- and intertrappean beds has recently been discussed in detail by Khosla and Verma (2014). It is now well understood from the diverse fossil assemblages that, despite its northward drift as an isolated landmass, India supported widely dispersed biota from both Laurasia (Sahni and Khosla 1994a; Prasad *et al*. 2010; Fernández and Khosla 2014; Khosla and Verma 2014) and Gondwana (Wilson *et al*. 2003; Prasad *et al*. 2010; Verma *et al*. 2012; Fernández and Khosla 2014) in addition to endemic species (Sharma and Khosla 2009; Whatley 2012; Bajpai *et al*. 2013; Khosla and Verma 2014) during the Late Cretaceous. Apart from charophyte and ostracod assemblages the infra- and intertrappean beds also contain vertebrate faunas of Laurasian affinity, though recently doubt has been cast on such relationships (Khosla and Sahni 2003; Prasad *et al*. 2010). The freshwater charophyte assemblages of Jabalpur in Central India have strong affinities with the Upper Cretaceous assemblages from Europe, Asia, America and Africa, not only at the generic level but also at the specific level and have interesting palaeobiogeographic implications (Text-fig. 3). For example, the genus *Platychara*, regarded previously as a Cretaceous–Palaeocene North–South American genus, has now also been recorded in the Upper Cretaceous of peninsular India, Europe and Africa. Similarly the genus *Microchara* also occurs in the Upper Cretaceous of peninsular India and also has wide distribution in Laurasia. The charophyte findings reported herein are in agreement with the evidence provided by other fossils, such as discoglossid and pelobatid frogs, anguimorph lizards, alligatorid crocodiles, eutherian mammals and palynomorph assemblages. All these groups have Laurasian affinities (Khosla and Sahni 2003; Khosla *et al*. 2004, 2009; Khosla and Verma 2014). There are, therefore, strong grounds to support the presence of Laurasian taxa in the northward drifting Indian continent which has been explained either by an early India/Asia contact (Jaeger *et al*. 1989) or by dispersals across intermittent islands between India and Asia (Bhatia *et al*. 1990 a, b, 1996; Khosla and Verma 2014). This conclusion was generally based on the presence of eutherian mammal (*Deccanolestes*) and pelobatid frogs of Laurasian affinities and the presence of notable endemism in the form of ostracods in the Late Cretaceous fauna of India (Khosla and Verma 2014). More recently, the co-existence of Laurasiatic biotas is now better understood in terms of a proposed northern sweepstakes mode of dispersal between India and Eurasia across the Kohistan-Dras volcanic island-arc system which could have provided the necessary land passage for the migration of Laurasiatic biota to India during the Late Cretaceous (Prasad *et al*. 2010; Khosla and Verma 2014). The infra- and intertrappean beds also contain representatives of Gondwanan taxa such as dinosaurs (abelisaurids), gondwanathere and haramyid mammals, baurusuchid crocodiles, pelomedusid and bothremydid turtles, madtsoiid and nigerophiid snakes, and leptodactylid, ranoid and hylid frogs, which show sister-group relationships with South American and Madagascan forms (Khosla and Sahni 2003; Wilson *et al*. 2003; Prasad *et al*. 2007 a, b; Verma *et al*. 2012; Fernández and Khosla 2014; Khosla and Verma 2014). Based on these biota, various land bridges have been proposed, such as a Late Cretaceous terrestrial connection between South America and India-Madagascar via Antarctica and the Kerguelen Plateau (Prasad *et al*., 2010), via "Greater Somalia" (Chatterjee and Scotese 1999), via Africa-Madagascar and the Arabia-Kohistan-Dras volcanic arc (Chatterjee and Scotese 1999).

Palaeoecology and palaeoenvironments

Upper Cretaceous charophyte assemblages from the Lameta Formation of Jabalpur occur in fine-grained siltstones and green marls in which the content of calcium carbonate is very high. The high content of calcium carbonate is due to two reasons. Firstly, it is most likely due to drying up of the sedimentary basin, which is inferred from the specific state of preservation of the gyrogonite. Secondly, the charophyte-bearing siltstone at Chui Hill is intercalated within the dinosaur eggs and eggshell-bearing Lower Limestone (Text-figs 1, 2) (Sahni and Khosla 1994 a, b).

Vertebrate and invertebrate remains such as charophytes and ostracods are associated with probable shallow floodplain channels, which show that at least once; a more permanent standing body of water must have existed, at least for a short time, which could have been a meandering cut-off lake. Therefore, Brookfield and Sahni (1987) described Lameta Formation around Jabalpur as the deposits of arid terrestrial environment with a river flowing through. The Green Sandstone was described as a point bar deposit, the Mottled Nodular Bed as a floodplain deposit with pedogenic concretions which represent the floodplain drainage channels (Brookfield and Sahni 1987). They described the Lower and Upper Limestone as pedogenic calcretes which are localized by the accumulation of small gravels.

At Bara Simla Hill the Lower Limestone has been considered a morphological surface (Tandon *et al*. 1990) representing additionally "relief highs" that have yielded abundant sauropod nests and eggshell fragments and "relief lows" (green marl facies). The marl bed has yielded dinosaur skeletal material (Huene and Matley 1933; Chatterjee 1978). The Lower Limestone was deposited in a semi-arid alluvial floodplain undergoing pedogenesis, as suggested from the extensive occurrence of carbonates and calcretes (Tandon *et al*. 1990). The Lower Limestone is characterized by brecciation, shrinkage and circumgranular cracks, nodular, and brecciated structures. Consequently, it is interpreted as a sub-aerially exposed palustrine flat with calcrete formation occurring on topographic highs of low relief plains (Tandon *et al*. 1990). In this floodplain context, the charophytes would possibly have grown in overbank ponds and lakes. A similar type of fluvio-lacustrine environment has been recorded from the Lameta Formation in the Nand-Dongargaon and Dhamni-Pavna sections, Maharashtra, which comprise different lithologies such as limestone and carbonate muds (marls and marlites), including different lithofacies, namely limestone-carbonate mud, clay-silt, varved clay, sandy gravel, septarian concretionary and fibrous/radaxial calcite facies. The lacustrine biota including charophytes (*Platychara* sp. and *Microchara* sp.) occur in close association with limnic fishes such as clupeids, *Pycnodus* sp., *Lepidotes* sp., gastropods and ostracods (Mohabey *et al*. 1993; Khosla and Verma 2014). The charophyte-yielding samples of Jabalpur are also extremely rich in freshwater lacustrine ostracods, e.g. *Candona*, *Eucypris* and *Paracandona* (Khosla and Sahni 2000). The entire biota, i.e. charophytes, ostracods, gastropods and fishes, clearly points to a predominantly alkaline, shallow, freshwater, lacustrine, palustrine (swampy) depositional setting for the green marl and siltstone beds of the Lameta Formation of Jabalpur.

The presence of fish taxa, such as *Phareodus* sp. in the Lameta Formation of Jabalpur, indicates a tropical freshwater environment (Sahni and Tripathi 1990; Khosla and Verma 2014). Another fish taxon, *Lepisosteus* sp., recorded in the intertrappean beds near Jabalpur (Dindori district, Madhya Pradesh) also represents a freshwater form (Khosla *et al*. 2004). There is no record of sharks or marine fossils from the Lameta Formation of peninsular India. The presence of rays suggests that the forms may have adapted to freshwater conditions and that eotrigonodontids may represent forms migrating upstream (Sahni and Khosla 1994 b).

Biostratigraphy

The age of the Lameta Formation has been based on both palaeontological and geochronological data. The current opinion is that the Lameta Formation is post-Turonian and possibly Maastrichtian in age, based mainly on the presence of primitive tyrannosaurids and on the revision of early stratigraphic correlations with Argentinean and Madagascan sequences proposed by Huene and Matley (1933).

Fish genera, such as *Stephanodus*, *Rhombodus* and *Apateodus*known, reported from the infratrappeans of Jabalpur (Sahni and Tripathi 1990; Khosla and Sahni 2000, 2003) support their Maastrichtian age. This age is also suggested by a unique ray, *Igdabatis*, recorded from the Maastrichtian of India (Prasad and Cappetta 1993), Niger (Courtillot *et al*. 1986) and Spain (Soler-

Gijon and Martinez 1998), where it is also associated with eotrigonodontids. The presence of an *Aquilapollenites* palynological assemblage from the green marl bed at Jabalpur also indicates its Maastrichtian age (Dogra *et al*. 1994).

Supporting evidence for a Maastrichtian age (Dogra *et al.* 1994) also comes from the Jabalpur ostracod assemblage, that suggests the common presence of endemic forms such as *Limnocythere*, *Candona*, *Cyclocypris, Cypridea* (*Pseudocypridina*)*, Cypridopsis, Cyprois*, *Mongolocypris*, *Paracandona*, *Paracypretta*, *Stenocypris*, *Zonocypris* and *Wolburgiopsis* sp. (Khosla and Sahni 2000; Khosla *et al*. 2011; Khosla and Verma 2014). Most of the ostracod assemblage is also known to occur in the dinosaur-bearing Lameta Formation of Nand-Dongargaon and the Dhamni-Pavna and Pisdura sections in Chandrapur District, Maharashtra (Mohabey *et al*. 1993; Khosla and Sahni 2003; Khosla *et al*. 2011).

Charophytes in the studied sections are not as abundant as ostracods but also contribute in assigning the age of the Lameta Formation. Although both *Platychara* and *Nemegtichara* have been recorded from the Upper Cretaceous through to Lower Palaeogene (Bhatia *et al*. 1990 a), the presence of *Platychara sahnii* in the formation suggest its Maastrichtian age. Recently, *P. sahnii* was also reported from the Maastrichtian of the Zagros Mountains, Iran (Colin *et al*. 2012), however, this report requires confirmation. *Platychara* occurs commonly in the Upper Cretaceous in Europe (Villalba-Breva and Martín-Closas 2012), and in North and South America (Musacchio 1973; Peck and Forester 1979; Jaillard *et al*. 1993). The genus *Nemegtichara* was firstly recorded from the Upper Cretaceous (Turonian-Maastrichtian) deposits of China (Wang Zhen 1978 a, b; Huang 1979; Wang Zhen *et al*. 1983; Wang Zhen and Wang Ke-Yong 1985; Bhatia *et al*. 1990a) and probably continues into Palaeocene of Mongolia and China (Karczewska and Ziembinska-Tworzydlo 1972, 1983; Wang Zhen 1978b; Huang, 1985; Bhatia *et al*. 1990a). The present record of *Nemegtichara* from Jabalpur extends its geographic distribution in India. Therefore, *Microchara* and *Nemegtichara* are the two common genera which have been recorded widely in the Upper Cretaceous sequences of China, Mongolia and India.

The Lameta Formation is overlain by the Deccan Traps, the oldest of which has been radiometrically dated at 65.6 ± 0.3 Ma (Courtillot *et al*. 1986). Based on the geochronology and magnetostratigraphy of the Deccan basalts, the Lameta beds are considered to represent the magnetochron 30N (Courtillot *et al*. 1986). The Deccan basalts are known from Chui Hill, Jabalpur, where they overlie the Lameta beds. The lower part of the basaltic sequence starts with the C30R or C31R (Mohabey and Udhoji 1996), the middle part is followed by a normally magnetised thin basalts, and the upper part is represented again by a thick pile of lava, with reverse magnetisation, identified as C29R (Vandamme and Courtillot 1992), which probably encompasses the Cretaceous–Palaeogene boundary. The reversed magnetic susceptibility patterns obtained from the sediments of the Lameta Formation at Chui Hill are in general agreement with C29R observed from the non-marine sediments of the North Horn Formation, Utah (Hansen *et al*. 1996). Therefore, the advent of the Deccan basalts at Jabalpur is in accord with the Cretaceous–Palaeogene boundary (Hansen *et al*. 1996). Since the Lameta Formation of Jabalpur has yielded dinosaur skeletal remains and their eggs, ostracods and palynomorphs, it is definitely Maastrichtian in age (Tandon *et al*. 1990; Sahni and Khosla 1994 b).

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PLATE 1

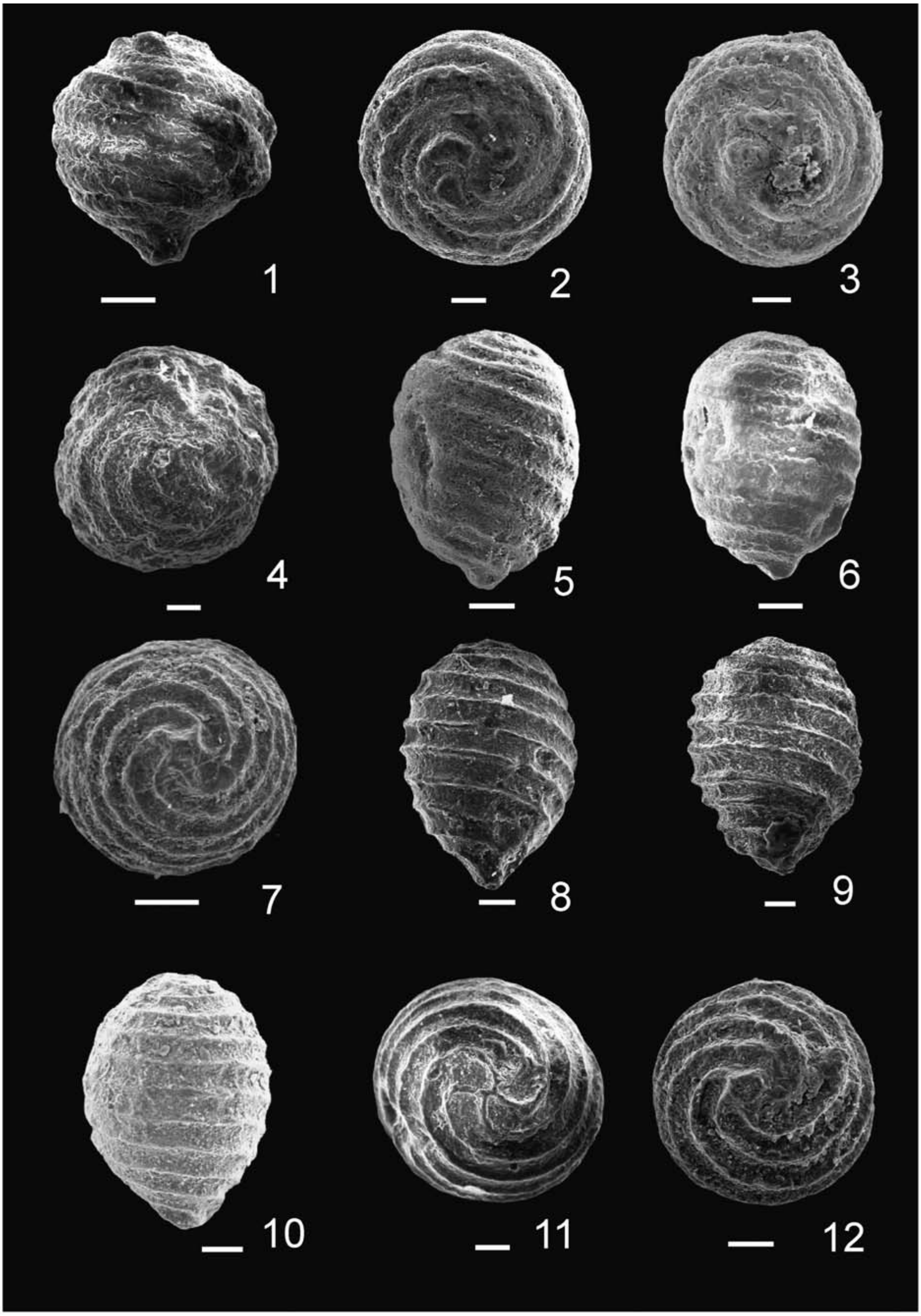
Gyrogonites of charophytes from the Upper Cretaceous of the Lameta Formation at Jabalpur.

1–4 – *Platychara* cf. *sahnii*, Rao and Rao, 1939 (Bhatia and Mannikeri, 1976), Bara Simla Hill section. 1 – lateral view, VPL/KH/3001; 2 – apical view, VPL/KH/3002; 3 – apical view, VPL/KH/3003; 4 – basal view, VPL/KH/3003.

5–7 – *Nemegtichara grambastii* (Bhatia, Riveline and Rana, 1990a), Bara Simla Hill section. 5 – lateral view, VPL/KH/3005; 6 – lateral view, VPL/KH/3006; 7 – basal view, VPL/KH/ 3006.

8–12 – *Microchara* sp., Bara Simla Hill section. 8 – lateral view, VPL/KH/3007; 9 – lateral view, VPL/KH/3009; 10 – lateral view, VPL/KH/3010; 11 – apical view, VPL/KH/3007; 12 – basal view, VPL/KH/3008.

Bar length in all figures is 100 μm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