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Ammonites as biological stopwatch and biogeographical black box – a case study from the Jurassic–Cretaceous boundary (150 Ma) of Kutch, Gujarat

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Some ammonites provide high time resolution and some others record precise palaeolatitudinal position of the sedimentary basins which harboured them. The Late Jurassic fossil record in Kutch was poor until recently. The present discovery of four genera, viz. *Micracanthoceras*, Spath, 1925; *Durangites*, Burckhardt, 1912; *Coronogoceras*, Spath, 1925 and *Tithopeltoceras*, Arkell, 1953 helps in drawing precisely the Jurassic–Cretaceous system boundary in Kutch and in palaeocontinental reconstruction. Besides, faunal migrational pathways across different palaeobiogeographical provinces have been discussed.

THE nature of the fossil record reveals that many taxa spent 'a little hour of grace' on the earth yet flourished and had wider and rapid biogeographic dispersal. They are aptly described as 'fleeting fossil'¹. Many ammonites are fleeting fossils and had great geochronological importance. In fact, they were used as zonal indices for slicing up the earth's rocks, especially the Mesozoic into finer time segments. Hence they are the biological stopwatch.

Besides, ammonites are environmentally sensitive. They are exclusively marine and often climatically and latitudinally restricted. Since the Jurassic, when the earth's last continental fragmentation started, land masses were wandering in different directions. Some continents broke away, while others collided. India, once a member of the lost Gondwana supercontinent, started rifting during the Late Cretaceous (90 Ma ago)² and made a solitary journey of about 5000 km before hitting the Asian plate; the collision resulted in the upheaval of the mighty Himalayas. The wandering continents, however, acted as a 'Viking funeral ship' or 'Noah's ark' and rafted fossils albeit ammonites with them. Ammonites, mostly being biogeographically and climatically restricted, inscribed their latitudinal signatures in the rock book like geomagnetic anomalies and thus acted as a black box^{2–4} thus helping reconstructing the continental disposition of the past^{5–7}.

During the Middle Jurassic, the Kutch basin came into being⁸. The first phase of Gondwana fragmentation separated West Gondwana comprising Africa and South

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America from East Gondwana consisting of India, Antarctica and Australia⁹. The eastern part of Africa and Madagascar and western coast of India support a typical endemic faunal assemblage belonging to the Indo-Madagascar faunal province. It is generally believed that India and the southern part of Africa were land-locked till the end of the Jurassic^{10,11}. During the Late Jurassic, major continental shelves of the world experienced fluctuating sea levels¹² and many marine deposits including those of Kutch were punctuated by sharp regressive phases¹³. These transgressive-regressive couplets were again locally induced by tectonic events¹⁴ and thus when India, during the Jurassic-Cretaceous transition experienced steep fall in sea level due to regression coupled with tectonic disturbance¹⁴, Madagascar witnessed open marine condition which supported earliest Cretaceous ammonites¹⁵. Many of the then-existing faunal provinces consequently show marked endemism during the Tithonian¹⁵. Only during the occasional eustatic high stand faunal exchanges were possible which helped in global bio- and chronostratigraphic correlations¹⁶. For example, the latest Tithonian witnessed a global flooding^{17,18} which blurred the so-called provincial boundary and made it possible for many ammonites to have circum-global distribution. While many major recent contributions in other areas have improved the chronostratigraphic resolution across the Jurassic-Cretaceous boundary in the regional scenario and enabled the intercontinental correlation with a much greater degree of confidence^{15,16,19,20}, Kutch geology has lagged behind in this regard because of dearth of any serious attempt to revise biostratigraphy and systematics of ammonites after Spath²¹. Many genera described by Spath²¹ are cosmopolitan and long-ranging, and therefore of little use in time correlation. The present investigation has yielded several time-diagnostic genera of the latest Tithonian from a single bed, which were hitherto unknown from Kutch basin. Thus the discovery will help in correlation of Kutch Tithonian stratigraphy in time and space.

The time-diagnostic genera discovered in this present haul are *Micracanthoceras*, *Durangites*, *Corongoceras* and *Tithopeltoceras*. Although previously described by Spath²¹, the stratigraphic position of *Micracanthoceras* was uncertain. The previous distribution pattern of *Tithopeltoceras* suggests 30°N latitude. The present discovery of this genus is second of its kind reported from outside the Submediterranean Province. It is shown that *Tithopeltoceras* was restricted only to the subtropics, on either side of the equator, and perhaps was constrained by temperature and latitudinal position of Kutch basin which was 30°S. *Micracanthoceras* and *Corongoceras*, in contrast to *Tithopeltoceras*, show wider palaeobiogeographic distribution. They have been reported from South America, Europe, Madagascar, Himalaya and Australia^{15,16}. Thus, it appears that they have peri-Gondwana distribution.

Kutch has been known worldwide for its marine Mesozoic rocks. The Mesozoic sediments of this region were

laid down during Bajocian to Aptian. The Jurassic part of these, i.e. Bajocian to Tithonian is a storehouse of ammonite fossils. The Mesozoic rocks of Kutch was first described by Wynne²². Waagen²³ has subdivided these rocks into four major divisions vide Patcham, Chari, Katrol and Umia. Subsequently, major revisions^{24,25} were made on the Kutch stratigraphy, where Waagen's first three units survived as rock stratigraphic units with due status, i.e. Formation and Bhuj Formation was introduced in the place of Umia.

While describing the Jurassic rocks of Kutch, Waagen²³ was preoccupied with the idea of finding European chronostratigraphic ammonite zonal indices and ignored the endemic assemblage. A comprehensive account of Jurassic ammonites was first published by Spath²¹. The Kutch ammonite assemblages are so characteristic, that they earned distinctiveness and are now described as fauna of a separate biogeographic province, i.e. Indo-Madagascan Faunal Province. After Spath, several workers visited Kutch and new data have come out on the mega invertebrate fossils and on cephalopoda in particular.

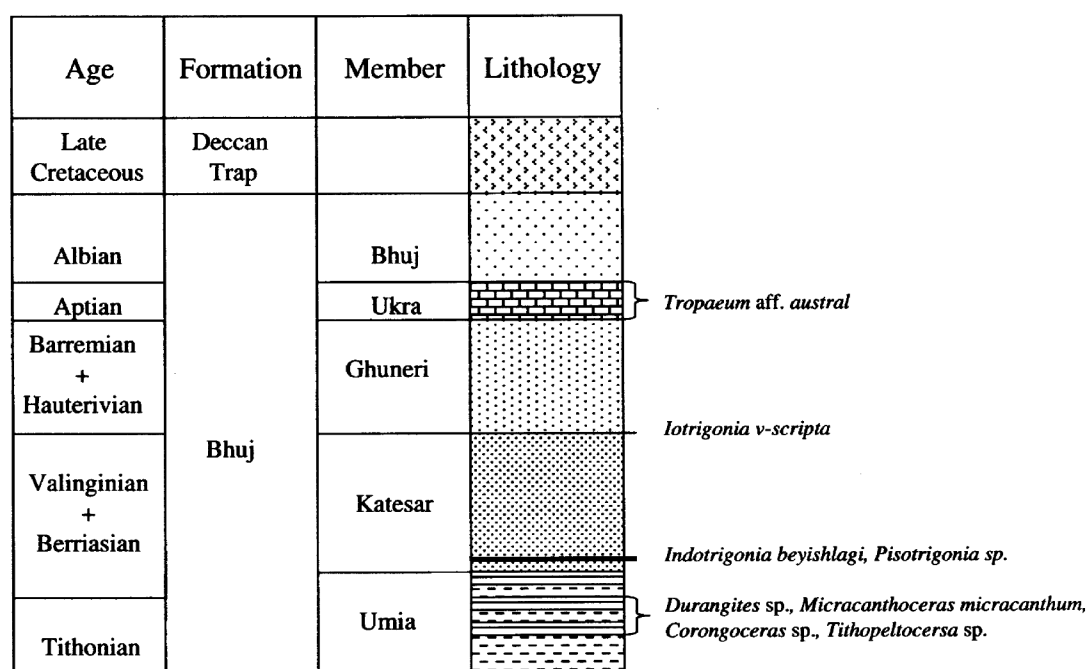
The rocks containing the ammonite fossils of the Late Tithonian age belong to the Umia Member of the Bhuj Formation²⁵. The base of this member is not exposed and it underlies the Katesar Member (Figure 1). It is characterized dominantly by repeated cycles of a heterolithic facies consisting of sharp-based, laterally discontinuous and hummocky, cross-stratified sheet sandstone, massive or plain laminated shale and occasional oolite; sandstone facies consist of paper-thin, torn sheets of mudstone and gritty sandstone facies. The organization of the above sedimentary facies indicates that the sequence experienced several transgression – regression couplets²⁶ and a major regression took place at the end of the Tithonian that is marked by the extinction of all Jurassic ammonites of Kutch, including several endemic and cosmopolitan genera. This regional extinction event coincides with the global mass extinction episode during the Jurassic-Cretaceous boundary⁷. The upper age limit of the Umia Member was previously placed at various levels. Some workers prefer to put it at the Tithonian/Berriasian boundary (Rudra pers. commun), others above the System boundary^{24,25,27,28}. But the last appearance of the Late Tithonian ammonites coincides with the second oolitic band of the oolitic facies mentioned above, which clearly appears to be time-transgressive. We therefore prefer to demarcate the top of the Umia Member at the end of the uppermost oolitic horizon, which yields the present ammonite genera in the section located 2 km northeast of Lakhapur (Figure 2). All specimens are kept in the museum of Department of Geological Sciences, Jadavpur University.

Family: BERRIASSELLIDAE Spath, 1922

Subfamily: HIMALAYITINAE Spath, 1925

Genus: *Micracanthoceras* Spath, 1925

Type species: *Ammonite micracanthus* Opell, 1968



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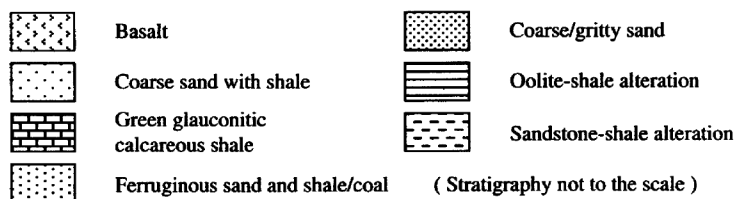


Figure 1. Stratigraphic column showing position of occurrence of reported taxa.

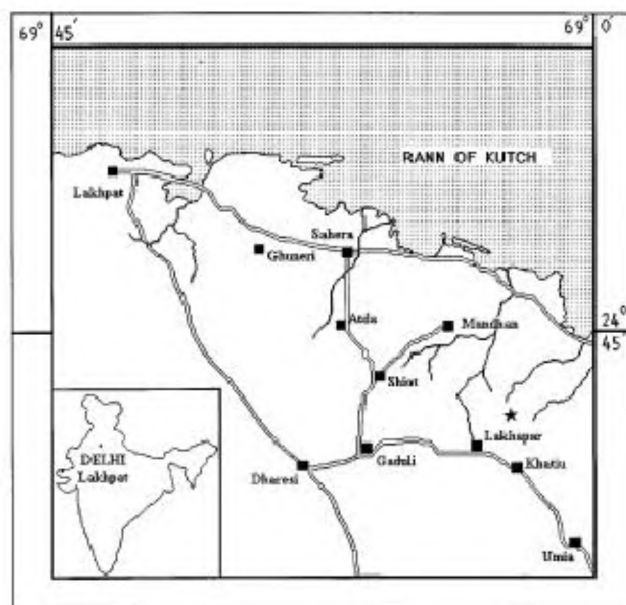


Figure 2. Locality map showing fossil occurrence (star mark).

Micracanthoceras aff. *Micracanthum* (Oppel)

(Figure 3 a and b)

1868. *Ammonite micracanthus* Oppel; Zittel, p. 93, pl.xvii, Figures 1–5

1910. *Himalayites micracanthus* (Oppel) Uhlig, p. 139

1925. *Micracanthoceras micracanthus* (Oppel) Spath, p. 144

1931. *Micracanthoceras* aff. *Micracanthum* (Oppel) Spath, p. 143, pl. XCII, Figures 3 a, b

Remarks: Spath (1933) described four species of *Micracanthoceras* which were based on single and incomplete specimens. All species come from a single locality, Lakhpur and poorly defined level, his 'Lower Umia Group'. The present specimen, along with *Durangites* and *Corongoceras*, comes from the middle part of the oolitic facies, i.e. second oolitic band which demarcates the Jurassic–Cretaceous boundary.

Genus: *Durangites* Burckhardt, 1912

Type species: *Durangites acanthicus* SD Roman, 1938
Durangites sp. (Figure 3 c and d)

Description: Shell strongly evolute, perisphinctoid coiling and whorl compressed. Whorl section subrectangular, position of maximum width lies near the umbilical margin. Flank flatish to slightly curved. Venter broad and flattened. Sharp, densely-spaced straight ribs divide on the upper middle of the flank and form sharp edges at the ventrolateral margin. The ribs are discontinuous over the venter at earlier growth stage, but at a later growth stage they join across the flattened venter.

D	U	W	H
87	39	19	27

(all in mm)

Genus: *Corongoceras* Spath, 1925

Type species: *Corongoceras lotenoense* Haupt, 1907
Corongoceras sp.
 (Figure 4 a and b)

Description: Shell is highly evolute, planulate, almost serpenticone. Whorl section is sub-ovate. Ribs sharp and evenly spaced on the inner and outer whorls. The primaries arise at the umbilical seam almost rectiradiate, bifur-

cate at the ventrolateral margin where they form a row of prominent tubercles. Ventral tubercles spinose.

D	U	W	H
63	34	18	20

(all in mm)

Genus: *Tithopeltoceras* Arkell, 1953

Type species: *Aspidoceras moriconii* Meneghini, 1885
Tithopeltoceras sp.
 (Figure 4 c and d)

Description: Shell strongly evolute, perisphinctoid coiling; whorls depressed throughout the ontogeny. Whorl section subquadrate, position of the maximum width lies near the umbilical margin. Flank flatish to slightly curved; both umbilical and ventrolateral margins gradual, umbilical wall inclined. Venter quite broad, slightly curved in early stage, becoming gradually flattened afterwards. Phragmocone consists of sharp, distant ribs. Some ribs, however, are closely spaced, thus intercostals areas appear to be constricted. Primary ribs are long, bifurcate near the mid-flank. Primaries originate from the umbilical margin, rise slightly rursiradiately, gaining more strength as these proceed

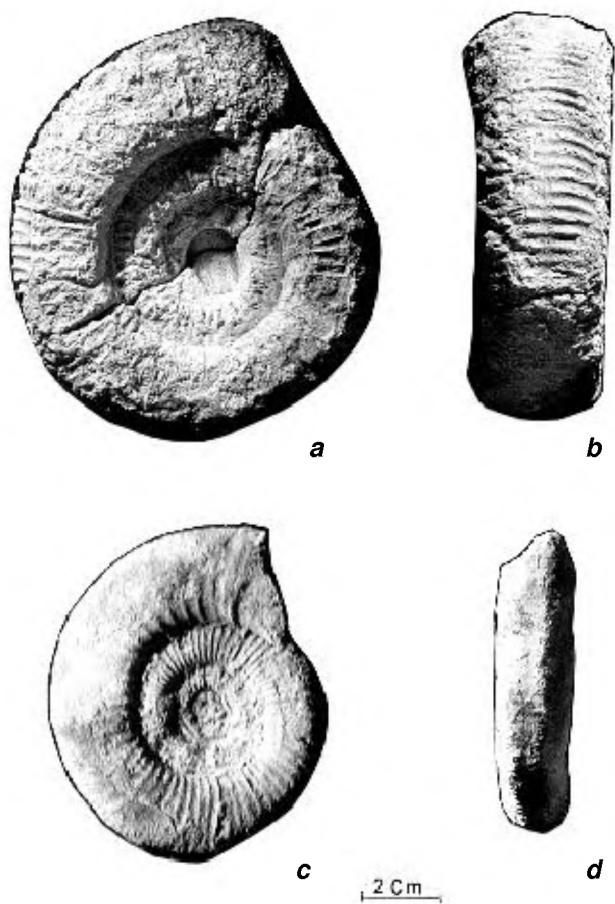


Figure 3. a and b, *Micracanthoceras* sp., lateral and ventral view. c and d, *Durangites* sp., lateral and ventral view.

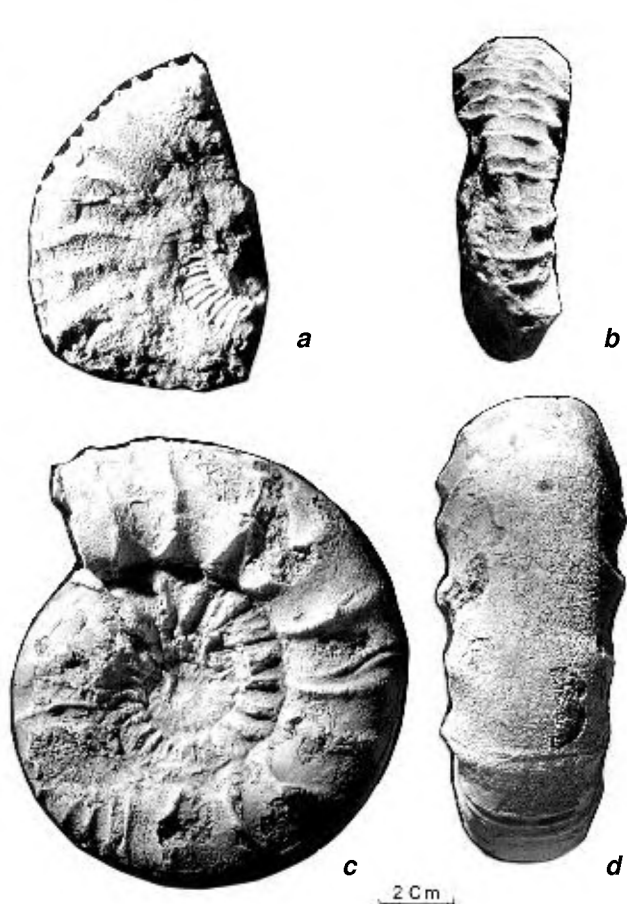


Figure 4. a and b, *Corongoceras* sp., lateral and ventral view. c and d, *Tithopeltoceras* sp., lateral and ventral view.

toward the mid-flank where they culminate to elongated bullae or nodose tubercles. Secondaries originate from elongated bullae or pyramidal tubercle and are straight, but show forward projection. Solitaries are irregularly placed. Ribs quickly lose strength sharply after crossing the tubercles and fade near the ventrolateral margin, rendering the venter smooth. Secondaries, while crossing the ventrolateral margin, may form elongated bullae or weak tubercles and cross the venter straight with blunt and low profile, yet occasionally disappear.

D	U	W	H
124	60	46	36
(all in mm)			

The Late Jurassic experienced frequent major regression events and subsequent shallowing up of many epicontinental basins¹⁵ of the world. Ammonites, being a vulnerable group quite sensitive to bathymetric fluctuations, showed decrease in diversity with the eustatic lowering. As a result, the Tithonian ammonites were mostly endemic to several provinces, which deterred to draw time equivalence among the then-existing faunal provinces^{15,16}. However, there are some ammonite genera which had greater biogeographic spread. The present genera, *Durangites*, *Corongoceras*, *Micracanthoceras* and *Tithopeltoceras*, are few of the important cosmopolitan taxa, but were uncommon in Kutch. All of them belong to the subfamily Himalayitinae of the family Berriasillidae. Until recently, these genera and Himalayitinae in general, were reported from the Himalayan Tethys, East Africa, Mediterranean and Pacific faunal provinces^{15,16,20,29}. The present discovery from Kutch signifies two important features: (i) their presence pinpoints the Jurassic–Cretaceous System boundary in Kutch and (ii) they help in reconstructing the palaeolatitudinal position of Kutch. All these genera mark the Late Tithonian in other areas and *Durangites* in particular, is the zonal index of the latest Tithonian in the Mediterranean¹⁵, where ammonites are most diverse. *Micracanthoceras*, previously had doubtful stratigraphic position in Kutch, but was reported elsewhere only from the later part of Tithonian. Its presence along with *Durangites* confirms its occurrence only during the latest Tithonian *Durangites* zone in Kutch. *Corongoceras* has been reported from the Mediterranean, Himalayan Tethys, Madagascar and northern part of South America. It is being debated whether India was completely separated from Africa during the Late Jurassic and also where Kutch was palaeolatitudinally positioned. Presence of *Tithopeltoceras* contributes in investigating this intrigue. Previously, it was only reported from the Submediterranean subprovince of the Mediterranean province^{30,31}. More interestingly, its distribution pattern suggests that it was restricted more or less within the 30°N latitude, even within this subprovince. The present discovery of *Tithopeltoceras* in Kutch is second of its kind from outside the Mediterranean Province. Among

many factors that control ammonite palaeobiogeographic distribution, temperature plays a significant role. The palaeoclimate and temperature in turn are influenced by palaeolatitudes which, in substantive measure, help the palaeogeographic reconstruction of the provinces¹⁵. It has been recently shown that *Tithopeltoceras* is latitudinally sensitive and its presence demarcates the position of Kutch similarly near 30° (ref. 32). Previously, it was believed that India was land-locked with Africa at its southern margin for most of the Jurassic, which resulted in strong dissimilarity between ammonites of the south and southeast Pacific and Indo-Madagascan faunal provinces. However, *Micracanthoceras* and *Corongoceras* have been recently reported from southern Argentina¹⁶; their presence in Himalayan Tethys, Madagascar, India, East Africa and Argentina suggests the prevalence of a sea route between India and Africa, at least during the latest Tithonian.

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Genetic diversity of rhizobia isolated from medicinal legumes growing in the sub-Himalayan region of Uttaranchal

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Diversity of rhizobia recovered from five medicinal legumes, *Trigonella foenum graecum*, *Abrus precatorius*, *Mucuna pruriens*, *Melilotus officinalis* and *Vicia angustifolia* was investigated. Nine bacterial strains isolated on yeast extract mannitol agar (YEMA) and showing tolerance to 2% NaCl were analysed along with reference strains, *Bradyrhizobium japonicum* SB102, *Sinorhizobium meliloti* 102F 34 and *Rhizobium gallicum* R602sp^T using restriction patterns produced by amplified DNA coding for 16S rDNA (ARDRA) with two enzymes *Hae*III and *Msp*I and were placed in six genotypes. Four isolates from *Trigonella*, i.e. PP1, PP2, PP3 and PP4 were placed in two genotypes; one genotype was closely related to *S. meliloti* 102F 34 and the other to *B. japonicum* SB 102. Genetic diversity was also assessed by repetitive PCR using BOX primers, wherein all the isolates were placed in five genotypes. Based on repetitive PCR, isolates from nodules of *Trigonella* were placed in single genotype. Nitrogen-fixing ability of the isolates was confirmed by amplification of 781 bp *nifH* fragment in five isolates, PP1, PP2, PP3, PP4 and PP9.

MICROBIAL diversity is considered as one of the most useful resources for bioprospecting. Rhizobia are of particular interest due to their symbiotic nitrogen fixing ability with members of Leguminosae¹ which is the second largest family of flowering plants and includes more important drugs than any other family. Genetic diversity of bacteria is being analysed increasingly by PCR-based genomic fingerprinting methods. As more knowledge is acquired and isolates from unexplored legumes are studied, new species are discovered and former species are split. Due to improved methods of characterization, the classification of rhizobia has undergone drastic changes^{2–7} and the phylogenetic analysis of the family Rhizobiaceae and related genera has been upgraded^{2–7}. Laguerre *et al.*⁸ applied the restriction fragment length polymorphism analysis of PCR-amplified 16S rRNA gene for identification of rhizobia. Since then, this technique has been utilized extensively by various workers and several novel species have been reported during the last decade^{9–14}. Applying these tech-

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