

## AMMONOID BIOCHRONOLOGY OF THE UPPER JURASSIC KIMMERIDGIAN STAGE IN KACHCHH, INDIA

JAI KRISHNA AND DEO BRAT PATHAK  
BANARAS HINDU UNIVERSITY, VARANASI - 221 005, INDIA

### ABSTRACT

Large new collections of ammonites have been made bed by bed from the lowest 40 m of the Lower Katrol Formation (Upper Jurassic) at Ler-Katrol, SE of Bhuj, Kachchh, Western India. The assemblages are dominated by a single lineage of *Virgatosphinctinae* of the family *Ataxioceratidae*, in the genera *Torquatisphinctes* - *Pachysphinctes* - *Katrolliceras*. The evolutionary stages of this lineage are made the basis of a new standard chronozonation of the Kimmeridgian Stage of Western India, consisting of four Zones and seven Subzones. The characteristic ammonites are widely distributed, found in part as far as Somalia, Kenya and Madagascar, suggesting that the new zonal classification may be applicable to the whole of the Indo-East-African faunal Province. They are, however, not found in the western Tethys. Correlation with the Submediterranean provincial standard therefore depends heavily on minor faunal elements common to both provinces, including *Aspidoceras*, *Hybonotoceras*, *Pseudowaagenia*, *Taramelliceras* and *Strelites*. The lowest *Alterneplacatus* Zone is correlated with approximately the West-Tethyan late Lower Kimmeridgian *Divisum* Zone. The highest *Katrolensis* Zone is correlated with the top upper Kimmeridgian *Beckeri* Zone. The lowest west-Tethyan Kimmeridgian Zones, the *Hypselocyclum* and *Platynota* Zones, appear to be missing in the Ler-Katrol area, lost in a major non-sequence between the base of Katrol Formation and the top of Dhosa Oolite member (Lower - Middle Oxfordian) of the underlying Chari Formation.

The ammonoid assemblages are briefly described as is the stratigraphy of the Lower Katrol Formation at Ler-Katrol.

### INTRODUCTION

The Kachchh (earlier spelled as Kachh, Kutch or Cutch) basin, situated in the western sector of the Indian plate in the state of Gujarat, is one of the most important Mesozoic sedimentary basins of India. In view of the abundance of stratigraphically significant ammonoids, it is considered the most important Jurassic locality of the entire Indo-East-African marine faunal province. The Mesozoic sediments, in the form of three more or less parallel east-west trending anticlinal ranges, unconformably overlie the Precambrian basement, and in turn are succeeded by latest Upper Cretaceous - early Palaeogene Deccan volcanics, followed further by Neogene and Quaternary rocks (Fig. 1). In general the Mesozoic sequence typifies shallow marine shelf cyclic sedimentation

under frequently changing sea level conditions (Krishna, 1987). It is about 1600 m thick, and with the exception of some Middle Jurassic carbonates in the early part of the exposed sequence, is made up largely of alternations of fine to coarse clastics. The sequence is highly fossiliferous.

Besides the ammonoids, the other prolific fossil groups are bivalves, gastropods, nautiloids, belemnoids, brachiopods, echinoids, corals, foraminifers, ostracods, coccoliths, dinoflagellates, pollen and spores, etc. Mega-plant remains are also present in plenty at several levels, while vertebrate remains are relatively less known.

The Kimmeridgian Stage, in India, in spite of its good development at Ler-Katrol, has been little studied in comparison with the (extensively studied) Pre-Kimmeridgian succession. Since the early works of Waagen (1873-75) and Spath (1924, 1927-33) on ammonoids, which mostly lack in stratigraphic precision, no serious studies were made until recently of Kimmeridgian biochronology in India. In comparison, the Kimmeridgian Stage in the Western Tethys has in recent decades been subdivided into six ammonoid Zones and numerous Subzones or Horizons. The present study is based on new collections of ammonoids made under the closest possible stratigraphical control. The main result is the establishment of a new standard ammonoid biochronological scale for the Indian Kimmeridgian, based

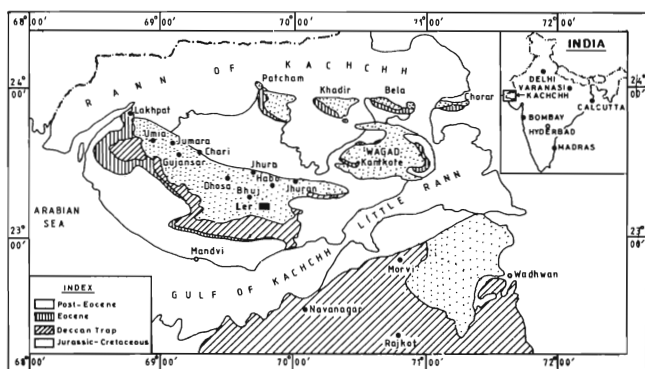


Fig. 1. Simplified geological map of Kachchh

practically on the evolutionary development of a single subfamily, the Virgatosphinctinae, and its correlation with the standard west Tethyan zonation. "Kimmeridgian" is used here in the currently accepted sense, or "sensu gallico" (see below).

Ler-Katrol, the area of present study, is the type area of the Katrol Formation (Waagen, 1871 & 1873-75). It forms part of the central hill range of the Kachchh Mainland (Fig. 1), situated about 12 km south-east of Bhuj, the district headquarters of Kachchh. It lies in toposheet 41 E/16 of the Survey of India, and is bounded by longitudes  $69^{\circ}45'44''$  to  $69^{\circ}48'$

$14''$  E and latitudes  $23^{\circ}10'33''$  to  $23^{\circ}11'59''$  N. The area has been mapped on a scale of 8 cm to 1 km (Fig. 2). It exposes the Katrol Formation and part of the succeeding Umia Formation. The Kimmeridgian corresponds broadly to the major part of the Lower Katrol Formation.

#### PREVIOUS WORK

Waagen (1873-75), working on collections made by Stolickzka, described six successive Jurassic ammonoid assemblages of which the youngest two corresponded to the Kimmeridgian - Tithonian. Later

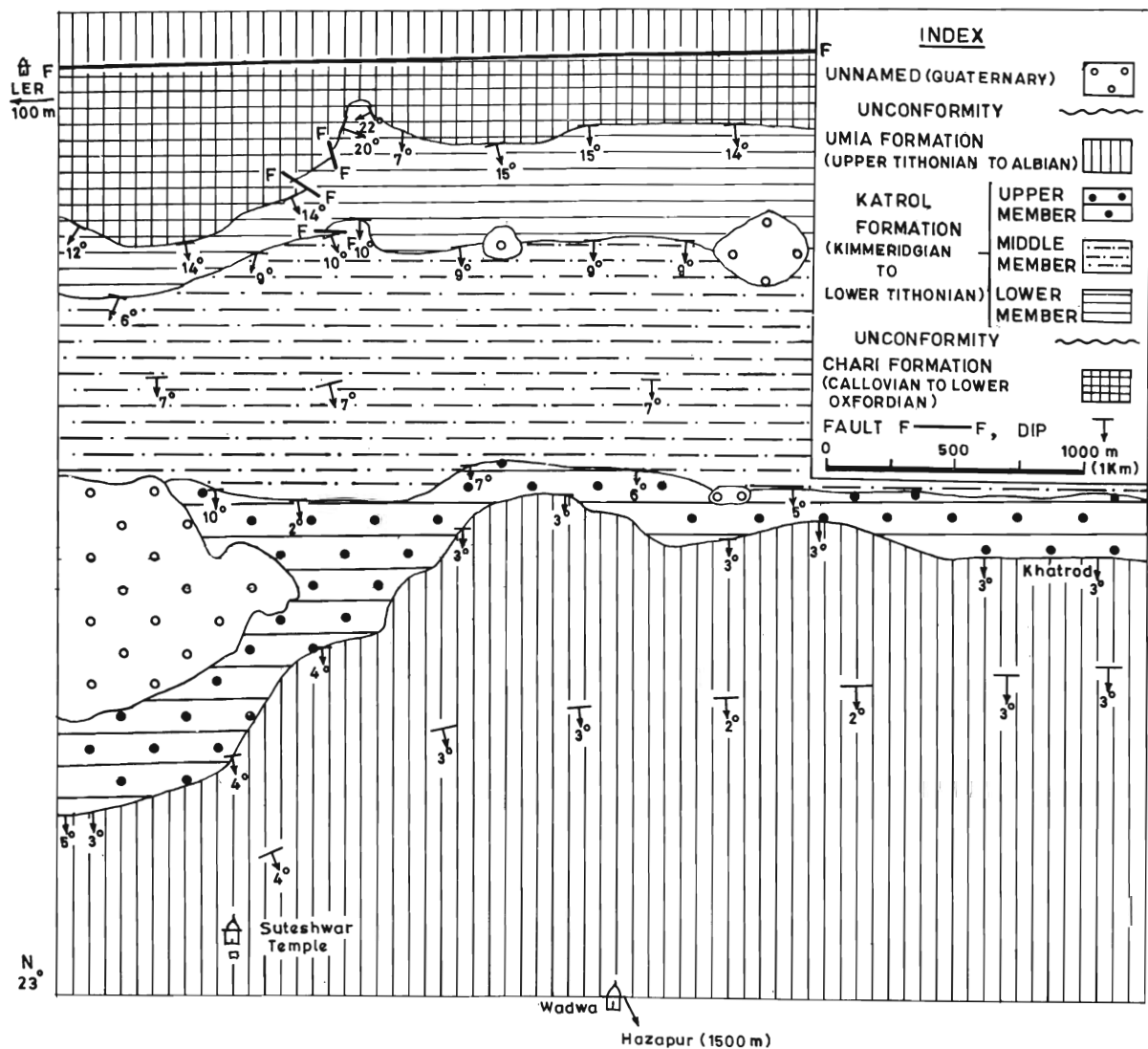


Fig. 2. Geological map of Ler-katrol area, Kachchh, Gujrat, India

Spath (1927-33), studying the collections of Blake, Smith and Rajnath, recognised 15 successive assemblages which he correlated with the British or German Zones of the time. His 'Eudoxus Zone' and 'Steraspis Zone' broadly corresponded to today's faunas : the *Alter neplicatus* Zone and *Katrolensis* Zone respectively.

#### PRESENT STATUS OF THE KIMMERIDGIAN STAGE

The Stage "Kimmeridgian" was defined by d'Orbigny in 1850 (d'Orbigny 1842-51) lying between the 'Corallian' and 'Portlandian' Stages, and named after the village of Kimmeridge in Dorset, England. The subsequent evolution of the concept of the Kimmeridgian is complex, deriving from two factors. The first was a mis-correlation of the base of the overlying Portlandian Stage. Its clearly-defined base in England was thought to coincide in age with the base of an arenaceous formation in northern France, whose true age was subsequently shown to be much older than that of what in England came to be called the base of the Middle (or for some authors, Upper) Kimmeridge Clay. There arose therefore two usages:

*Kimmeridgian sensu anglico* : from Oxfordian to Portlandian *sensu anglico*, divided into Lower, Middle and Upper.

*Kimmeridgian sensu gallico* : from Oxfordian to base of Middle Kimmeridgian *sensu anglico*, misidentified as Portlandian.

Modern international consensus has adopted the second interpretation. 'Kimmeridgian' today therefore means 'Kimmeridgian *sensu stricto*, *sensu gallico*' = Lower Kimmeridgian *sensu anglico*. This meaning is followed here (Middle/Upper Kimmeridgian *sensu anglico* is equivalent to Lower Tithonian).

The second factor is the recognition of strong ammonoid bioprovincialism in the regions of western Europe in which the Kimmeridgian has been most closely studied. As a result, it has become necessary to subdivide the Kimmeridgian Stage into two parallel, biprovincial standard zonal scale : one for the type region of north-west Europe, principally Britain – the Subboreal Province; and another for central-southern Europe, the Submediterranean Province. Correlations between these two zonations at zonal level are still somewhat tentative. The faunal resemblance of Kachchh are closest with Submediterranean Province, and so it is the Submediterranean Kimmeridgian that will be used as standard of reference here.

The lower boundary of the Kimmeridgian in this sense (Oxfordian/Kimmeridgian boundary) is at the base of Platynota Zone. The upper boundary of the Kimmeridgian stage is now internationally drawn at the top of the Beckeri Zone, which coincides with the base of the lower Zone of the Tithonian, the *Hybonotum* Zone.

Biochronologically the Kimmeridgian has been divided into six standard Zones within the Submediterranean and five standard Zones within the Subboreal Province and in turn into Subzones/Horizons. The time duration of the Stage ranges from 156 m.y. to 150 m.y. according to Harland et al. (1982), from 156 to 152 m.y. according to Westermann (1985) and from 146 to 141.5 m.y. according to Haq *et al.* (1987). In terms of the magnetic polarity time-scale the Oxfordian/Kimmeridgian boundary i.e. the base of the Platynota Zone has been placed between Chron M25 and reverse polarity Chron M24B, while the Kimmeridgian/Tithonian boundary i.e. the base of *Hybonotum* Zone is placed within or near the base of normal polarity Chron M23 and top of M22A (Ogg & Steiner, 1985).

#### GEOLOGIC AND STRATIGRAPHIC FRAMEWORK

As already stated earlier, neither Waagen (1873-75) nor Spath (1927-33) could provide any worthwhile geological account of Ler-Katrol area. Even Rajnath (1932) and Biswas (1971 & 1977), who described the lithostratigraphic framework of the Kachchh Mesozoic in considerable detail, provided only general, scanty and passing reference to Ler-Katrol. The sequence in the area investigated represents the southern limb of a major anticline whose northern limb has been consumed by a major fault (Fig. 2). A thin, oolitic member capping the Chari Formation, the Dhosa Oolite is prominent on the periphery of the semi-elliptical exposure. The outcrop of the Lower Katrol Formation is almost parallel to that of the Dhosa Oolite Member, and generally dips southward at an average 22°. The contact with the underlying Chari Formation (Callovian - Middle Oxfordian) is disconformable. The lithology comprises mainly hard, highly fractured, deep brown to maroon-coloured, highly fossiliferous sandstones and gypsiferous shales with concretionary nodules. The base of the conformably overlying Middle Member is marked by a thick, fine to medium grained, hard persistent, light coloured massive sandstone.

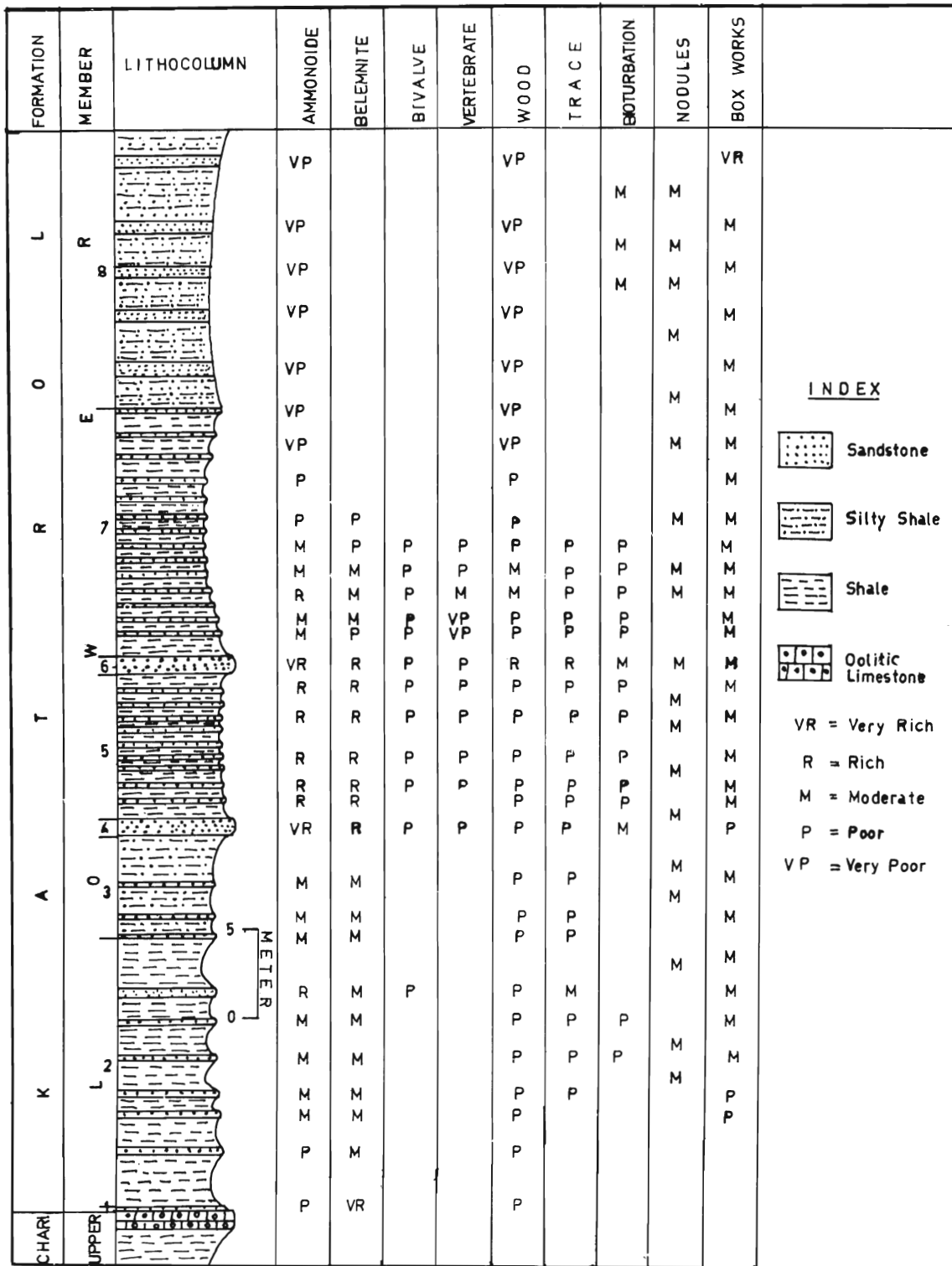


Fig. 3. Lithocolumn with observed physical and biogenic features.

The composite lithocolumn, with all the observed data, is shown in Fig. 3. The ammonoids have been collected from as many as 27 levels spread over seven distinct beds. In general, the entire succession may be interpreted as a shallowing upward, regressive sequence. Numerous small sedimentary cycles are present - shale/siltstone, fine to medium grained sandstone and maroon coloured bioturbated sandstone in that order. The maroon calcareous sandstone beds yield most of the ammonoids.

The physical and biogenic features of the beds are given below, while the ammonoid taxonomic ranges are indicated in Fig. 4. From below :

- Middle Oxfordian : top Chari Formation, Dhosa Oolite.
- Undulating surface, sharp change in lithology.
- Kimmeridgian : Lower Katrol Formation.

*Bed 1* : Maroon, fine grained, very hard and compact, highly fractured sandstone, rich in belemnites, poor in ammonoids, rare wood also found.  
0.2 m.

*Bed 2* : Greyish gypsiferous shale alternating with subordinate maroon to yellowish brown, fine grained, relatively thin (15 to 20 cm thick) hard and compact bands of box-worked, poorly bioturbated sandstone; calcareous sandstone nodules frequent in shale; entire bed moderately fossiliferous, ammonoids and belemnites common, bivalves, fossil wood and trace fossils rare.  
15 m.

*Bed 3* : Mainly greyish white silty shale with intercalations of 3 more or less similar sandstone bands as in bed 2; moderately fossiliferous, ammonoids and belemnites frequent, fossil wood and trace fossils rare.  
5.5 m.

*Bed 4* : Thick marker bed, easily recognizable throughout the investigated area; maroon to ashy brown, fine to medium grained, moderately hard, box-worked and bioturbated sandstone; highly fossiliferous, ammonoids frequent, belemnites common, bivalves, vertebrates, fossil wood and trace fossils rare.  
1 m.

*Bed 5* : Alternate bands of silty shale with ammonoid-bearing nodules and maroon to deep brown coloured, medium grained, thin (15 to 30 cm. thick), hard and compact, box-worked and bioturbated sandstone; highly fossiliferous, ammonoids and

belemnites frequent, bivalves, vertebrates and fossil wood rare.  
10 m.

*Bed 6* : Marker bed, easily recognizable throughout the investigated area, deep brown, medium grained, not very compact, box-worked sandstone with concretionary nodules; relatively more fossiliferous than previous beds, very rich in ammonoids and trace fossils, less so in belemnites, fossil wood, vertebrates and bivalves rare.  
1 m.

*Bed 7* : Whitish grey silty shale (with calcareous nodules) alternating with yellowish brown to maroon, fine to medium grained, thin (10 to 30 cm thick), very hard and compact, highly fractured, box-worked sandstone; relatively less fossiliferous than previous bed, rich in ammonoids, belemnites common, bivalves, vertebrates, fossil wood and trace fossils rare.  
13.5 m.

*Bed 8* : Greyish, moderate to soft greyish laminated shale with concretionary nodules alternating with reddish brown, medium to fine grained, very thin (5 cm thick), hard and compact, box-worked sandstone, very poorly fossiliferous, ammonoids rather rare, belemnites and fossil wood extremely rare.  
15 m.

#### BIOCHRONOLOGY

The Kachchh Kimmeridgian ammonoid zonal assemblages are by and large made up of geographically restricted elements, which are mostly absent in the corresponding standard zones of the West Tethyan province. However, rare elements in common with the Tethyan province help much in the correlation.

As usual, mostly the first appearances and sometimes also the last appearances have been used to demarcate the zonal time boundaries, while the individual Zones are found characterized by their representative assemblages as a whole. The Zones have been named after a characteristic and commonly present species which either appear at the base of the Zone or otherwise significant within the Zone. Horizons are the smallest biostratigraphic units. When the horizons are found extending in a wide area (of the order of 100 km. or more), these have been raised to the status of Subzones. As shown later, many of these Subzones, and even the individual Kachchh Horizons, are unambiguously recognizable almost

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Note : The terms poorly, moderately and highly fossiliferous/ ammonitiferous have been used for the relative abundance of fossils/ammonoids as observed in the field during the course of the present study.

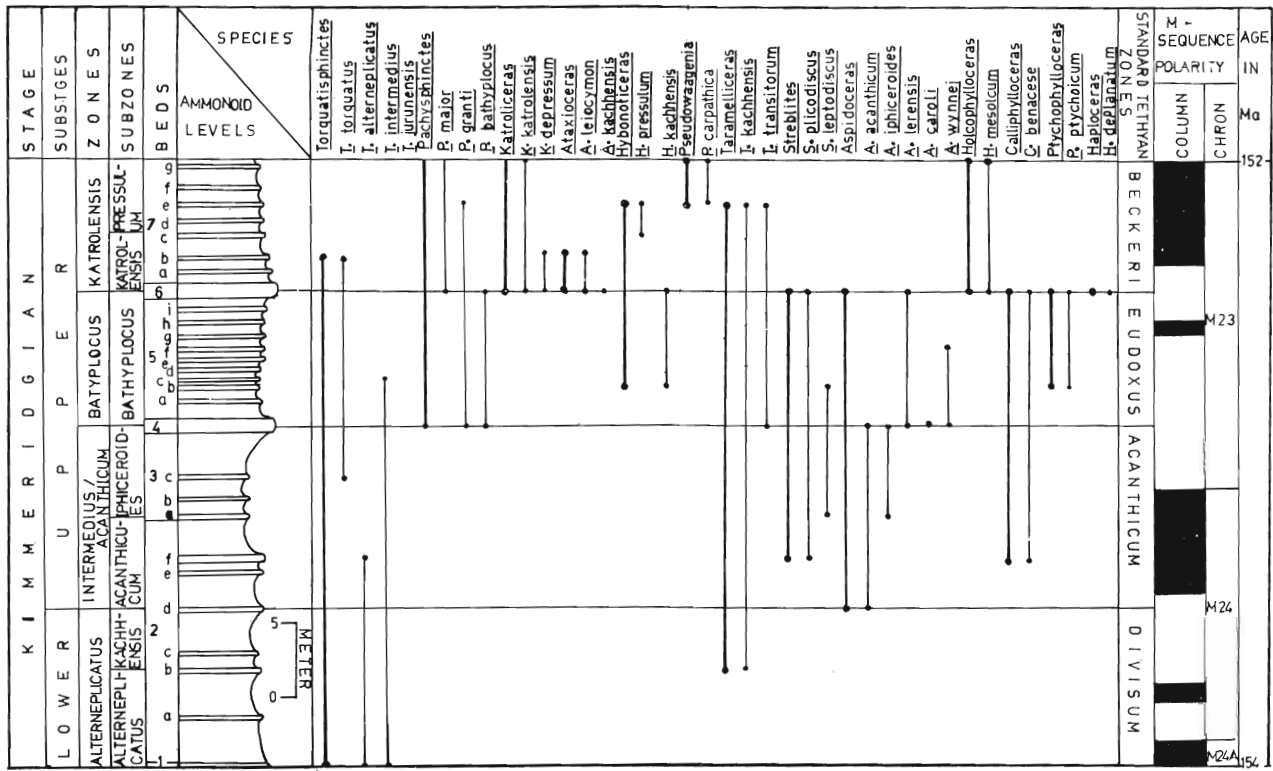


Fig. 4. The Stratigraphic occurrence and ranges of the various species of ammonoids within Kimmeridgian beds at Ler-katrol area, Kachchh, India.

throughout the whole of the Indo-East-African province.

AMMONOID ZONES AND CORRELATION WITH TETHYAN STANDARD (FIG. 4)

The Ler-Katrol Kimmeridgian ammonoid fauna has all the requisites and potential for the development of an independent zonation, likely to be useful within the Indo-East-African province areas as a provincial standard. The standard Submediterranean scheme for Kimmeridgian is based on the families Ataxioceratidae and Aspidoceratidae, with a supplementary role of the family Opelidae. The Ler-Katrol Kimmeridgian ammonoid zonal assemblages in essence are dominated by the same families but by different subfamilies : the Subfamily Virgatospinctinae of the family Ataxioceratidae is the most abundant in Kachchh. Great stratigraphic care and precision make it possible to establish 4 Zones and 7 Subzones within the part of the Kimmeridgian represented at Ler-Katrol. The new zonation is based on the evolutionary stages of a single Virgatospinctinae lineage : *Torquatisphinctes*

- *Pachysphinctes* - *Katrolceras*. The successive zones are as follows :

*Alterneplacatus* Zone (Fig.4: beds 1 to 2d, 10.5 m):

The base of the Zone is indicated by the first appearance of *Torquatisphinctes* Spath, by the zonal index *T. alterneplacatus* (Waagen). This Zone is relatively poorly fossiliferous at Ler-Katrol. *Torquatisphinctes* and *Taramelliceras* are the only genera present. The index as well as the other species, although known widely in the Indo-East-African province areas, are so far not known from the Kimmeridgian of any of the West Tethyan province areas, thus making the correlation of this Zone with the standard Tethyan scheme rather difficult. It is significant (to note) that *Ataxioceras*, the characteristic genus of the standard Tethyan Lower Kimmeridgian Platynota and Hypselocyclum Zones, is absent in the *Alterneplacatus* Zone. Further Kimmeridgian opelids and aspidoceratids, richly present in most of the West Tethyan areas almost from the beginning of Kimmeridgian, do not appear in Kachchh until the start of

the Acanthicum Zone. The Subfamily Virgatosphinctinae, present both in the Kachchh Alterneplacatus Zone and West Tethyan Divisum Zone, is represented by different genera - *Torquatisphinctes* and *Crussoliceras* respectively. Rare *Torquatisphinctes* has also been reported in Western Tethys, although only from much higher Lower Tithonian; while *Crussoliceras* is totally unknown in Kachchh or any other Indo-East-African faunal province areas. On the strength of the above rather indirect evidence, the Alterneplacatus Zone of Ler-Katrol is here considered post Hypselocyclum Zone in age. As such, underlying the first appearance of *A. acanthicum* (Oppel), the best correlation of the Alterneplacatus Zone of Ler-Katrol is with the West Tethyan Divisum Zone of the latest Lower Kimmeridgian. The early Lower Kimmeridgian has, therefore, not yet been positively identified and may be missing in the major non-sequence above the Dhosa Oolite.

Two Subzones have been recognised within the Alterneplacatus Zone :

*Alterneplacatus Subzone* (Fig.4: beds 1-2b, 6.5 m) :

The base of this poorly fossiliferous unit is indicated by the first appearance of the genus *Torquatisphinctes* through the index species *T. alterneplacatus* (Waagen) and *T. intermedius* Spath.

*Kachchensis Subzone* (Fig. 4 : beds 2b-2d, 4 m) :

It is relatively more fossiliferous in comparison to the underlying Subzone. The base is indicated by the first appearance of *Taramelliceras* through *T. kachchensis* (Waagen), while *Torquatisphinctes alterneplacatus* (Waagen) and *T. intermedius* Spath continue from the previous Subzone.

*Intermedius/Acanthicum Zone* (Fig. 4 : beds 2d to 4, 12m) :

The base of the Zone is indicated by the first appearance of *Aspidoceras acanthicum* (Oppel) which is also the first appearance of *Aspidoceras* in Kachchh. On the other hand, *Torquatisphinctes intermedius* is the most significant species of the restricted Virgatosphinctinae. This Zone is relatively more highly fossiliferous than the underlying Zone, with frequent ammonoids. *Torquatisphinctes* and *Taramelliceras* continue, while *Streblites* and *Calliphylloceras* make their first appearance within this Zone.

The interval precisely corresponds to the interval of the Submediterranean Acanthicum Zone. *A. acan-*

*thicum* (Oppel) is one of the rare characteristic forms common at this level in the Tethyan realm. However, the other species of the Intermedius/Acanthicum Zone at Ler-Katrol, although common in Indo-East-African province areas, are mostly unknown from Western Tethys. On the strength of common *A. acanthicum* (Oppel), the Kachchh Intermedius Zone can be precisely equated with the Acanthicum Zone of the Western Tethys. Besides, the clear cut correlation in terms of the common ammonoid elements the correlation is also supported by the global sedimentary discontinuities at the base and top of the Zone in Kachchh as also in the Submediterranean province (Hantzpergue 1987, Krishna and Pathak 1989). Precise correlations achieved in recent years clearly suggest that the species common among different provinces invariably have the same geological range in all the provinces. Even in the case of earlier Jurassic Stages, like Callovian, Submediterranean Zones have been extended to Kachchh e.g. the early Middle Callovian *Anceps* Zone.

The Intermedius Zone has been further subdivided into 2 Subzones:

*Acanthicum Subzone* (Fig. 4: beds 2d-3a, 6 m) :

The base of this fairly highly fossiliferous unit is indicated by the first appearance of *Aspidoceras*. *Streblites plicodiscus* (Waagen) and *Calliphylloceras benacense* (Catullo) also make their first appearance, while the last *Torquatisphinctes alterneplacatus* (Waagen) occurs within this Subzone. *T. intermedius* Spath continues from the previous Subzone.

*Iphiceroides Subzone* (Fig. 4 : beds 3a-4, 6 m) :

The base of this fairly highly fossiliferous unit is indicated by the first appearance of *Aspidoceras iphiceroides* Waagen and *Streblites leptodiscus* Spath. *Torquatisphinctes torquatus* (Sowerby) also makes its first appearance, while *T. intermedius* Spath, *S. plicodiscus* (Waagen) and *C. benacense* (Catullo) continue from the previous Subzone.

*Bathyplocus Zone* (Fig. 4 : beds 4-6, 9.6 m)

The base of this Zone is indicated by the first appearance of *Pachysphinctes* through the zonal index *P. bathyplocus* (Waagen).

This is the Kimmeridgian Zone richest in ammonoids. The other characteristic genera continuing from the subjacent Zone are *Torquatisphinctes*, *Taramelliceras*, *Aspidoceras*, and *Calliphylloceras*, while *Hybonoticeras* and *Ptychophylloceras* mark

their first appearance at Ler-Katrol within this Zone. The species *P. granti* Spath, *Taramelliceras transitorius* Spath, *Aspidoceras lerensis* Spath, *A. wynnei* Waagen first appear, while *A. acanthicum* (Oppel), *A. iphiceroides* Waagen, *Torquatisphinctes intermedius* Spath, *Streblites leptodiscus* Spath make their last appearances, *Torquatisphinctes* aff. *T. intermedius* Spath, *T. jurunensis* Spath, *Subplanites* sp. indet., *Hybonotoceras kachhensis* (Spath), *A. caroli* Spath, *A. wynnei* Waagen, and *Ptychophylloceras ptychoicum* (Quenstedt) are restricted to this zone, while *Torquatisphinctes torquatus* (Sowerby), *Taramelliceras kachhensis* (Waagen), *Calliphylloceras benacense* (Catullo) continue from below.

The rare occurrences of the West Tethyan genera *Hybonotoceras*, *Taramelliceras*, *Streblites* and *Aspidoceras*, although mostly through different species, help the correlation of the Bathyplocus Zone with the standard Tethyan Eudoxus Zone. *Hybonotoceras* appears both in Kachchh and Western Tethys only at the close of the Intermedius/ Acanthicum Zone and Acanthicum Zone respectively.

*Katrolensis* Zone (Fig.4 : beds 6-7g, 8.7 m) :

The base of this highly fossiliferous terminal Kimmeridgian Zone of Kachchh is indicated by the first appearance of *Katroliceras* through the zonal index. *K. katrolensis* (Waagen). *Pachysphinctes*, *Hybonotoceras* and *Taramelliceras* continue from below, while *Pseudowaagenia* and *Holcophylloceras* appear for the first time.

The index and other species of *Virgatospinctinae*, although very common and widely present in the Indo-East-African province, are unknown in Western Tethys. However, the first occurrence of species of *Pseudowaagenia* at Ler-Katrol coupled with *Hybonotoceras pressulum* (Neum.), characteristic of the West Tethyan Beckeri Zone, indicates fairly good correlation of the Katrolensis Zone of Kachchh with the Beckeri Zone of the standard Tethyan scheme.

The Katrolensis Zone has been further subdivided into 2 Subzones :

*Katrolensis* Subzone (Fig. 4: beds 6-7c, 4.3 m) :

This Subzone is as fossiliferous as the one below. Its base is indicated by the first appearance of *Katroliceras* through the index species *K. katrolensis* (Waagen). *Pachysphinctes major* Spath,

STAGE	SUBSTAGES	STANDARD TETHYAN	KACHCHH (Here)	JASSALMER (Krishna 1984, 1987)	SPITI-MALLA-JOHAR (Uhlig 1903-10)	NEPAL (Bordet et al. 1971, Gradstein et al. 1989)	PAKISTAN (Spath, 1939, Fatmi, 1972)
KIMMERIDGIAN	UPPER	BECKERI	KATROLENSIS				<i>Hybonotoceras</i> <i>Katroliceras</i> <i>Pachysphinctes</i> <i>Aspidoceras</i>
		EUDOXUS	BATHYLOCUS	<i>Pachysphinctes</i> <i>Torquatisphinctes</i>	?		
	LOWER	ACANTHICUM	INTERMEDIUS/ACANTHICUM			<i>Aspidoceras</i>	
		DIVISUM	ALTERNEPLC-ATUS		?		
		HYPSELOCYCLUM					
		PLATYNOTA					

Fig. 5. Correlation of Kimmeridgian Ammonoid Faunas/Zones within Indian Subcontinent.



*Katrolliceras depressum* Spath, *Ataxioceras leiocymon* (Waagen) and *Holcophylloceras mesolcum* (Dietrich) appear first, while *Pachysphinctes bathyplocus* (Waagen), *Hobonoticerias kachhensis* (Spath), *Streblites plicodiscus* (Waagen), *Aspidoceras lerensis* Spath, *Calliphylloceras benacense* (Catullo) and *Ptychophylloceras ptychoicum* (Quenstedt.) make their last appearances. *Torquatisphinctes torquatus* (Sowerby), *Pachysphinctes* sp. n. sp., *Katrolliceras depressum* Spath and *Ataxioceras kachhensis* Spath are restricted to this Subzone. *Pachysphinctes granti* Spath, *Taramelliceras kachhensis* (Waagen) and *T. transitorium* Spath continue from the previous Subzone.

*Pressulum* Subzone (Fig. 4: beds 7c-7g, 4.4 m) :

It is relatively less fossiliferous than the Katrolensis Subzone. The base is indicated by the first appearance of *Hybonoticerias pressulum* (Neumayr). *Pachysphinctes granti* Spath, *Katrolliceras katrolensis* (Waagen), *Taramelliceras kachhensis* (Waagen), *T. transitorium* Spath make their last appearances in this Subzone, while *H. pressulum* (Neumayr), *Pseudowaagenia carpathica* Spath, *P. sp. indet.* are restricted to this Subzone. *Pachysphinctes major* Spath and *Holcophylloceras mesolcum* (Dietrich) continue from the previous Subzone.

CORRELATION WITH BETTER KNOWN AREAS OF INDIAN SUBCONTINENT (Fig. 5)

Within the Indian subcontinent Kimmeridgian ammonoids are so far not known from Western Kachchh, Spiti and Malla-Johar. They have, however, been reported from Jaisalmer (Spath 1933, Krishna 1983, 1984 and 1987) and Pakistan (Spath 1930, 1933 and 1939 and Fatmi 1972, 1973 & 1977).

The *T. alterneplicatus* assemblage and *Pachysphinctes* assemblage respectively of the Kimmeridgian and Lower Tithonian in Jaisalmer (Krishna 1987) can be broadly correlated with the *Alterneplicatus* Zone to *Bathyplocus* Zone interval of Ler-Katrol on the strength of common presence of *T. alterneplicatus* (Waagen), *P. bathyplocus* (Waagen) and other common forms of *Torquatisphinctes* and *Pachysphinctes* of late Lower Kimmeridgian and Upper Kimmeridgian ages. In view of the range of *Pachysphinctes* almost exclusively within Upper Kimmeridgian, the *Pachysphinctes* assemblage of Jaisalmer (Krishna, 1987) assigned earlier to the Lower Tithonian is here revised as being of Upper Kimmeridgian age.

The Pakistan assemblage assigned to 'Lower Kimmeridgian' (= entire Kimmeridgian *sensu stricto*) by Fatmi (1972) mainly comprises species of *Pachysphinctes*, *Katrolliceras*, *Pseudowaagenia*, *Hybonoticerias*, and *Ptychophylloceras*. In terms of the Ler-Katrol zonation, it can be correlated best with the collective interval of *Bathyplocus* Zone and *Katrolensis* Zone of the Upper Kimmeridgian. As in Kachchh, the basal Kimmeridgian Zones seem also to be absent in Pakistan, and the stratigraphic gap at this level appears to be regionally extensive.

In Nepal, the genus *Aspidoceras* has been reported from Nupra Formation of Thakkhola region by Bordet *et al.* (1971) which evidences the presence of Upper Kimmeridgian in Nepal.

#### CONCLUSIONS

New and stratigraphically controlled collections at Ler-Katrol make it possible now to propose a high resolution ammonoid zonation of the Kimmeridgian Stage in India, which may be applicable more widely over the whole area of the Indo-East-African faunal province. The scheme is largely or almost exclusively based on a single evolutionary lineage of *Virgatospinctinae*. The succession of assemblages leads to a zonation into four Zones and seven Subzones. The degree of biochronological refinement nearly equals the best in the world, with an average resolution of 0.25 m.y. for a Subzone and 0.5 m.y. for a Zone. The new zonation at Ler-Katrol has been satisfactorily correlated with the standard Tethyan scheme.

It is significantly observed that many of the essentially West Tethyan genera appear in Kachchh distinctly later through different species, while the common species are believed to be geographically synchronous. This has been interpreted in terms of successive phases of eustatic rise and related expansion of West Tethyan elements towards south and east into areas of the Indo-East-African faunal province on the pattern suggested during Callovian (Krishna & Cariou 1986, Cariou & Krishna 1988).

The apparent absence of the *Platynota* Zone and *Hypselocyclum* Zone of Lower Kimmeridgian at Ler-Katrol confirms and dates the stratigraphic gap between the Chari and Katrol Formations at Ler-Katrol.

There are certain discrepancies between the ranges of genera and species worked out here and those of earlier works in the Indo-East-African province. The genus *Torquatisphinctes*, generally cited as Lower

Tithonian, is found to be restricted to the Kimmeridgian. Another virgatosphinctinae genus, *Katrolliceras*, is recorded here from the base of Katrolensis Zone onwards, with *K. katrolensis* (Waagen) restricted to the Katrolensis Zone of the late Upper Kimmeridgian.

Other important observations relate to the stratigraphic ranges in Kachchh of Tethyan genera like *Ataxioceras*, *Taramelliceras*, *Aspidoceras*, *Pseudowaagenia*, *Hybonotoceras*, *Streblites*, etc. These appear in Kachchh Kimmeridgian distinctly later and with shorter ranges than in the Western Tethys, and mostly in the form of different species restricted to the Indo-East-African faunal province. However, the relatively rare presence of these Tethyan genera in Kachchh, with their shorter ranges, has proved crucial for correlation with Western Tethys. They also help to understand the timings of ammonoid faunal expansions from relatively warm water near equatorial areas southwards and eastwards into the Indo-East-African faunal province. These expansions may have been consequential to relatively climatic warming and associated eustatic rises of sea-level.

#### ACKNOWLEDGEMENTS

The authors express their thankfulness to the Banaras Hindu University for provision of working facilities; to the Oil and Natural Gas Commission for funding the research and grant of Research Fellowship to Dr. D.B. Pathak; to Mr. Nageshwar Dubey, Mr. Bindhyachal Pandey and Mr. Jai Ram Ojha for help in field and laboratory, and lastly to Mr. Sita Ram Singh for typing of the manuscript.

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## EXPLANATION OF PLATES

## PLATE I

1. *Hybonoticeras pressulum* (Neumayr), 11582, microconch, outer half whorl as body chamber, Bed 7e, Pressulum Subzone, Katrolensis Zone, late Upper Kimmeridgian, South-east of Ler, natural size, lateral view.
2. *Aspidoceras acanthicum* (Oppel), 11486, macroconch, septate, Bed 4, Iphiceroides Subzone, Intermedius/Acanthicum Zone, early Upper Kimmeridgian, South-east of Ler, natural size, Lateral view.
3. *Aspidoceras iphiceroides* Waagen, 11502, septate, microconch Bed 4, Iphiceroides Subzone, Intermedius/Acanthicum Zone early Upper Kimmeridgian, South-east Ler, natural size, lateral view.
4. *Torquatisphinctes alterneplicatus* (Waagen), 11026, microconch septate, Bed 2d, Alterneplicatus Zone, late Lower Kimmeridgian, South-east Ler, natural size, lateral view.
5. *Pachysphinctes bathyplocus* (Waagen), 11102, microconch, 2/3rd of outer whorl as body chamber, Bed 6, Bathyplocus Zone, Upper Kimmeridgian, South-East of Ler, natural size, ventral view.

## PLATE II

1. *Katroliceras katrolensis* (Waagen), 11171, microconch, 2/3rd of outer whorl as body chamber, Bed 7d, Katrolensis Subzone, Katrolensis Zone, late Upper Kimmeridgian, South-east of Ler, natural size, lateral view.
2. *Pachysphinctes bathyplocus* (Waagen) 11099, microconch, outer 3/4th whorl as body chamber with lappet, Bed 6, Bathyplocus Zone, Upper Kimmeridgian, South-east of Ler, lateral view, (X. 75).
3. *Taramelliceras kachhensis* (Waagen), 11413, macroconch, septate, Bed 2C, Kachhensis Subzone, Alterneplicatus Zone, late Lower Kimmeridgian, South-east of Ler, natural size, a. lateral view, b. ventral view.
4. *Hybonoticeras pressulum* (Neumayr), ventral view of Plate 1, fig. 1.

