Journal of the Palaeontological Society of India
Volume 66(2), December 31, 2021: 182-189

ISSN 0552-9360

Ammonoid biozonation in the lower Albian (Lower Cretaceous) succession of the Ariyalur Sub-basin, Cauvery basin, south India

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The ever-recognized Lower Albian succession of the Cauvery Basin has been revisited in conjunction with the revision of the exact extent of the Lower Albian horizons. This work also entails the formulation of ammonoid biozones in the précised Lower Albian record in the Ariyalur Sub-basin of the Cauvery Basin. This endeavor embodies the formal creation of *Tetragonites rectangularis* Zone in the revised Lower Albian sedimentary record of the Cauvery Basin for the first time which has been further differentiated into four *Beudanticeras newtoni*, *Beudanticeras revoili, Jauberticeras collignoni*, and *Jauberticeras villoutreysi* subzones in ascending order. The occurrences of distinctive Lower Albian ammonoid fauna in the *Tetragonites rectangularis* Zone make its close resemblance with *Douvilleiceras mammillatum* Zone of the standard ammonoid zonal framework. This biostratigraphic refinement is a noteworthy input in the marine Cretaceous biostratigraphy of the Cauvery Basin. It will also enhance the knowledge of the exposed marine Lower Cretaceous sedimentary record in India and abroad.

ARTICLE HISTORY

Manuscript received: 31/10/2020
Manuscript accepted: 22/05/2021

Keywords: Lower Cretaceous, Lower Albian, ammonoids, biostratigraphy, Cauvery Basin.

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INTRODUCTION

The Cauvery Basin of South India is a NE - SW trending peri-cratonic rift basin developed as a consequence of Mesozoic extensional tectonism and occurs on the eastern margin of Peninsular India (Sastri *et al*., 1981; Biswas *et al*., 1993). It is the largest and extensively worked out the Cretaceous sedimentary basin of India (Acharyya and Lahiri, 1991). It holds the record of almost complete shallow marine Cretaceous sedimentation ranging from Barremian to Maastrichtian (Ramkumar, 2015; Gautam *et al*., 2015, 2019a, b). The shallow marine Cretaceous succession of this basin is characterized by the plentiful, well preserved, and stratigraphically significant ammonoid fauna (Venkatachalapathy and Ragothaman, 1995; Sundaram *et al.,* 2001; Ayyasami, 2011; Gautam *et al*., 2015, 2019a, b; Gautam, 2020).

The Cauvery Basin (Fig. 1) has five sub-basins *viz.,* Sivganga-, Thanjavur-, Ariyalur-, Vriddachalam and Puducherry from south to north (Banerji, 1972; Ayyasami, 2011; Gautam *et al*., 2019 a, b). However, nearly continuous Barremian - Maastrichtian successions are exposed only in the Ariyalur Sub-basin (Fig. 2). The oldest exposed marine deposit in this sub-basin belongs to Terani Formation (= Sivaganga Formation/Uttatur Plant Beds) which has yielded two Barremian ammonoids *Gymnoplites* Spath and *Pascoeites* Spath (Mamgain *et al*., 1973; Ramkumar, 2015).

The exposed marine Cretaceous rocks of this sub-basin are originally classified into Uttatur, Trichinopoly, and Ariyalur Groups in ascending order (Blanford, 1862). This classification has been subjected to numerous modifications by later workers through the creation of formations and members within these three groups (Ramanathan, 1968; Banerji, 1972; Sastry *et al*., 1972; Sundaram and Rao, 1986; Ramasami and Banerji, 1991; Tewari *et al*., 1996b;

Table 1. Modified Lithostratigraphic framework of the marine Cretaceous sedimentary succession exposed in the Ariyalur Sub-basin of the Cauvery Basin (modified after Sundaram *et al*., 2001; after Gautam *et al*., 2019b; Gautam, 2020; Pandey *et al*., 2021).

GROUP	FORMATION	MEMBER	AGE
Ariyalur	Kallamedu		Maastrichtian
	Kallankurichchi		Santonian - Campanian
	Sillakkudi		
Trichinopoly	Anaipadi		Turonian - Coniacian
	Kulakkalnattam		
Unconformity			
Uttatur	Karai	Kunnam	Albian-Cenomanian
		Odiyam	
	Dalmiapuram		Barremian-Aptian
	Terani		
Unconformity			
Crystalline Basement (Precambrian)			

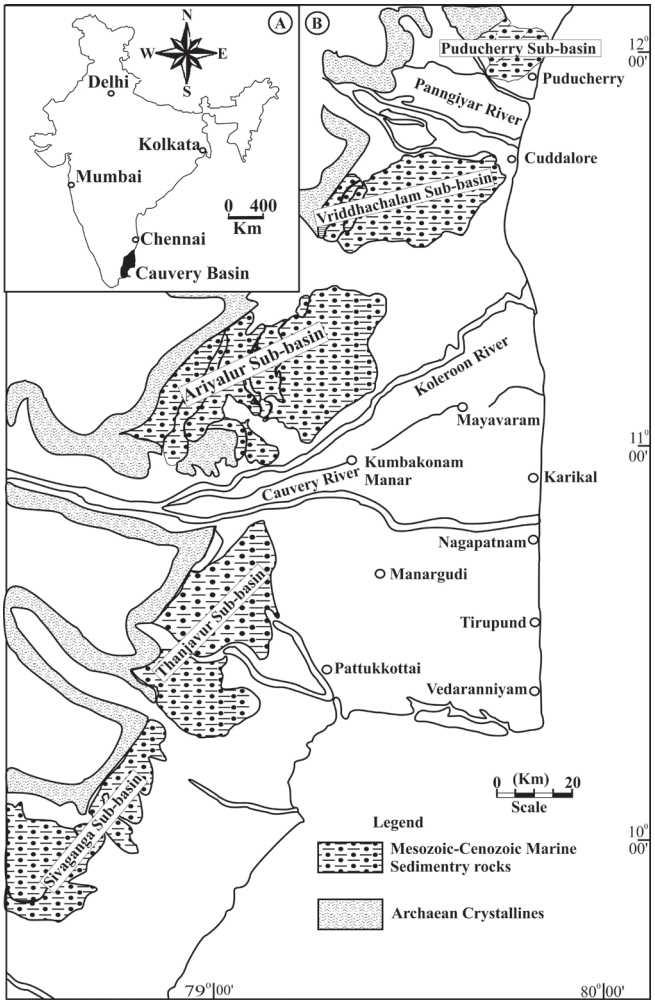

Fig. 1 A. Location of the Cauvery Basin in the East Coast margin of India. B. Spatial distribution of five sub-basins in the Cauvery Basin (modified after Banerji, 1972; Gautam, 2020).

Sundaram *et al*., 2001; Ramkumar *et al*., 2004; Sathish *et al*., 2017). The lithostratigraphic framework of Sundaram *et al*. (2001) is broadly followed by minor changes (Gautam *et al*., 2015, 2019a, b; Gautam, 2020; Pandey *et al*., 2021). In this modified classification, the Uttatur Group consists of Terani, Dalmipuram, and Karai Formations in ascending order (Table-1). Sundaram *et al*. (2001) created confusion by proposing a new Arogyapuram Formation above the Terani Formation. However, it has been found that the Arogyapuram Formation of Sundaram *et al*. (2001) and Terani Formation of Ramasami and Banerji (1991) of the Uttatur Group in the Ariyalur Sub-basin have more or less similar lithology and stratigraphic position between Crystalline Basement and Dalmiapuram Formation. Therefore, Terani Formation and Arogyapuram Formation are considered the same instead of separate lithounits. Since the Terani Formation has priority on pages over the Arogyapuram Formation and more common in usage, it is envisioned here that Terani Formation represents the oldest marine Cretaceous lithounit in the Ariyalur Sub-basin immediately underlying the Dalmiapuram Formation. Hence, the modified lithostratigraphic classification (Table 1) of Sundaram *et al*. (2001) which includes Terani Formation only as the basal unit of the Uttatur Group has been used here as also corroborated by Gautam *et al*. (2019b).

The stratigraphic distribution of ammonoids throughout the Cretaceous sedimentary succession of the Ariyalur Sub-basin is used here as a prime tool for bio-chronostratigraphic refinement. The work on ammonoid palaeontology in the Cauvery Basin dates back to Forbes (1846) followed by Blanford (1862), Stoliczka (1865), and Kossmat (1895-98) in the 19th Century. Subsequently, in the 20th century, several articles on the taxonomy and biostratigraphy of the Cretaceous ammonoids of the Cauvery Basin are available (Sastry *et al*., 1968; Mamgain *et al*., 1973; Chiplonkar and Phansalkar, 1976; Phansalkar and Kumar, 1983; Ayyasami and Banerji, 1984; Ayyasami and Rao, 1984; Vartak and Ghare, 1987; Ayyasami, 1990; Das and Ayyasami, 1996; Ramkumar, 2015). However, many of these stratigraphic works do not reflect the proper distribution of ammonoids in their studied lithological sections, adequate ammonoid systematics, and meaningful biostratigraphic implications.

Recently, Gautam *et al*. (2015, 2019a, b), Gautam (2020) and Gale *et al*. (2019) have made significant contributions towards ammonoid taxonomy and biostratigraphy in the marine Cretaceous record of the Cauvery Basin. Additionally, Gautam *et al*. (2015, 2019a) established the presence of Lower Albian succession for the first time in the Karai Formation of the Ariyalur Sub-basin of the Cauvery Basin whose upper limit is further revised and extended.

MATERIALS AND METHODS

This present investigation deliberates the subsequent improvements over the work of Gautam *et al*. (2015, 2019a) on the Albian ammonoid biostratigraphy by focusing on the precisely collected ammonoids from ~60. 35 m thick succession of the lower part of the Odiyam Member of the Karai Formation (Uttatur Group) cropping out with unexposed base near the Karai village of the Ariyalur Sub-basin (Fig. 3). The Lower Albian succession of this site has been differentiated into 34 beds consisting of alternate beds of shale/silty shale and sandstones. The sandstone beds are coarse to medium and even fine-grained. The shale/silty shale beds are occasionally gypsiferous with frequent phosphatic concretions/nodules. Each of these shale/silty shale beds consists of a very thin (< 5 cm) highly ferruginous maroon to brownish, medium to fine-grained, bioturbated, and splintery sandstone band. These thin bands are highly fossiliferous and yielded most of the ammonoids used in the present interpretations. 9 ammonoid levels have been recognized in the studied stratigraphic section near Karai village (Fig. 3), among which 8 levels have yielded identifiable ammonoids.

The present investigation includes the previous records of Lower Albian ammonoids from the Karai Formation (Gautam *et al*., 2015, 2019a) and supplemented by fresh ammonoid collections from this site which contains the occurrences of *Tetragonites rectangularis*, *Tetragonites* cf. *subtimotheanus subtimotheanus*, *Beudanticeras newtoni*, *Beudanticeras revoili*, *Beudanticeras* sp. *Zelandites*

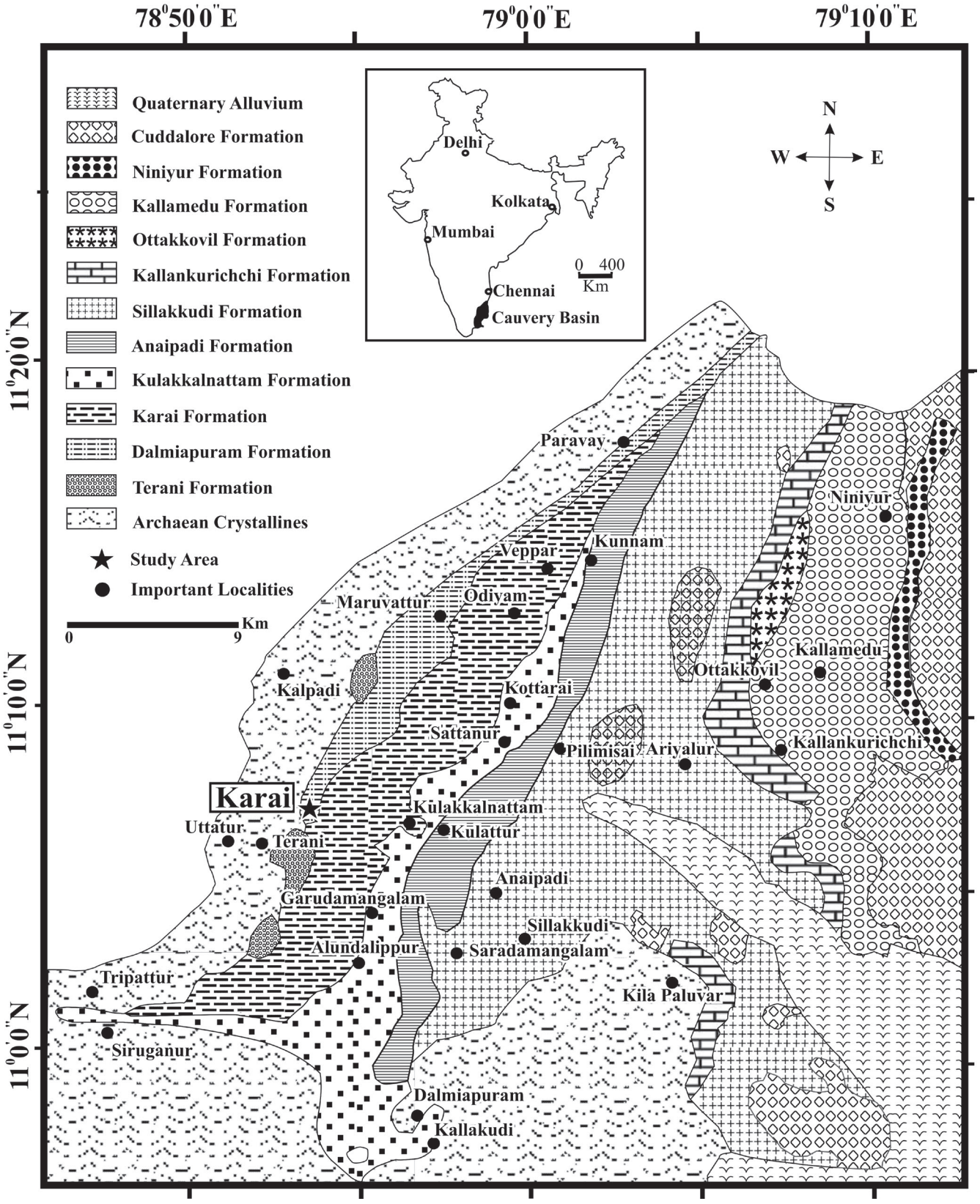

Fig. 2. Geological map of the Ariyalur Sub-basin with location of the study section near Karai village (modified after Sathish *et al*., 2017; after Gautam, 2020; Pandey *et al*., 2021).

odiensis, *Desmoceras* (*Desmoceras*) cf. *latidorsatum, Puzosia* (*Puzosia*) *quenstedi*, *Jauberticeras collignoni*, *Jauberticeras* cf. *jaubertianum*, *Jauberticeras villoutreysi* and *Obataceras manjiense* from the revisited Lower Albian succession of the Karai Formation of the Ariyalur Sub-basin (Gautam, 2020). Their stratigraphic ranges have also been plotted against the measured lithocolumn (Fig. 3). Out of these *Puzosia* (*Puzosia*) *quenstedi*, *Jauberticeras collignoni*, *Jauberticeras* cf. *jaubertianum*, *Jauberticeras villoutreysi* and *Obataceras manjiense* represent their first record from the studied section. However, the first record of *Tetragonites rectangularis*, *Beudanticeras newtoni,* and *Beudanticeras revoili* have already been established by Gautam *et al*. (2015, 2019a) from the same section of the Ariyalur Sub-basin.

The above record provide excellent and significant information for the biostratigraphic refinement by extending the upper limit of recently recognized Lower Albian succession of the Karai Formation by Gautam *et al*. (2015, 2019a) in the Ariyalur Sub-basin, Cauvery Basin and development of ammonoid biozonation within it. The present biostratigraphic scheme consists of the formulation of a single *Tetragonites rectangularis* Zone together with its four subzones (*Beudanticeras newtoni*, *Beudanticeras revoili*, *Jauberticeras collignoni,* and *Jauberticeras villoutreysi*) in the studied Lower Albian succession of the Ariyalur Sub-basin (Fig. 3). This newly formulated ammonoid zone is observed to be adequately correlatable with the Lower Albian *Douvilleiceras mammillatum* Zone of the standard ammonoid zonal scheme (Reboulet *et al.*, 2011, 2014, 2018; Ogg *et al*., 2016).

AMMONOID BIOZONATION IN THE PRESENTLY STUDIED LOWER ALBIAN SUCCESSION OF ARIYALUR SUB-BASIN, CAUVERY BASIN

The status of the Lower Albian sedimentary succession in the Ariyalur Sub-basin of the Cauvery Basin has been modified under the present work. It reveals that the Lower Albian sequence is found developed only in the exposed lower part of the Odiyam Member of the Karai Formation near the village Karai in the Ariyalur Sub-basin. The fresh present precise Lower Albian sedimentary record comprises the *Tetragonites rectangularis* Zone and its associated four subzones (Fig. 3). The characteristic details of this biostrigraphic framework and correlation in the Cauvery Basin are given below:

Ammonoid Zone (Fig. 3)

Tetragonites rectangularis Zone (Beds 1 to 34)—The nomenclature of this zone is based on the first appearance of the zonal index species *Tetragonites rectangularis* in bed 3. The preceding beds 1 and 2 although consisting of bivalves, belemnites, and fossil woods, but devoid of ammonoids. The ~ 5.2 m thick succession (beds 1 and 2) constitute the lowermost exposed part of this zone. The ammonoid species *Beudanticeras newtoni*, *Beudanticeras revoili*, *Beudanticeras* sp., *Desmoceras* (*Desmoceras*) cf. *latidorsatum*, *Zelandites odiensis*, *Puzosia* (*Puzosia*) *quenstedti*, *Jauberticeras collignoni*, *Jauberticeras* cf. *jaubertianum*, *Jauberticeras villoutreysi* and *Obataceras manjiense* are found restricted to this zone. *Tetragonites* cf. *subtimotheanus subtimotheanus* first appears in bed 15 and continues along with *Tetragonites rectangularis* throughout this zone. These two taxa further extend to higher up in the studied section.

Subzones (Fig. 3)

Beudanticeras newtoni Subzone (Beds 1 to 14) —The base of this subzone corresponds to the base of *Tetragonites rectangularis* Zone. *Beudanticeras newtoni* appears first in bed 7. This ammonoid species is worldwide restricted occurrences in the Lower Albian (Gautam *et al*., 2019a) and it is the persistent element of *Douvilleiceras mammillatum* Zone. Hence, the name of this subzone is assigned after this diagnostic ammonoid element. The *Tetragonites rectangularis* is coming from the lower stratigraphic level and extends up into higher horizons.

Beudanticeras revoili Subzone (Beds 15 to 22)—*Beudanticeras revoili* has its first appearance in bed 15 which marks the beginning of this subzone. It is accompanied by *Tetragonites* cf. *subtimotheanus* which also marks its first presence in bed 15 and extends further up to bed 27. *Zelandites odiensis* and *Beudanticeras* sp. also have common range with the subzonal marker *Beudanticeras revoili*. *Desmoceras* (*Desmoceras*) cf. *latidorsatum* has been recorded only from bed 15. *Puzosia* (*Puzosia*) *quenstedti* appears first in bed 19 and ranges up to bed 23 (base of a succeeding subzone). The *Tetragonites rectangularis* and *Beudanticeras newtoni* are coming from below and moving towards a higher horizon.

Jauberticeras collignoni Subzone (Beds 23 to26) —Its base is marked at the base of bed 23 by the first occurrences of *Jauberticeras collignoni* and *Jauberticeras* cf. *jaubertianum* in the same bed. However, the name of this subzone is *Jauberticeras collignoni*. *Puzosia* (*Puzosia*) *quenstedti* represents its last occurrence in bed 23 which coincides with the base of this subzone. *Beudanticeras newtoni*, *Tetragonites rectangularis,* and *Tetragonites* cf. *subtimotheanus subtimotheanus* continue to occur in this subzone.

Jauberticeras villoutreysi Subzone (Beds 27 to 34) —It is named after the subzonal index *Jauberticeras villoutreysi* which co-occurs with *Obataceras manjiense* in bed 27 representing the base of this subzone. Both the species are restricted in this subzone. *Beudanticeras newtoni*, *Jauberticeras collignoni* and *Jauberticeras* cf. *jaubertianum* persist from lower stratigraphic levels and mark their last occurrences in bed 31 of this subzone. *Tetragonites rectangularis* and *Tetragonites* cf. *subtimotheanus subtimotheanus* are coming from preceding subzones and go up in the higher horizons across *Tetragonites rectangularis* Zone of the present work.

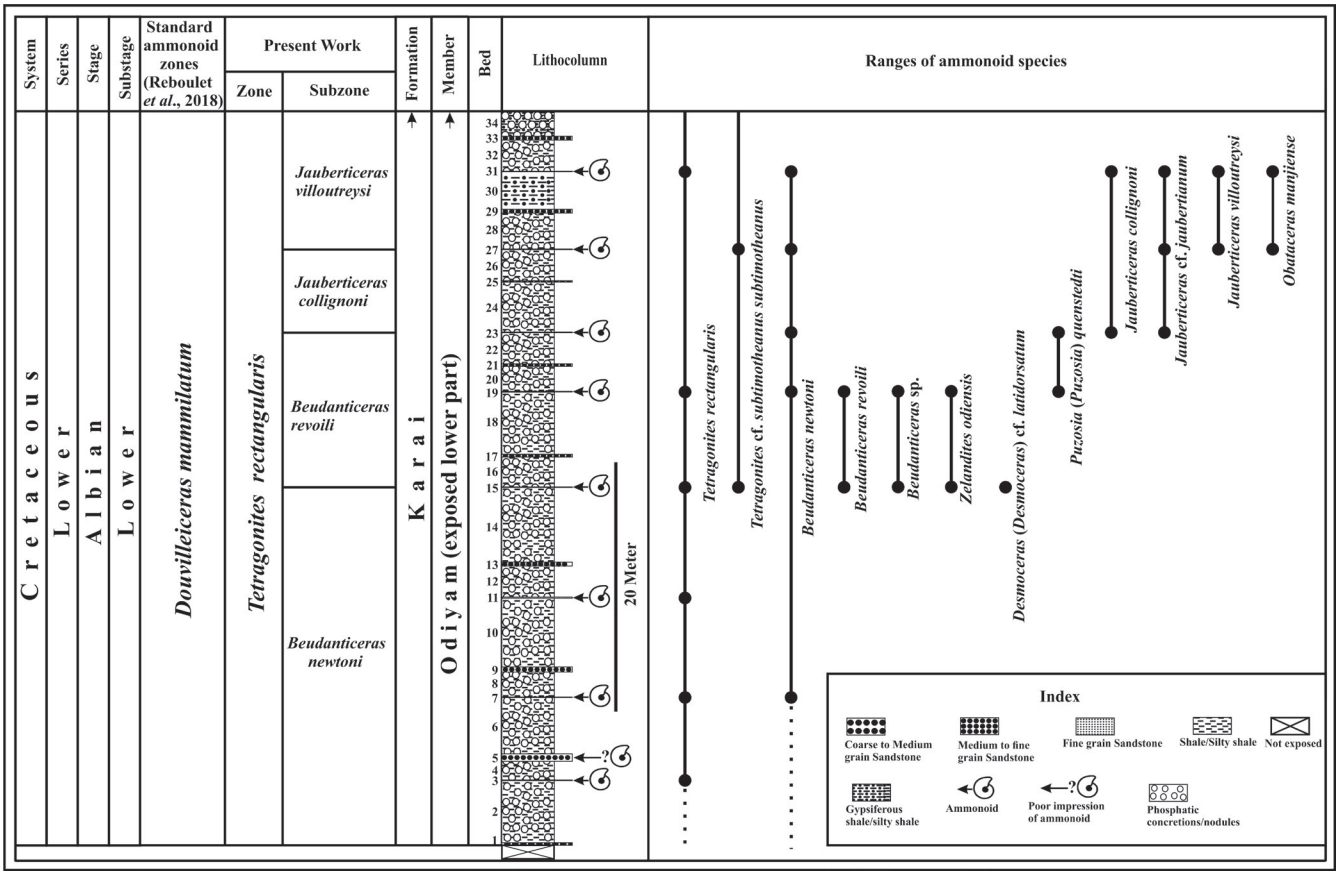

Fig. 3. Ammonoid taxon ranges and development of *Tetragonites rectangularis* Zone in the revised Lower Albian record of the Karai Formation exposed near Karai village, Ariyalur Sub-basin and biozonal correlation with the standard ammonoid zone (modified after Gautam *et al*., 2015, 2019a; Gautam, 2020).

CORRELATION OF *TETRAGONITES RECTANGULARIS* ZONE WITH THE STANDARD AMMONOID ZONE

The important zonal marker and age potential ammonoid taxa, like *Beudanticeras newtoni*, *Beudanticeras revoili* and *Jauberticeras* cf. *jaubertianum* of newly identified *Tetragonites rectangularis* Zone (Fig. 3) are typical elements of the globally known Lower Albian successions (Kennedy and Klinger, 1977; Riccardi and Medina, 2002; Szives, 2007; Latil, 2011; Gautam *et al*., 2015, 2019 a; Gautam, 2020; Robert *et al*., 2018). Moreover, *Beudanticeras newtoni* and *Beudanticeras revoili* (Fig. 3) are diagnostic markers of Lower Albian *Douvilleiceras mammillatum* Zone of the standard ammonite zonal scheme (Riccardi and Medina, 2002; Latil, 2011; Reboulet *et al.*, 2014, 2018; Gautam *et al*., 2015, 2019a; Gautam, 2020). Accordingly, this *Tetragonites rectangularis* Zone in the Lower Albian succession of the Ariyalur Sub-basin (Fig. 3, Table-2) is precisely correlated with *Douvilleiceras mammillatum* Zone of Reboulet *et al.* (2011, 2014, 2018) and Ogg *et al*. (2016).

DISCUSSION

The two successive zones, *viz., Leymerriella tardefurcata* and *Douvilleiceras mammillatum* were predicted in the Lower Albian by Breistroffer (1947) and Casey (1957) which were later included in the revised standard ammonite zonal scheme (Reboulet *et al.*, 2014, 2018). Earlier, Strombeck (1856) and Stolley (1908) recognized *Leymeriella tardefurcata* Zone in North Germany due to the vertical continuity of the Subfamily Leymeriellinae. Brinkmann (1937) subsequently recognized three successive zones, *viz*., *L. schrammeni* Zone, *L. tardefurcata* Zone, and *L. regularis* Zone within it. However, Spath (1941-42) reinstated *L. tardefurcata* Zone in agreement with original scheme of Strombeck (1856) and Stolley (1908). He further strengthened his view by creating *L. schrammeni*, *L. acuticostata* and *L. regularis* subzones within *L. tardefurcata* Zone. However, the occurrence of *L. tardefurcata* Zone in rest of the Europe and other parts of the world remained enigmatic (Casey, 1957; Lucas, 1995, 2000; Riccardi, 2018; Obata and Mutsukawa, 2018; Futukami and Haggart, 2018 and Bengtson, 2018).

The present observation reveals that the base of the studied succession of the Ariyalur Sub-basin is not exposed

Table 2. Correlation of the Lower Albian ammonoid zone/subzone of the Ariyalur Sub-basin, Cauvery Basin with the standard ammonoid zonal scheme (modified after Gautam, 2020).

<table>
<tr><td rowspan="2">Stage</td><td rowspan="2">Substage</td><td rowspan="2">Standard ammonoid zones (Reboulet et al., 2014, 2018)</td><td colspan="4">Ammonoid Zone/Subzone in the Ariyalur Sub-basin, Cauvery Basin</td></tr>
<tr><td>Sastry et al., 1968</td><td>Ayyasami, 1990</td><td>Gale et al., 2019</td><td colspan="2">Present work</td></tr>
<tr><td rowspan="6">Albian</td><td rowspan="6">Lower</td><td rowspan="5">Douvilleiceras mammillatum</td><td rowspan="5">?</td><td rowspan="5">?</td><td rowspan="5">?</td><td rowspan="5">Zone
T. rectangularis</td><td>Subzone</td></tr>
<tr><td>J. villoutreysi</td></tr>
<tr><td>J. collingnoni</td></tr>
<tr><td>B. revoili</td></tr>
<tr><td>B. newtoni</td></tr>
<tr><td>Leymerilla tardefurcata</td><td colspan="2">No record</td></tr>
</table>

and thus its transition with the underlying Dalmiapuram Formation could not be explored. Conclusively, the presence or absence of the basal Lower Albian standard *Leymeriella tardefurcata* Zone (=*Leymeriella* (*Leymeriella*) *tardefurcata* Zone of Reboulet *et al.*, 2011) is uncertain (Table 2) and needs further investigation. The exposed part of the revised/ précised Lower Albian succession belonging to *Tetragonites rectangularis* Zone (Fig. 3) in the Ariyalur Sub-basin of the Cauvery Basin is represented only by the standard Lower Albian *Douvilleiceras mammillatum* Zone. Further, the upper limit of the Lower Albian succession recognized by Gautam *et al*. (2015, 2019a) has been extended up to the upper limit of the present *Jauberticeras villoutreysi* Subzone of the *Tetragonites rectangularis* Zone (Gautam, 2020).

CONCLUSIONS

In light of the above-mentioned findings of ammonoids from the Lower Albian succession of Ariyalur Sub-basin following conclusions have been deduced:

1. The accurate extent and the upper limit of the Lower Albian sedimentary succession, recorded earlier by Gautam *et al*. (2015, 2019a), have been respectively established and extended in the Ariyalur Sub-basin of the Cauvery Basin.
2. New ammonoid biozonation has been attempted for the first time in the revised Lower Albian Succession of the Karai Formation of the Ariyalur Sub-basin, Cauvery Basin.
3. The Lower Albian biostratigraphic scheme of the present study envisages a single *Tetragonites rectangularis* Zone and its four subzones (*Beudanticeras newtoni*, *Beudanticeras revoili*, *Jauberticeras collignoni,* and *Jauberticeras villoutreysi* in ascending order) which is found equivalent to the *Douvilleiceras mammillatum* Zone of the standard ammonoid zonal framework.
4. Based on the published and fresh ammonoid record from the studied Lower Albian succession mentioned above in the text, it is opined that the occurrences of ammonoid species *Tetragonites rectangularis*, *Beudanticeras newtoni*, *Beudanticeras revoili*, *Puzosia* (*Puzosia*) *quenstedi, Jauberticeras collignoni*, *Jauberticeras* cf. *jaubertianum*, *Jauberticeras villoutreysi* and *Obataceras manjience* mark not only their first record from Lower Albian sediments of the Karai Formation of the Cauvery Basin but also from other known Lower Albian horizons of India.
5. The stratigraphic succession equivalent to standard basal Lower Albian *Leymeriella tardefurcata* Zone so far appears to be unrepresented in the Cauvery Basin.
6. This ammonoid-based biostratigraphic refinement is the singular effort so far made in India, which not only improves our knowledge about the Lower Albian record in India but is equally useful in the understanding of Lower Cretaceous ammonoid stratigraphy in the global perspective.

ACKNOWLEDGEMENT

The authors are thankful to the Department of Geology, BHU for extending available facilities. J. P. Gautam acknowledges the financial support from UGC-Rajiv Gandhi National Fellowship.

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