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Upper Jurassic–Lower Cretaceous Biostratigraphy and Fauna of South Primorie (Russian Far East)

I. I. SEY and E. D. KALACHEVA
Karpinskiy All-Russian Geological Institute, St. Petersburg

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The paper deals with the detailed (zonal) biostratigraphy of the Upper Jurassic and the lowermost Cretaceous of South Primorie. Lower and middle Tithonian deposits have been recognized in the Upper Jurassic, and the lowermost Berriasian has been identified in the Lower Cretaceous sequence of the area. Ammonite and buchian assemblages are described. The ammonite assemblages, dominated by typically European taxa, have allowed a correlation with the European scale. The joint occurrence of Tethyan ammonites and Boreal buchians in the assemblages has enabled a Boreal–Tethyan correlation and the identification of the Jurassic/Cretaceous boundary in the Boreal scale. The specific character of the Primorie ammonites, which have no analogs in SE Asia and North America, make the solution of some paleobiogeographic problems rather ambiguous.

INTRODUCTION

The topmost Jurassic and lowermost Cretaceous deposits of South Primorie, and their stratigraphic subdivision and faunal assemblages, are of great interest not only in a regional context, but also in terms of general, global problems of Mesozoic stratigraphy and paleobiogeography, such as Boreal–Tethyan correlation, the position of the Jurassic/Cretaceous boundary, and the migration and faunal relations between individual zoochores, often distant from one another.

Upper Jurassic and Lower Cretaceous deposits are widespread in Russia's Far East. The most complete sequences with abundant fauna are located to the north, in the western Okhotsk region, where all three stages of the Upper Jurassic are known. There is a detailed zonal scale based on buchians and there is also a more schematic scale, based on ammonites, with alternating beds and units containing Tethyan and Boreal ammonites [10], [12], [35]. The terminal stage, characterized mostly by a Boreal fauna (buchians), is the

Volgian Stage; the overlying strata are referred to the Boreal Berriasian[a]. The Upper Jurassic deposits of South Primorie show a different sequence and are characterized by different faunal assemblages. Along with data on the Okhotsk sequences, this enables us to consider the above mentioned general stratigraphic and paleobiogeographic problems.

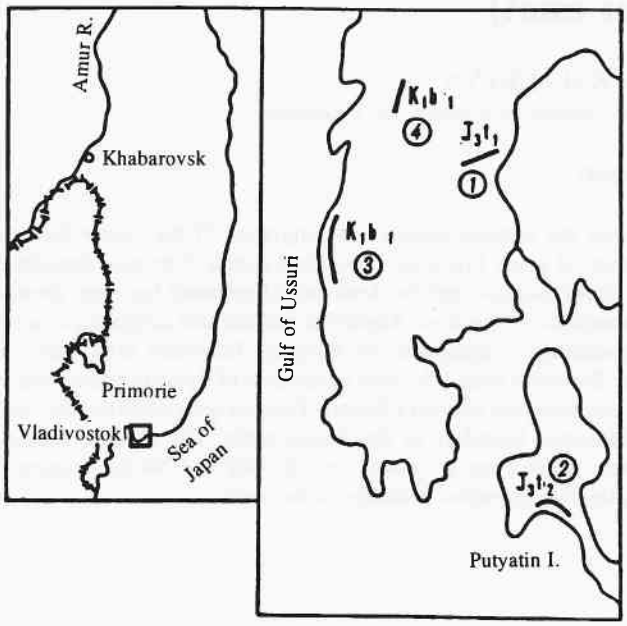


Figure 1 Location of the main study areas in South Primorie. Figures in circles: 1 — Promyslovka (Tikhookeanskiy) settlement; 2 — southern coast of Putyatin Island; 3 — Gulf of Ussuri coast; 4 — Strelok railway station.

Until recently, there were two different views about the Upper Jurassic stratigraphy of Primorie. K. M. Khudoley [14] believed that all the stages of the Upper Jurassic were present in the region. He had discovered and described Tithonian ammonites [15–17] and proposed the Tithonian Stage as the terminal stage of the Jurassic in the study area. A different view was supported by I. V. Konovalova [4], who had spent a few years on detailing the Upper Jurassic stratigraphy of Primorie, and studying bivalves, including buchians. She came to the conclusion that the bulk of the Upper Jurassic there belonged

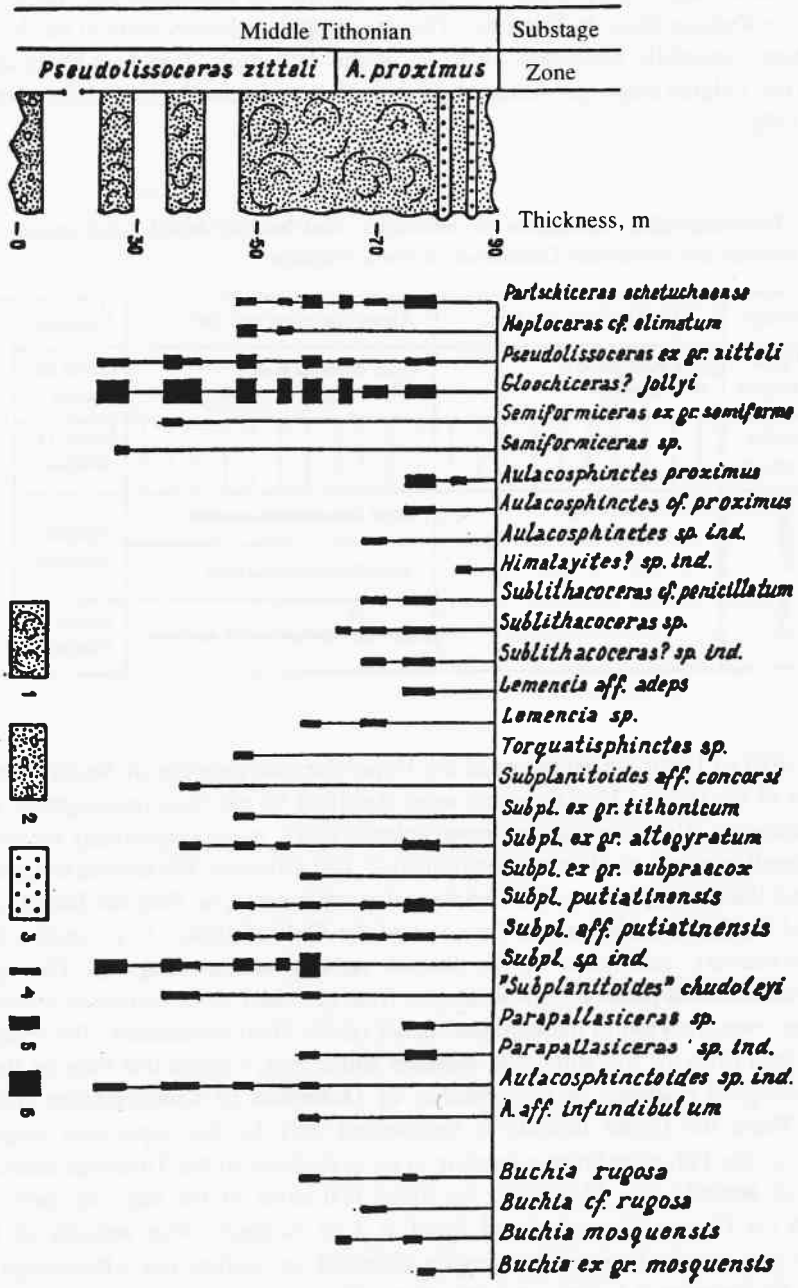
[a] The term "the Boreal Berriasian" is used here to emphasize the inadequate identification of this stage in the Boreal and Tethyan regions [13].

to the uppermost stage. Using Boreal buchians to confirm the geological age, Konovalova identified the Volgian Stage in Primorie. The stratigraphic schemes worked out by these stratigraphers, especially Khudoley's scheme of the Tithonian Stage and Konovalova's scheme of the Volgian Stage, proved to be incompatible and caused a long debate between them [4], [19].

Table 1 Biostratigraphic correlation of ammonite- and buchian-based subdivisions of the uppermost Jurassic and lowermost Cretaceous in South Primorie.

Boreal scale	Substage	Buchia zones and beds	Ammonite zones and beds	Substage	Tethyan scale
	Upper Volgian	Zone *Buchia piochii - B. terebratuloides*	Zone *Berriasella jacobi - Pseudosubplanites grandis*	Lower Berriasian	
	Middle Volgian			Upper Tithonian	
	Lower Volgian	Beds with *B. rugosa* u *B. mosquensis*	Zone *Aulacosphinctes proximus*	Middle Tithonian	
			Zone *Pseudolissoceras zitteli*		
			Beds with *Virgatosphinctes cf. mexicanus*	Lower Tithonian	

In the 1970 to 1980s we investigated the Upper Jurassic deposits of South Primorie, mostly east of the Gulf of Ussuri, which were classified by previous investigators as the Chigan Formation. These deposits are mostly clastic rocks, mainly calcareous sandstones, with very small amounts of siltstone, conglomerate, and gritstone. We studied the geologic sections near the Promyslovka and Tikhookeanskiy settlements, on Putyatin Island, on the left bank of the Petrovka River, on the coast of the Gulf of Ussuri (type section of the Chigan Formation), and north of the Strelok railway station (Fig. 1). During our fieldwork we collected paleontological samples from each bed. A collection of ammonites and buchians was analyzed in monographic detail (about 2000 specimens). The results of our study, data from the literature, and museum collections, suggest that thus far there is no paleontological evidence of the presence of Oxfordian or Kimmeridgian rocks in Primorie. There the Upper Jurassic is represented only by the uppermost stage; we identified it as the Tithonian Stage according to the prevalence of the Tithonian ammonites in the faunal assemblages. Moreover, we found that some of the deposits, previously ascribed to the Chigan Formation and dated as Late Jurassic, were actually of Early Cretaceous age. On the basis of the samples collected we worked out a biostratigraphic scheme for the uppermost Jurassic and lowermost Cretaceous deposits of South Primorie, comprising two independent scales, one based on ammonites, the other, on buchians.


Middle Tithonian
Substage
Pseudolissoceras zitteli
A. proximus
Zone
0
30
50
70
90
Thickness, m
Partschiceras schetuchaense
Haploceras cf. elimatum
Pseudolissoceras ex gr. zitteli
Gloochiceras? jollyi
Semiformiceras ex gr. semiforme
Semiformiceras sp.
Aulacosphinctes proximus
Aulacosphinctes cf. proximus
Aulacosphinctes sp. ind.
Himalayites? sp. ind.
Sublithacoceras cf. penicillatum
Sublithacoceras sp.
Sublithacoceras? sp. ind.
Lemencia aff. adeps
Lemencia sp.
Torquatisphinctes sp.
Subplanitoides aff. concursi
Subpl. ex gr. tithonicum
Subpl. ex gr. altogyratum
Subpl. ex gr. subpraecox
Subpl. putiatinensis
Subpl. aff. putiatinensis
Subpl. sp. ind.
"Subplanitoides" chudoleyi
Parapallasiceras sp.
Parapallasiceras sp. ind.
Aulacosphinctoides sp. ind.
A. aff. infundibulum
Buchia rugosa
Buchia cf. rugosa
Buchia mosquensis
Buchia ex gr. mosquensis
1
2
3
4
5
6

TITHONIAN STAGE

Lower Tithonian

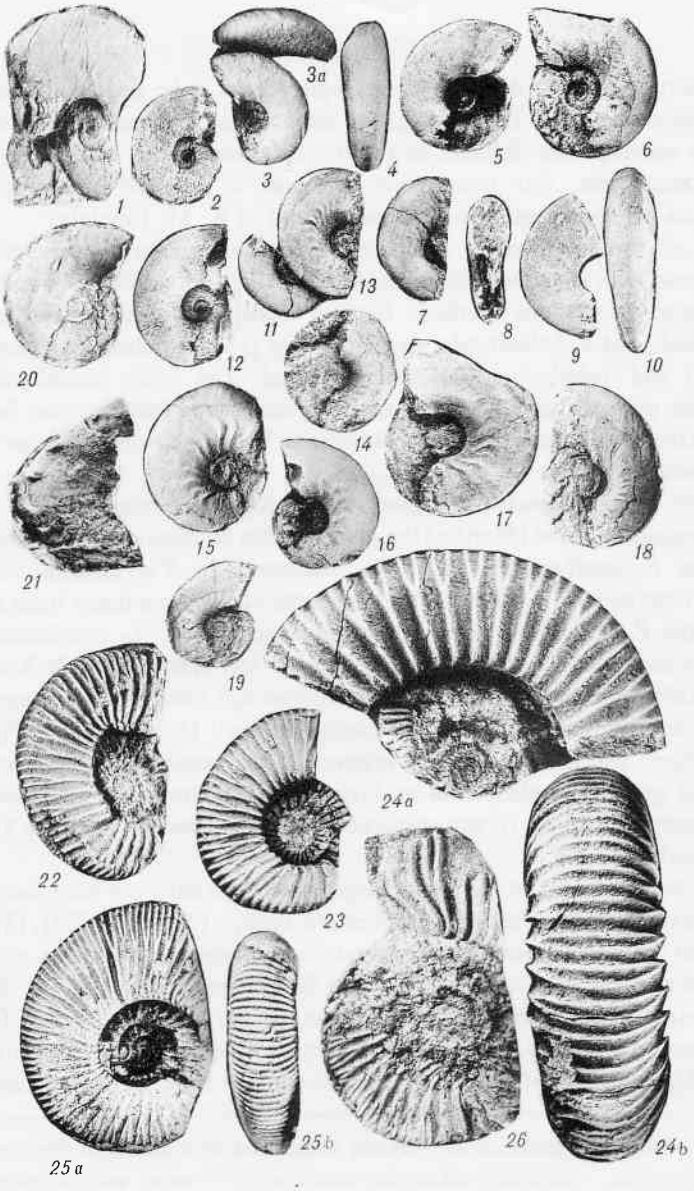
The stratigraphically lowermost deposits of the region seem to be deposits found in the area of the Promyslovka and Tikhookeanskiy settlements. Because they are poorly exposed, or their outcrops are difficult to reach, our observations in this part of the sequence were incomplete. For this reason, we had to use the stratigraphic and paleontological data of other geologists, primarily those of K. M. Khudoley.

This interval of the sequence is composed of inequigranular, poorly cemented, calcareous sandstone with characteristic spheroidal jointing and scarce, 2–3 meter thick limestone and conchoidal siltstone interbeds. In these deposits we identified *Partschiceras schetuchaense* Chud. and *Subplanitoides* sp.; Khudoley [15] described *Virgatosphinctes contiguus* (Zittel) and *Subplanites putiatinensis* Chud. The rocks contain abundant bivalves, trigoniids, pinnes, camptonecteses, etc., and occasional indeterminate buchians. The apparent maximum thickness of these sediments is 30 m; their relationships with the underlying and overlying rocks are unknown.

On the basis of *Virgatosphinctes contiguus*, K. M. Khudoley referred these deposits to the lower Tithonian. Later he identified the genus of this ammonite as *Subplanites* [18] and still later, as *Parapallasiceras* [19]. He correlated the Far Eastern beds with *Parapallasiceras contiguus* with a lower Tithonian zone of the same name from southern France, or with the *P. pallatinum* zone of Central Europe [40]. As mentioned above, because of the incompleteness of our own collection we examined with Khudoley's specimens, especially with *V. "contiguus"* as a principal age indicator. Our examination revealed that it was different from the type *contiguus* fossil [22, Table 16, Fig. 3] in almost all parameters, and hence cannot be referred to the genus *Parapallasiceras*. We consider its initial generic identification as *Virgatosphinctes* to be more correct, and believe that it is comparable with *Virgatosphinctes mexicanus* (Burck.) from the Tithonian of Central and South America.

Unfortunately the age limits of the genus *Virgatosphinctes* have not been ascertained. In the opinion of experts on the Tithonian of Western Europe [22], [24], [32], [37], [41], this genus is absent on the European continent and are characteristic members of the East Tethyan ammonite assemblages from East Africa to Central and South America. But even there, the distribution of the taxon and its age limits are not fully understood. In recent years there has been a tendency to restrict this genus to the lower-mid Tithonian. For instance, the *Hildoglochiceras–Virgatosphinctes* assemblage from the Spiti Shale (India)

Figure 2 Middle Tithonian sequence on Putyatin Island and distribution of ammonites and buchians. 1 — fine-grained, conchoidal, calcareous sandstone; 2 — same, with occasional small pebbles; 3 — medium-grained, massive sandstone; 4–6 — number of ammonite and buchian specimens: 4 — 1–5; 5 — 5–10; 6 — a few tens.


1
2
3
3a
4
5
6
7
8
9
10
11
12
13
14
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16
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18
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20
21
22
23
24a
24b
25a
25b
26

×4/5

is generally regarded as mid Tithonian [29]. According to A. Zeiss [40], a similar assemblage on Madagascar is equivalent to the *Semiforme* Zone, i.e. to the base of the European middle Tithonian. At the same time, according to H. Leanza [30], who has carried out the most comprehensive nomenclatural analysis of the genus *Virgatosphinctes*, and in Argentina the latter never extends beyond the lower Tithonian and forms the core of the *Virgatosphinctes mendozanus* Zone ammonite assemblage, which includes *V. mexicanus*. On the basis of these data we recognized the beds with *V.* cf. *mexicanus* in Primorie and correlated them with the uppermost lower Tithonian *V. mendozanus* Zone of Argentina.

The other rare components of the Primorie assemblage do not contradict this date. We have referred the ammonite, identified by Khudoley as *Subplanites putiatensis*, to the genus *Subplanitoides*. The latter, according to Zeiss [40], is restricted to the lower Tithonian in European sequences, although Enay and Geyssant [24] believe that it extends into much of the middle Tithonian.

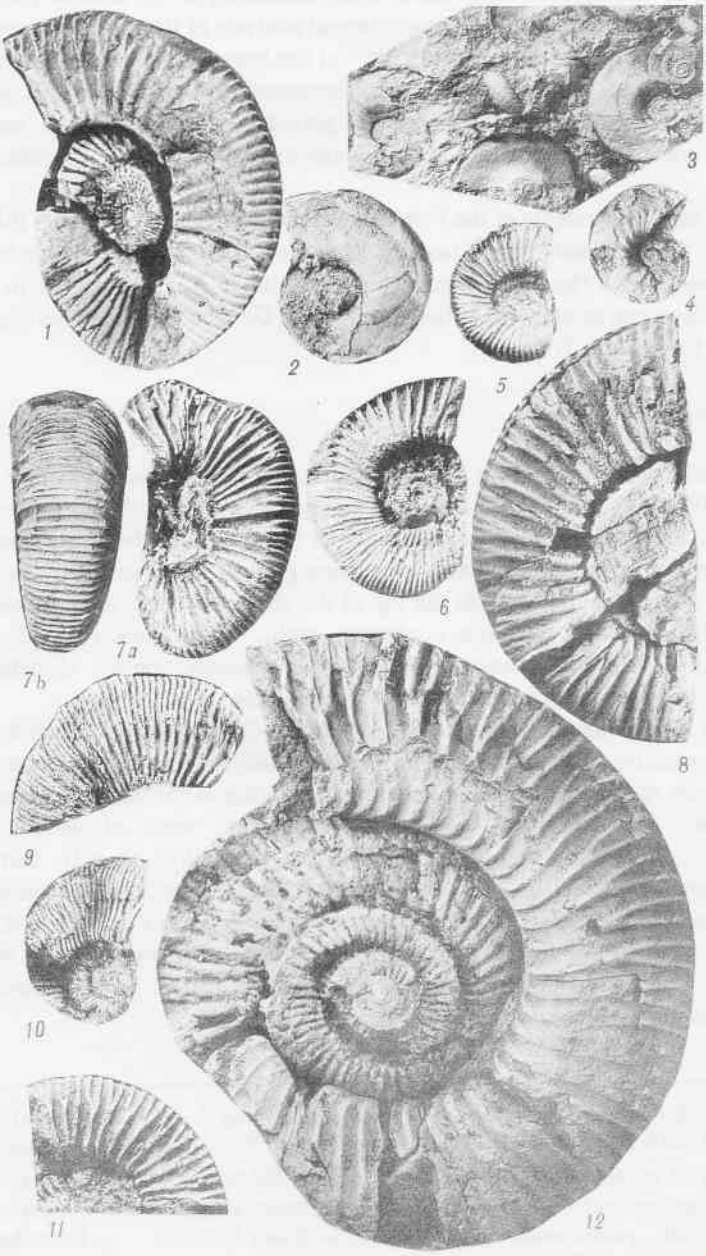
Middle Tithonian

The deposits of Putyatin Island, in South Primorie, are referred to the Middle Tithonian. In terms of lithology and fauna they are closely associated with the lower Tithonian deposits from the Promyslovka area. The rocks occur within the Cretaceous volcanic rocks and are homogeneous brownish-gray, fine-grained calcareous sandstones with a characteristic conchoidal parting. At the top of the sequence, there are two beds of light-colored, medium-grained, massive sandstone, each ~1 m thick (Fig. 2). The total apparent thickness is approximately 87 m. The deposits contain abundant various ammonites, which can be grouped into two assemblages.

The lower assemblage is dominated by small (25–35 mm across), smooth or slightly sculptured ammonites, often occurring in groups of several tens of specimens (there are about 1000 such specimens in our collection), belonging to the families Oppeliidae and Haploceratidae. The dominant species are oppeliides, most of which have been conventionally referred to the genus *Glochiceras–G.? jollyi* (Oppel); there are also occasional *Semiformiceras* ex gr. *semiforme* (Oppel). The haploceratides are less abundant: *Pseudolissoceras* ex gr. *zitteli* (Burck.), *Haploceras* cf. *elimatum* (Oppel), and *H.* sp. ind. (1–21 in Plate 1; 2, 3 in Plate 2). Because of poor preservation, the genus or even the family of many ammonites cannot always be identified; we have classified these as "smooth" ammonites.

Plate 1: figs 1, 2 — *Pseudolissoceras* ex gr. *zitteli* (Oppel); figs 3–11 — *Haploceras* cf. *elimatum* (Oppel); figs 12–19 — *Glochiceras? jollyi* (Oppel); fig. 20 — *Semiformiceras* sp.; fig. 21 — *Semiformiceras* ex gr. *semiforme* (Oppel); figs 22, 23 — *Subplanitoides* ex gr. *altegyratum* Zeiss; fig. 24 — *Torquatisphinctes* sp.; fig. 25 — *Subplanitoides* ex gr. *tithonicum* Zeiss; fig. 26 — *Subplanitoides* aff. *putiatinensis* (Chud.). 1, 2 — South Primorie: 1 — Petrovka River; figs 2–26 — Putyatin Island Middle Tithonian: 1–16, 18–26 — *P. zitteli* Zone, 17 — *A. proximus* Zone. Hereafter all fossils have been collected by the authors. Full-size specimens are given here and in the plates that follow.

×1.5
×4/5



× 4/5

The Perisphinctaceae superfamily is considerably less common. It is dominated by medium-sized ammonites with a rapidly expanding last volution and thin, mostly bifid, barely branching ribs. We have referred them to the genus *Subplanitoides* Zeiss, which was widely developed in the lower and upper Tithonian of Western Europe. In spite of the general similarity of our specimens to European forms, they are fairly distinctive. Therefore, considering their poor preservation, they can be identified, mostly in terms of open nomenclature, as *Subplanitoides* ex gr. *tithonicus* Zeiss, *S.* aff. *concordi* (D. et E.), *S.* ex gr. *altegyratum* Zeiss, and *S.* ex gr. *subpraecox* (D. et E.). Also present are the local forms of *S. putiatinensis* (Chud.) and *"S." chudoleyi* S. et K. (22, 23, and 25 in Plate 1; 5–8 in Plate 2). The assemblage also comprises single forms of *Aulacosphinctoides* aff. *infundibulum* (Uhlig), *Torquatisphinctes* sp., *Lemencia* sp. ind., and *Parapallasiceras* sp. ind. (24 in Plate 1; 9, 10 in Plate 2).

This assemblage has been dated with certainty from the presence of *Semiformiceras* ex gr. *semiforme*, close to the index species of the lower zone of the middle Tithonian on the European scale[a]. This date is supported by *Pseudolissoceras* ex gr. *zitteli*, which is most similar to *P. zitteli* from the lower middle Tithonian of Cuba and Mexico [39]. The unit with *Pseudolissoceras* is probably a high-ranking stratigraphic, because forms of this genus indicate the middle Tithonian zones of Germany, on the one hand (*P. bavaricum* Zone [41], and of Argentina, on the other (*P. zitteli* Zone [30]. The sudden appearance of haploceratides in the lowermost middle Tithonian is observed in the well-studied sections of Spain [23]. Another typical form of the "smooth" ammonite group, *Glochiceras? jollyi* (Oppel), is present in the *Hildoglochiceras kobelli* Zone of Madagascar, usually placed within the lower–middle Tithonian [39], although Zeiss [40], as has been mentioned above, has restricted its age limits and has correlated it with the *Semiforme* Zone. Zeiss considered the *Subplanitoides* genus, which is the dominant genus among the Perisphinctaceae, as lower Tithonian [40]. At the same time Enay and Geyssant [24] have reported more than seven species of this genus from the middle Tithonian *semiforme* and *Fallauxi* zones of Spain. Oloriz [32] has reported a wide range of *Subplanitoides* from the middle Tithonian of Spain. *Aulacosphinctoides* and *Torquuatisphinctes* are rather unusual genera in the assemblage. They are more typical of the upper Kimmeridgian–lower Tithonian. However, numerous *Aulacosphinctoides* spp. have been reported from the above mentioned *Hildoglochiceras kobelli* Zone of Madagascar. Krishna *et al.* [29] place the *Aulacosphinctoides–Torquatisphinctes* assemblage from the

Plate 2: figs 1, 11 — *Subplanitoides* ex gr. *altegyratum* Zeiss; figs 2–4 — *Glochiceras? jollyi* (Oppel); figs. 5, 6 — *Subplanitoides putiatinensis* (Chud.); fig. 7 — *"Subplanitoides" chudoleyi* Sey et Kalach.; fig. 8 — *Subplanitoides* ex gr. *subpraecox* (D. et E.); figs 9, 10 — *Lemencia* sp. ind.; fig. 12 — *Aulacosphinctoides?* sp. ind. South Primorie, Putyatin Island, middle Tithonian: figs 1–3, 5–10, 12 — *P. zitteli* Zone; figs 4, 11 — *A. proximus* Zone. (× 4/5)

[a] At present there is no universal subdivision of the Tithonian into substages; a two-member subdivision is used in Southern Europe (France and Italy) and a three-member subdivision has been adopted in Central Europe, with the lower and middle substages corresponding with the lower Tithonian of Southern Europe. We adhere to a three-member subdivision.

Himalayan Spiti Shale below the *Hildoglochiceras–Virgatosphinctes* level and date it as lower Tithonian, whereas Leanza [30] raises the upper age limit of this genus to the top of the Middle Tithonian. These data suggest that it is necessary to revise the taxonomic and age limits of the genus *Aulacosphinctoides*, a typical form in the East Tethyan ammonite faunas, along with *Virgatosphinctes*. This also applies to the genus *Torquatisphinctes*. *Parapallasiceras* and *Lemencia*, which are rare in this assemblage, appear at the top of the lower Tithonian and are most numerous in the middle Tithonian, especially in the upper part of this substage [20], [24], [32].

Therefore the lower assemblage from Putyatin Island, including forms of European, Indian–Ethiopian, and American ammonite faunas, is highly specific and has no direct analogs among the contemporaneous ammonite assemblages. In terms of the abundant "smooth" ammonites, it is comparable with the assemblage of the *Pseudolissoceras zitteli* Zone of Argentina [30], which is also dominated by haploceratides and oppeliides. Considering the presence, in the Putyatin assemblage, of specimens similar to the index species of this zone, we identified a *P. zitteli* Zone in South Primorie (Table 1) and correlated this with the Argentinian and Cuban zones of the same name and also with the European *P. bavaricum* Zone. The latter is presently correlated with the *semiforme* and *fallauxi* zones of Southern Europe [41].

A similar biostratigraphic zone was recognized in Primorie by Khudoley [14], who identified beds with *Primorytes primoryensis* and referred them to the top of the lower Tithonian. Later [18] he included *Primorytes* as a subgenus of the genus *Pseudolissoceras*, and referred the partially renamed beds to the lower middle Tithonian. We consider *Primorytes primoryensis* Chud to be a synonym of *Pseudolissoceras* ex gr. *zitteli*.

The upper ammonite assemblage of the Putyatin section is very different from the lower one in terms of its species composition and dominant species. It contains far fewer haploceratides and oppeliides, even though they do occur up to the top of the sequence and include *Pseudolissoceras* ex gr. *zitteli* and *Glochiceras? jollyi*. The upper assemblage is dominated by the Perisphinctaceae, some of which survived from the lower part of the sequence, and some of which are new. The common forms in both assemblages are *Subplanitoides* and *Parapallasiceras*, the former making up the basic background of the upper assemblage. The upper assemblage is distinguished by the appearance of *Lemencia*, one specimen of which is closely similar to a specimen from Frankenalb (Germany), identified by Zeiss [40] as *Lemencia* aff. *adeps* (Schneid) (14 in Plate 3).

The newly discovered forms include *Sublithacoceras* and *Aulacosphinctes*. Large sublithacocerases were identified as *S.* cf. *Penicillatum* (Schneid); *S.* cf. *diffusum* (Schneid) was identified among the smaller specimens (6 and 13 in Plate 3). The forms of the *Aulacosphinctes* genus rank second after the basic *Subplanitoides* group of the assemblage. These microconchoidal forms have an evolute shell, a flattened ventrum, and a more-or-less distinct furrow on the phragmocone (2–5 and 7 in Plate 3) and were identified as *Aulacosphinctes proximus* (Steuer), which has been described from the Tithonian of Argentina. At the top of the sequence, an ammonite fragment was found, bearing a distinctive sculpture of coarse bifid ribs and bosses at the branching point (12 in Plate 3), resembling the sculpture of Himalayatidae.

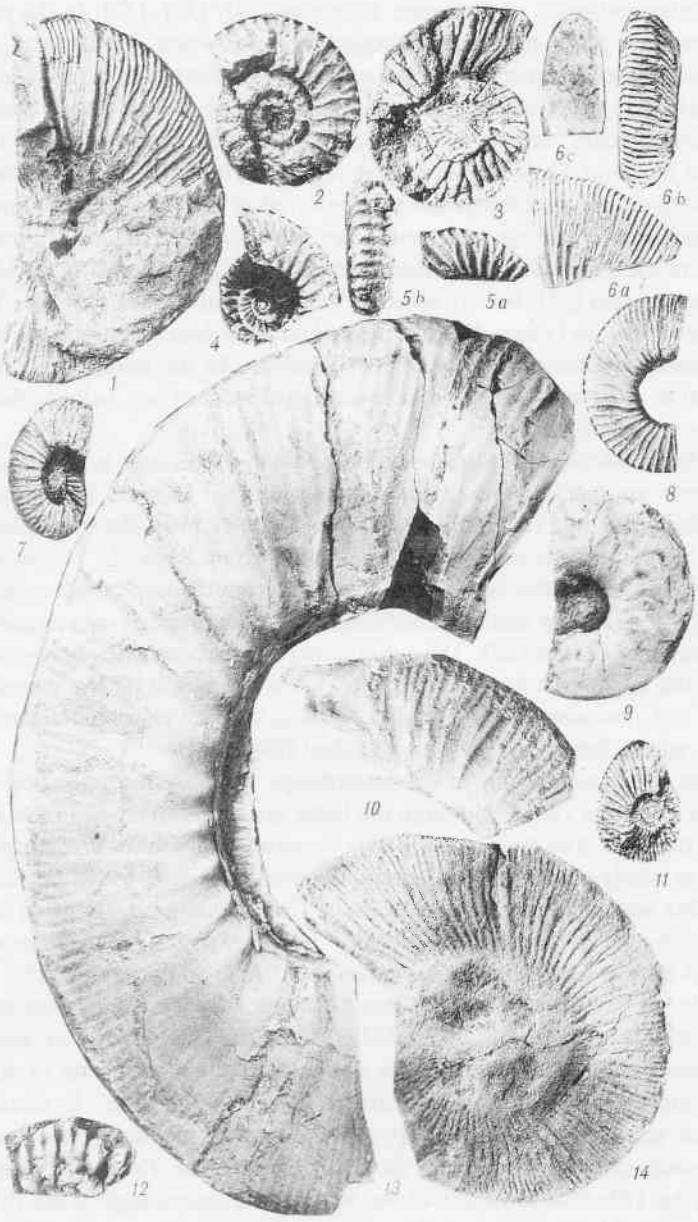
The genus *Aulacosphinctes* is of critical importance for the dating of the upper

assemblage. This genus is more typical of the Eastern Tethys but is also known from Europe (Southern Spain) where quite a few species have been identified in the top of the middle Tithonian and much of the upper Tithonian [24], [32], [37]. In the eastern sector of the Tethys, this genus has been identified in East Africa, Madagascar, Himalayas, Argentina, and Chile. However, as in the case of other East Tethyan taxa, no agreement has been reached as to its volume and age. According to Verma and Westermann [39], *Aulacosphinctes* occurs mostly in the uppermost middle Tithonian and in the upper Tithonian. In the Spiti Shale of the Laptal region of India, the *Himalayites–Corongoceras–Aulacosphinctes* assemblage has been referred to the bottom of the upper Tithonian [29]. An assemblage containing *Aulacosphinctes, Parapallasiceras*, and *"Virgatosphinctes"* etc., similar to the Primorie assemblage, has recently been identified in the Spiti Shale from Zankhar in India [33], but are dated as early Tithonian to earliest late Tithonian. In Argentina, according to Leanza [30], *Aulacosphinctes* is found between the middle of the middle Tithonian and the top of the upper Tithonian. In the middle Tithonian we have recognized an *A. proximus* Zone; we have identified most of our *Aulacosphinctes* spp. as the index species of this zone.

Another form, which is presumably useful as an age indicator, is *Sublithacoceras*; but unlike the previous species, this taxon is known only in Europe: in Germany, France, Spain, and Bulgaria. In Frankenalb, according to Zeiss [40], the sublithacocerases are confined to the lowermost middle Tithonian *Bavaricum* Zone. In southern Spain, this genus was reported from the *Semiforme* Zone and from the uppermost middle Tithonian *Ponti* Zone [24], [32]. An abundant *Sublithacoceras* assemblage was reported from the middle Tithonian of France [22]. The sublithacocerases of our assemblage most probably characterize the upper part of the substage. This is supported by the increasing amount of *Lemencia* spp., because in South Spain *Lemencia* spp. are restricted to the *Fallauxi* and *Ponti* zones, where they are also quite abundant [24], [32].

Out of the other components of the assemblage, the *Subplanitoides* and *Parapallasiceras* show a wide age range, although the latter are more common in the upper part of the middle Tithonian. The distribution of the "smooth" ammonites that are present in this assemblage as fairly similar. A fragment of ammonite was found at the top of the sequence. This was similar to *Himalayites* or *Corongoceras* in terms of its sculpture, suggesting a higher stratigraphic position, because the *Corongoceras–Himalayites* assemblage is typical of the upper Tithonian of SE Asia and America [29], [30], [39].

The results of this analysis indicate that the upper Putyatin assemblage most probably corresponds with the upper part of the middle Tithonian. The presence of *Aulacosphinctes proximus* allows it to be correlated with the zone of the same name in Argentina and enables the identification of the *A. proximus* Zone in Primorie. It should be noted, however, that apart from the index species these zones do not contain any forms in common. Leanza [30] mentioned that the assemblage of the *Proximus* Zone was poorly preserved in the Tithonian sequence of the Andes. The assemblage of the Primorie zone, on the contrary, is highly diverse and comprises about ten genera, the bulk of which are European genera. This accounts for the distinctive nature of this assemblage. Like the lower assemblage, it has no analogs in near-Pacific or East Asian countries. The only exception, in a sense, is the above-mentioned assemblage from the Spiti Shale of Zankhar



× 4/5

(India) [33]. Leanza referred the Argentinian *Proximus* Zone to the middle part of the middle Tithonian. Recently, especially after a detailed study in Southern Spain, this zone was placed within the top of the middle Tithonian and correlated with the European *Microcanthoceras ponti* and *Burckhardiceras* Zones [38], [41]. Accordingly, this age was adopted for the *Proximus* Zone of Primorie; this is supported by the above analysis of the fauna.

The description of the two Putyatin assemblages can be supplemented by buchians, accounting for a small proportion of the associated various bivalve fauna: trigoniids, camptonecteses, pinnas, plagiostomes, lophas, etc. Occasional small buchians have been found, mostly in the upper part of the sequence, and comprise *Buchia rugosa* (Fisch.) and *B. mosquensis* (Buch). In accordance with the Buchia scale, these deposits are classified as beds containing *B. rugosa* and *B. mosquensis* and are identified with a Buchia zone of the western Okhotsk Region [12]. The latter is largely lower Volgian, although it probably also includes the lower beds of the middle Volgian.

The lower–middle Tithonian deposits are widespread in South Primorie, east of the Gulf of Ussuri, in the drainage basins of the Petrovka and Litovka rivers and in the adjacent districts. The sequence that we studied along the Petrovka River exhibits the same biostratigraphic units, with relatively abundant "smooth" ammonites in its lower part, including *Pseudolissoceras* ex gr. *zitteli* and *Glochiceras? jolli*, associated with *Subplanitoides* and possibly *Virgatosphinctes*, succeeded by *Aulacosphinctes* and *Subplanitoides* in the upper part. There are also beds with *B. rugosa* and *B. mosquensis*.

The above discussion on the Tithonian deposits of South Primorie can be summarized as follows. They contain three ammonite biostratigraphic units, zones and fossiliferous beds, which have been correlated with the South American (Argentinian) ammonite scale on the basis of identical or similar index species. In general, however, the Primorie assemblages show "European" characteristic, which distinguishes them from the ammonite assemblages of adjacent areas and enables them to be correlated, approximately, with the zonal subdivisions of the Western European Tithonian (Table 2).

BERRIASIAN STAGE

Lower Berriasian

The rocks dated as Early Berriasian are some beds of the Chigan Formation that were previously interpreted as Late Jurassic in age. These deposits occur along the coast of the Gulf of Ussuri near Cape Otkrytyi (Chigan), immediately east of the Strelok railway station.

Plate 3: fig. 1 — *Sublithacoceras* sp. ind.; figs. 2–5, 7 — *Aulacosphinctes proximus* (Steuer); fig. 6 — *Sublithacoceras* sp. (cf. *diffusum*); fig. 8 — *Subplanitoides putiatinensis* (Chud.); fig. 9 — *Glochiceras? jollyi* (Oppel); fig. 10 — *Parapallasiceras* sp.; fig. 11 — *Subplanitoides* aff. *putiatinensis* (Chud.); fig. 12 — *Himalayites?* sp. ind.; fig. 13 — *Sublithacoceras* cf. *penicillatum* (Schneid); fig. 14 — *Lemencia* aff. *adeps* (Schneid). South Primorie, Putyatin Island, Middle Tithonian, *A. proximus* Zone. × 4/5

The sequence outcropping along the coast (type section of the Chigan Formation) rests upon the Lower–Middle Triassic deposits with a thick (160 m) unit of boulder and pebble conglomerates, conglomerate-like gritstones, and coarse sandstones. The bulk of the sequence comprises a greenish-gray, stratified, fine- to medium-grained sandstone with abundant plant debris and occasional <3 m interbeds of light-colored, coarse-grained, massive sandstone. In the middle of the sequence there is a member comprising thinly interbedded coarse sandstones, siltstones, and carbonaceous shales with thin stringers and lenses of coal. The total thickness of the sequence is 620 m.

In contrast to the Tithonian, these deposits are characterized mostly by buchians; ammonites are fairly rare: their identifiable remains were found at only three stratigraphic levels in the sequence, along the coast of the Gulf of Ussuri. The high correlation potential of buchians enables them to be used, together with ammonites, for biostratigraphic analysis and dating of sedimentary strata. The first buchians were encountered 180–200 m above the base of the sequence, almost immediately above the coarse basal layer. They were identified as *Buchia piochii* s.l., *B. terebratuloides* (Lah.), *B. unschensis* (Pavl.), *B. fischeriana* (Orb.), *B. trigonoides* (Lah.), *B. volgensis* (Lah.), and *B.* aff. *okensis* (Pavl.). This assemblage, with the exception of *B.* aff. *okensis*, has been traced, in a varying amounts, throughout the sequence up to its top [9], indicating that the sequence belongs to one Buchia unit. This assemblage is typical of the upper Volgian Substage in the boreal areas of Europe, Asia, and North America, and is characteristic of the sediments referred to the upper Tithonian in British Columbia and California[a]. The assemblage is dominated by *B. terebratuloides, B. unschensis* and *B. piochii* s. l.

On the Russian Platform, *B. terebratuloides* appears in the *Fulgens* Zone (or even at the top of the middle Volgian), it is most widely distributed in the *Subdites* and *Nodiger* Zones, and evidently extends into the lowermost beds of the Ryazanian Horizon [1], [34]. In northern Siberia and in the drainage area of the Pechora River, this species is restricted to the upper Volgian Substage. In Siberia, it tends to be localized, including *B. obliqua*, in the *Okensis* and *Taimyrensis* Zones [2], [3]; in the Pechora Region it is localized, in the *Fulgens* and *Subdites* zones [5]. In north-east Russia, its age interval is late Volgian–early Boreal Berriasian [8], similar to eastern Greenland, where it probably extends to the *H. kochi* Zone [36]. In Russia's Far East [12] and in Arctic Canada [26], *B. terebratuloides* most probably does not extend beyond the upper Volgian; in British Columbia and California, it is restricted to the top of the "upper Tithonian" [27], [28].

B. unschensis is a less-widespread species, with the exception of northern Siberia, where the *Unschensis* Superzone encompasses most of the Upper Volgian and the lowermost Boreal Berriasian up to the *H. kochi* Zone [3]. Approximately the same range has been reported for this species, from the Russian Platform [6], the Pechora drainage basin [5], and eastern Greenland [36]. In Arctic Canada [25] and Russia's Far East [12], it seems to be restricted to the Upper Volgian. Occasional specimens of *B. unschensis* have been reported from the top of the "upper Tithonian" in British Columbia [27].

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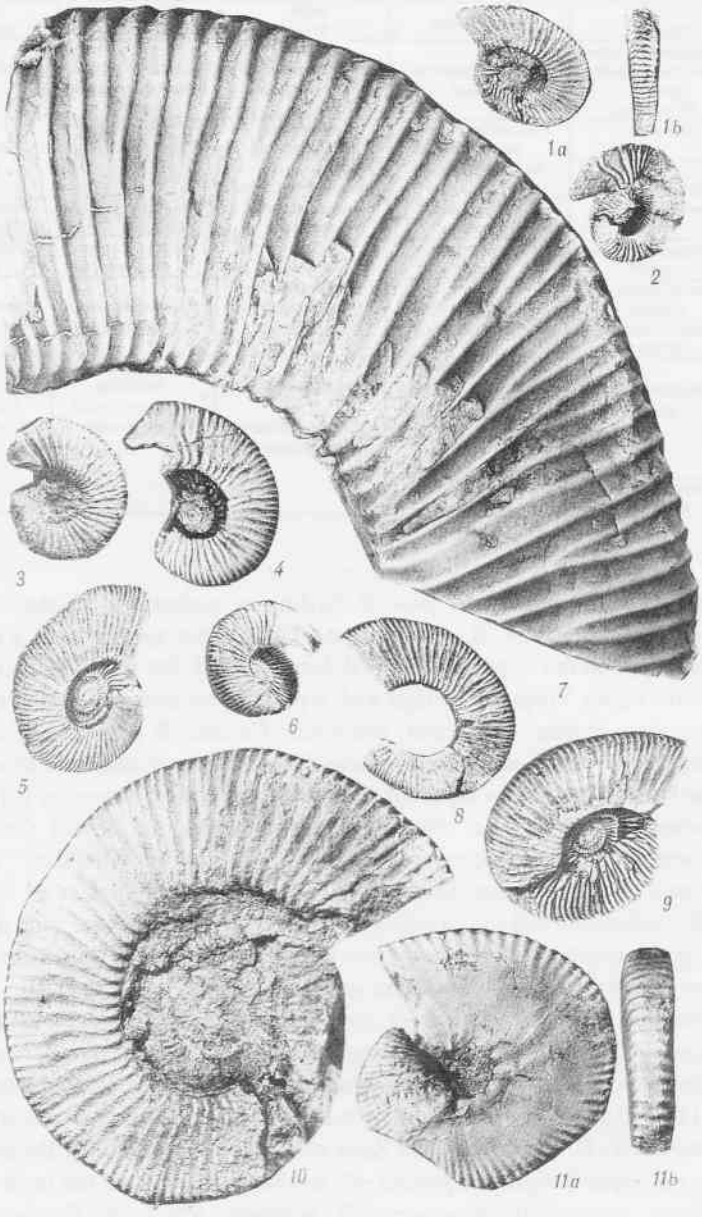
[a] Many investigators have recently revised the age of the upper Tithonian deposits of these areas and dated them as early Berriasian [11], [13], [38], [41], etc.

Table 2 Correlation chart for the Tithonian and Lower Berriasian deposits of Europe, India, Russia's South Primorie, and Argentina.

	Sub-stage	S France, S Spain	Central Europe	India, Spiti	Russia's S Primorie	Argentina, Neuquen Province
Lower Cretaceous	L. Berriasian (bottom)	*Berriasella jacobi-Pseudosubplanites grandis (P. euxinus)*	*Pseudosubplanites euxinus*	assemblage *Neocosmoceras-Distoloceras*	*Berriasella jacobi-Pseudosubplanites grandis*	*Substeuroceras koeneni*
Upper Jurassic	U. Tithonian	*Durangites*	*Paraulacosphinctes transitorius, Microcanthoceras microcanthum*	assemblage *Blanfordiceras*		*Corongoceras alternans*
		Microcanthoceras microcanthum		Комплекс *Himalayites-Corongoceras-Aulacosphinctes*		
			Pseudovirgatites scruposus			*Windhauseniceras internispinosum*
	M. Tithonian	*Microcanthoceras ponti*	*Pseudovirgatites puschi*	assemblage *Hildoglochiceras-Virgatosphinctes*	*Aulacosphinctes proximus*	*Aulacosphinctes proximus*
		Semiformiceras fallauxi	*Pseudolissoceras bavaricum*		*Pseudolissoceras zitteli*	*Pseudolissoceras zitteli*
		Semiformiceras semiforme				
	L. Tithonian	*Neochetoceras darwini*	*Danub. palatinum*	assemblage *Torquatisphinctes-Aulacosphinctoides*	Beds with *Virgatosphinctes cf. mexicanus*	*Virgatosphinctes mendozanus*
			Franconites vimineus			
			Ussel. parvinodosum			
			Danub. triplicatus			
			Ussel. tagmerheimense			
		Hybonoticeras hybonotum	*Hybonoticeras hybonotum*			

This group is dominated by *B. piochii* (Gabb) as understood in the wide sense, including *B. tenuicollis* (Pavl.), *B. krotovi* (Pavl.), and other species with a narrow and high shell, that occur in the uppermost Boreal Jurassic [12]. On the Russian Platform, it is restricted to the upper Volgian substage with a peak in the beds containing *Craspedites* [1], [34]. In northern Russia, Greenland, and Arctic Canada, *B. piochii* s.l. has not been identified except for in north-east Russia, where this species is widespread throughout the Upper Volgian beds and has been reported from the base of the Cretaceous [8]. *B. piochii* is widely known on the Pacific coast of North America, in British Columbia and California, where its stratigraphic zone is limited by the "upper Tithonian"; dominantly by the lower part of this substage [27], [28]. Among the other species of the Primorie assemblage, *B. fischeriana* and the closely similar *B. trigonoides* have a wide distribution, from the top of the middle Volgian to the lower part of the boreal Berriasian.

In the West Okhotsk region, all of these species constitute a characteristic assemblage in the upper Volgian beds; a *B. piochii–B. terebratuloides* Zone has been identified there within the upper Volgian Substage, resting immediately above the *B. russensis–B. fischeriana* Zone from the top of the middle Volgian containing the late Tithonian *Durangites* [12], [13]. This combination of buchians is also characteristic of the upper Volgian *B. tenucollis–B. terebratuloides* Zone of north-east Russia [7]. By analogy with these regions, the upper Volgian *B. piochii–B. terebratuloides* Zone has been recognized in South Primorie, although the presence of *B. volgensis*, a typically Berriasian species, and of *B.* aff. *okensis* from the top of the "upper Tithonian" of California and British Columbia, suggests that the Chigan sequence of Primorie contains the upper beds of this zone [9].



× 4/5

Along with buchians, the ammonites of the Tethyan ammonite assemblages have been found in the sequence along the coast of the Gulf of Ussury; this allowed a back-up date to be determined based on this faunal group. In contrast to the buchians, the ammonite remains are much rarer. In the middle of the sequence (320 m above the base) a well-preserved berriasellid was discovered; it has flattened subparallel lateral sides and a flattened ventrum with a pronounced sagittal line (11 in Plate 4). Morphologically it is most closely similar to *Dalmasiceras* Djan., characterized by the similarly smooth sculpture of the last volution and its pronounced umbonal bosses. The Primorie specimen differs from most forms of this genus by its involute shell and the specific sculpture on its inner volutions, although species with an involute shell are known among the European dalmasicerases, e.g. *D. biplanum* Maz. from the lower Berriasian of the type locality in France [21] (2 in Plate 3). Nevertheless our specimen is specific enough to be identified as *Dalmasiceras* sp. nov.

This genus is known only in Southern Europe (Western Tethys), in France, Spain, Bulgaria, Crimea, and the Caucasus, where it is confined to the Berriasian Stage and occurs mostly in its lower substage, with its peak distribution at the base of the substage, in the *Jacobi/grandis* Zone, where *D. biplanum* has been found, a species which the Primorie ammonite most closely resembles.

In the upper part of the sequence (550 m above the base), we found poorly preserved *Pseudosubplanites* sp ind. and *Berriasella* sp. nd.; the top of the sequence (interval 570–600 m) contains an abundant but uniform ammonite assemblage. The background fauna is composed of small ammonites (microconchs) with well-defined auricles. On the basis of the whorl pattern, the flatness of the lateral sides and ventrum, the presence of a smooth outline, and the general type of sculpture, they can be attributed to the genus *Berriasella*. Most of them are closely similar to *B. jacobi* Maz. and were identified as *B.* ex gr. *jacobi* (1–4 and 6 in Plate 4), and the remaining species, as *B.* sp. (5, 8, 9 in Plate 4) or as *B.* sp. ind. The other group consists of rarer large ammonites referred to the genus *Pseudosubplanites*. One of them, more than 200 mm across, was identified as *P.* cf. *grandis* (Maz.) (7 in Plate 4); the others, as *P.* aff. *combesi* Le Heg. and *P.* sp. (10 in Plate 4). The presence of *Berriasella* ex gr. *jacobi* and *Pseudosubplanites* cf. *grandis* definitely indicates the lower part of the Berriasian Stage — the *Jacobi/grandis* Zone of the European scale. This proves that this occurs zone in the South Primorie.

The ammonite fauna of the sequence along the Gulf of Ussuri coast is therefore of Cretaceous age and corresponds with the lower Berriasian of the ammonite scale. At the same time the Buchia scale dates these deposits of Jurassic and places them in the upper Volgian Substage. This evidence, as well as the discovery of the late Tithonian *Durangites* in the top of the middle Volgian Substage of the Okhotsk Region, is of critical importance for solving the problem of the Jurassic/Cretaceous boundary. Along with evidence from other regions, including North America, these data indicate that the terminal Jurassic stages (Tithonian and Volgian) are inadequately defined, and that the upper Volgian Substage belongs to the Cretaceous, thereby placing the Jurassic/Cretaceous boundary

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Plate 4: figs 1–4, 6 — *Berriasella* ex. gr. *jacobi* Mazenot; figs 5, 8, 9 — *Berriasella* sp.; fig. 7 — *Pseudosubplanites* cf. *grandis* (Mazenot); fig. 10 — *Pseudosubplanites* sp.; fig. 11 — *Dalmasiceras* sp. nov. South Primorie, Gulf of Ussury coast. Lower Berriasian, *Jacobi/grandis* Zone.

near its base. We have discussed these problems in more detail in our previous work [11], [13].

The Berriasian ammonite assemblage of Primorie can be regarded as the analog of the lower Berriasian assemblages of SE France and other southern European countries. At the same time, as in the Tithonian assemblages, this assemblage differs dramatically from the coeval assemblages of East Tethyan countries, with the exception of ammonites recently discovered in the Himalayas and southern China [31]. This assemblage consists mostly of berriasellas, among which mainly European species have been identified (10 out of 12), including *Berriasella jacobi*. *Pseudosubplantes* cf. *grandis* has been mentioned from this assemblage, although, in our opinion, the specimens referred to this taxon cannot be accurately identified because of their poor preservation. Apart from the berriasellas, the assemblage includes *Blanfordiceras, Himalayites, Spiticeras, Corongoceras*, characteristic of the East Tethyan ammonite faunas. In this connection, Chinese geologists consider that the Himalayan assemblage is intermediate between the Western and Eastern Tethys. This does not hold for the South Primorie assemblage: it occurs farther east and includes only European taxa.

It should be emphasized, in conclusion, that the Tithonian and early Berriasian faunas of South Primorie are a phenomenon unique to Russia and also over a larger area they facilitate the solution of interregional and global stratigraphic and paleobiogeographic problems. This is only the second time that these faunas have been identified in Russia. They allow detailed zonal subdivision of the Tithonian–Berriasian deposits of South Primorie. The mixed composition of these faunas, including Tethyan ammonites and Boreal buchians, and the occurrence of similar faunas in the Okhotsk Region, allow Boreal–Tethyan correlation and help to locate the position of the Jurassic/Cretaceous boundary on the Boreal scale. Moreover, the specific character of the Primorie ammonite assemblages, dominated by specifically European taxa, can be instrumental in solving a number of problems related to paleobiogeographic environments and migration relations during Late Jurassic–Early Cretaceous times in South-east Asia [13].

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