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Biostratigraphy and correlation of the Turonian – Coniacian succession and the Turonian – Coniacian boundary problem in the Far East Russia based on ammonites and inoceramids

TATIANA D. ZONOVA[1] & ELENA A. YAZYKOVA[2]

[1] *VSEGEI, 74 Srednii pr., 199106 St. Petersburg, Russia*
[2] *University of Silesia, Department of Earth Sciences, Labortatory of Paleontology & Stratigraphy, Będzińska Str. 60, PL-41-200 Sosnowiec. E-mail: yazykova@ultra.cto.us.edu.pl*

ABSTRACT:

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The stratigraphy, ammonite and inoceramid content of the Turonian – Coniacian deposits of Far East Russia are presented. The evolution of North Pacific ammonites and inoceramids at the boundary of the two stages was studied and the levels of fundamental changes within the ammonite and inoceramid biota are recognized. The established palaeobiogeographic difference between the Sakhalin and the North-East region palaeobasins is reflected in the existence of two independent local zonal schemes. The main criteria of the Turonian-Coniacian stage boundary in the Far East of Russia were established on the basis of the two schemes. The Turonian/Coniacian (T/C) boundary is clearly marked by the change in the taxonomic diversity of the zonal inoceramid assemblages. It is defined at the base of the *Inoceramus uwajimensis* Zone. The appearance of the endemic ammonite species *Jimboiceras mihoense* MATSUMOTO is the ammonite criterion for recognising the T/C stage boundary in Sakhalin. This is supported by occurrences of the cosmopolitan Coniacian genera *Peroniceras* and *Forresteria*.

INTRODUCTION

Upper Cretaceous deposits are widely distributed in Far East Russia, in Sakhalin and the Kuril Islands; and also in North-East Russia, within north-western Kamchatka, in the Koryakia Upland, and on the north coast of the Sea of Okhotsk (Text-fig. 1). They are represented mostly by marine deposits and contain rich marine faunas with abundant ammonites and inoceramids. The study of representatives of these two groups has shown the high degree of endemism of the faunal assemblages from the Pacific palaeobiogeographic Realm. Moreover, numerous investigations in Russia, Japan, Australia, New Zealand, California and Alaska allowed two (northern and southern) provinces to be defined in this huge realm (VERESHCHAGIN 1964, KHUDOLEY 1979). The part of the Pacific Realm discussed in this paper belongs to the North Pacific province. Within the Pacific Coast of Russia two faunal and depositional areas can be distinguished: Sakhalin

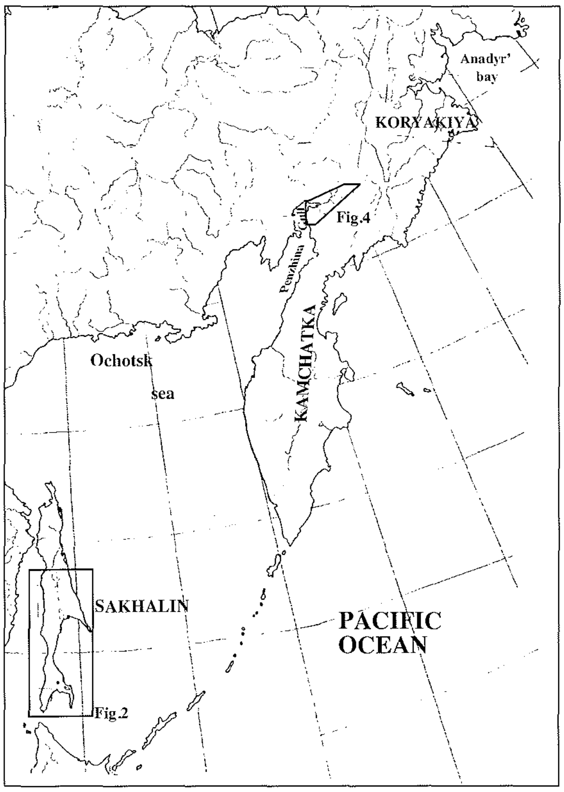

Fig. 1. Location map of the investigated regions of Far East Russia

and the North-East region (Kamchatka and Koryakia). Paleobiogeographically, the former resembles closely Japan, whereas the latter is more similar to Alaska, particularly in respect of the occurrence of some species typical of North America, California and Vancouver Island.

The Turonian – Coniacian sequences are found (Text-fig. 1) in Sakhalin (the West Sakhalin Mountains); and in North-East Russia, in the Anadyr-Koryakia region (Penzhina Gulf, Ugol'naya Bay and the Koryakia Upland) (PERGAMENT 1961, 1971; POYARKOVA 1987; ZONOVA & *al.* 1993).

The endemic species comprise nearly 80% of the faunas from the T/C boundary sequences, including many long-ranged taxa. Consequently, development of refined zonal schemes is very problematic, as is their correlation.

The aim of the present paper is to confirm the position of the T/C boundary in Far East and North-East Russia, and to try to correlate this level with other regions of the world. We carried out detailed investigations of the numerous sections in Sakhalin and in North-East Russia and determined the characteristic species of ammonites and inoceramids from our collections, as well as from the collections of Dr. V.N. VERESHCHAGIN, and Yu.G. MIROLUBOV, both VSEGEI, St. Peterburg, Russia. All of the specimens are housed in the TSNIIGR Museum of VSEGEI in St. Petersburg, nos 10693, 11799, 11886, and 12580, 12632,12769, 12940.

PREVIOUS RESEARCH

Researches on the Cretaceous biostratigraphy of the Pacific Coast of Russia were begun by KRISHTOFOVICH (1932) and BODYLEVSKII (1937), VERESHCHAGIN & MIKHAILOV (1958), EFIMOVA (1955), and LIVEROVSKAYA (1959a-b). In the 1920s and 1930s, the southern part of Sakhalin was intensively studied by Japanese geologists (*e.g.* YABE 1927). Later the results of their researches were used for zonal subdivision of the Upper Cretaceous succession of Japan (MATSUMOTO 1942-43, 1959). The most important contributions to the study of the Turonian – Coniacian fauna were made by PERGAMENT (1961, 1971, 1974), VERESHCHAGIN (1963), IVANOV & POKHIALAINEN (1973), POKHIALAINEN (1982), VERESHCHAGIN & *al.* 1965), ZONOVA (1970, 1974), DUNDO & EFREMOVA (1974). The most recent palaeontological studies were by ZONOVA and YAZYKOVA (ZONOVA 1991, YAZYKOVA 1992, ZONOVA & *al.* 1993).

GEOLOGICAL SETTING

In a tectonic context, the Koryak Upland and the north-western coast of the Kamchatka Peninsula form part of the Cretaceous Koryak – Kamchatka thrust and fold belt. This belt is the Asian margin of the Pacific Ocean. It stretches from the western coast of the Kamchatka Peninsula into the Koryak Upland and the Alaskan Peninsula. It consists of very complicated thrust sheets and fragments of Palaeozoic – Mesozoic island arcs, marginal sea and oceanic complexes. At present, fragments of these structures are described as terranes (SOKOLOV 1992, NOKLEBERG 1994, FILATOVA 1995, KHUDOLEY & SOKOLOV (*in press*). The Koryak – Kamchatka thrust and fold belt formed as a result of mid-Cretaceous accretion. The Koryak – Kamchatka and the Verkhoyansk – Chukotka thrust and fold belts are unconformably overlain by the Okhotsk – Chukotka marginal volcanic belt (SOKOLOV 1992, FILATOVA 1995, KHUDOLEY & SOKOLOV (*in press*). Thus Sakhalin and the Kuril Islands are elements of the extensive complex of island arcs and marginal seas that was formed in Jurassic – Cretaceous time along the Pacific periphery. The Okhotsk – Chukotka belt had its continuation in the Japanese – Korean – Chinese region (LIANSHI & RONGFU 1988), in southeast Asia, and in eastern Australia (MOULADE & NAIRIN 1983). The fragments of this global system of volcanic belts

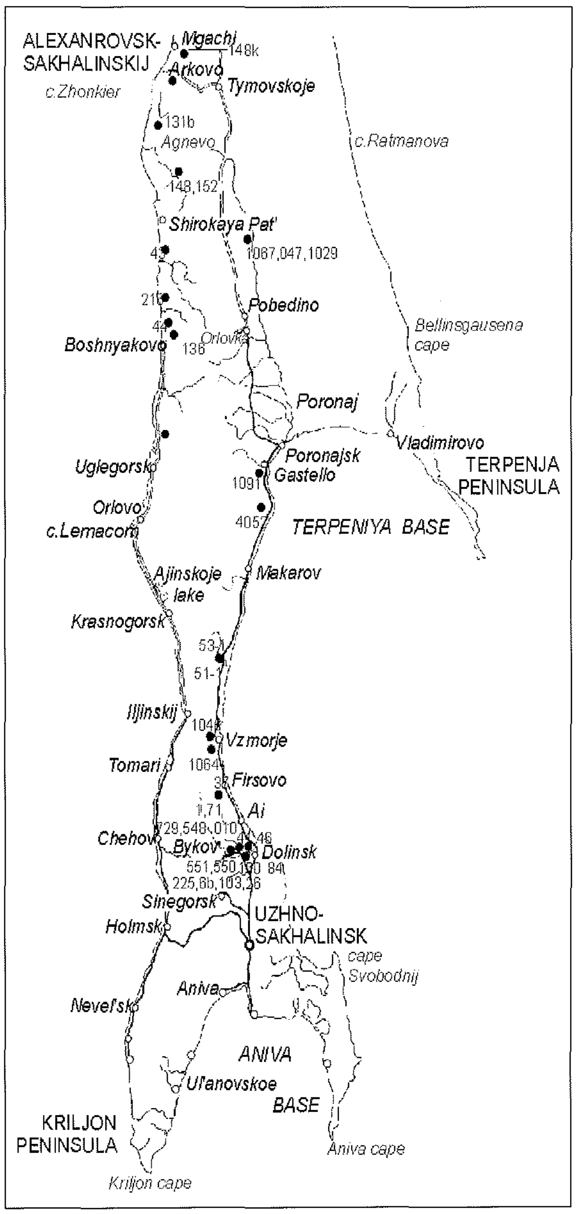

Fig. 2. Location map of the Turonian – Coniacian sections in the island of Sakhalin

developed at the continental margins of North and South America. This process coincided with the highest rate of ocean-floor spreading of the Pacific. It caused the appearance of new convergent boundaries along the continental margins and a speeding-up of the subduction of the oceanic plates. The supra-subductional calc-alkaline volcanism developed on the continental margins (ZINKEVICH 1981, FILATOVA 1995). The complex tectonic construction of the regions studied is a serious obstacle to the definition of clear stratigraphical boundaries.

In Sakhalin the Turonian – Coniacian successions were studied in the West Sakhalin mountains (Text-fig. 2). These deposits belong to the Bykov Formation in the south of the island, to the Tymovsk and Verblud formations in the central part, and to the Arkovo Formation in the north. They are represented by rhythmic alternations of mudstones and sandy mudstones with thin intercalations of sandstones, tuffaceous sandstones and sporadic marly fossiliferous concretions. The reference section for the Cretaceous deposits of Sakhalin is in the Naiba River valley Text-fig. 3 in the south of the island (POYARKOVA 1987). It is the most complete and uninterrupted section available, which is the reason for it being chosen as the basis for this study. In addition, there are another 20 sections from different localities in the island. The maximum thickness of the Turonian – Coniacian succession in Sakhalin is 1300m.

As mentioned above, North-East Russia is tectonically complex. The Turonian – Coniacian succession was studied there in the Koryak-Anadyr' region (Text-fig. 1). It comprises the famous Turonian – Coniacian succession on the Penzhina Gulf and in the Mamet river valley (PERGAMENT 1971), in north-western Kamchatka (Text-fig. 4); and the Penzhina river section, in the Pontoney and Slovutnye mountains on the spurs of the Penzhina range. In the north-eastern part of the region, successions are available in the Anadyr' river basin, along the coast of the Ugol'naya Bay and in the north-eastern part of the Koryakia Mountains.

The Turonian – Coniacian successions in North-East Russia are represented by similar alternators of mudstone and sandy mudstone as in Sakhalin, with intercalations of sandstones, tuffaceous sandstones and tuffaceous mudstones, bentonites (volcanic clay) and marly concretions. The latter commonly form concretion layers. The maximum thickness of the Turonian – Coniacian succession in North-East Russia is 1000m.

For a long time, previous workers recognized many different formations here. The authors of the present paper follow the classificaton of VERESHCHAGIN (1979), whereby the Turonian – Coniacian deposits of the Penzhina Gulf palaeobasin belong to the Penzhina Formation (=Pel'-Al' Formation in PERGAMENT 1971), and the deposits of Omgon Cape – to the Mainachsk Formation. The Albian – Turonian succession of Ugol'naya Bay is the Ginterovsk Formation and the Coniacian – Early Campanian succession was named the Barykovsk Formation.

INOCERAMID ZONATION

The authors worked out two independent local schemes using inoceramids (Text-figs 4, 6). There are now five zones in Sakhalin, comrising three zones in the Turonian and two in the Coniacian.

The same inoceramid zones are used in North-East Russia, except for *Inoceramus teshioensis – Mytiloides incertus* Zone; which is replaced here by the the *Inoceramus multiformis* Zone. The latter zonal taxon is probably the vicarious species of *I. teshioensis*. Moreover, the *Inoceramus mihoensis* Zone from the Coniacian of Sakhalin is not recognised here, because there are no records so far of the zonal index.

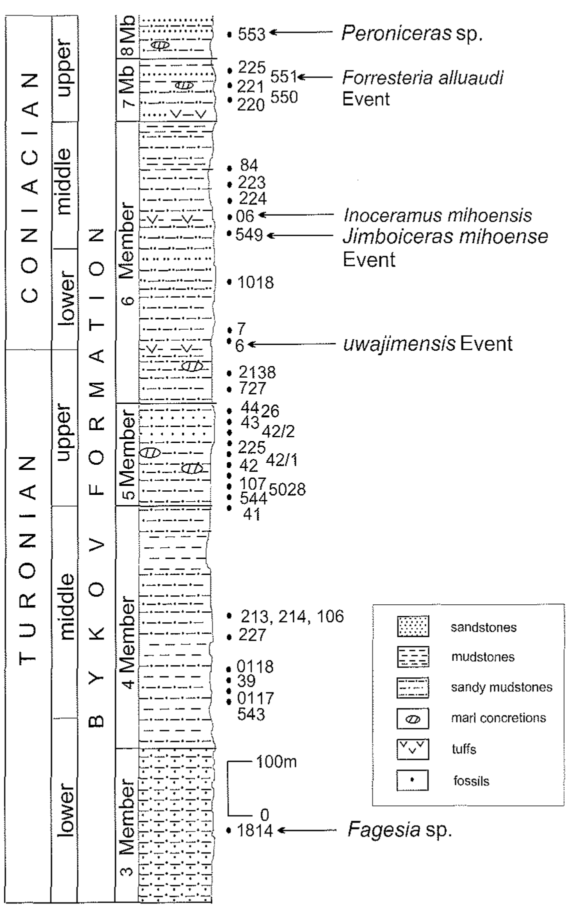

Fig. 3. General lithologic and stratigraphic succession of the Turonian – Coniacian stages in Sakhalin (Naiba reference section)

Mytiloides aff. labiatus Interval Zone

This zone was first distinguished within the Naiba section of Sakhalin by MATSUMOTO (1959). In the studied areas, the zone is characterized by *Mytiloides* aff. *labiatus* (SCHLOTHEIM), *Inoceramus concentricus costatus* NAGAO & MATSUMOTO and *I. umboceramus* ZONOVA. The zonal interval is from the first appearance datum (FAD) of the nominative species to the FAD of *Inoceramus hobetsensis* NAGAO & MATSUMOTO. In Sakhalin and Japan, *Mytiloides* aff. *labiatus* has been found in association with *Fagesia* sp. (MATSUMOTO 1973, MATSUMOTO & MURAMOTO 1978, POYARKOVA 1987). The zone corresponds to the zone of *Inoceramus* nov. sp. aff. *Inoceramus saxonicus* in Japan (TOSHIMITSU & *al.* 1995).

The Pacific *Mytiloides* aff. *labiatus* Zone probably corresponds approximately to the range of *Mytiloides labiatus* (SCHLOTHEIM), *M. mytiloides* (MANTELL), *M. kosmatti* (HEINZ) and *M. hattini* (ELDER) in the European and Mediterranean realms (KAUFFMAN 1978 a,b; KAUFFMAN & *al.* 1978, WALASZCZYK 1992, MARCINOWSKI & *al.* 1996, HARRIES & *al.* 1996).

Inoceramus hobetsensis Interval Range Zone

This zone was first distinguished within the Naiba section of Sakhalin by MATSUMOTO (1959a). Besides *Inoceramus hobetsensis*, the characteristic inoceramid species occurring within the zone are *I. iburiensis* NAGAO & MATSUMOTO, *I.* aff. *I. lamarcki* PARKINSON, *I. capitatus* ZONOVA, *I. obiraensis* NODA & MATSUMOTO, *I. cuvierii* SOWERBY, *I. cuvieriformis* PERGAMENT.

The lower boundary of the zone marks the FAD of the index taxon. The upper boundary is taken at the FAD of *Inoceramus teshioensis* NAGAO & MATSUMOTO.

The nominative species occurs in Japan (MATSUMOTO 1959, 1977; MATSUMOTO & TAKAYANAGI 1982; TOSHIMITSU & *al.* 1995) and North America (MATSUMOTO 1959). *Inoceramus hobetsensis* co-occurs with the cosmopolitan ammonite species *Romaniceras (Yubariceras) ornatissimum* (STOLICZKA) and the Pacific endemic taxon *Scaphites planus* (YABE) in Sakhalin (POYARKOVA 1987, ZONOVA & *al.* 1993). The latter is a typical Turonian zonal index of Sakhalin and North-East Russia, and it is also widespread in Japan (YABE 1910, TANABE 1977). This zone largely corresponds to the Japanese *Inoceramus costatus* and *Inoceramus hobetsensis – Mytiloides teraokai* zones (TOSHIMITSU & *al.* 1995).

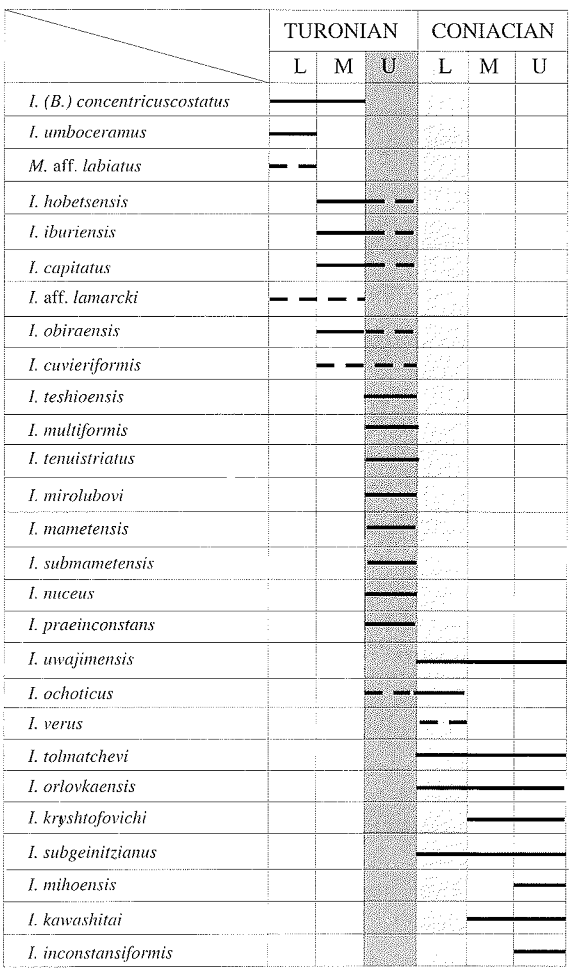

Fig. 4. Stratigraphic distribution of the Turonian – Coniacian inoceramids in the Russian Pacific coast succession

Inoceramus teshioensis – Mytiloides incertus Interval Range Zone

The *Inoceramus teshioensis* Zone was first distinguished in Japan by MATSUMOTO (1959). Later ZONOVA (*in* POYARKOVA 1987) proposed it for Sakhalin. The authors of the present paper accept this zone, with two zonal index species, but with revised limits. The zone is now taken as the interval from the FAD of either of the two zonal indexes to the FAD of *Inoceramus uwajimensis* YEHARA.

In the studied areas the zone is characterized by *Inoceramus teshioensis*, *I. mirolubovi* ZONOVA, *I. tenuistriatus* NAGAO & MATSUMOTO, and *I.* aff. *multiformis* PERGAMENT.

In Sakhalin, both zonal species have been found associated with the cosmopolitan ammonite taxon *Subprionocyclus* sp. Moreover, in Japan *I. teshioensis* co-occurs with *Subprionocyclus bravaisianus* (D'ORBIGNY), *S. normalis* (ANDERSON) and *Reesidites minimus* (HAYASAKA & FUKUDA) (MATSUMOTO 1977). The present zone correlates with the *Inoceramus multiformis* Zone of North-East Russia and the *I. teshioensis* Zone in Japan (TOSHIMITSU & *al.* 1995).

Inoceramus multiformis Interval Zone

PERGAMENT (1971) first established this zone in North-East Russia, on the coast of the Penzhina Gulf. The present authors revise the limits of the zone herein. The lower boundary is marked by the FAD of the index taxon. The upper boundary is taken at the FAD of *Inoceramus uwajimensis*. Besides numerous specimens of *Inoceramus multiformis* PERGAMENT, the characteristic inoceramid species occurring within the zone are *I. nuceus* ZONOVA, *I. mametensis* PERGAMENT, *I. submametensis* ZONOVA, *I. praeinconstans* PERGAMENT, *I. mirolubovi, I. tenuistriatus, I. ochoticus (*PERGAMENT*),* and scarce remains of *Inoceramus teshioensis*.

PERGAMENT (1971) inferred that the deposits of this zone represent the Lower Coniacian. However, *Inoceramus multiformis* co-occurs with Turonian ammonites, such as *Jimboiceras planulatiforme* (JIMBO), *Nipponites mirabilis* MATSUMOTO and *Scaphites planus* (YABE). The age of this zone is therefore Late Turonian.

Inoceramus uwajimensis Interval Zone

This zone was first described from Japan and Sakhalin by MATSUMOTO (1959). It ranges from the FAD of *Inoceramus uwajimensis* to the FAD of *Inoceramus amakusensis* NAGAO & MATSUMOTO, the Santonian index in the North Pacific province. In the studied areas, the zone is characterized by *Inoceramus uwajimensis* (including subspecies *chirovoensis* ZONOVA), *I. ochoticus*, *I. verus* (PERGAMENT), *I. tolmatchevi* ZONOVA, *I. subgeinitzianus* ZONOVA, *I. mihoensis* MATSUMOTO, *I. kawashitai* NODA, *I. inconstansiformis* (ZONOVA), *I. orlovkaensis* ZONOVA, and *I. kryshtofovichi* ZONOVA.

This zone is divided into two parts. In the lower part small forms of *I. uwajimensis* predominate and are common, while in the upper part it is the large forms that predominate. The lower part additionally contains numerous Coniacian scaphitids. Its base is inferred to equate with the base of the *Inoceramus* (*Cremnoceramus*) *rotundatus* Zone in Japan (TOSHIMITSU & *al.* 1995) and probably corresponds also to the same zone in Europe (KAUFMANN & *al.* 1996). The small forms of *I. uwajimensis* are more widespread in the Penzhina succession, but the level with larger shells is better developed in Sakhalin.

The present zone corresponds to the zone of the same name in Japan, Alaska and California (MATSUMOTO 1959).

Inoceramus mihoensis Interval Zone

This comprises the interval from the FAD of the index species to the FAD of *Inoceramus amakusensis* NAGAO & MATSUMOTO. This zone was first distinguished within the Naiba section of Sakhalin by MATSUMOTO (1959).

Inoceramus mihoensis MATSUMOTO is found in association with *Peroniceras* sp. and, at the extreme base, with *Forresteria alluaudi* MATSUMOTO, supporting the inferred Coniacian age of this interval.

AMMONOID ZONATION

The present study has additionally led to the establishment of an ammonite zonal scheme for the Turonian – Coniacian succession of the Russian Pacific Coast (Text-figs 5-6).

Scaphites planus Interval Zone

VERESHCHAGIN (1977) distinguished the *Scaphites planus* beds within the Naiba section of Sakhalin. The present zone is proposed for North-East Russia only. The zone ranges from the FAD of the index taxon to the FAD of *Jimboiceras planulatiforme* (JIMBO).

Besides *Scaphites planus* (YABE), the characteristic ammonite species are *Sc. perrini* (ANDERSON), *Sc. gracilis* YABE, *Sc. pseudoaequalis* YABE, *Sc.* (*Otoscaphites*) *yonecurai* (JIMBO), *Mesopuzosia pacifica* MATSUMOTO, *Gaudryceras tenuiliratum* YABE, *Scalarites scalaris* JIMBO and *Diplomoceras* sp. (MATSUMOTO 1954, POYARKOVA 1987).

The nominative species is a dominant form in Japan in the Upper and Middle Turonian successions (YABE 1910, TANABE 1977).

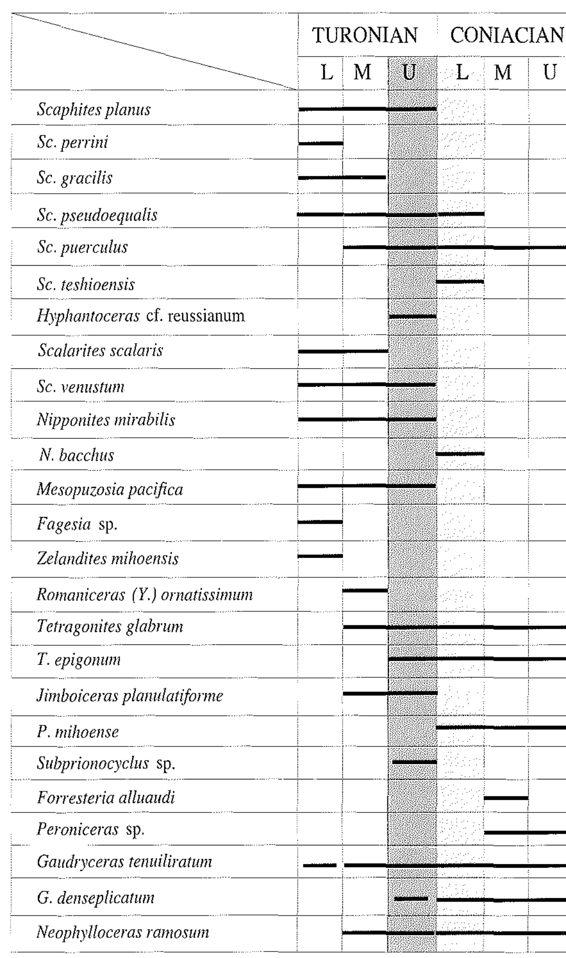

Fig. 5. Stratigraphic distribution of the Turonian – Coniacian ammonites in the Russian Pacific coast succession

Stage	Substage	North-EastRussia: Ammonoid zones andsubzones	North-EastRussia: Inoceramid zones	Sakhalin: Ammonoid zones andsubzones	Sakhalin: Inoceramid zones	Japan: Ammonoid zones	Japan: Inoceramid zones
CONIACIAN	upper			*Peroniceras* sp.	*Inoceramus mihoensis*	*Paratexanites orientalis*	*Inoceramus mihoensis*- *I. (Cordiceramus) kawashitai*
CONIACIAN	middle	*Forresteria alluadi*	*Inoceramus uwajimensis*	*Forresteria alluadi*	*Inoceramus uwajimensis*	*Forresteria alluadi*	*Inoceramus uwajimensis*
CONIACIAN	lower	*Scaphites* ssp.		*Pachydesmoceras mihoense*		*Forresteria (Harleites) pertrocoriensis*	*Inoceramus (Cremnoceramus) rotundatus*
TURONIAN	upper	*Jimboiceras planulatiforme*	*Inocerasmus multiformis*	*Subpriono-cyclus* sp.	*I. teshioensis*	*Subprionocyclus neptuni*	*I. tenuistriatus* *I. teshioensis*
TURONIAN	middle		*Inoceramus hobetsensis*	*Jimboiceras planulatiforme* *Romaniceras (Y.) ornatissimum*	*Inoceramus hobetsensis*	*Romaniceras deverianum* *Collognoniceras woollgari*	*I. hobetsensis*- *M. teraokai* *I.costatus*
TURONIAN	lower	*Scaphites planus*	*Mytiloides* aff. *labiatus*	*Fagesia* sp.	*Mytiloides* aff. *labiatus*	*F. thevestensis*- *M.* aff. *nodosoides* *Pseudaspidoceras flexuosum*	*M. subhercynicus* *M. mytiloides* *M* aff. *columbianus* *M. sackensis* *I.* aff. *saxonicus*

Fig. 6. Turonian – Coniacian inoceramid and ammonoid zonation applied to Russian Pacific coast succession by the authors and a comparison with the same of Japan (*after* TOSHIMITSU & *al.* 1995)

The Fagesia sp. Zone

VERESHCHAGIN (1977) distinguished "the Beds with *Fagesia sp*." within the Lozovaya section in Sakhalin. The boundaries of the present subzone approximately correspond to those of the *Mytiloides* aff. *labiatus* Zone. In the studied area, the deposits of this subzone are characterized by *Fagesia* sp., *Scaphites planus* YABE, *Zelandites mihoensis* MATSUMOTO (MATSUMOTO 1977) and *Gaudryceras tenuiliratum*. In Japan the upper part of the same interval is separated off as the *Fagesia thevestensis – Mammites* aff. *nodosoides* Zone (TOSHIMITSU & *al.* 1995). Representatives of the genus *Fagesia* are widespread in the Turonian of the Mediterranean Realm (KHAKIMOV 1970, COLLIGNON 1962, SEIBERTZ 1979).

Romaniceras (Yubariceras) ornatissimum Taxon Range Subzone

"The Beds with *Romaniceras* (*Yubariceras*) *ornatissimum*" were proposed for Sakhalin by YAZYKOVA (*in* ATABEKIAN & *al.* 1991). The boundaries of the present subzone are placed at the FAD and LAD of the nominative species.

In the studied area this subzone is characterized by *Romaniceras (Yubariceras) ornatissimum, Gaudryceras tenuiliratum,* the small-sized forms of *Tetragonites glabrum* (JIMBO), *Nipponites mirabilis* YABE, *Scaphites planus, Sc. puerculus* (JIMBO), *Sc. pseudoaequalis, Sc. gracilis, Scalarites scalaris.*

This subzone could correspond to the *Romaniceras (Yubariceras) ornatissimum* Zone of the European Realm (MORTIMORE 1986, WOOD & *al.* 1987, GALE 1996).

Jimboiceras planulatiforme Interval Zone

This zone was first established in Japan (MATSUMOTO 1959), but VERESHCHAGIN (1977) subsequently recognised it in Sakhalin. The lower boundary of the zone is marked by the FAD of the index taxon. The upper boundary is drawn at the FAD of *Pachydesmoceras mihoense* MATSUMOTO.

The ammonite fauna recorded within the zone is diverse, comprising *Jimboiceras planulatiforme* (JIMBO), *Scaphites planus*, *Sc. puerculus*, *Sc. pseudoaequalis, Sc. gracilis, Mesopuzosia pacifica*, *Gaudryceras tenuiliratum*, *Scalarites scalaris*, *Nipponites mirabilis,* and the small forms of *Tetragonites glabrum*.

The index taxon is also widespread in Japan (MATSUMOTO 1954, 1959, 1977).

Subprionocyclus sp. Subzone

"The Beds with *Subprionocyclus* sp." were first proposed for Sakhalin by YAZYKOVA (*in* ZONOVA & *al.* 1993). The boundaries of the present subzone are placed at the FAD and LAD of *Subprionocyclus* sp. The latter was found in association with *Tragodesmoceras subcostatus* MATSUMOTO, *Jimboiceras planulatiforme*, *Mesopuzosia pacifica*, *Gaudryceras tenuiliratum* and *Tetragonites glabrum*. This subzone probably corresponds to the *Subprionocyclus neptuni* Zone of Japan (TOSHIMITSU & *al.* 1995) and Europe (HANCOCK 1991).

Pachydesmoceras mihoense Interval Zone

"The Beds with *Pachydesmoceras mihoense*" were first distinguished by ZAKHAROV (ZAKHAROV & *al.* 1996). The present authors propose to regard them as an independent zone, with the Naiba succession of Sakhalin suggested as the stratotype section. The lower boundary is placed at FAD of the index taxon and the upper boundary at the FAD of *Texanites* (*Plesiotexanites*) *kawasakii* (KAVADA) of the Santonian.

Besides *Pachydesmoceras mihoense*, the characteristic ammonite species occurring in the zone are *Forresteria alluaudi* MATSUMOTO, *Peroniceras* sp., *Gaudryceras denseplicatum* JIMBO, *G. tenuiliratum*, *Neophylloceras ramosum* (MEEK), *Tetragonites glabrum*, *Damesites damesi* JIMBO and *Sc. puerculus* (JIMBO).

The zonal index occurs commonly in Japan (TOSHIMITSU & *al.* 1995).

Scaphites spp. Zone

The zone, first distinguished in North-East Russia by VERESHCHAGIN (*in* RESHENIYA 1982), is characterised by an abundant and diverse Coniacian scaphitid assemblage, comprising *Scaphites obscurus* ALABUSHEV, *Sc. puerculus* JIMBO, *Sc.* (*O.*) *teshioensis* (YABE), *Sc.* *(O.)* *stephanoides* YABE and *Sc.* *(O.)* *klamathensis* ANDERSON (ALABUSHEV 1989). There are numerous additional records of the large-sized forms of *Tetragonites glabrum*.

The inferred Coniacian age of this zone is supported by the occurrence of *Forresteria alluaudi*.

Forresteria alluaudi Subzone

"The Beds with *Forresteria alluaudi*" were distinguished by POKHIALANEN (1988) within the Koryk – Anadyr' region of North-East Russia. The limits of the present subzone are placed approximately at the FAD and LAD of the index taxon respectively. The *Forresteria (F.) alluaudi* Zone is recognised in the Middle Coniacian of Japan (TOSHIMITSU & *al.* 1995). Species of the genus *Forresteria* are indicators of the Coniacian in many regions of the world (KAUFFMAN & *al.* 1996).

Peroniceras sp. Subzone

"The Beds with *Peroniceras* sp." were established within the Naiba section of Sakhalin by VERESHCHAGIN (*in* RESHENIYA 1982). Species of the genus *Peroniceras* are widespread in Coniacian successions worldwide (KLINGER & WIEDMANN 1983).

TURONIAN/CONIACIAN BOUNDARY

The Turonian – Coniacian boundary is one of the most discussed levels of the Upper Cretaceous (Text-fig. 8). Recently the FAD of *Cremnoceramus rotundatus* (TRÖGER *non* FIEGE) was recommended as the basal boundary criterion for the Coniacian stage (KAUFFMAN & *al.* 1996). In Europe, this boundary lies between the LAD of the ammonite *Prionocyclus germari* and the FAD of the ammonite *Forresteria (Harleites) petrocoriensis*; in North America it lies between the LAD of *P. germari* and the FAD of the *Forresteria peruana* and *F. branconi* (KAUFFMAN & *al.* 1996).

Within the North Pacific Province, the position of this boundary is much more controversial because of the predominantly endemic fauna. We tried to define this boundary based on biostratigraphy and the event levels in ammonite and inoceramid evolution. The latter gives an additional framework for the establishment of biozones and the definition of the stratigraphical boundaries.

The main ammonite criterion for the Turonian – Coniacian stage boundary in Far East Russia is the FAD of *Pachydesmoceras mihoense* MATSUMOTO. This boundary lies between the LAD of *Subprionocyclus* sp., and the FAD of representatives of the cosmopolitan Coniacian genera *Forresteria* and *Peroniceras*.

The T/C boundary also marks a significant change in the taxonomic composition of the ammonite assemblages, involving the appearance of new morphotypes. For example, the thick-shelled *Pachydesmoceras mihoense*, with high strong ribs, replaces the thin-shelled Late Turonian *J. planulatiforme*, with numerous faint ribs and constrictions. The appearance of coarser elements during the Coniacian also characterized the representatives of the genus *Gaudryceras,* e.g. *G. denseplicatum* (JIMBO). In addition, the Coniacian is marked by the appearance of a new *Scaphites* assemblage. The Coniacian species of *Scaphites* differ from the Turonian species in their larger shells and more complex ornamentation. Some of them are very similar to European and North American Coniacian taxa. For example, *Sc. obscurus* ALABUSHEV is very similar to *Sc. geinitzii* D'ORBIGNY and *Scaphites corvensis* COBBAN. *Sc. puerculus* (JIMBO) closely resembles *S. preventricosus* COBBAN. The Turonian – Coniacian successions of the North Pacific province are generally characterized by the dominance of the heteromorph ammonites. Many cosmopolitan genera were widespread here during this time, including: *Scaphites*, *Scalarites, Worthoceras, Bostrychoceras, Nipponites, Sciponoceras, Neancyloceras* and *Hyphantoceras*. However, by the beginning of the Santonian, the heteromorph ammonite diversity was very low, and the non-heteromorph elements had become the dominant elements in the ammonite assemblages.

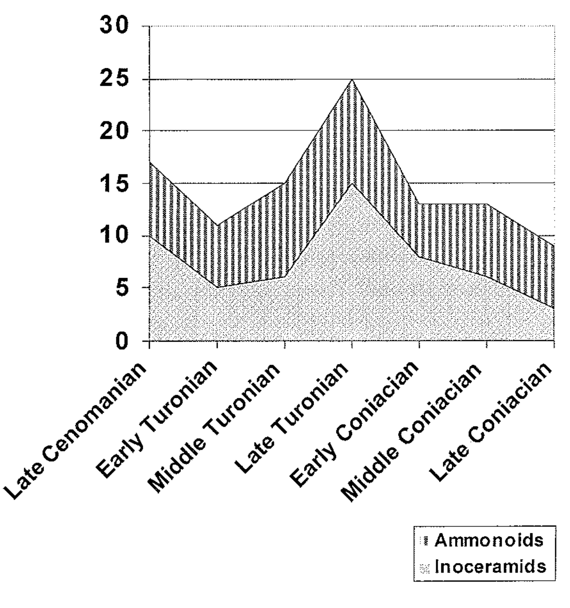

Fig. 7. Chart of the change in inoceramid and ammonoid taxonomic diversity as recorded in the Upper Cenomanian through Upper Coniacian succession of the Pacific coast succession of Russia

The T/C boundary is also marked by distinct changes in the taxonomic diversity of the inoceramid assemblages (Text-fig. 7).

At the base of the Coniacian in the studied areas there is a predominance of the small forms of *Inoceramus uwajimensis* YEHARA and other species of this group. The upper part of the Coniacian succession is characterized by the predominance of the large forms of inoceramids of the *I. uwajimensis* and *I. mihoensis* groups.

SUMMARY AND CONCLUSIONS

Turonian – Coniacian deposits are widespread within the Pacific palaeobiogeographic Realm, and they have yielded numerous faunal records. These records provided the framework for later detailed investigations with the aim of defining the T/C boundary and developing the present ammonite and inoceramid zonal schemes. As a result of finding some cosmopolitan taxa, we were able to correlate the studied sequences approximately with those in other regions of the world. In addition, the criteria for the recognition of the position of the T/C boundary in Far East Russia were identified. Study of the evolutionary development of the North Pacific ammonites and inoceramids has supported the proposed position of the boundary.

In summary, zonal subdivision of the Turonian – Coniacian successions in Far East Russia (Sakhalin) and North-East Russia has been established by means of ammonites and inoceramids. The main composite criteria for the definition of the T/C boundary in the Russian Pacific Coast are the following taxa: *Inoceramus uwajimensis* YEHARA and *Pachydesmoceras mihoense* MATSUMOTO. The T/C boundary is situated between the LAD of *Subprionocyclus* sp. and *Jimboiceras planulatiforme* (JIMBO) and the FAD of *Forresteria* (*F.*) *alluaudi* MATSUMOTO and *Peroniceras* sp. Our researches on ammonite and inoceramid palaeobiogeography have highlighted the predominance of endemic taxa within the two Turonian – Coniacian depositional areas of the Russian Pacific Coast (Far East Russia and North East Russia), and have also identified some differences in the taxonomic composition of the assemblages between these two areas. The latter differences caused the necessity of establishing two independent local zonal schemes. However, these local schemes can be readily correlated with one another, and they collectively correspond to the zonal scheme used in Japan (Text-fig. 6).

The evolution of the North Pacific ammonites and inoceramids during the Turonian – Santonian interval followed the same stages of post-crisis development as found in other periods of the Late Cretaceous. After the Cenomanian – Turonian boundary mass extinction, the survival interval lasted throughout the Early Turonian, with the subsequent recovery interval spanning the mid- to Late Turonian. The maximum diversity of both groups was in the Late Turonian (Text-fig. 7), which corresponded to a phase of active radiation. The T/C boundary bio-event was marked by the appearance of new ammonite morphotypes and by some reduction in their taxonomic diversity. This is the stage of nomismogenesis in ammonite evolution (WALLISER 1995). The inoceramid development was slightly diachronous in comparison with that of the ammonites. The Cretaceous inoceramids exhibit their maximum taxonomic diversity at the beginning of a regressive cycle. By this time, the ammonites have already lost their taxonomic diversity, because Cretaceous ammonite diversity maxima usually coincided with the period of peak transgression. Consequently the inoceramids passed from the radiation event to the stage of nomismogenesis in the middle of the Turonian a little later then the ammonites (Text-figs. 7).

The present researches permit intra- and interregional correlation of the Russian Pacific Coast successions of the North Pacific Province, and also long-range direct correlation between that region and the European and Mediterranean Realms.

Acknowledgements

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PLATES 1 – 14

PLATE 1

1 – *Inoceramus hobetsensis* NAGAO & MATSUMOTO, No. 34/12580; *I. hobetsensis* Zone, Middle Turonian, N-E Russia, Penzhina Gulf coast, loc. 55

2 – *Inoceramus* aff. *cuvieri* SOWERBY, No. 37/12580; *I. hobetsensis* Zone, Middle Turonian, N-E Russia, Penzhina Gulf coast, loc. 54

3 – *Inoceramus* cf. *capitatus* ZONOVA; *I. hobetsensis* Zone, Middle Turonian, N-E Russia, Penzhina Gulf coast, loc. 53

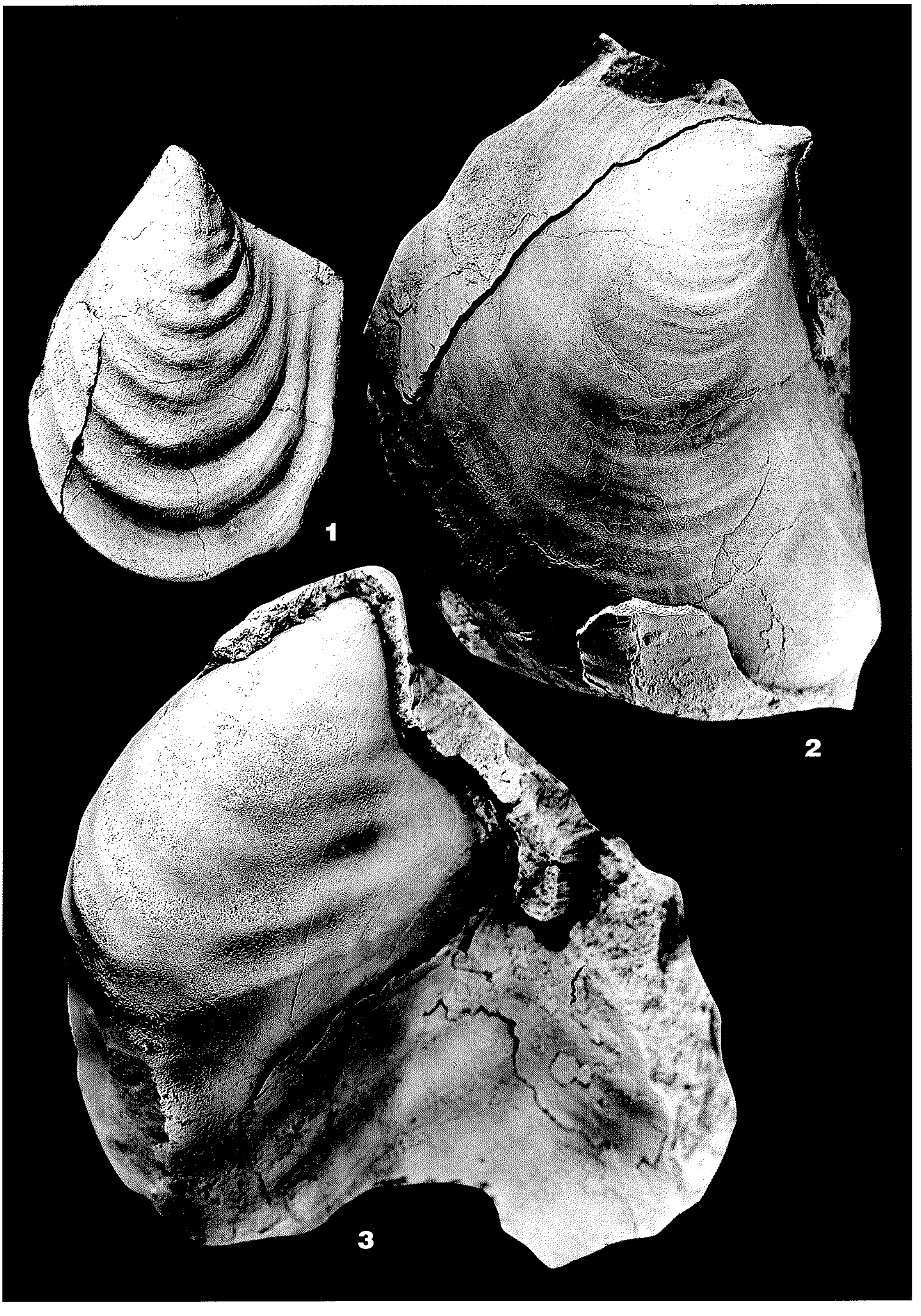
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PLATE 2

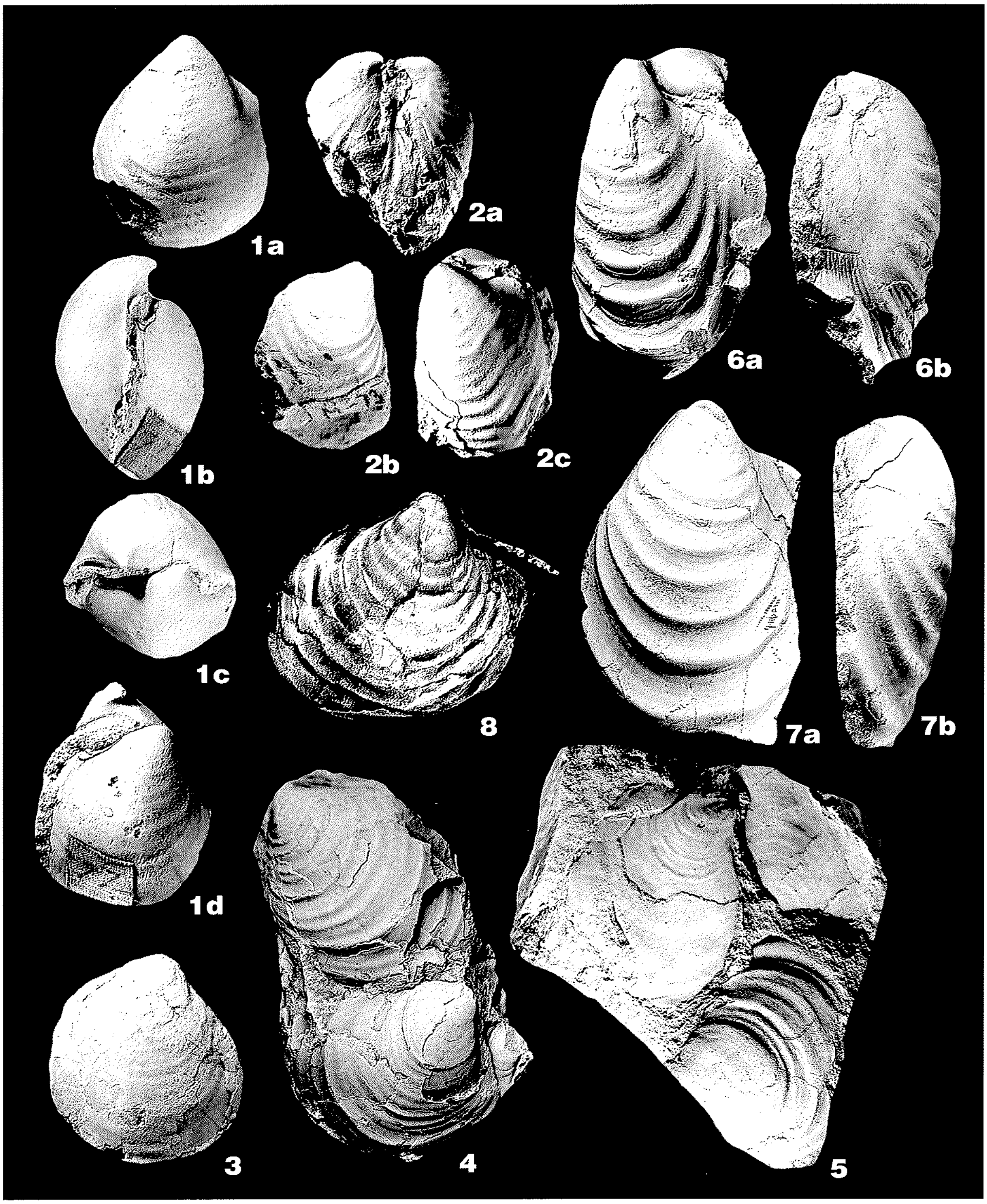
1 – *Inoceramus nuceus* ZONOVA, No. 49/12580; *I. multiformis* Zone, Upper Turonian, N-E Russia, Karmalivayam River, loc.77

2 – *Inoceramus multiformis* PERGAMENT, No. 45/12580; *I. multiformis* Zone, Upper Turonian, N-E Russia, Niklekuyul River, loc. 631

3-5 – *Inoceramus teshioensis* NAGAO & MATSUMOTO
3 – Specimen 47/12580; *I. multiformis* Zone, Upper Turonian; N-E Russia, Povorotnaya River, loc. 8
4 – Specimen 48/12580; *I. multiformis* Zone, Upper Turonian; N-E Russia, Penzhina Gulf coast, loc. 010
5 – Specimen 228/10693; *I. teshioensis – M. incertus* Zone, Upper Turonian; Sakhalin, Kuma River, Naiba River valley, loc. 26

6-7 – *Inoceramus verus* PERGAMENT; *I. uwajimensis* Zone, Lower Coniacian, N-E Russia, Asgichnivayam River, loc. 05/2
6 – Specimen 42/12580
7 – Specimen 43/12580

8 – *Inoceramus* aff. *multiformis* PERGAMENT, Specimen 46/12580; *I. teshioensis – M. incertus* Zone, Upper Turonian, Sakhalin, Kuma River, Naiba River valley, loc. 26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6a
6b
1b
2b
2c
1c
8
7a
7b
1d
3
4
5

PLATE 3

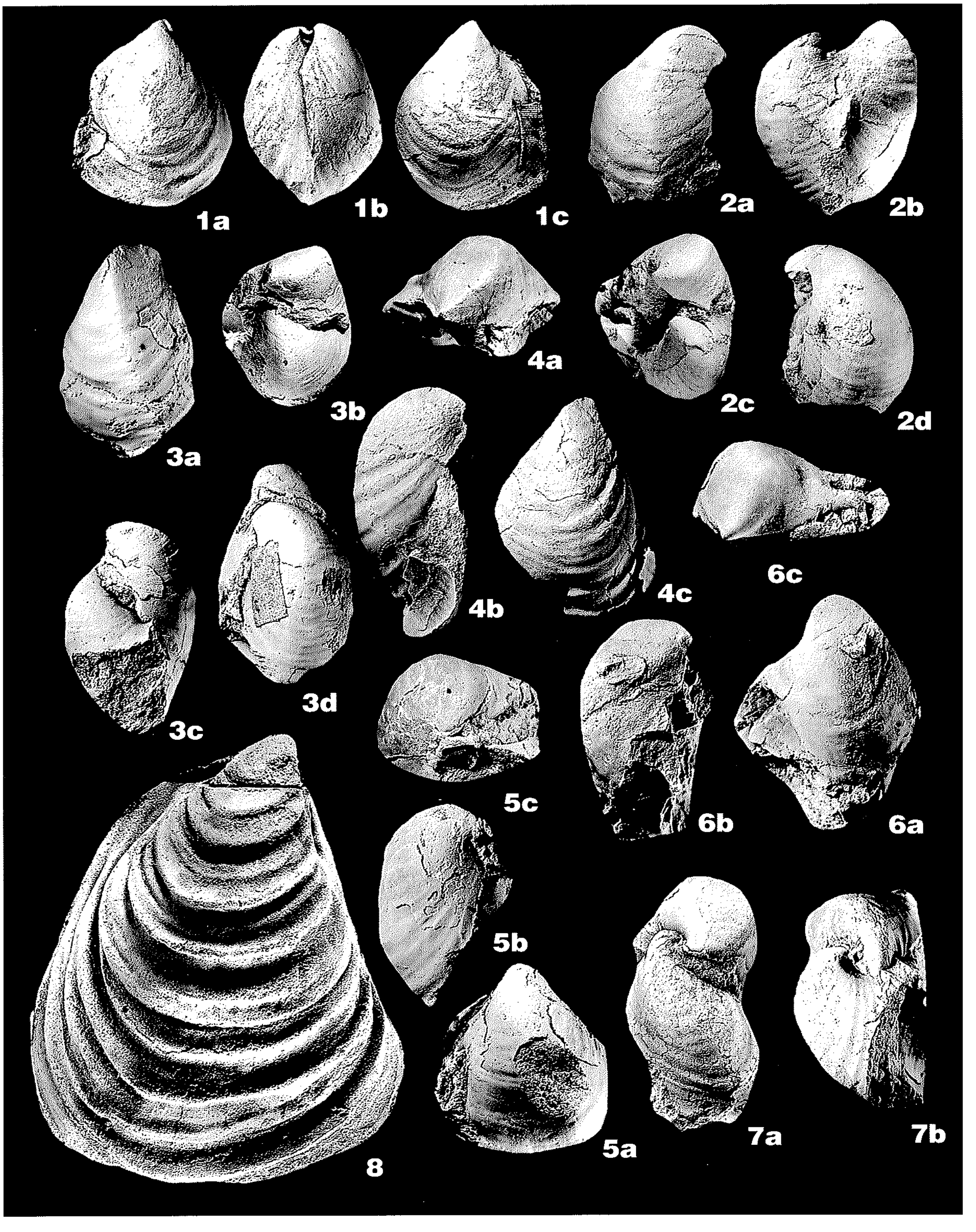
1 – *Inoceramus nuceus* ZONOVA, No. 51/12580; *I. multiformis* Zone, Upper Turonian, N-E Russia, Karmalivayam River, loc. 77

2-7 – *Inoceramus mirolubovi* ZONOVA, *I. multiformis* Zone, Upper Turonian

2-6 – Specimens 58-62/12580, N-E Russia, Karmalivayam River, loc. 77

7 – Specimen 62/12580, Penzhina Gulf coast, loc. 09

8 – *Inoceramus uwajimensis* YEHARA, No. 26/8335, *I. uwajimensis* Zone, Middle Coniacian, Sakhalin, Bolshaya Orlovka River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3b
4a
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2d
3c
3d
4b
4c
6c
5c
6b
6a
5b
5a
7a
7b
8

PLATE 4

1-2 – *Inoceramus kawashitai* NODA, 1 – No. 2/12575, 2 – No. 274/10693; *I. mihoensis* Zone, Upper Coniacian, Sakhalin, Krasnoyarka River, Naiba River valley, loc. 84

3 – *Inoceramus* aff. *apicalis* WOODS, No. 55/12580; *I. multiformis* Zone, Upper Turonian, N-E Russia, Penzhina Gulf coast, Truba spring, loc. 64a


1
2
3a
3b
3c

PLATE 5

1 – *Inoceramus uwajimensis chyrvoensis* ZONOVA, No. 8/12025; *I. uwajimensis* Zone, N-E Russia, Golodnyi streacy, Penzhina River Valley, loc. 108

2-4 – *Inoceramus mihoensis* MATSUMOTO; *I. mihoensis* Zone, Upper Coniacian, Sakhalin, Naiba River valley, loc. 551

2 – Specimen 1/12575
3 – Specimen 10/12575
4 – Specimen 6/12575


1a
1b
4b
2
3
4a

PLATE 6

1, 9 – *Inoceramus tolmatchevi* ZONOVA; *I. uwajimensis* Zone, Lower Coniacian, N-E Russia, Ugol'naya Bay, loc. 85/3

2, 8, 10 – *Inoceramus uwajimensis* YEHARA; *I. uwajimensis* Zone, Lower Coniacian
- 2 – loc. 540, N-E Russia, Koryak Upland
- 8 – No. 131/12765; *I. uwajimensis* Zone, Lower Coniacian, Sakhalin, Malaya Orlovka River, loc. 44
- 10 – No. 130/12765, *I uwajimensis* Zone, Lower Coniacian, Sakhalin, Khoe River

3-5 – *Inoceramus subgeinitzianus* ZONOVA
- 3 – No. 11/8335, *I. uwajimensis* Zone, Lower Coniacian, Sakhalin, Agnevo River, loc. 131d
- 4 – No. 9/8335; *I. uwajimensis* Zone, Lower Coniacian, Sakhalin, Agnevo River, loc. 131d
- 5 – No. 10/8335, *I. uwajimensis* Zone, Lower Coniacian, Sakhalin, Bolshaya Orlovka River, loc. 216

6 – *Inoceramus uwajimensis chirovoensis* ZONOVA, *I. uwajimensis* Zone, Lower Coniacian, N-E Russia, Penzhina River Valley, loc. 108

7 – *Inoceramus krishtofovichi* ZONOVA; *I. uwajimensis* Zone, Lower Coniacian, N-E Russia, Penzhina River Valley, loc. 108

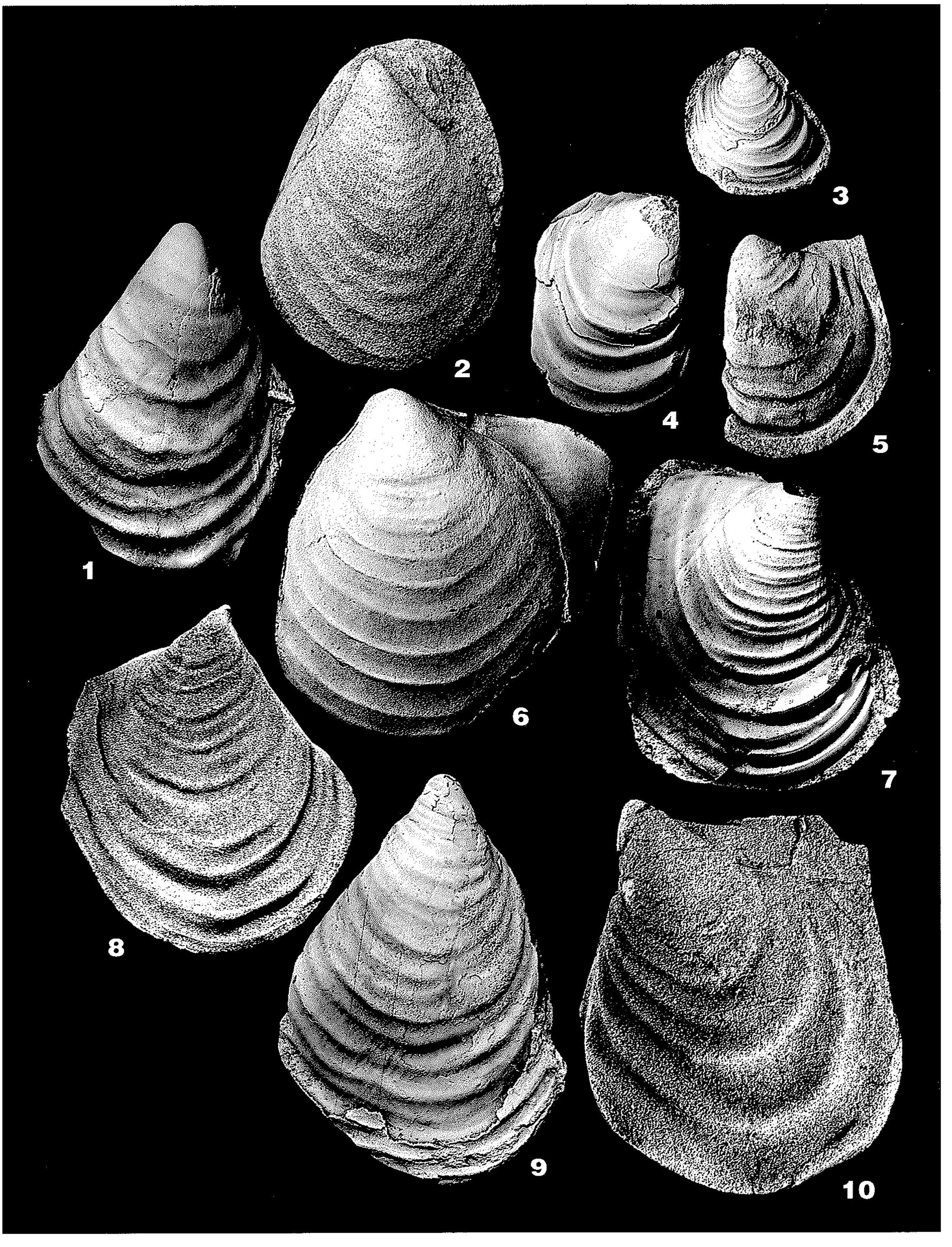
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PLATE 7

1-2 – *Romaniceras (Yubariceras) ornatissimum* (STOLICZKA)

1 – Specimen 12693, *Romaniceras (Yubariceras) ornatissimum* Subzone, Middle Turonian, Sakhalin, Naiba River, loc. 38

2 – Specimen 3/12632; *Romaniceras (Yubariceras) ornatissimum* Subzone, Middle Turonian, Sakhalin, Polyakovka River, Gastellovka River Valley, loc. 1091

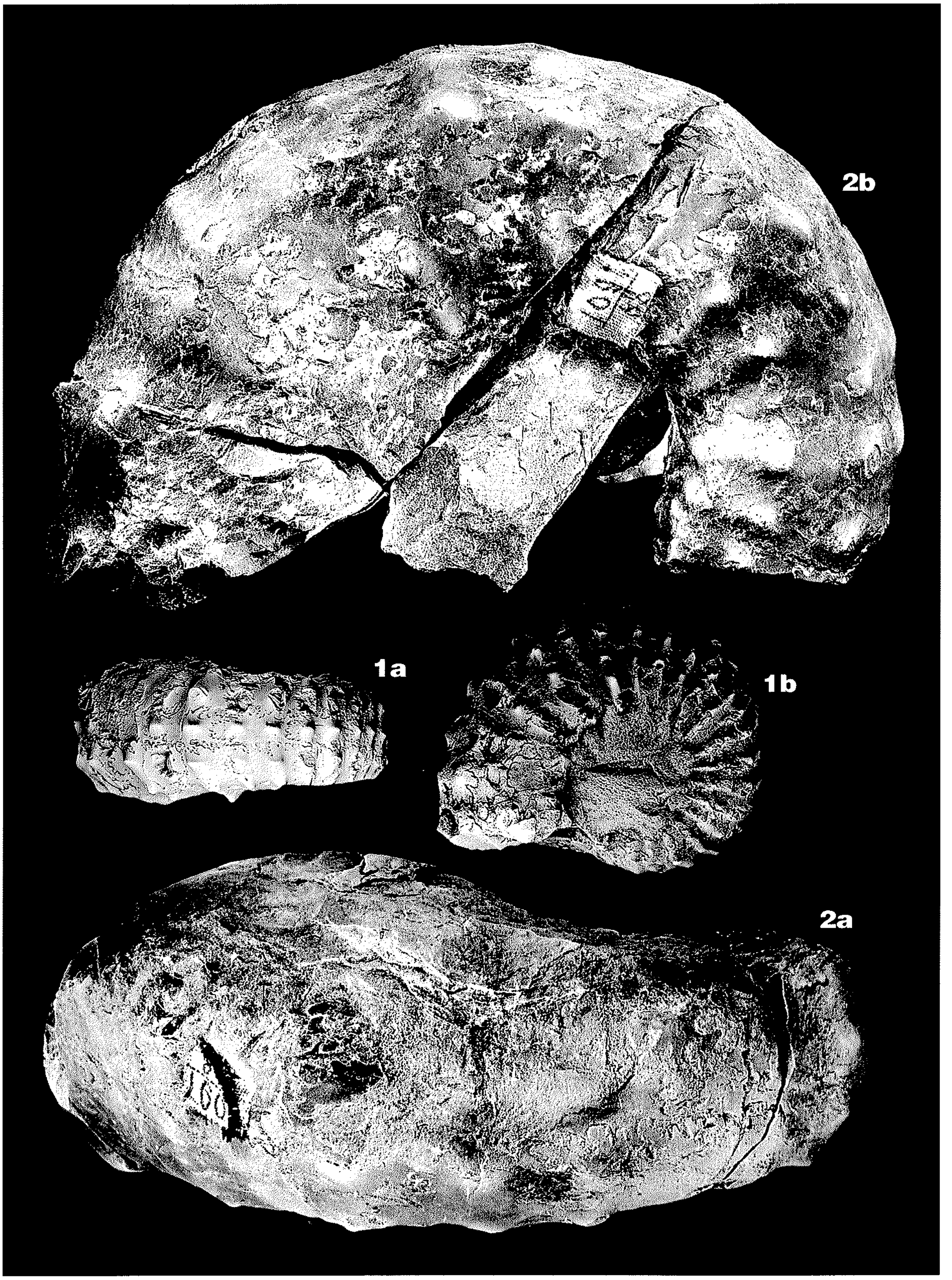
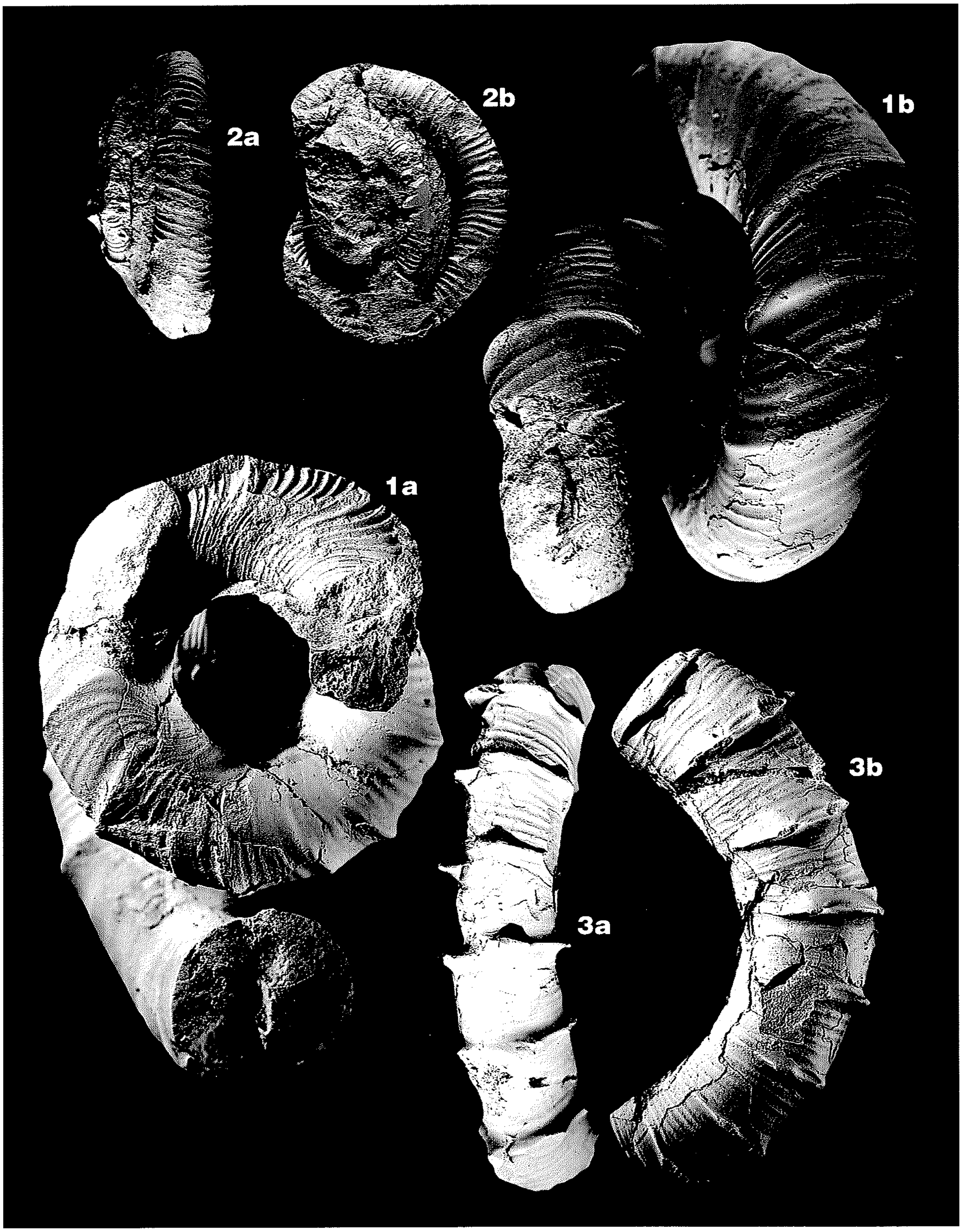

2b
1a
1b
2a

PLATE 8

1 – *Scalarites venustum* YABE, No. 38/11799; *Jimboiceras planulatiforme* Zone, Upper Turonian, N-E Russia, Penzhina Gulf Coast

2 – *Scalarites scalaris* JIMBO, No. 30/11799; *Jimboiceras planulatiforme* Zone, Upper Turonian, N-E Russia, Penzhina Gulf Coast

3 – *Hyphantoceras* cf. *reussianum* (SCHLÜTER), No. 29/11799; *Jimboiceras planulatiforme* Zone, Upper Turonian, N-E Russia, Penzhina Gulf Coast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1b
1a
3b
3a

PLATE 9

1,10 – *Scaphites* cf. *perrini* ANDERSON, 9 – No. 32/11799; *Scaphites planus* Zone, Lower Turonian, N-E Russia, Penzhina Gulf Coast, loc. 320

2-3, 7-8, 11 – *Scaphites pseudoaequalis* YABE; 7 – No. 50/11799; *Scaphites planus* Zone, Lower Turonian, N-E Russia, Penzhina Gulf Coast, loc. 320

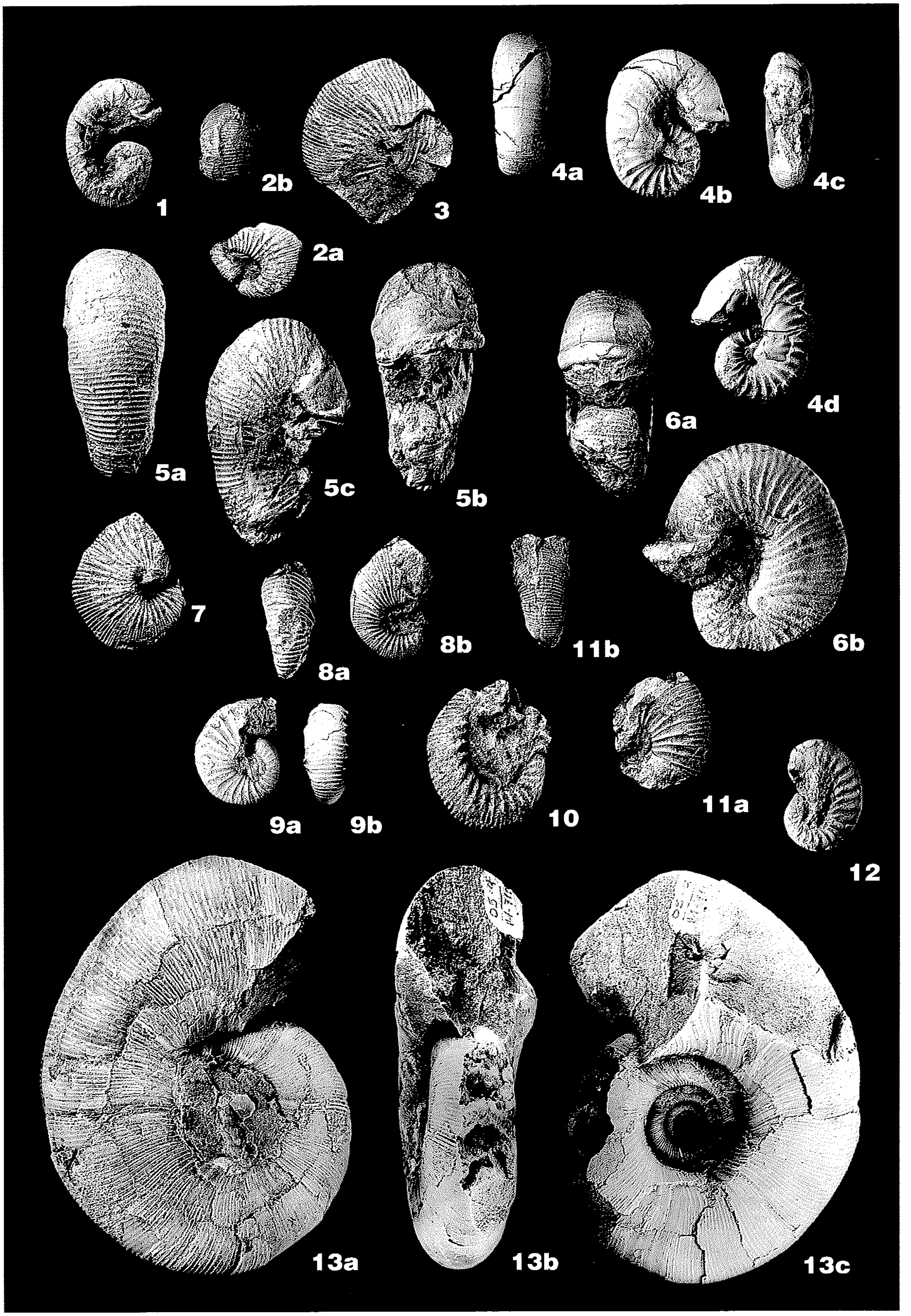
4 – *Scaphites* (*Scaphites*) *planus* YABE; *Scaphites planus* Zone, Lower Turonian, N-E Russia, Penzhina Gulf coast, loc. 320

5-6 – *Scaphites (Scaphites) gracilis* YABE, 5 – No. 31/11799; *Scaphites planus* Zone, Lower Turonian, N-E Russia, Penzhina Gulf Coast, loc. 320

9 – *Scaphites* (*Otoscaphites*) *teshioensis* (YABE); *Scaphites planus* Zone, Lower Turonian, N-E Russia, Penzhina Gulf coast, loc. 320

12 – *Scaphites* (*Yezorkes*) *puerculus* (JIMBO); *Scaphites planus* Zone, Lower Turonian, N-E Russia, Penzhina Gulf coast, loc. 320

13 – *Gaudryceras tenuiliratum* YABE; *Scaphites planus* Zone, Lower Turonian, N-E Russia, Penzhina Gulf coast, Asgichnivayam River, loc. 05-a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5b
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6b
7
8a
8b
9a
9b
10
11a
11b
12
13a
13b
13c

PLATE 10

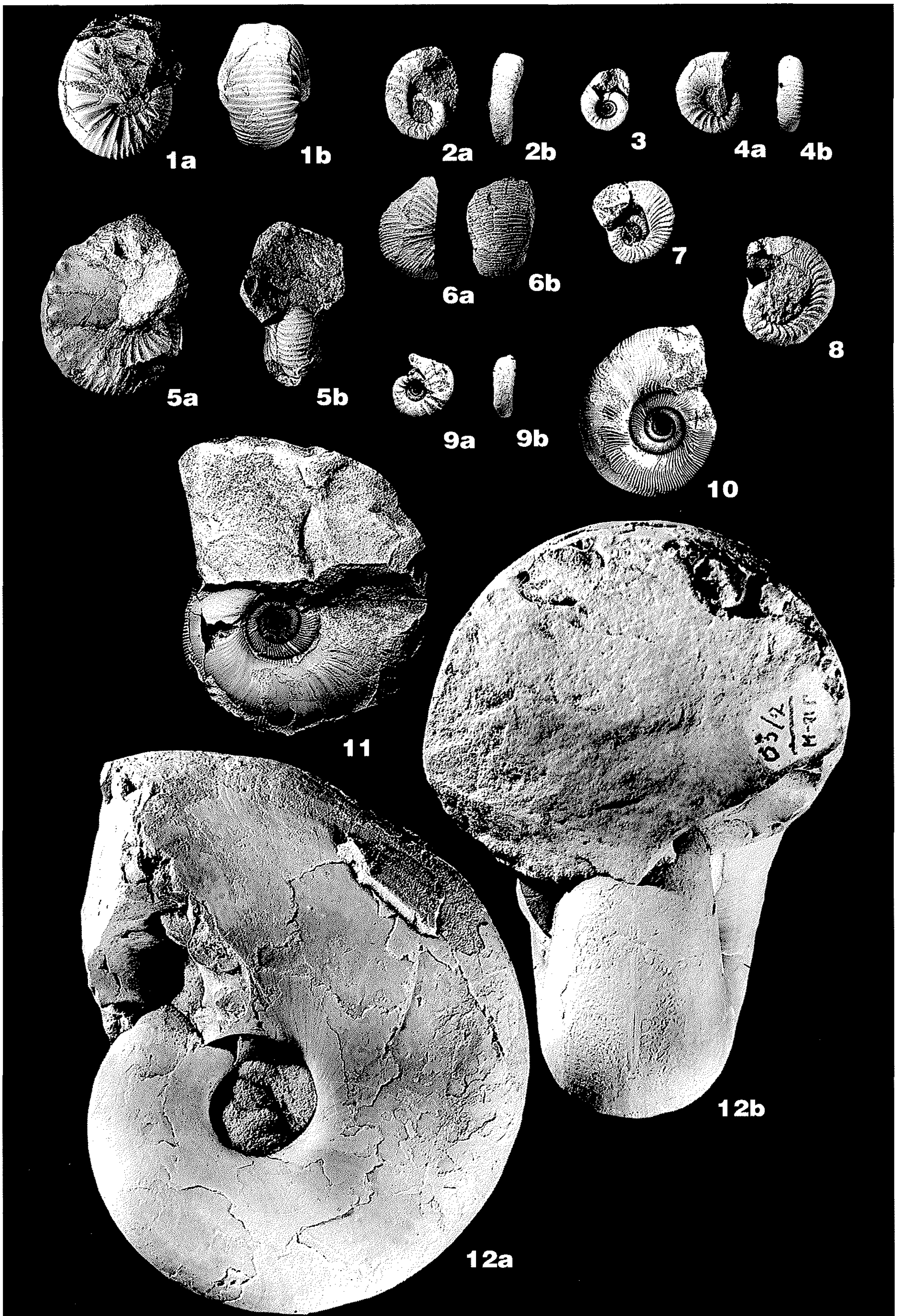
1-4, 9 – *Scaphites* (*Otoscaphites*) *teshioensis* (YABE); 4, 9 – *Jimboiceras planulatiforme* Zone, Upper Turonian, N-E Russia, Penzhina Gulf Coast, Asgichnivayam River, locs. 05, 320; 1, 3 – juvenile form – *Scaphites* spp. Zone, Lower Coniacian, N-E Russia, Omutnaya River, Penzhina River Valley, loc. 35

5, 6 – *Scaphites pseudoaqualis* YABE, *Scaphites planus* Zone, Lower Turonian, N-E Russia, Penzhina Gulf Coast, Asgichnivayam River, 11 – loc. 2088; 12 – loc. 320

2, 7, 8 – *Scaphites* (*Yezorkes*) *puerculus* (JIMBO)
2 – Lower Coniacian, *Scaphites* spp. Zone, Omutnaya River, Penzhina River Valley, loc. 35
7 – *Scaphites planus* Zone, Lower Turonian, N-E Russia, Penzhina Gulf Coast, loc. 65
8 – No. 49/11799; Lower Coniacian, *Scaphites* spp. Zone, Ugol'naya Bay, loc.14a .

10-11 – *Gaudryceras tenuiliratum* YABE
10 – Specimen 32/12769; *Jimboiceras mihoense* Zone, Coniacian, Sakhalin, Naiba River, loc. 551
11 – Specimen 9/12632; *Scaphites planus* Zone, Lower Turonian, N-E Russia, Omgon Cape

12 – *Tetragonites glabrum* (JIMBO); *Jimboiceras planulatiforme* Zone, Upper Turonian, N-E Russia, Penzhina Gulf Coast, Asgichnivayam River, loc. 03/2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6a
6b
7
5a
5b
8
9a
9b
10
11
12b
12a

PLATE 11

1 – *Jimboiceras planulatiforme* (JIMBO); *Jimboceras planulatiforme* Zone, Middle Turonian, N-E Russia, Penzhina Gulf Coast, Asgichnivayam River, loc. 148

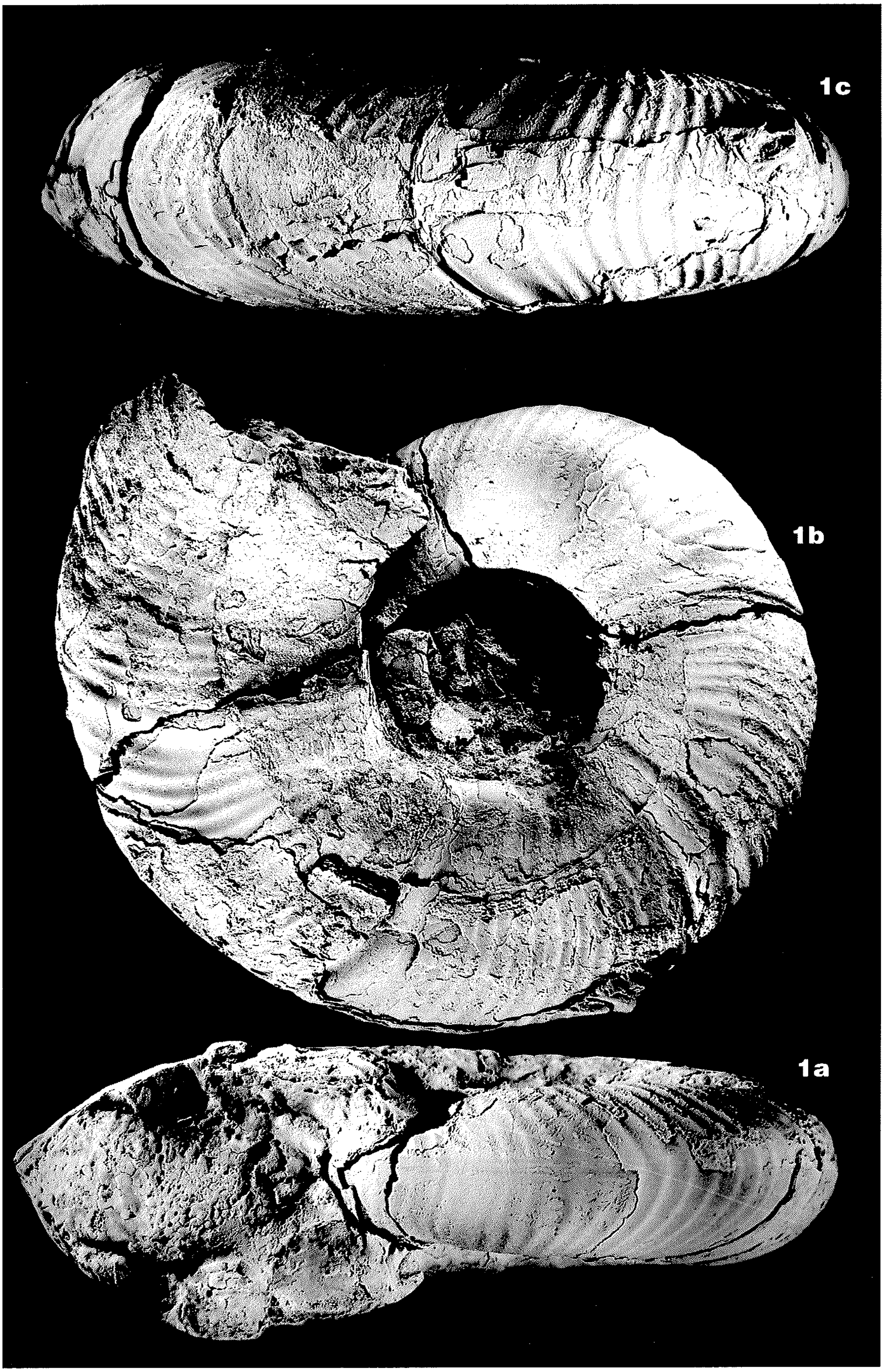
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PLATE 12

1-2 – *Jimboiceras mihoense* MATSUMOTO, 1 – No. 391/10693, 2 – No.31/12769; *Jimboiceras mihoense* Zone, Coniacian, Sakhalin, Naiba River, locs. 551, 550

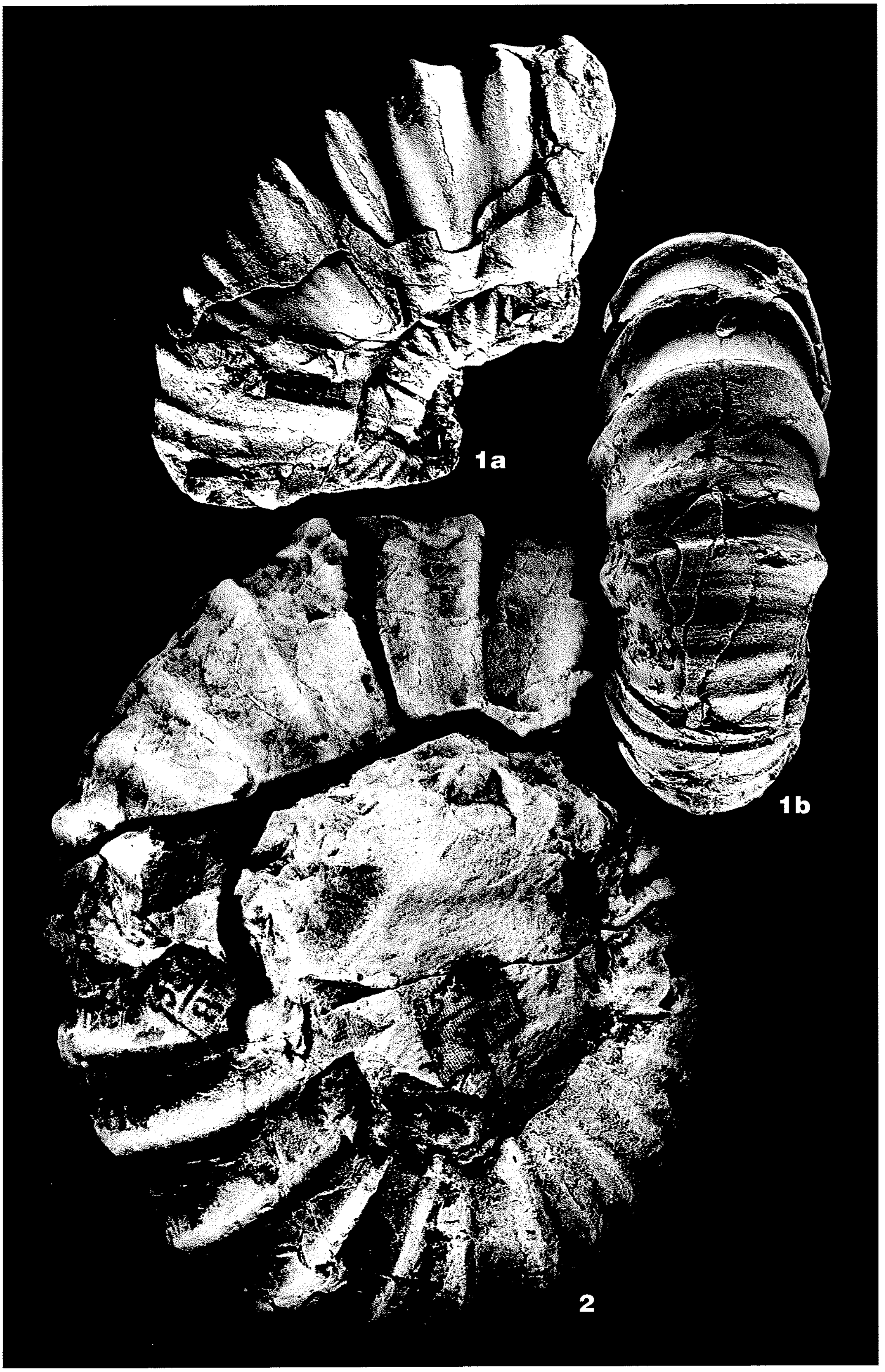
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PLATE 13

1 – *Gaudryceras denseplicatum* JIMBO, No. 5/12632; *Forresteria alluaudi* Subzone, Middle Coniacian, N-E Russia, Koryak Upland, Melkaya River, loc. 3050

2 – *Pachydesmoceras mihoense* MATSUMOTO; *Pachydesmoceras mihoense* Zone, Coniacian, Sakhalin, Naiba River, loc. 550

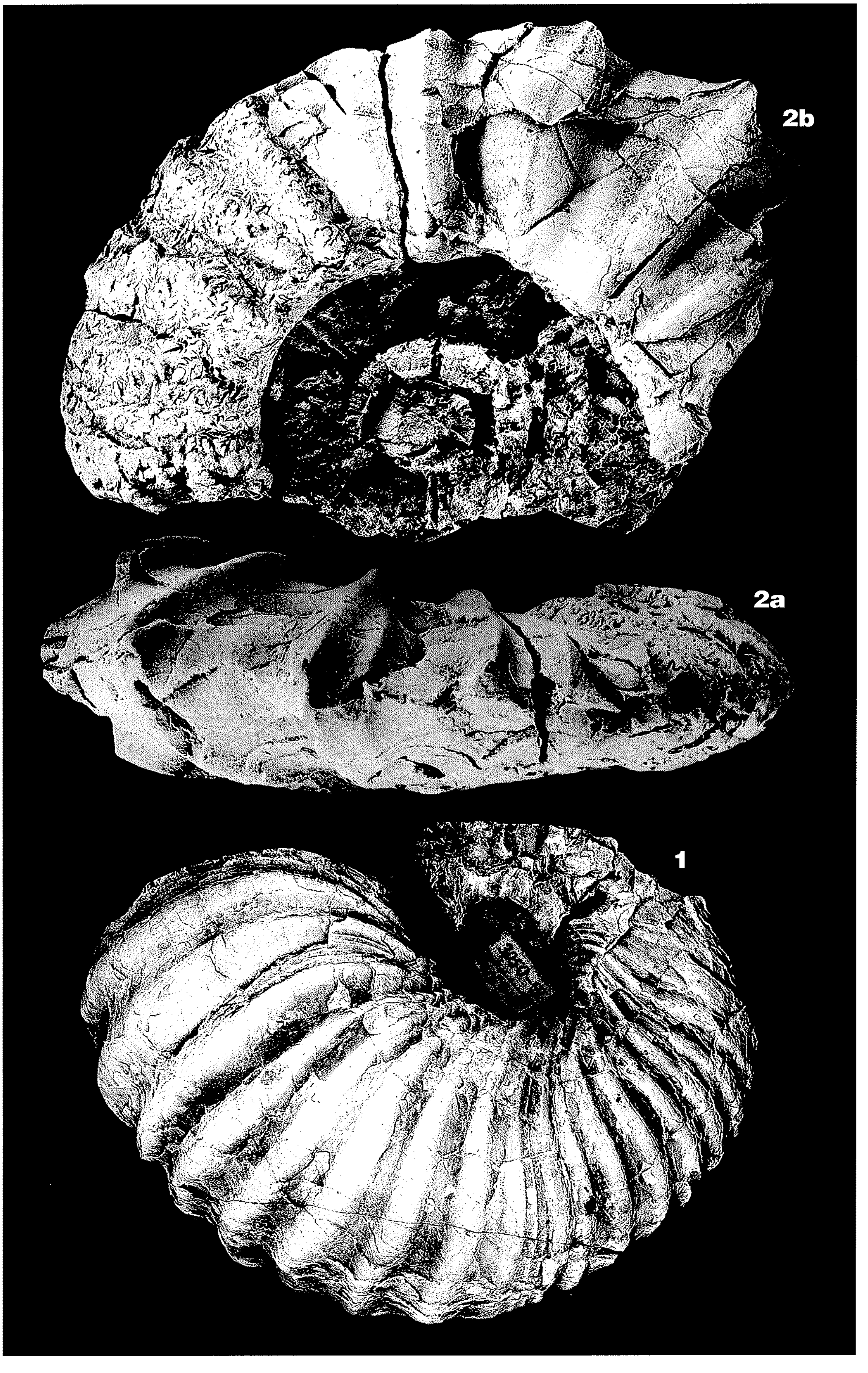
2b
2a
1

PLATE 14

1 – *Neancyloceras* aff. *pseudoarmatum* SCHLÜTER, No. 25/11799; *Jimboiceras planulatiforme* Zone, Upper Turonian, N-E Russia, Penzhina Gulf Coast, loc. 31

2 – *Gaudryceras denseplicatum* JIMBO; *Jimboiceras planulatiforme* Zone, Upper Turonian, N-E Russia, Penzhina Gulf Coast, Asgichnivayam River, loc. 145


1a
1b
2a
2b
2c