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RECENT DEVELOPMENTS ON TRIASSIC STRATIGRAPHY

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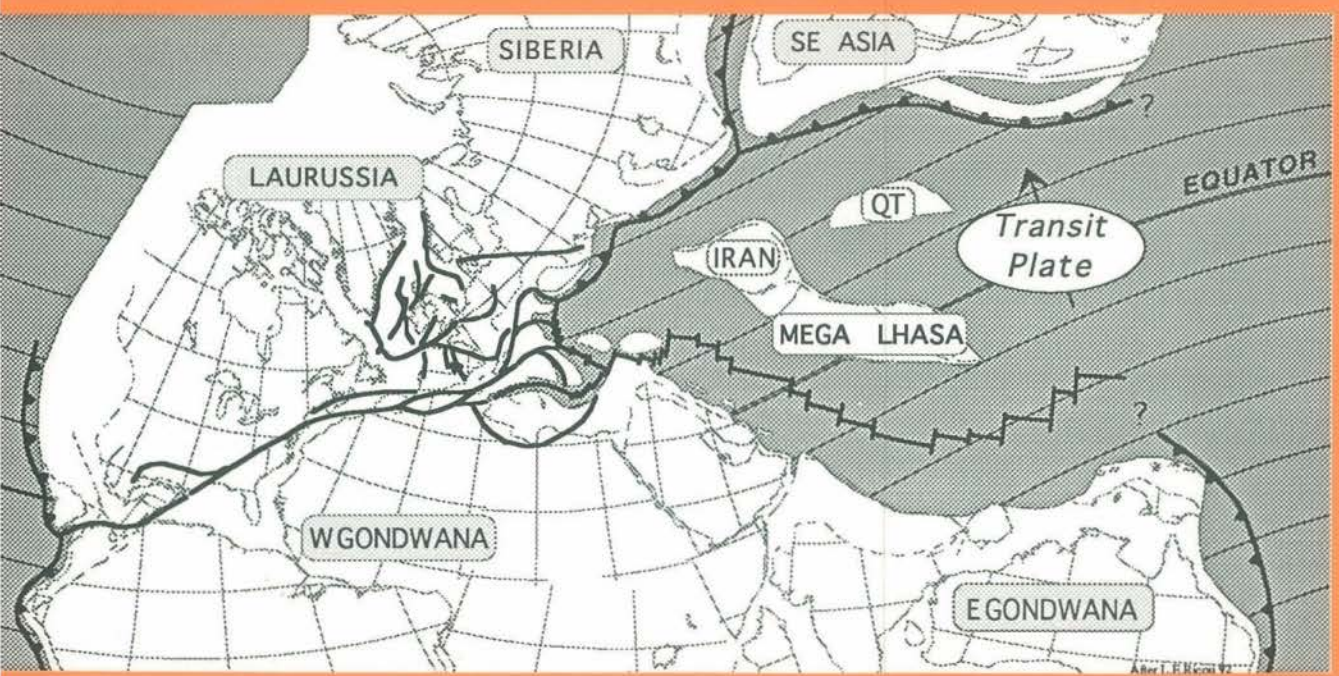

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STRATIGRAPHIC RANGE OF TRIASSIC BOREAL NAUTILOIDEA

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Introduction

Nautiloids were not applied until recently to the subdivision and correlation of the Boreal Triassic. Detailed examination of a number of stratigraphic sections in Taimyr, Verkhoyansk Ridge, in basins of the Olenek, Indigirka, and Kolyma rivers and at the Okhotsk coast have shown that although nautiloid deposits are relatively scarce, they occur almost throughout the Triassic (Fig. 1). Siberian material revised by the author revealed the rather high taxonomic diversity of nautiloid evolution (Sobolev, 1989). It became evident that nautiloids can be successfully used in zonal stratigraphy.

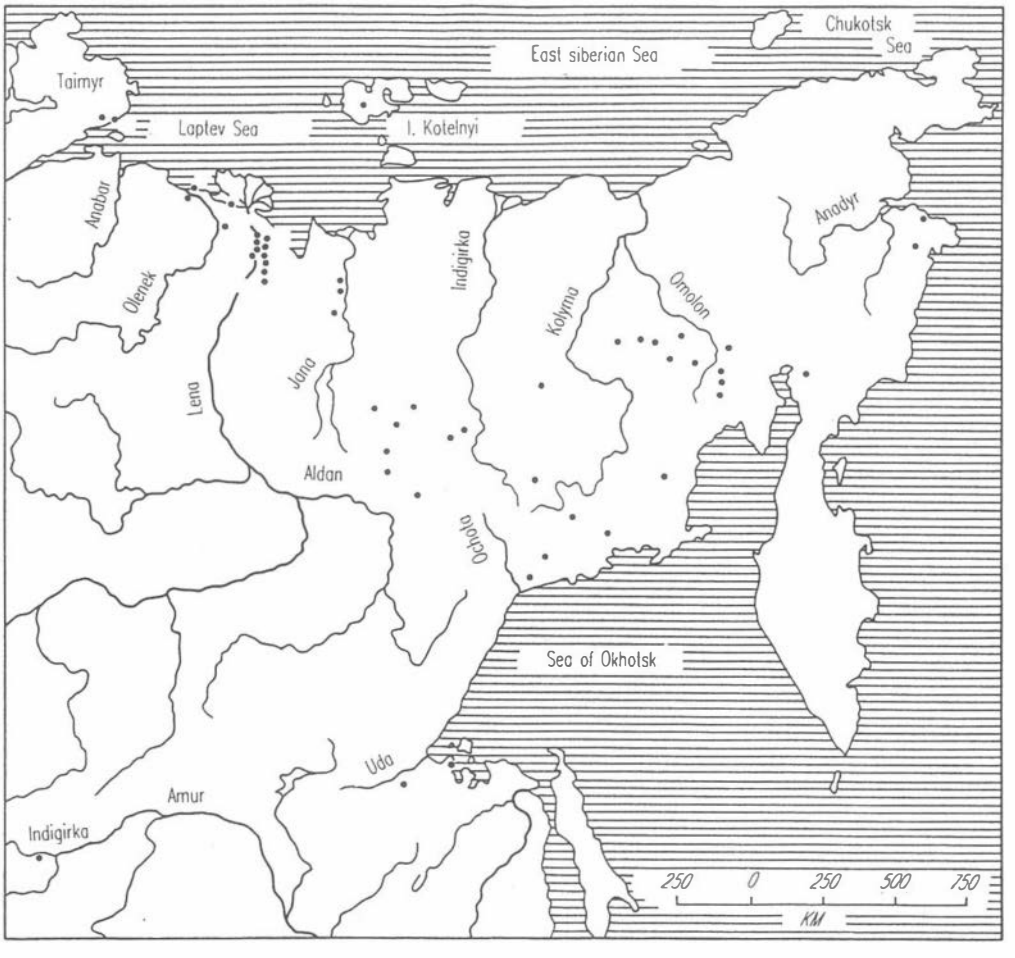

Fig. 1. Map of occurrences of Triassic nautiloids in northeastern Asia.

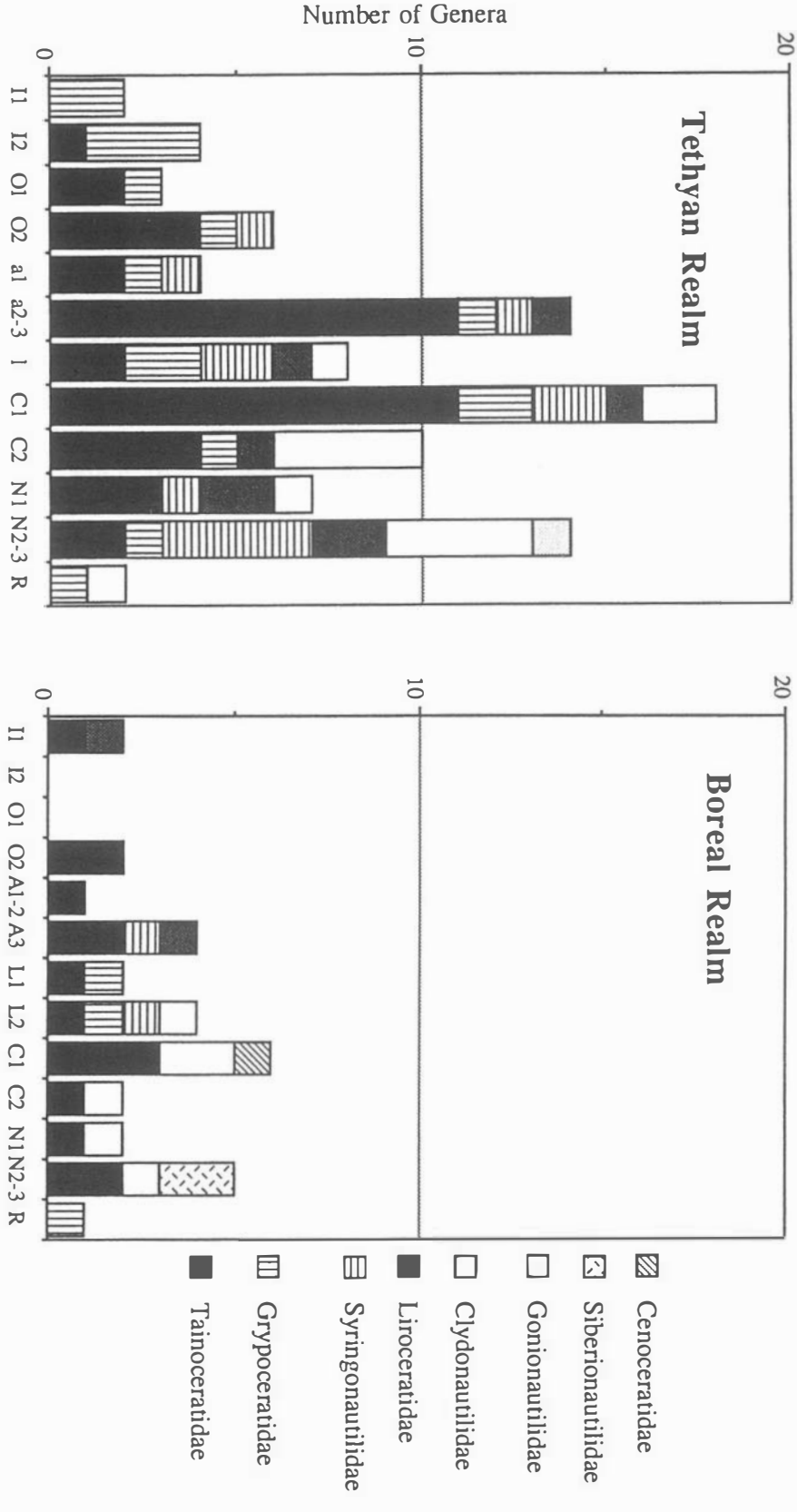

Fig. 2. Differentiation of nautiloid genera structure in Triassic paleoaquatoriums.

Nautiloid Zonation

The Triassic zonal scheme for Siberia developed by Dagys et al. (1979) and Dagys (1986) is used in this article as the reference scale. Two major stages can be recognized in the history of development of Triassic nautiloids. The first stage comprises Early and Middle Triassic and is characterized by the dominance of three families, Tainoceratidae, Grypoceratidae and Liroceratidae, transient from the Upper Paleozoic. Many of the genera from these three families originate in the Triassic. The second stage comprises Late Triassic and is marked by a burst of new forms originating. There appear Clydonautilidae typical of Late Triassic, which are characterized by strongly dissected suture lines. The first representatives of the suborder Nautilina, which continue into the Jurassic, appear at this stage. Within the two stages, nautiloids were irregularly developed. Although development within the stages differs, these are not significant systematic changes, but rather relate to dynamics of genera development (Fig. 2). In the Tethyan and Boreal realms they were developed more or less synchronously, showing less systematic diversity in the Boreal realms.

During the late Triassic burst of new genera varieties, nautiloids migrated from the Tethyan realm to the Boreal realm. Some of these migrants gave rise to the start of endemic phyletic lineages, which developed in the Boreal realm for long periods. The proposed chart is developed based on the evolution of such long-existing phyletic lineages of nautiloids.

Lower Triassic

In the Induan nautiloids are scarce in all aquatoriums. The Tethyan is characterized by grypoceratids with subventral and ventral siphuncles. In the Boreal realm common at that time were liroceratids (genus *Tomponautilus*, which is represented by species *T. setorymi* Sobolev), probable descendants of the Upper Permian genus *Permonautilus*, and a few representatives of the Upper Permian genus *Tainionautilus* (Fig 3). This assemblage of nautiloids is distributed in the Lower Induan Zones, such as Concavum, Boreale and Nielseni and may be recognized as an independent Zone of *Tomponautilus setorymi*.

In all Upper Induan and Lower Olenekian (Hedenstroemi Zone) Boreal regions, nautiloids are absent. However, in the Early Olenekian of Siberia widely distributed are forms with straight conchs, which immigrated from the Tethyan at the beginning of the Kolymensis phase. Based on these orthocones there was recognized a Trematoceras boreale Zone, which was subdivided into Pseudotemperoceras pulchrum and Trematoceras boreale subzones precisely corresponding to the Kolymensis and Tardus ammonoid standard Zones.

In Upper Olenekian the burst of new genera occur in the Tethyan basins, among nautiloid assemblages dominated by tainoceratids, which prevail in nautiloid fauna until the beginning of the Upper Carnian. Coiled nautiloids migrated to Boreal regions. In the Boreal Realm throughout the Olenekian distinctly dominant was the endemic line of the *Phaedrysmocheilus* genus from tainoceratids on whose evolution the zonal chart has been developed.

The main phylogenetic sequence of the genus in Siberia consists of the following species: *Phaedrysmocheilus ornatus - P. evolutus – P. subaratus* (Fig. 3). *Phaedrysmocheilus ornatus* Sobolev is an initial species. It is characterized by moderately evolute conch with angular outline and many prominent transverse ribs on the first two whorls. This species made its first appearance in the *Euomphala* phase and initiated a phylogenetic sequence that evolved in the direction of intensification of the conch involution and a weakening in its ornamentation.

The next species in the sequence *Phaedrysmocheilus evolutus* Sobolev (*Contrarium* phase) is characterized by moderately evolute conch, showing a roundish outline and fewer ribs.

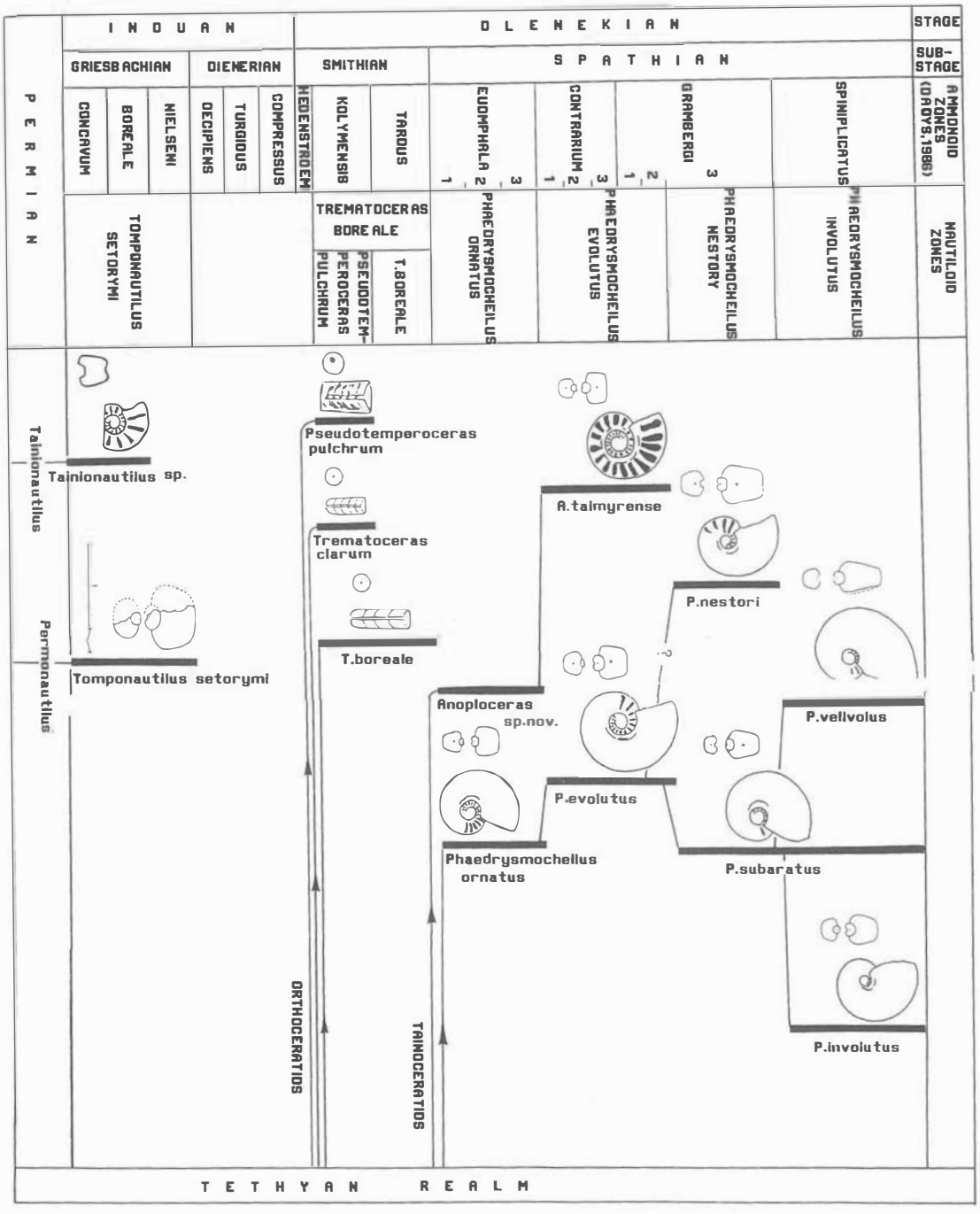

Fig. 3. Regularities of the development of Boreal Nautiloids and Triassic zonal stratigraphy (Lower Triassic).

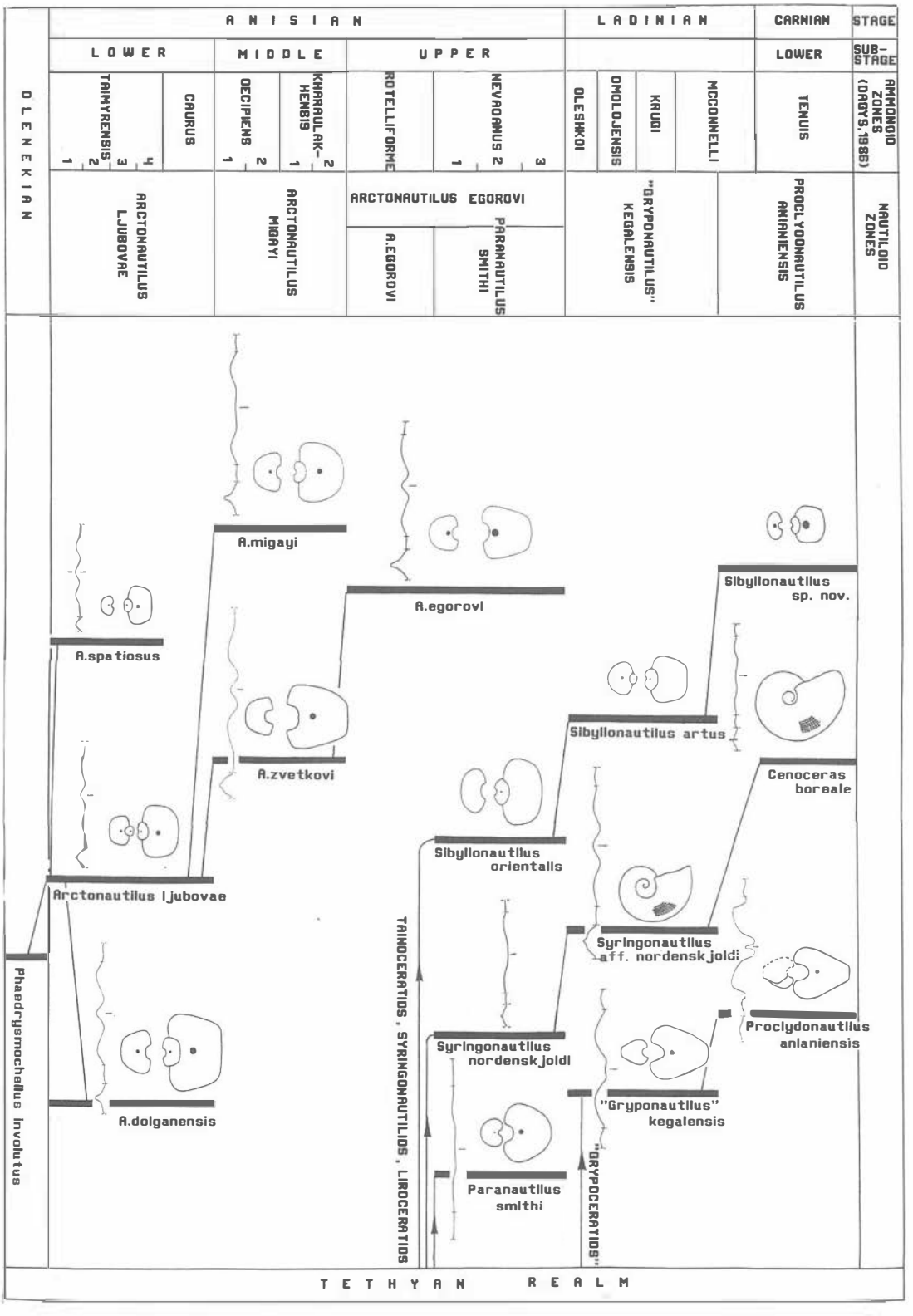

Fig 4. Regularities in the development of Boreal Nautiloids and Triassic zonal stratigraphy (Middle Triassic).

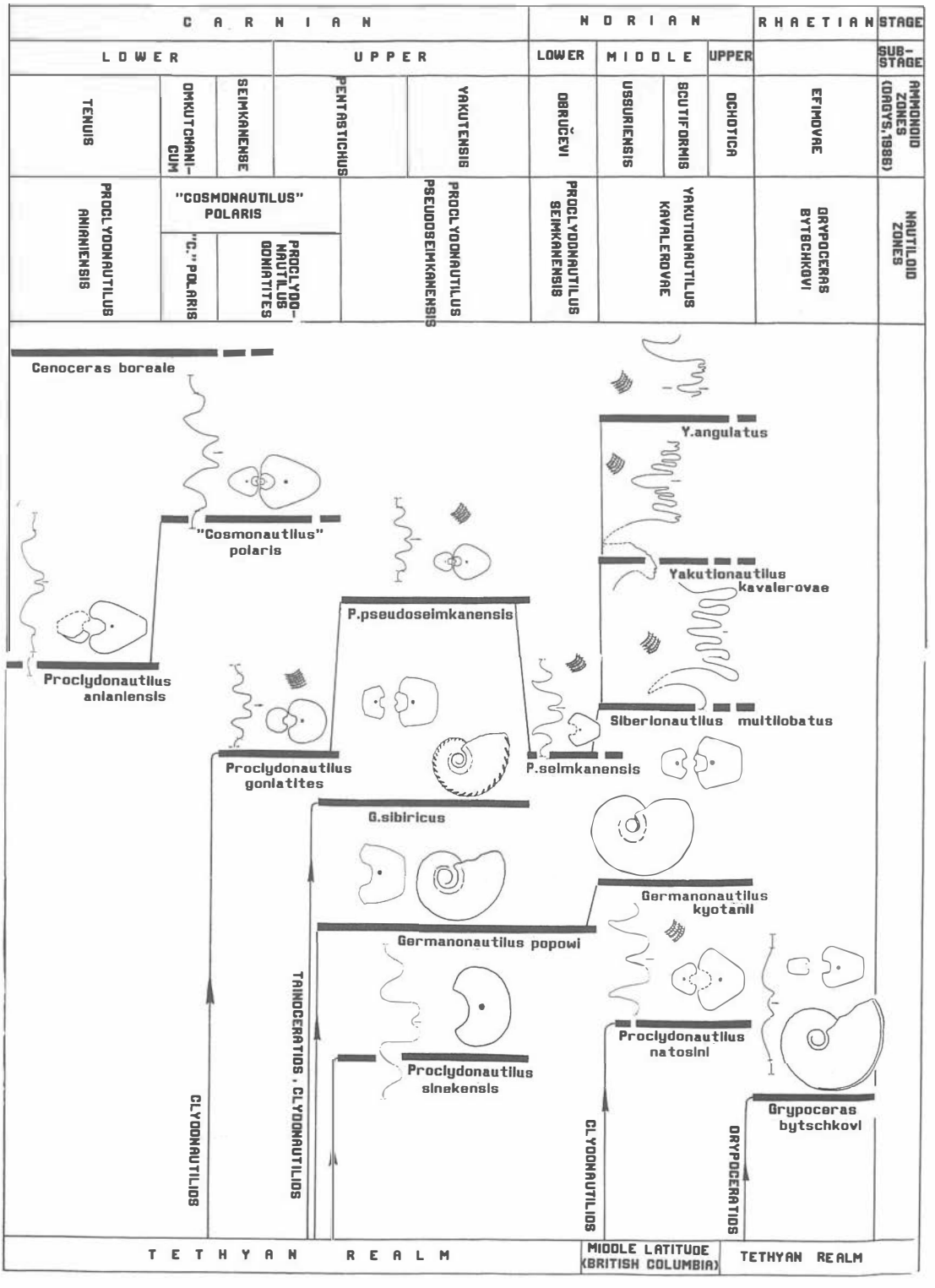

Fig. 5. Regularities in the development of Boreal Nautiloids and Triassic zonal stratigraphy (Upper Triassic).

The *Grambergi* phase yields *Phaedrygmocheilus subaratus* (Keyaerling), showing moderately involute conch and badly developed ribs. Originating from it in the *Spiniplicatus* phase are *Phaedrysmocheilus velivolus* Sobolev and *Phaedrysmocheilus involutus* Sobolev. The latter species is characterized by the most involute conch in this genus and barely evident ribs, which are only developed on one-and-a-half initial whorls. Origin of *Phaedrysmocheilus nestori* (Shimansky) species is not quite clear. Probably this species, having a well-sculptured moderately involute conch appeared as a branch of the single generic stock in the *Grambergi* phase.

The Phaedrysmocheilus ornatus Zone is the oldest and contains index-species and a new species from the genus *Anoploceras*. It corresponds to the *Euomphala* ammonoid Zone. The next zone, *Phaedrysmocheilus evolutus*, comprises Contrarium and a greater part of the Grambergi ammonoid Zones. For the upper part of the Grambergi Zone, *Parasibirites efimovae* Bytschkov is a characteristic and very specific assemblage of nautiloids. The Phaedrysmocheilus nestori Zone is identified by index-species as well as on the first appearance of representatives of *Phaedrysmocheilus subaratus*, which are characteristic of the uppermost zone. The Phaedrysmocheilus involutus upper Zone includes index-species, *Phaedrysmocheilus subaratus* and *Ph. velivolus*. The presence of similar species from *Phaedrysmocheilus* and *Anoploceras* genera suggests a strong similarity between the assemblage from Ornatus and Evolutus Zones in Siberia and nautiloid assemblages from the Columbites parisiianus Zone of Idaho (Kummel, 1953) and Mangyshlak (Schastlivtseva, 1988).

Middle Triassic

The Early and partly Middle Anisian nautiloids are relatively monotypic both in the Tethyan and Boreal realms. The nautiloid endemic phyletic lineage continues to develop in the Boreal realm (Fig. 4). Genus *Arctonautilus* being most characteristic of the Anisian deposits in Siberia, appears to be a direct descendant of the Early Triassic genus *Phaedrysmocheilus*.

Within the genus *Arctonautilus* outlinea is a certain phylogenetic sequence which is represented by the species of *Arctonautilus ljubovae* (Schastlivtseva) - *A. svetkovi* Sobolev - *A. egorovi* Sobolev the range of which coincides with that of the Anisian substages. The representatives of the sequence which constantly retained a large convex discoidal conch with radial ribs on one-and-a-half initial whorls and deep narrow ventral lobe in the suture line are characterized by a steady increase in the height of whorls at the late stages of ontogeny, deeper annular lobes in the suture line and the disappearance of the siphuncle toward the dorsal side. During the evolution of the genus *Arctonautilus* there appeared forms that lost some generic characters. For example, the Middle Anisian species *Arctonautilus migayi* Sobolev, unlike the other species of the genus, shows the suture line on the ventral side to be almost straight. Two Arctonautilus zones (*A. ljubovae* and *A. migayi*) are established, which correspond to the Lower and Middle Anisian.

Nautiloid taxonomical diversity increases sharply in the Upper Anisian Tethys, when another migration of the group to Boreal aquatoria occurred. Endemic genus *Arctonautilus* continues to evolve. Typical species *Arctonautilus egorovi* Sobolev gave the name to the zone that corresponds to the Upper Anisian. The genera of *Paranautilus* and *Syringonautilus* immigrated from the Tethys and allowed this zone to be subdivided into two subzones, which are consistent with the Rotelliformis and Nevadanus Zones on the ammonoid scale. The Arctonautilus egorovi Zone correlates quite well with the Meeki and Occidentalis ammonoid Zones from Nevada due to the presence of the species *Paranautilus* smith Kummel.

In the Ladinian stage in major world aquatoria taxonomic diversity decreases in nautiloids as well as in other cephalopods (Shevyrev, 1986). This decrease in diversity affects also the Boreal fauna. Rare representatives of the cosmopolitan genera of *Sibyllonautilus, Syringonautilus* and "*Gryponautilus*" are represented here by local species. It is currently proposed to distinguish "Gryponautilus" kegalensis Zone for almost all the Ladinian stage. Forms similar to zonal index-species and described as

"*Indonautilus*" awadi Kummel and "*Nautilus*" sp. ex aff. *N. griesnachi* Diener are known from the Fassan of Israel, Arabia (Parnes, 1986) and the Himalaya (Diener, 1895).

The boundary between the Ladinian and Carnian stages is confined to one of important reconstructions in systematic composition of nautiloids, that was discussed above. After retardation of nautiloid evolution tempo in all realms during the Ladinian age, the beginning of the Carnian age is marked by a burst of new forms.

Upper Triassic

In Boreal regions the appearance of two major groups of nautiloids (Clydonautilina and Nautilina) is confined to the beginning of the Carnian. Upper Triassic zones recognized by nautiloids in the Boreal realm are based on clydonautilins development (Fig. 5). The oldest among clydonautilins in the Boreal realm is considered to be the species *Proclydonautilus anianiensis* (Shimansky) which probably is derived from endemic species "*Gryponautilus*" *kegalensis* Sobolev with its similar conch shape. Saltation in this phyletic line resulted in the appearance in descendants of a narrow and deep ventral lobe in the suture line and disappearance of the annular lobe. The species "*Cosmonautilus*" *polaris* Sobolev is a direct descendant of *Proclydonautilus anianiensis*. In this phylogenetic sequence the development proceeded in the direction of changing in conch outline from discoidal with a narrow and flattened ventral side and narrow ventral lobe in the suture line to phacoidal with a convex ventral side and wide ventral lobe in the suture line.

The oldest Carnian deposits, referred to as the *Proclydonautilus anianienais* nautiloid Zone, yield, apart from index-species, the first representatives of the genus of *Cenoceras*, which may be descendants of the local lineage of *Syringonautilus*, which evolved in the direction of intensification of the conch involution (Dagys and Sobolev, 1989). In addition, the last representatives of the genus *Sibyllonautilus* occur in deposits of this zone.

The boundary between the Ladinian and Carnian stages, adopted currently by ammonoids is not consistent with the range of Nautiloidea. The Proclydonautilus anianiensis Zone confidently known from stratigraphic intervals to be equal to the Tenuis ammonoid Zone, comprises also the upper part of the Macconnelli Zone in modern interpretation.

The "Cosmonautilus" polaris Zone is identified by the first appearance of index-species. The zone is subdivided into two subzones ("*Cosmonautilus*" *polaris* and *Proclydonautilus goniatites*). The upper subzone is characterized by the appearance in Boreal Nautiloid assemblages of first clydonautilins with reticular ornamentation of the species of *Proclydonautilus goniatites* (Hauer) which migrated from the Tethys realm at the beginning of Seimkanense phase. This species is also known from the Julian substage of the eastern Alps, Afghanistan, Tibet and Timor Island.

The species *Proclydonautilus goniatites* marked the beginning of a new phylogenetic sequence for clydonautilids with reticular ornamentation, which occurs in the Late Carnian and Early Norian of Siberia. This sequence includes the following species: *Proclydonautilus goniatites* (Hauer) - *P. pseudoseimkanensis* Sobolev - *P. seimkanensis* Bytschkov. The evolution proceeded here in the direction of conch outline changing from subspherical in the initial species to phacoidal with a convex ventral side poorly expressed in intermediate species to discoidal conch clearly expressed in intermediate species to discoidal conch with a clearly expressed, flattened ventral side in the latter species.

In Siberia the first representatives of the genus *Germanonautilus*, widely distributed in low latitudes in the Middle and beginning of the Late Triassic, appear in the upper part of the "Cosmonautilus" polaris Zone. The "Cosmonautilus" polaris Zone in its range corresponds to Omkutchanicum and Seimkanense ammonoid Zone and to the lower part of Pentastichus Zone.

In Late Carnian the retardation of evolution tempo occurs at the generic level in both realms. In

Boreal regions Late Carnian nautiloids are represented by two genera: *Proclydonautilus* and *Germanonautilus*. However, specific diversity increases at that time. The Proclydonautilus pseudoseimkanensis Zone corresponds in its range to the upper part of the Pentastichus Zone and the Zone of Yakutensis in ammonoid standard and is characterized, apart from index-species, by the following species: *Proclydonautilus sinekensis* Popov, *Germanonautilus sibiricus* Sobolev and *G. popovi* Sobolev.

The Carnian-Norian boundary is not clearly delineated by nautiloids. In the Boreal realm the Proclydonautilus seimkanensis Zone is identified at the base of the Norian stage. It correlates with the Obrucevi ammonoid Zone. The assemblage from this zone is poor, not diverse, and includes index-species and *Germanonautilus popowi*.

The nautiloid assemblage is greatly renewed in the Tethyan and Boreal realms at the lower and Middle Norian. In Siberia this level (Ussuriensis Zone) yields the first endemic family Siberionautilidae, represented by two genera (*Siberionautilus* and *Yakutionautilus*), which show the most complete suture line for nautiloids. Family Siberionautilidae originated in *Usauriensis* phase from Siberian representatives of the genus *Proclydonautilus* with reticular ornamentation (possibly from *P. seimkanensis*). Saltation is expressed in a more complex suture line due to appearance of additional lobes between the ventral and lateral lobes. The genus *Siberionautilus* is probably the first representative of the new family. The family evolved very fast, the evolution proceeding by further complications of the suture line. In the same phase the genus *Yakutionautilus* is characterized by a denticulate saddle in the suture line, which separates it from *Siberionautilus*.

The stratigraphic interval comprising the Ussuriensis Scutiformis and Ochotica Zones in the northern standard and characterized by the species *Siberionautilus multilobatus* Popow, *Yakutionautilus kavalerovae* Arkhipov et Barskov, *Y. angulatus* (Popow), *Proclydonautilus natosini* McLearn and *Germanonautilus kyotanii* Nakazawa is thought to identify the Yakutionautilus kavalerovae nautiloid Zone. In the future a more detailed divison of the Triassic deposits of the interval composed by this group will be possible due to progress in the study of suture lines. The correlation of the Middle and Upper Norian in Tethyan and Boreal realms based on nautiloids is somewhat difficult because of maximum endemic forms in nautiloid fauna from both regions. *Proclydonautilus natosini* appears to be the single species common to Siberia and mid-paleolatitude fauna of British Columbia (McLearn, 1946).

At the Norian-Rhaetian boundary (according to Dagys and Dagys, (1990) a Siberian Efimovae Zone is interpreted as Rhaetian stage for the present article) almost all nautiloid genera and families die out in all aquatoria of the globe. In Siberia only one species (*Grypoceras bytschkovi* Sobolev) is known from terminal Triassic deposits. Only the family Cenoceratidae crosses the Triassic-Jurassic boundary. The oldest Jurassic deposits in Siberia contain the only representatives of this family. In the Lower Hettangian beds Psiloceras species of the genus *Cenoceras* are common.

Nautiloid Zonation

A nautiloid-based zonation including 19 biostratons suggests a rather detailed subdivision of Triassic deposits. The zones mostly have wide ranges and in many cases suggest detailed correlations within the entire Boreal realm (Figs. 6, 7). Wider correlations are ordinarily hampered, because of the lack of thorough studies of the Tethyan nautiloids. However, there are some datum levels (Phaedrysmocheilus ornatus and P. evolutus Zones in the Upper Olenekian, Paranautilus smithi subzone in the Upper Anisian and Proclydonautilus goniatites subzone in the Lower Carnian), due to recurrent waves of nautiloid immigration to Boreal regions from the Tethys, which allow wide correlation of Boreal and Tethyan charts to be made.

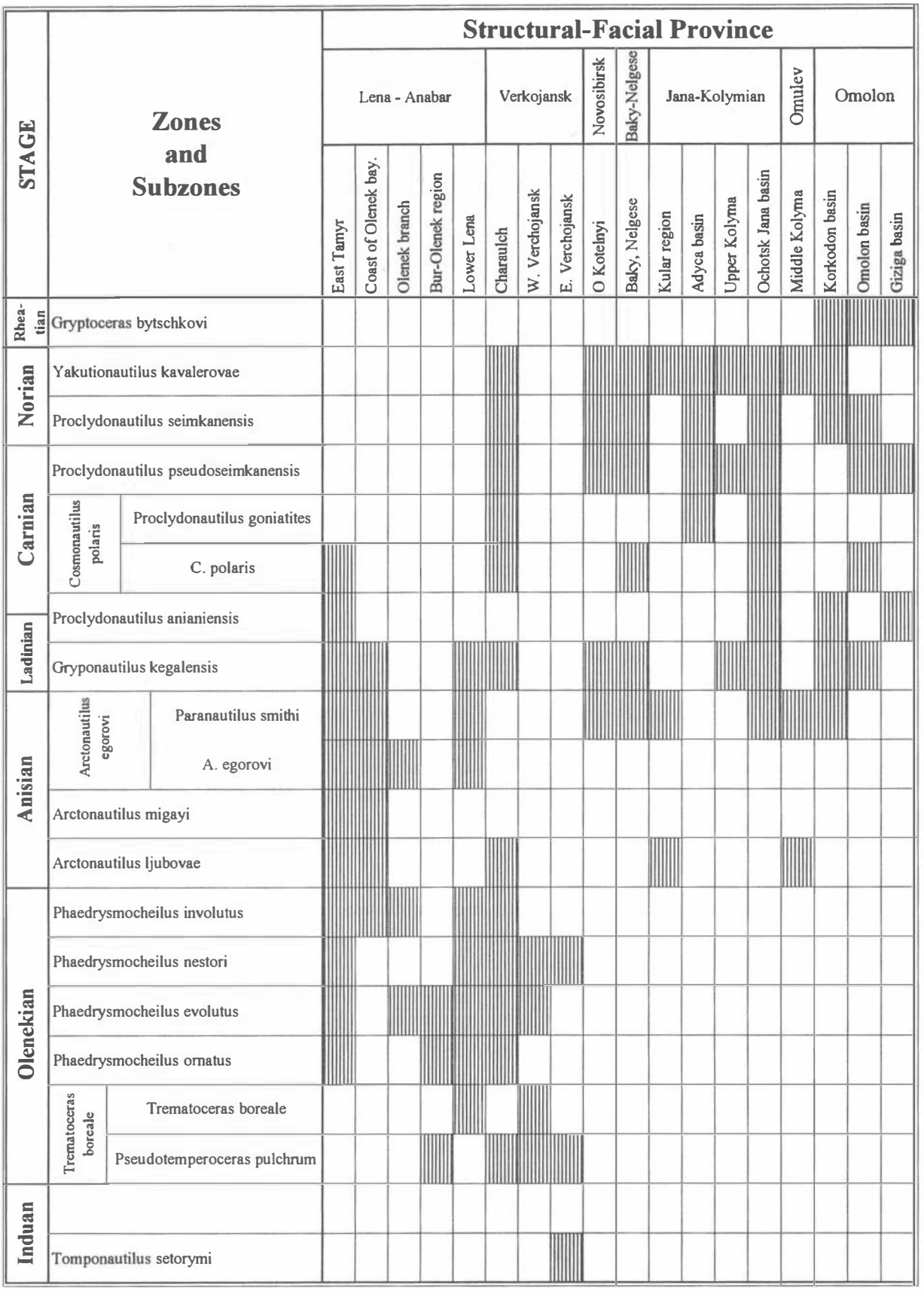

Fig. 6. Geographic distribution of the characteristic nautiloid zonal assemblages in various structural-facial provinces of Siberia.

STAGE	Ammonoid zones	Nautiloid zones		Nautiloid Fauna
Rhaetian	Efimovae	Gryptoceras bytschkovi		Grypoceras bytschkovi Sob.
Norian	Ochotica	Yakutionautilus kavalerovae		Yakutionautilus kavalerovae Archipov et Barsk Siberionautilus multilobatus Popow, Yakutionautilus angulatus Popow, Yakutionautilus angulatus Popow, Germanonautilus kyotanii Nakaz., Proclydonautilus natosini Mc Learn.
	Scutiformis			
	Ussuriensis			
	Obrucevi	Proclydonautilus seimkanensis		Proclydonautilus seimkanensis Bytschk., Germanonautilus popowi Sob.
Carnian	Yakutensis	Proclydonautilus pseudoseimkanensis		Germanonautilus sibiricus Sob., G. popowi Sob., Proclydonautilus pseudoseimkanensis Sob., P. spirolobus (Dittmar), P. sinekensis Popow.
	Pentastichus	Cosmonautilus paularis	Proclydonautilus goniatites	Cosmonautilus polaris Sob., Proclydonautilus goniatites (Hauer), Cenoceras boreale Dagys et Sob.
	Seimkanense			
	Omkutchanicum		C. polaris	
	Tenuis	Proclydonautilus anianiensis		Proclydonautilus anianensis (Shim.), Sibyllonautilus sp. nov., Cecnoceras boreale Dagys et Sob.
Ladinian	Mcconnelli	Gryponautilus kegalensis		Gryponautilus kegalensis Sob., Sybyllonautilus artus Sob., Syringonautilus aff. nordenskjöldi (Lindstr.)
	Krugi			
	Omolojensis			
	Oleshkoi			
Anisian	Nevadanus	Arctonautilus egorovi	Paranautilus smithi	Arctonautilus egorovi Sob., Trematoceras ex gr. latiseptatum (Hauer), Arctonautilus orbiculatus Sob., Sibyllonautilus orientalis Sob., Syringonautilus nordenskjöldi (Lindstr.), Papanautilus smithi Kumm.
	Rotelliforme		A. egorovi	
	Kharaulakhensis	Arctonautilus migayi		Arctonautilus migayi Sob., A. zvetkovi Sob., Trematoceras aff. spitiense Diener
	Decipiens			
	Caurus	Arctonautilus ljubovae		Arctonautilus spatiosus Sob., A. ljubovae (Schastl.), A. dolganensis Sob.
	Taimyrensis			
Olenekian	Spiniplicatus	Phaedrysmocheilus involutus		Phaedrysmocheilus involutus Sob., P. velivolus Sob.,P. subaratus (Keys.), Trematoceras subcampanile Kipar.
	Grambergi	Phaedrysmocheilus nestori		Phaedrysmocheilus nestori (Shim.), P. subaratus (Keys.), Trematoceras subcampanile Kipar.
	Contrarium	Phaedrysmocheilus evolutus		Phaedrysmocheilus evolutus Sob., Anoploceras taimyrense (Schastl.).
	Euomphala	Phaedrysmocheilus ornatus		Phaedrysmocheilus ornatus Sob., Anoploceras sp. nov.
	Tardus	Trematoceras boreale	T. boreale	Pseudotempoceras pulchrum Schastl., Trematoceras clarum Schastl., T. boreale Schastl.
	Kolymensis		Pseudotemperoceras pulchrum	
	Hedenstroemi			
Induan	Compressus			
	Turgidus			
	Decipiens			
	Nielseni	Tomponautilus setorymi		Tainionautilus sp., Tomponautilus setormyi Sob.
	Boreale			
	Concavum			

Fig. 7. Characteristic fauna of the Triassic Nautiloid zones in Siberia.

The main changes in systematic composition of Triassic Boreal ammonoids and nautiloids coincide in time, consequently many boundaries also coincide, however, this coincidence is not complete. For example, the boundary between the Phaedrysmocheilus evolutus and P. nestori Zones is placed in the upper part of the Grambergi Zone, the boundary between the "Gryponautilus" kegalensis and Proclydonautilus anianiensis Zones is placed in the upper part of the Macconnelli Zone, among others. A zonal chart based on nautiloids allows considerable correction of the divisions and correlations of the sections from Boreal regions.

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