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# The marine Permian of East and Northeast Asia: an overview of biostratigraphy, palaeobiogeography and palaeogeographical implications

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**Abstract**

The Permian marine biostratigraphy, faunal successions and mutual correlations (where possible) throughout East and Northeast Asia are synthesized, region by region, based on both published literature and the author's field observations in certain parts of the region. The correlation of the Permian marine successions of NE Asia with the Permian international timescale and, in particular, with Gondwanan Permian marine sequences remains a major challenge, due to profound marine provincialism during the Permian. However, by employing biogeographically mixed faunas from East Asia (SE Mongolia, NE China, South Primorye of Far East Russia and the South Kitakami Terrane of Japan) as 'biostratigraphic gateways', coupled with some bipolarly and bi-temperately shared Permian marine taxa and faunas, it has been possible to correlate, with reasonable confidence, some of the high-palaeolatitude Permian marine rock units and faunas of NE Asia with those of the Tethyan region and Gondwana.

Palaeobiogeographically, the Permian marine faunas of East and NE Asia are assigned to four major provinces: Verkolyman, Sino-Mongolian–Japanese, Cathaysian and Panthalassan provinces, on the basis of their palaeogeographical distribution patterns and characteristics of faunal assemblages. Of these, the Sino-Mongolian–Japanese Province has considerable significance for regional palaeogeographical, plate tectonic and palaeoceanographical reconstructions during the Middle Permian, because of its conspicuously mixed cool- and warm-water marine biota. The origin of this biogeographically mixed marine biota is interpreted to have resulted from a combination of some key factors, including the increased tectonic convergence between the Bureya–Jiamusi Terrane and the Sino-Korean Platform during the Permian and the intermingling of both warm- and cold-water ocean currents off the eastern coastal areas of the Bureya–Jiamusi Terrane and the Sino-Korean Platform during the Middle Permian.


*Keywords:* Permian; Biogeography; Biostratigraphy; East Asia; Northeast Asia; Palaeogeography

## 1. Introduction

East and Northeast Asia referred to in this review includes NE China, Mongolia, Korean Peninsula, Japan and eastern Russia (Fig. 1). Current understanding of the geological history of this vast region is rather meagre partly because of the limited data available and also the apparently extremely complex geological structures across the entire region. The latter aspect is most notably characterized by the juxtaposition of the older (mainly Palaeozoic to early Mesozoic), generally east–west trending Palaeo-Tethys (or Palaeo-Asian Ocean in some literature) derived fold belts and those of the younger (mainly late Mesozoic to Cenozoic), generally north–south or NE–SW fold belts of the Palaeo-Pacific Ocean orogens (Ren et al., 1999). As emphasized in several regional tectonic studies (e.g. Li, 1999; Ren et al., 1999), the transition from the Palaeozoic Palaeo-Tethys-dominated tectonic regime, to the Mesozoic–Cenozoic Palaeo-Pacific-dominated regime, apparently took place during the Late Palaeozoic through to the early Mesozoic, an interval that also saw profound environmental and biotic changes for the rest of the world, including the final formation of Pangea, the drastic shift of the global climate from a Permo-Carboniferous icehouse state to a Permo-Triassic greenhouse-style condition (e.g. Veevers, 2004), and the greatest mass extinction in earth history at the

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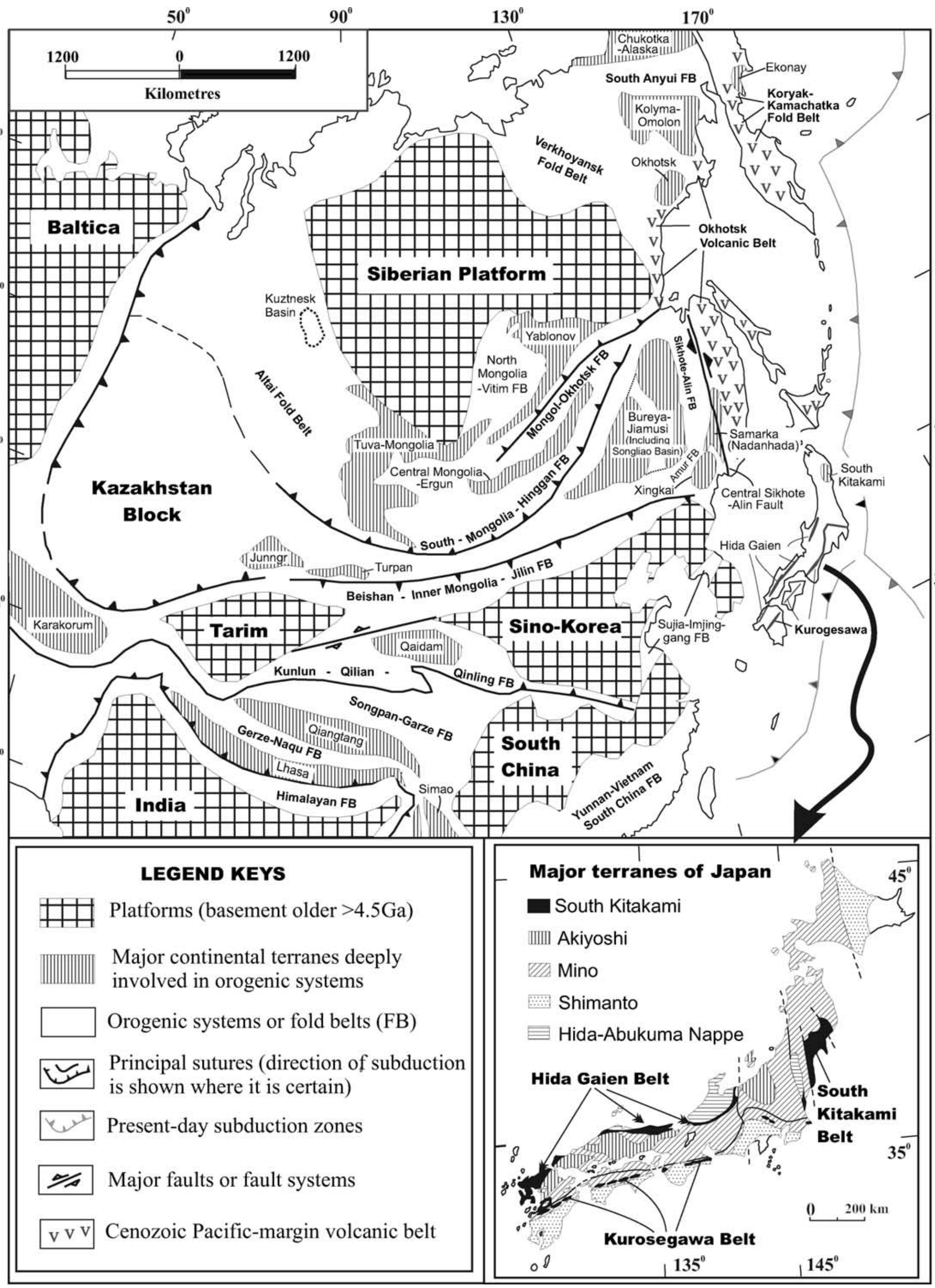


Fig. 1. Schematic diagram showing main tectonic subdivisions of central and eastern Asia (modified from numerous sources, especially Taira and Tashiro, 1987; Natal'in and Borukayev, 1991; Parfenov et al., 1993; Sokolov et al., 1997; Nokleberg et al., 1999; Ren et al., 1999).

Permian–Triassic boundary. Thus, it is clear that the Permian marks an important period in the geological evolution of East and NE Asia. At present, much of the knowledge concerning the Permian of this region, especially the geodynamic processes of its changing palaeogeographical, biogeographical and tectonic configurations through the Permian and Permian–Triassic transition, remains elusive, and few regional syntheses on these aspects are yet available.

As a prelude to this special issue on the Permian of East and NE Asia, this paper is aimed at presenting an overview of the marine Permian of this region, with particular focus on the following key facets: (1) a brief overview, region by region, of the Permian marine biostratigraphy; (2) an overview of the key characteristics of its marine biotas and their significance for Permian regional and global correlations; and finally; (3) a discussion of its notoriously mixed warm-water Cathaysian and cool-water Boreal marine faunas in the context of regional palaeogeography, palaeoceanography and plate tectonic configurations during the Permian.

## 2. Regional geological and tectonic setting

The region under discussion represents a tectonic collage, comprising several large tectonic blocks nested in a matrix of interwoven sutures (i.e. ophiolitic rock belts), microcontinents (or terranes), fold belts and accretionary complexes (Fig. 1). The present-day tectonic framework of this region has been reviewed and discussed in many papers (e.g. Parfenov and Natal'in, 1985; Taira and Tashiro, 1987; Ruzhentsev et al., 1989; Zonenshain et al., 1990; Tang, 1990; Hsü et al., 1991; Natal'in and Borukayev, 1991; Natal'in, 1993; Parfenov et al., 1993, 1999; Shao and Tang, 1995; Sengör and Natal'in, 1996; Ren et al., 1999; among others) and so will not be detailed here, but a brief summary is necessary to provide a tectonic background for this special issue and further discussions in this paper. The terminology of tectonic units referred to here follows principally Natal'in (1993), Parfenov et al. (1999) and Ren et al. (1999), in that three main categories of tectonic elements are adopted: Platforms, fold belts and terranes (Fig. 1).

### *2.1. Platforms and their surrounding fold belts*

The two largest and oldest tectonic blocks in East and Northeast Asia are the Siberian Platform to the north and the Sino-Korea Platform in the south. Both of these platforms have a long geological history dating back to the Archaean, and both had been stable continental plates since at least the beginning of the Palaeozoic (Zonenshain et al., 1990; Ren et al., 1999). Today the intervening region between these two platforms constitutes a complex tectonic collage composed of several major orogenic belts, and a number of terranes that had also been deeply involved in the tectonic processes of the adjoining orogenic belts. Of these, the Great Tianshan–Mongol–Hinggan orogenic system requires some comments, as it not only hosts much of the Permian that will be discussed in detail in some of the papers in this special issue, it also marks the main tectonic boundary between the Siberian and Sino-Korean platforms. This broad, roughly E–W trending orogenic system comprises a stack of tectonic slices, represented by a diverse range of rock assemblages, ages and tectonic settings (e.g. island arc, fore-arc, back-arc, slope, trench and oceanic settings). As such, it is clearly not a simple zone formed by a single tectonic event; rather it is widely regarded as a collage of several parallel fold belts or sutures ranging in age (i.e. age of 'suturing') from Silurian to Late Permian (Wang and Liu, 1986; Ruzhentsev et al., 1989; Hsü et al., 1991; Sengör and Natal'in, 1996; Robinson et al., 1999; Xiao et al., 2003). This diverse age range of suturing events suggests that repeated subductions of the Palaeo-Asian oceanic plate occurred throughout the Palaeozoic, involving probably a series of island arcs and microcontinents or continental fragments. In comparison, the Mongol–Okhotsk orogenic belt seems to have a less complex geological record; it is generally treated as an integral part of the circum-Pacific orogenic system and as such has been widely regarded as the legacy of a segment of the Palaeo-Pacific Ocean (Gordienko, 1994; Tang et al., 1995), which was closed either gradually in a west-to-east progressive manner from Triassic to Late Jurassic (Zonenshain et al., 1990; Sengör and Natal'in, 1996) or in a single collisional phase at the Early/Middle Jurassic boundary (Zorin, 1999).

In Siberia, the Verkhoyansk fold belt (including the Chersky Ranges) is the largest orogenic system in NE Asia; it extends in a general NNW–SSE direction from the Arctic to the Okhotsk Sea, bordering the Siberian Platform to the west, the Kolyma–Omolon Terrane to the east, and the Okhotsk Terrane to the south (Fig. 1). The stratigraphic history of the Verkhoyansk fold belt commenced in the latest Devonian-Early Carboniferous when a major rifting event took place on the eastern margin of the Siberian Platform (Khudoley and Guriev, 1994). This was then followed by a long history of growth and demise till the Late Jurassic, when it was finally closed as a result of the collision between Siberia and the Kolyma–Omolon Terrane (Fujita and Newberry, 1982; Prokopyev, 1998; but see Shapiro and Ganelin, 1988 for a different view). Further to the northeast beyond the Kolyma–Omolon Terrane lies the South Anyui fold belt, a roughly E–W trending tectonic assemblage of Upper Triassic turbidites and Jurassic oceanic basalts and pelagic sediments. This fold belt is believed to have resulted from the accretion of the Alaska–Chukotka Terrane to NE Siberia in the mid-Cretaceous (Fujita and Newberry, 1982).

### *2.2. Terranes*

Nested within the above-mentioned orogenic belts are a number of relatively small (relative to Siberian and Sino-Korean platforms), but internally coherent (in a structural and stratigraphic sense) tectonic blocks that are believed to have been deeply involved, and hence severely modified, in the course of the evolution of the Palaeo-Asian and Palaeo-Pacific oceans. These smaller tectonic units are herein treated as terranes, defined as fault-bounded tectonic blocks that differ greatly in geological history from adjacent terranes. In East and NE Asia, some of these terranes have a Precambrian crystalline (sialic) basement overlain by a variety of younger sedimentary covers. As such they have been variably classified either as 'microcontinents', 'massifs', 'megablocks', 'terranes', or 'superterranes'. Some other terranes may be represented merely by a unique rock assemblage testifying to a particular tectonic environment, such as an island arc setting or a back-arc basin. These types of ocean-borne terranes are numerous in the study area, but their outcrops are usually rather small and fragmented, so they cannot be all realistically represented in Fig. 1 (interested readers are referred to Shao and Tang, 1995; Li, 1999; Nokleberg et al., 1999; Hendrix and Davis, 2001). Among the terranes within the East Eurasian continent the most prominent are the Kolyma–Omolon Terrane in NE Siberia; the Central Mongolia–Ergun Terrane, the Bureya–Jiamusi Terrane in NE China and adjacent parts in SE Russia and Mongolia; the Xingkai (Khanka) Terrane in the interjunction area of NE

China, Korea and SE Russia; and the South Kitakami Terrane, Akiyoshi Terrane and Mino Terrane of Japan (Fig. 1).

The Kolyma–Omolon Terrane, as currently understood (e.g. Parfenov et al., 1993), is probably a composite terrane made up of a few smaller terranes with different geological histories. This terrane has a nearly complete succession of Palaeozoic to Jurassic sedimentary sequences overlying an early Precambrian crystalline basement. In general, the Precambrian-Lower Palaeozoic (Cambrian to Devonian) rocks of this terrane share significant similarities with those of the adjacent parts of the Siberian Platform, an observation that has recently led Abramovich et al. (1999) to suggest that the Kolyma–Omolon Terrane may have originally been derived from the Siberian Platform, a view however contrary to some earlier beliefs that advocated a more southerly origin as an exotic terrane (Shapiro and Ganelin, 1988). The Upper Palaeozoic to Jurassic successions of the Kolyma–Omolon Terrane are characterized mainly by clastic sediments of both shallow- and deep-marine origin. In addition, there are also ophiolitic suites and island-arc rock assemblages of different ages in various parts of the terrane, suggesting that it must have been involved in multiple stages of rifting and accretion (Parfenov et al., 1993). The final accretion of this terrane to the Siberian Platform is generally considered to be in the Late Jurassic, as indicated by Lower Cretaceous molasse sediments and collision-related granitoids and volcanic rocks (Parfenov et al., 1993).

The Tuva–Mongolian and Yablonov terranes to the immediate south of the Siberian Platform (Fig. 1) are generally believed to have accreted to the southern margin of Siberia in late Proterozoic (Ren et al., 1999). The Central Mongolia–Ergun Terrane is probably composed of several tectonic slivers, all with an Archaean and/or Proterozoic metamorphic basement, overlain by Palaeozoic, predominantly shallow marine, sediments and Mesozoic non-marine clastic rocks (Badarch et al., 2002). In places the Phanerozoic sedimentary cover of this terrane also contains extensive volcanic and volcaniclastic rocks of island arc affinity and post-accretion granitic complexes. The origin of this terrane is uncertain at present, but it may have originated as several continental slivers fragmented from southern Siberia in the mid-Proterozoic (Tang, 1990), existing as independent but mobile blocks from Neoproterozoic to Early Palaeozoic and amalgamated together to form a single composite terrane during the middle Palaeozoic (Badarch et al., 2002); its western end was accreted to southern Siberia in the Early Permian, heralding the formation of the Mongol–Okhotsk Ocean (Zorin, 1999).

The combined Bureya–Jiamusi Terrane in NE China and adjacent SE Russia, following Ren et al. (1999), is herein treated as a single entity, notwithstanding the fact that it may well represent a collage of several smaller continental fragments, including the Songliao Massif of Ren et al. (1999), the Jiamusi Massif of Tang et al. (1995), and Amuria of Zonenshain et al. (1990). All these smaller blocks share a similar Precambrian crystalline basement, although the ages of these basements are not necessarily identical. The sedimentary cover overlying the Precambrian basement is composed of a thick succession of Palaeozoic–Triassic shallow marine sediments and volcanic and granitoid suites of magmatic arc and island arc affinities (Natal'in, 1993).

The Xingkai (Khanka) Terrane is located to the southeast of the Bureya–Jiamusi Terrane, from which it is separated by the Amur Suture (Natal'in, 1993) or the Dunhua–Mishan Fault (Jia et al., 2004), and from the Sino-Korean Platform to the south and southeast by the Central Jilin fold belt (Jia et al., 2004) (Fig. 1). According to Shao et al. (1995), this terrane is likely also a composite terrane made of a Precambrian metamorphic basement and several small continental-margin and oceanic fragments of Palaeozoic to Mesozoic ages (e.g. it may include the Laoelin–Grodekovsk, Voznesensk and Okrainsk terranes of Natal'in, 1993), but it is generally believed to have acted as a single entity during the Late Palaeozoic until it was accreted to the Sino-Korea Platform in the Late Permian to Early Triassic (Jia et al., 2004).

In Japan, three Late Palaeozoic terranes require some comments. The newly re-defined South Kitakami Terrane (s.l.) of Tazawa (2004) incorporates the South Kitakami, Hida Gaien and Kurosegawa belts (inset map in Fig. 1), all of which possess an Ordovician ophiolitic basement overlain by Ordovician–Devonian metasediments and tuffs, Carboniferous–Permian shallow marine sediments and volcanics, and Mesozoic marine and continental sediments (Tazawa, 2000). The palaeo-positions and the tectonic mechanisms by which these tectonic belts were emplaced have been, and remain, a hot topic of debate (see recent reviews of Otoh et al., 1999; Tazawa, 2002, 2004; Ishiwatari and Tsujimori, 2003), but a general consensus is apparent among the different authors that these belts represent continental-margin fragments and were located in a continental shelf setting bordering a major continental plate during the Permian (e.g. Maruyama et al., 1997; Ehiro, 2001; Hada et al., 2001; Tazawa, 2002, 2004; Kobayashi, 2003; among others). Unlike the South Kitakami Terrane of supposedly continental margin origin, both the Akiyoshi and Mino terranes, as defined in Tazawa (2004), have been widely accepted as ocean-borne entities (e.g. Ichikawa, 1990; Isozaki, 1997a; Maruyama et al., 1997; Tazawa, 2004). The former is a severely disrupted seamount-type terrane, incorporating a wide range of Permo-Carboniferous carbonate rock bodies of varying sizes, distributed throughout the Inner Zone of SW Japan; it includes the Akiyoshi, Atetsu, Taishaku, Omi areas, and also possibly the Maizuru Belt. The oceanic seamount origin of this terrane is evidenced by its thick rock succession, composed of a Carboniferous basaltic basement overlain by Carboniferous–Permian reef limestone and radiolarian-bearing cherty units (Sano and Kanmera, 1988; Maruyama et al., 1997). This terrane is generally believed to have accreted to Proto-Japan during Permo-Triassic times (Isozaki, 1997a). The Mino Terrane, on the other hand, represents a Jurassic accretionary complex composed of Permian greenstone–limestone successions of mid-oceanic reefal-seamount affinities, Permian–Lower Jurassic bedded radiolarian cherts and Jurassic terrigenous rocks (sandstones and conglomerates) (Mizutani, 1990; Isozaki, 1997b; Kojima et al., 2000; Sano et al., 1992).

### 2.3. Pacific-margin terranes and fold belts

The Pacific margin of East and NE Asia forms part of the circum-Pacific orogenic system and is principally a tectonic collage of nappes, displaced terranes, accreted island arcs and accretionary complexes (Sokolov, 1990; Sokolov et al., 1997; Parfenov et al., 1999). The formation of this collage is generally attributed to the convergence between the Palaeo-Pacific plate and the eastern Eurasian continent, a process that remains active today (Sokolov et al., 1997). Within this Pacific-margin orogenic system, the Koryak-Kamachatka fold belt, the Sikhote-Alin fold belt and the Okhotsk volcanic belt are the most significant (Fig. 1). The Koryak-Kamchatka fold belt is characterized by NE–SW and E–W trending structures that incorporate many far-travelled exotic blocks (terranes) of varying sizes, and as such has been widely considered as a typical example of an accretionary continental margin (Sokolov et al., 1997). The broadly defined Sikhote-Alin fold belt here refers to a nearly N–S belt extending north from the southern shoreline of the Okhotsk Sea south to the northern margin of the Japan Sea. In South Primorye, it includes the Samarkinsk, Zhuravlyovsk–Tuminsk, Olginsk, and Taukhinsk terranes of Natal'in (1993); its southern extension across the Japan Sea is probably represented by the Mino Terrane in SW Japan (Kojima et al., 2000), while to the west it would include the Nadanhada Terrane in the Helongjiang Province of NE China (Shinjiro et al., 1989) (Fig. 1). The fold belt is composed of Carboniferous and Permian limestones (usually as olistostromic blocks) and greenstones, Triassic–Jurassic bedded radiolarian cherts and siliceous shale, set in a matrix of mélanges of Late Jurassic to Early Cretaceous deep marine shale and mudstones. Studies of these rock successions and their fossil contents suggest that all the constituent terranes in the Sikhote-Alin fold belt (including the Nadanhada and Mino terranes) may have originated as a single block near the tropical to subtropical zone in the Carboniferous–Triassic, and were accreted, probably by dextral strike-slip movements, to the southeastern continental margin of Eurasia in Late Jurassic to Early Cretaceous (Shinjiro et al., 1989; Natal'in, 1993; Shao et al., 1995; Kojima et al., 2000; Otoh et al., 1999; Ishiwatari and Tsujimori, 2003).

The Okhotsk volcanic belt is the longest and also youngest tectonic unit to be found along the Pacific margin of Eurasia; it is dominated by Tertiary volcanics and volcaniclastic rocks formed as a result of the continuous tectonic interactions between the Pacific Plate and Eurasia (Sokolov et al., 1997; Parfenov et al., 1999).

## 3. The marine Permian in East and Northeast Asia: distribution, biostratigraphy and correlation

### 3.1. General comments

Permian sedimentary, volcano-sedimentary and intrusive rocks are widely distributed in East and Northeast Asia (Fig. 2) and occur in almost all of the main tectonic units reviewed above. As such, the Permian System clearly demonstrates an extremely diverse range of depositional settings and tectonic environments. The stratigraphy and biostratigraphy of the Permian rocks in the various parts of East and NE Asia are detailed in some other papers of this special issue and so will not be repeated here, but a general overview of the Permian successions across the entire region is useful to provide background information for further discussions (biogeography and palaeogeography aspects) later in the paper. This section is focused primarily on Permian marine sedimentary sequences and biotas. Permian non-marine sedimentary rocks and macrofloras are also widespread in the study area and have been reviewed comprehensively by Meyen (1982, 1991), Li and Shen (1992), Huang (1995) and Shen (1995).

Although almost all major marine fossil groups are known from the Permian strata of the study region, their abundance and ubiquity is rather heterogeneous and hence their significance for biostratigraphical correlation is greatly varied. Among the major marine fossil groups, brachiopods are the most ubiquitous across the entire region and also the best-documented group in terms of taxonomy and biostratigraphy. Detailed local successions of biostratigraphical zones based on brachiopods are now available for most of the areas concerned here, and have served as a primary tool for biostratigraphic correlations in the study region (Tables 1 and 2). Bivalve faunas are also common and well documented from many local sections in NE Asia where they have proved significant as a biostratigraphic tool for regional correlations (e.g. Astafieva, 1998; Biakov, 2000), but the details of these faunas elsewhere in the study region remain poorly known. Despite their generally sporadic occurrences, the ammonoid faunas have received considerable attention from palaeontologists in recent years due to their primary significance for dating and correlating sedimentary rock units (Andrianov, 1985; Kutygin, 1999, in press; Kutygin et al., 2002). As will be detailed below, in many of the Permian rock units in the study region ammonoid faunas occur together with brachiopods and bivalves, therefore allowing the possibility of calibrating age determinations from these three key fossil groups (Table 1).

Conodonts, despite their primary importance in establishing the Permian global timescale, are extremely rare in the study area, and so far have only been known from NE China (Wang et al., 2000, 2004) and South Primorye of Far East Russia (Kotlyar et al., 2003). Nevertheless, as discussed below and also shown in Table 2, they provide important chronologic tie points for constraining the ages of some of the Permian rock units. Like conodonts, Permian fusulinoidean fossils are also rather scarce in many of the Permian rocks units of East and NE Asia. However, some important fusulinoideans have been found in the Bureya–Jiamusi, Xingkai and South Kitakami terranes where they are associated with mixed warm-water and cool-water brachiopod faunas. As will be elaborated further in Section 5 below, this biogeographical admixture of both warm- and cool-water faunal elements has proved very significant because these mixed faunas can act as 'biostratigraphic gateways' to correlate Permian high palaeo-latitude faunas and rock units of NE Asia with those of the lower palaeo-latitude regions such as South China.

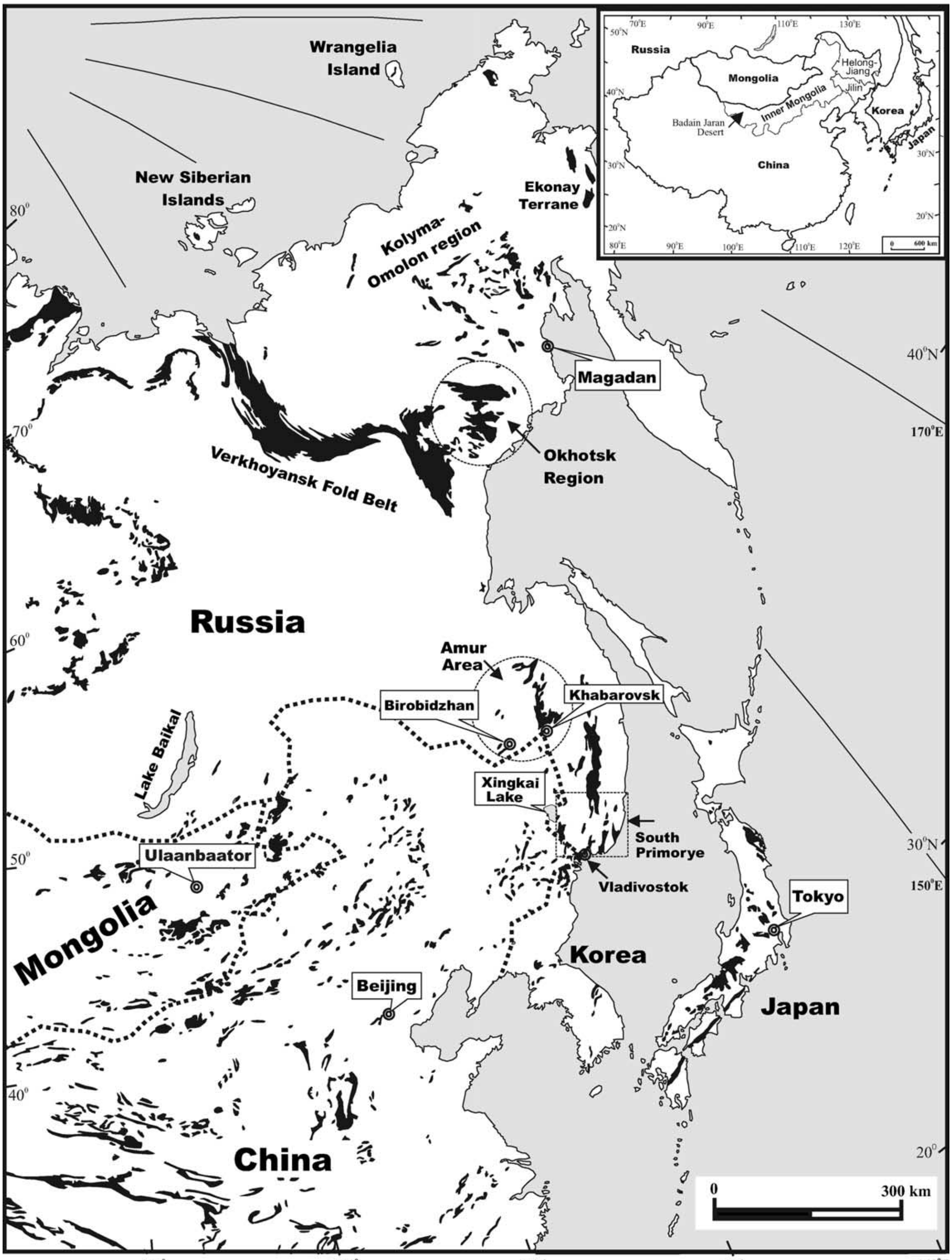


Fig. 2. Distribution of Permian rocks in East and Northeast Asia (data primarily from Chinese Academy of Geological Sciences, 1975; Geological Survey of Japan, 1992). The inset map shows the three Chinese provinces in northeast China mentioned in text, as well as the Badain Jaran Desert in western Inner Mongolia, also mentioned in text.

Finally, some brief comments are necessary regarding the usage of the Permian timescale and the standardization of stratigraphical terminology. In this paper, the three-fold Permian chronostratigraphical scale (Jin et al., 1997; Wardlaw et al., 2004) is followed, but a tentative correlation of this timescale with the traditional Russian (East European) (e.g. Grunt, 2005) and the Tethys-based scales (Leven, 2004) is also provided as a reference (Table 1). Where possible and necessary, the basis on which the correlations are established is also provided and discussed. The Russian term ‘Horizon’, which is not recognized as a formal stratigraphic unit in the international stratigraphic code (Salvador, 1994), is

Table 1
A correlation of composite biostratigraphical schemes of selected key Permian marine fossil groups for East and NE Asia

| Internat. | Tethys | Russian | Brachiopoda (Kashik et al., 1990; Ganelin et al., 2003) | Bivalvia (Biakov, 2000; Ganelin et al., 2003) | Foraminiferida (Kimura, 1991; Shen et al., 2006; Kotlyar and Nikitina et al., 2006) | Ammonoidea (Kutygin et al., 2002; Kutygin, 2006) | Conodonta (Wang et al.,2000, 2004; Kotlyar et al., 2003) |
|---|---|---|---|---|---|---|---|
| Chang. | Doras. | Tatarian | *Stepanoviella paracurvata* Assemblage | *Intomodesma costatum* Zone | *Colaniella parva* Zone | *Huanonoceras quinjiangensis*, *Iranites* | *Clarkina* cf. *deflecta* |
| Wuchia. | Dzhulf. | | | *Maitaia tenkensis* Zone | | *Cyclolobus kiselevae*, *Xenodiscus subcarbonartus* | *Clarkina* ex gr. *deflecta* |
| Capitan. | Midian | | *Cancrinelloides obrutschevi*-*C. curvatus* Zone | *Maitaia bella* Zone | *Metadoliolina lepida*-*Lepdolina kumanensis* Z.<br>*Parafusulina stricta* Z. | *Stacheoceras orientale*, *Timorites markevichi*, *Roadoceras* | *Jinogondolella* cf. *wilcoxi*<br>*Clarkina* cf. *bitteris*<br>*Mesogondolella* cf. *postbitteri* |
| Wordian | Midian / Murg | Tatarian / Kazanian | *Magdania bajkurica* Zone<br>*Terrakea korkodonensis* Zone<br>*Terrakea borealis* Zone | *Kolymia multiformis* Z.<br>*Kolymia plicata* Zone | *Monodiexodina sutschanica* - *Metadoliolina dutkevitchi* Zone | *Timorites*, *Waagenoceras*, *Tauroceras*<br>*Sverdrupites* Assemblages | *Mesogondolella asserrata* |
| Road. | Kuber. | Kazanian | *Omolonia snjatkovi* Zone<br>*Mongolosia rusiensis* Zone | *K. inoceramiormis* Z.<br>*Aphania dilatata* Z. | | *Daubichites* Assemblage | |
| Kungurian (s.l.) | Bolorian | Kungur.-Ufimian | *Kolymaella ogenerensis* Z.<br>*Megousaia kuliki* Zone<br>*Anidanthus aagardi* Zone | *Aphanaia andrianovi* Zone<br>*Aphanaia lima* Zone | *Misellina claudiae* Zone (NE China) | *Epijuresanites musalitini* Assemblages<br>*Tumaroceras yakutorum* Assemblage | |
| Artinskian | Artinskian | Artinskian | *Jakutoproductus burgaliensis*-*Spirelyth kislakovi* Zone<br>*Jakutoproductus rugosus*-*Alispiriferella* Zone | *Lithophaga gigantea* Beds<br>*Palaeocosmoya omolonica* Beds | *Pseudofusulina fusiformis* Zone | *Eotumaroceras endybalense* Assemblage | |
| Sakmarian | | | *Jakutoproductus terekhovi* Z.<br>*Jakutoproductus insignis* Z. | *Cypricardinia eopermica* Beds<br>*Merismopteria permiana* Beds | *Chalaroschwagerina vulgaris* Zone | *Uraloceras subsimense* Assemblage | |
| Asselian | | | *Verkhojania expositus* Zone<br>*Verchojania mirandus* Zone | *Palaeonello parentica* Zone | *Robutoschwagerina schellwieni* Zone | *Bulunites mezhvilki* Assemblage | |

Dashed lines indicate possible correlations.

nevertheless retained here as a useful regional (as opposed to global) biostratigraphical name for a body of sedimentary strata definable principally (but not exclusively) by palaeontological characteristics and clearly traceable within a geographical region, a palaeo-basin, or a palaeobiogeographical province (Zhamoida et al., 1979). In this sense, a 'horizon' may be compared with a 'stage' or 'biozone' in the international stratigraphic code (Yuri Zakharov and Aleksander Klets, personal communication 2005). Occasionally (e.g. Ganelin et al., 2003), horizons have been grouped into 'Superhorizons' in recognition of certain regularities in the development of both faunal associations and palaeoenvironmental conditions within a major sedimentary basin or palaeobiogeographical region or province.

### 3.2. Permian in the Kolyma–Omolon Terrane

Permian sedimentary rocks occur widely in this region and their lithofacies may be distinguished as two primary types: one dominated by shallow water marine carbonate rocks deposited on uplifted areas of the terrane, and the other dominated by deep-water clastic sediments found more commonly in the flanking areas of the terrane, especially on its eastern marginal areas where a complete succession of the Permian System is present (Ganelin in Kotlyar and Stepanov, 1984). The Permian stratigraphy and biostratigraphy of this terrane have been summarized and reviewed comprehensively by Ustritskiy (1971), Ganelin (in Kotlyar and Stepanov, 1984), Kashik et al. (1990), Ganelin (1997), Biakov (2000, 2004), Ganelin et al. (2003), and Ganelin and Biakov (2006). Of these works, the recent paper by Ganelin et al. (2003) was probably most significant in that it has erected a composite biostratigraphical framework for the Permian of the Kolyma–Omolon region, with a view to extending it to the whole NE Asian territory as a regional standard. This newly proposed framework, which is adopted here, divides the Permian sedimentary succession into four superhorizons and nine horizons (Table 2), all of which have been defined primarily on the basis of brachiopod and bivalve faunas, supplemented by data from foraminiferal, ammonoid and bryozoan faunas.

#### 3.2.1. The Munugudzhakian Superhorizon

This superhorizon is named after the Munugudzhak Formation, which at its type locality is composed of a 70 m (including unexposed intervals) thick sequence of richly fossiliferous sandstone beds (Biakov, 2005). The superhorizon has been divided into two horizons based on the development of its marine faunas: the Orochian and Ogonerian horizons, in ascending order. Both horizons are confined to sedimentary units of relatively deep-water facies on the southeastern flanks

Table 2
Ages and correlation of Permian marine biostratigraphical successions in East and NE Asia (vertically lined boxes indicate times of non-marine deposition or erosion

| Internat. | Tethys | Russian | Kolyma-Omolon Terrane (Kashik et al., 1990; Ganelin et al., 2003) | Verkhoyansk Fold Belt (Klets et al., 2001b; 2006) | Transbaikal-C. Mongolia (Kotlyar et al., 2002; Afanas'yeva et al., 2003) | Bureya-Jiamusi Terrane (SE Mongolia-NE China) (Manankov, 1998, 1999; Shen et al., 2006) | Xingkai Terrane (Kotlyar et al., 1999; 2003; Wang et al., 2000; 2004) | South Kitakami Belt, NE Japan (Kimura, 1991; Ehiro, 1998; Tazawa, 2002) |
|---|---|---|---|---|---|---|---|---|
| Chang. | Doras. | Tatarian | Kolymian Superhorizon; Khivachian Horizon: *Stepanoviella paracurvata* Zone / *Intomodesma costatum* Zone | ????; Khalpirkian Horizon: *Crassispirifer monumentalis* Zone / *Intomodesma costatum* Zone | ????; Zabaikalskiy; Binder: non-marine; *Attenuatella* sp. *Polidevcia zabaikalica* | Linxin Fm: non-marine | Lyudyanza; Kaishantun Fm: *Huananoceras*, *Iranites*; *Clarkina* cf *deflecta*; *Colaniella parva* Assemblage | Toyoma Series; Nakoshi.: *Colaniella parva* Zone / *Cyclolobus* ?*Paratirolites*; *Eolyttonia, Megousia, Paramarginifera* |
| Wuchia. | Dzhulf. | Tatarian | Kolymian Superhorizon; Khivachian Horizon: *Maitaia tenkensis* Zone | Khalpirkian Horizon: *Maitaia tenkensis* Zone | Zabaikalskiy / Togotuisk.; Binder: non-marine | Linxin Fm: non-marine | Lyudyanza; Kaishantun Fm: *Cyclolobus*, *Xenodiscus*; *Clarkina* cf *orientalis*; *Anidanthus -Squamularia* Zone | Toyoma Series; Maeham.: *Xenodiscus*, *Araxoceras*, *Stacheoceras*; No brachiopods found |
| Capitan. | Midian | Tatarian | Kolymian Superhorizon; Gizhigian: *Maitaia bella* Zone; *Cancrinellodies obrutschevi -C. curvatus* Zone | Dulgalakh. Horizon: *Maitaia bella* Zone; *Cancrinellodies obrutschevi -C. curvatus* Zone | Togotuisk. / Sosuche.; Binder: *Timorites* / *C.* cf. *curvatus*; *C. obrutschevi-Attenuatella alexivi* Ass. | Solonk. / Tsagan-Ula; Yihewusu: *Schwagerina-Codonofusiella*; *Timorites*; *Richthofenia cornuformis-Enteletes andrewsi-Echinauris nucleolus* Ass. | Chandalaz; Dasuangou Fm: *Meta-Lepi.*, *Parafusu.*; *Roadoceras, Tomorites*; *Clarkina* cf. *bitteri*; *Prorichthofenia ussrica* Zone | Kanokura Series; Iwaizakian: *Lepidolina multiseptata* Z.; *Timorites*; Predominantly Cathaysian-type brachiopod fauna |
| Word. | Murg | Kazanian | Omolonian S. H.; Bo.: *Magdania bajkurica* Z.; Olyn.: *Terrakea korkodonensis* Z., *Terrakea borealis* Z. | Delendzhian Horizon: *Tumarinia zavodovskyi* Z.; *Terrakea korkodonensis* Z.; *Terrakea borealis* Zone | Sosuche. / Antiinskiy; Tsagantemet: *Magdania baikurica - M. modotonensis* Ass.; *Terrakea korkodonensi*, *Terrakea arguta* Ass. | Tsagan-Ula; Zhesi: *Monodiexodina sutchanica* Zone; *Road-Waggeno*; *Mesogondolella asserata*; *Spiriferella-Kochiproductus -Yakovlevia* Zone | Chandalaz; Dasuangou Fm: *Monodiexod.-Metadoliolina*; *Waggenoceras -Timorites* Ass.; *Mesogondolella Asserata*; *Leptodus-Spiriferella -Yakovlevia* Ass. | Kanokura Series; Kattisawan: *Monodiexodina & Colania* Zones; *Timorites-Cibolites-Waagenoceras* Ass.; *Leptodus nobilis* Zone (mixed fauna) |
| Road. | Kuber. | Kazanian | Omolonian S. H.; Russco-: *Omolonia snjatkovi* Z., *Mongolosia rusiensis* Z. | Delendzhian Horizon: *Mongolosia rusiensis* Z. | Antiinskiy; Tsagantemet: *Mongolosia morenkovi* Assemblage | Tsagan-Ula; Baogete: *Yakovlevia unsinuata-Waagenoconcha humboldt* Assemblage; *Daubichites, Paragastrioceras* | Vladiv.; Dasuangou Fm: *Daubichites orientalis* | Sakamotozawa Series; Kabayaman Stage: *Pseudofusulina fusiformis* Zone |
| Kungu. (s.l.) | Bolorian | Kung.-Ufimian | Dzhigdalinian S.H.; Khalalian: *Kolymaella ogonerensis* Zone, *Megousia kuliki* Zone | Tumarian Horizon: *Kolymaella ogonerensis* Zone; *Megousia kuliki* Zone; *Anidanthus aagardi* Z. | Kizhiginsk-Alentui.: non-marine | Khovsgol; Baogete / Sanmianjing: *Misellina claudiae* Zone; *Kolymaella ogonorensis-Rhynoleichus dsilensis* Ass. | Abrek; Dasuangou Fm / ?: non-marine; *Primorewia-Tomiopsis* Assemblage / *Epijuresanites* Ass. | Sakamotozawa Series; Kabayaman Stage: *Pseudofusulina fusiformis* Zone |
| Artinskian | Bolorian / Artinskian | Artinskian | Dzhigdalinian S.H.; Koargy.: *Anidanthus aagardi* Z., *Jakutoproductus burgaliensis* Zone | Echian Horizon: *Jakutopro. burgaliensis-Spirelytha kislakovi* Z. | Kizhiginsk-Alentui.: non-marine | Khovsgol; Sanmianjing: *Agathiceras-Artinskia-Paragastrioceras*; *Anidanthus aagardi-P. nativa* Assemblage | Abrek / Dunai; Shanxiuling: non-marine | Sakamotozawa Series; Kabayaman Stage: *Chalaroschwagerina vulgaris* Zone |
| Artinskian | Artinskian | Artinskian | Munugudzhakian S.H.; Ogonerian: *Jakutoproductus rugosus* Zone | Echian Horizon: *Jakutoproductus rugosus-Alispiriferella gydanensis* Zone | Zhipkhoshinskiy; Adatzag: *Jakutoproductus zabaicalicus-Anidanthus halinae* Assemblage | "Totoshan"; Gegenaobao: *Jakutoproductus* Assemblage | Dunai; Shanxiuling: **Shanxiuling Fm.**: displaced limestone blocks with abundant fusulinoidean fossils ranging in age from probably Late Carboniferous to Guadalupian) | Sakamotozawa Series; Kawaguchian: *Robustoschwagerina schellwieni* Zone |
| Sakmarian | | | Munugudzhakian S.H.; Ogonerian: *Jakutoproductus terekhovi* Zone, *Jakutoproductus insignis* Zone | Khorokytian Horizon: *Jakutoproductus verchoyanicus-Spirelytha fredericksi* Zone | Zhipkhoshinskiy; Adatzag: *Jakutoproductus zabaicalicus-Anidanthus halinae* Assemblage | "Totoshan"; Gegenaobao: *Jakutoproductus* Assemblage | Dunai; Shanxiuling (?): non-marine, Shanxiuling Fm. | Sakamotozawa Series; Kawaguchian: *Robustoschwagerina schellwieni* Zone |
| Asselian | | | Munugudzhakian S.H.; Orochian: *Verchojania expositus* Z., *Verchojania mirandus* Z. | Khorokytian Horizon: *Bulunites mezhvickii* Assemblage | non-marine | Agui-Ula; Amushan: *Pseudoschwagerina* Zone | Shanxiuling ?: non-marine ? | ??? |

Question marks indicate possibility of age range extension of certain formations or biozones).

of the Kolyma–Omolon Terrane, and are dominated by sandstone and volcaniclastic rocks. Marine faunas are not diverse, but distinctive in that the brachiopod genus *Verchojania* made its last appearance, while *Jakutoproductus* appeared for the first time (Ganelin and Biakov, 2006). This implies that the phylogenetic transition of the two related genera in the family Plicatiferidae had been completed during this time, most likely at the boundary between the two horizons. At present, the age of the Orochian Horizon is poorly constrained, due to lack of biostratigraphically diagnostic species. However, the age of the Ogonerian Horizon is well defined by the appearance of some ammonoid species, including *Bulunites* sp., *Uraloceras omolonense,* and *U. kolymense* (Ganelin et al., 2001; Bogoslovskaya and Boiko, 2002), all pointing to a Sakmarian age.

### 3.2.2. The Dzhigdalinian Superhorizon

The Dzhigdalinian Superhorizon is much more extensively distributed in the Kolyma–Omolon Terrane and occurs in both shallow-water (mainly limestone and sandstone rocks) and deep-water (siltstone, sandstone and volcaniclastic sediments). A succession of four brachiopod zones have been recognized (Table 2). The Koargychanian Horizon is defined by the *Jakutoproductus burgaliensis* Zone in the lower part and the *Anidanthus aagardi* Zone in the upper. Within both zones there are abundant brachiopods, many of which also occur in the Russian Platform and the Urals, for example: *Sowerbina, Waagenoconcha,* and *Spiriferella*. The two zones, however, are clearly separable, because the *Anidanthus aagardi* Zone completely lacks *Jakutoproductus* on the one hand and, on the other, contains first appearance of *Inoceramus*-like bivalves, notably represented by the genus *Aphanaia*, which locally form conquina beds in hydrogene sulphate limestones (Ganelin, 1997; Ganelin and Biakov, 2006). Ammonoids also became relatively more common, compared with the underlying horizons, with *Paragastrioceras josse* occurring in the Koargychanian Horizon and *Epijuresanites, Neouddenites, Tumaroceras,* and *Uraloceras* in the Khalalinian Horizon. The ammonoid fauna as a whole has been closely compared with similar faunas of the Russian Platform and the Urals, suggesting a direct correlation with the Kungurian Stage of the Cisuralian (Bogoslovskaya et al., 1999; Kutygin et al., 2002).

### 3.2.3. The Omolonian Superhorizon

This superhorizon is distinguished from the underlying Dzhigdalinian Horizon most characteristically by the abundant and ubiquitous occurrences of Kolymiid bivalves and the emerging abundance of thin-ribbed linoproductoid brachiopods. Three horizons have been delineated, based on the stratigraphic distribution of key fossil groups (Table 2). The Russco–Omolonian Horizon is defined by the first appearance of a number of brachiopod genera, notably *Mongolosia* and *Terrakea*, both being thin-ribbed linoproductoid genera, locally forming coquina beds. Also significant is the first appearance in this horizon of the ammonoid genus *Sverdrupites*. This is a biostratigraphically important genus characteristic for the lower Kazanian Stage of the Russian Platform and northern Urals, where it is associated with Roadian conodonts (Bogoslovskaya et al., 1999; Kotlyar et al., 2004; Grunt, 2005). The Olynian Horizon is distinguished particularly by abundant *Terrakea* in association with the bivalve *Kolymia* and the last appearance of *Aphanaia*. In many respects, the overlying Bocharian Horizon marks a major biostratigraphical boundary in view of its high species diversity, origination of numerous new taxa and extinction of some enduring forms. Newly emerged brachiopod genera include *Cancrinelloides* and *Kungaella* (Ganelin et al., 2003). *Magadania* became diversified in place of *Terrakea*, which saw its last occurrence in this horizon. Among the bivalves, the Kolymiid fauna, dominated by *Kolymia*, became further diversified, with the introduction of a number of new genera including *Myonia* and *Maitaia*; locally they appear to have formed dense benthic communities now represented by the 'kolymic limestone' of Ganelin (1997).

No ammonoids have been reported from either the Olynian or Bocharian horizon, but the top of the latter is distinctively marked by a palaeomagnetic level that has been correlated to the $N_1P$ Orthozone of the Illawarra Hyperzone (Loshikina et al. in Kashik et al., 1990). The same paleomagnetic zone has also been traced through the Lower Tatarian of the Russian Platform and the base of the Capitanian Stage in the Guadalupian Mountains in southwest USA (Molostovskii, 2005). Thus, this, combined with the ammonoid data (*Sverdrupites*) from the underlying Russco–Omolonian Horizon, would constrain the ages of both Olynian and Bocharian horizons to be within the Wordian.

### 3.2.4. The Kolymian Superhorizon

The Omolonian–Kolymian boundary in NE Asia appears to correspond to a major extinction event in that many of the genera that prevailed in the underlying horizons had completely vanished by the end of the Omolonian (Biakov and Ganelin, 1998). Notable examples of extinct genera are *Kolymia* (s.s.) among the bivalves; and *Terrakea*, *Magadania*, *Omolonia* and *Mongolosia* among the brachiopods. On the other hand, some other genera that emerged prior to the boundary became the leading forms of the Kolymian Superhorizon: for example, *Cancrinelloidies*, *Spitsbergiana* and *Stepanoviella* among the brachiopods; and *Maitaia* and *Intomodesma* among the bivalves.

The Kolymian Superhorizon has been divided into two horizons, distinguished by significant differences both in taxonomic composition and lithology. The Gizhigian Horizon is most distinctively characterized by extensive diamictites. The diamictites, previously interpreted by some as tillites (e.g. Mikhaylov and Ustritskiy, 1970), are now generally considered to be debris-flow deposits formed in offshore to continental slope environments (Biakov, 2003). The fauna of the Gizhigian Horizon is marked by low diversity, dominated by representatives of *Cancrinelloides* in shallow-water facies and *Spitsbergiana* in relatively deeper-water settings. Among the bivalves, *Maitaia bella* is particularly common throughout the entire horizon. The occurrence of this bivalve species is significant in terms of dating this horizon. In the Amur area of the Khabarosvk region (see below), this bivalve species occurs together with *Cancrinelloides obrutshewi* and *Timorites*, the latter being an index ammonoid genus for the Capitanian (Kotlyar et al., 1999). The Khivachian Horizon is poor in fossils in its lower part, but has yielded a rich fauna in the upper part consisting of some brachiopods (mainly *Stepanoviella paracurvata*), bivalves (mainly species of *Intomodesma* and *Polidevcia*) and a highly diversified foraminiferal assemblage of more than 40 species (Karavayeva in Kashik et al., 1990). From the very top of this horizon (the Pautovaya Formation), Biakov (2001) has reported *Claraia* aff. *primitiva,* a species originally described from the uppermost Changhsingian of South China. The discovery of this species has led Biakov to conclude that unlike many other Permian sections in NE Asia, the Permian–Triassic boundary in parts of the Kolyma–Omolon Terrane is probably continuous as it is in many sections of South China.

### 3.3. Permian in the Verkhoyansk fold belt and Okhotsk Terrane

The Permian stratigraphy of the Verkhoyansk fold belt and the Okhotsk Terrane (Fig. 2) share greater similarities to each other than they do to the Kolyma–Omolon Terrane (Klets et al., 2000); therefore they are treated together in this section. In general, the Permian system in the fold belt is characterized by a succession of eustatically-mediated megacycles or super-sequences, believed to have accumulated in a vast sedimentary basin on the eastern passive continental margin of Siberia (Budnikov et al., 1994). This succession includes a diverse range of sedimentary facies from continental through marginal marine, deltaic, shallow marine to offshore and deep-marine facies. Despite its enormous spatial facies variations from north to south and from to west to east, a broad biostratigraphical unity has been recognized from fossil assemblages throughout the entire fold belt including the Okhotsk Terrane (e.g. Klets et al., 2000, 2001a,b). By using this biostratigraphical unity, the Permian succession of the Verkhoyansk fold belt has been divided into six horizons (Klets et al., 2006) (Table 2).

#### 3.3.1. The Khorokytian Horizon

The Khorokytian Horizon is a 250–400 m succession of sandstone, siltstone and mudstone. Marine fossils are abundant in this horizon and dominated by brachiopods of the *Jakutoproductus verchoyanicus–Spirelytha fredericksi* Zone. Co-occurring with the brachiopods are a few ammonoid species dominated by the genera *Bulunites* and *Somoholites* (Kutygin, 1999, in press) and a bivalve assemblage (Kutygin et al., 2002) characteristic of the *Palaeoneilo parentica* Zone and the *Merismopteria permiana*-bearing beds of the Kolyma–Omolon Terrane (Biakov, 2000). The age of the horizon has been determined as Asselian to Early Sakmarian, principally by ammonoid species of *Juresanites* and *Tabanlites*, both comparable to species from the type Asselian to lower Sakmarian of the south Urals (Kutygin, 2006).

#### 3.3.2. The Echian Horizon

This horizon comprises a succession of mudstone and siltstone, grading upwards to coarse-grained sandstone and conglomerate (Klets et al., 2001b). The horizon contains abundant marine fossils, especially brachiopods, bivalves and ammonoids. Two brachiopod assemblage zones have been distinguished (Klets et al., 2001a): *Jakutoproductus rugosus–Alispiriferella gydaensis* Zone, followed by the *Jakutoproductus burgaliensis–Spirelytha kislakovi* Zone. In general, the most distinctive features of the brachiopod faunas of this horizon are the last occurrence of *Jakutoproductus* and the first appearance of a number of significant spiriferid genera such as *Kungaella*, *Kyutepia* and *Cyrtella* (Klets, 1998; Solomina, 2001). The brachiopod assemblages are also accompanied by ammonoids, mainly represented by the species of *Agathiceras*, *Andrianovia*, *Metalegoceras* and *Uraloceras* in the lower part, and *Eotumaroceras*, *Neoudde-nites*, *Paragastrioceras* and *Uraloceras* in the upper (Kutygin, in press). Both ammonoid assemblages are readily correlatable with the Late Sakmarian–Artinskian ammonoid faunas of the south Urals. The uppermost part of the horizon (the Khabakh Formation) contains only sparse brachiopods and ammonoids, but bivalves are common, dominated by species of *Aphanaia*. This bivalve assemblage can be directly correlated with the *Aphanaia lima* Zone of the Kolyma–Omolon Terrane, of latest Artinskian to early Kungurian age (Biakov, 2000). Therefore, taking the evidence from brachiopods, ammonoids and bivalves into account, the age of the Echian Horizon would span from Late Sakmarian to earliest Kungurian (Table 2).

#### 3.3.3. The Tumarian Horizon

This horizon incorporates three formations (the Orol, Takamkyt and Kadachan formations in ascending order) with a total thickness varying between 210 and 750 m (Klets et al., 2006). The horizon is dominated by alternating sandstone and siltstone beds, with marine fossils occurring throughout. A succession of three brachiopod assemblage zones have been recognized consistently by brachiopod workers in different parts of the Verkhoyan fold belt (Klets et al., 2000, 2001a,b, 2006; Solomina, 1997, 2001), namely the *Anidanthus aagardi* Zone, *Megousia kuliki* Zone, and the *Kolymaella ogonerensis* Zone, in ascending order (Table 2). Among the brachiopods the most characteristic features for this horizon are the first appearance of a new licharewiid genus *Neotumarinia* (Solomina, 2001) and abundant occurrences of *Anidanthus* and *Megousia*. Associated with the lower two brachiopod assemblages are abundant ammonoids and, locally, also bivalve faunas. The ammonoid fauna of the horizon as a whole is most characteristically defined by the first and abundant appearance of *Tumaroceras* and *Epijuresanites*, allowing the recognition of the *Tumaroceras yakutorum* assemblage in the lower part and the *Epijuresanites musalitini* assemblage in the upper (Kutygin, 2006). Both of these ammonoid assemblages enable a direct correlation of the Tumarian Horizon with the Kungurian (s.l.) Stage of the Russian Platform (Andrianov, 1985; Grunt, 2005; Kutygin, 2006).

*3.3.4. The Delendzhian Horizon*

This horizon is defined by the origin of many new brachiopod genera and species, notably *Mongolosia*, *Terrakea*, and *Tumarinia*, and, in the upper part of this horizon, *Batugania* and *Cancrinelloides*, allowing the delineation of four brachiopod zones, all of which can be directly correlated with the same zones in the Kolyma–Omolon Terrane (Klets et al., 2006) (Table 2). The *Mongolosia rusiensis* Zone and the two succeeding *Terrakea* zones are associated with an ammonoid assemblage dominated by *Sverdrupites* species. This ammonoid fauna locally (e.g. in the Baraja River Basin in the southern Verkhoyan) also contains species of *Daubichites* (Kutygin, 2006). It is of note that *Sverdrupites* and *Daubichites* have recently been found together in the Lower Kazanian Stage in the Volga region of the Russian Platform (Leonova et al., 2002), where a low-diversity conodont fauna, comparable to the Roadian conodont fauna of the USA, has also been reported (Grunt, 2005). This would suggest a direct alignment of the lower Delendzhian Horizon with the Roadian. The upper Delendzhian subhorizon is characterized by a brachiopod assemblage dominated in abundance by *Tumarinia zavodovskyi*, along with *Cancrinelloides juregensis*, *Strophalosia sibirica*, and *Wimanoconcha wimani* (Klets et al., 2006). Associated bivalves are dominated by species of *Kolymia* and, to a lesser extent, *Maitaia* and *Myonia*. However, there are no ammonoid species found in this subhorizon; therefore, its age has not been resolved with certainty, but it is clearly constrained to be within Roadian–Wordian by the Roadian *Sverdrupites–Daubichites* fauna below and the Capitanian *Cancrinelloides curvatus–C. obrutschewi* Zone above (see below).

*3.3.5. The Dulgalakhian Horizon*

This horizon is typically exposed in the central Verkhoyansk region, where it is dominated by mudstone in its lower part, and inter-bedded conglomerate, sandstone and siltstone in the upper, varying in thickness between 380 and 900 m (Klets et al., 2006). This horizon is clearly distinguished from the underlying horizon by the dominance of *Cancrinelloides* species and conspicuous absence of *Kolymia*. The *Cancrinelloides*-dominated brachiopod assemblage can be correlated directly with the *Cancrinelloides obruttschevi–C. curvatus* Zone of the Kolyma–Omolon Terrane. Likewise, the associated bivalve fauna of the Dulgalakhian Horizon also shares many species with the *Maitaia bella* Zone of the Kolyma–Omolon Terrane, hence allowing a direct correlation of the Dulgalakhian Horizon with the Gizhigian Horizon of the latter region. No in situ ammonoid faunas are known from this horizon, but Popow (1970) reported *Mexicoceras* (*Paramexicoceras*), of Wordian–Capitanian age, from alluvium within the outcrop area of this horizon. This may suggest that the Dulgalakhian Horizon could be of middle to late Guadalupian age. This age inference is consistent with the fact that key elements of both the brachiopod and bivalve faunas of this horizon, including the nominal index species of both faunas, also occur in the Transbaikal and Khabarovsk areas of SE Russia, where they co-occur with *Timorites*, a diagnostic ammonoid genus for the Capitanian (Kotlyar et al., 1999) (Table 2).

*3.3.6. The Khalpirkian Horizon*

This recently recognized horizon represents the uppermost part of the Upper Palaeozoic succession in the Verkhoyansk fold belt, with its type section at the Baraiy River in the southern part of eastern Verkhoyansk region (Solomina, 1997). It is primarily a succession of sandstone, siltstone and, towards its upper part, conglomerate, locally reaching 750 m thick. Bivalves become dominant in this horizon, along with a relatively small brachiopod assemblage characterized by *Crassispirifer monumentalis*, *Grantonia grandis* and *Marginalosia*? *magna*. Two bivalve assemblages have been recognized, and both can be correlated directly with the same two bivalve zones of the Khivachian Horizon of the Kolyma–Omolon Terrane. The lower *Maitaia tenkensis* Zone consists principally of species of *Atomodesma*, *Maitaia, Polidevcia* and *Streblopteria*, while the succeeding *Intomodesma costatum* Zone is defined by numerous species of *Intomodesma, Myonia* and *Polidevcia* (Klets et al., 2006).

As there are no ammonoids found in this horizon, and the brachiopod and bivalve faunas outlined above, also do not offer conclusive correlations with those from the Russian Platform, the age of this horizon remains ambiguous. However, Biakov (2000) considered that many of the bivalve species of the *Intomodesma postpartum* Zone have Late Permian (Late Tatarian in his terminology) Tethyan aspects. If this interpretation is followed, the entire Kalpirkian Horizon may be assigned to the Lopingian, in agreement with the Capitanian age for the underlying Dulgalakhian Horizon (Table 2).

*3.4. Permian in the Transbaikal and North Mongolia region*

As already indicated, much of the geology of the Transbaikal region to the east of Lake Baikal in southern Siberia can be correlated directly with those of central and northern Mongolia. This is certainly true for the Permian as many of the Permian sedimentary units in Transbaikal extend along strike into north and central Mongolia; therefore, it is not surprising to see that these two areas share much of the characteristics in their Permian sedimentary sequences and marine faunas. In both areas, the Permian marine succession has been divided into a number of horizons: five for Transbaikalia (Kotlyar et al., 2002) and four for central and northern Mongolia (Afanas'yeva et al., 2003; Manankov et al., in press) (Table 2). The lowermost horizon in both areas is defined by the shell beds of *Jakutoproductus*. In Transbaikalia, these shell beds have been named the *Jakutoproductus zabaikalicus–Anidanthus halinae* assemblage (Kotlyar et al., 2002) while similar shell beds in central and northeastern Mongolia are grouped into the *Jakutoproductus adatsagensis–J.ganelini* assemblage (Manankov, 2004). Other common brachiopod species restricted to both assemblages also include *Anidanthus boikovi, Tomiopsis laevis* and *Costatumulus sidorkini*. The presence and dominance of *Jakutoproductus* in both assemblages strongly suggests a correlation with the *J. verchoyanicus–Spirelytha fredericksi* and *J. rugosus–Alispiriferella gydanensis* zones of the Verkhoyansk fold belt, or the *J. insignis, J. terekhovi* and *J. rugosus* zones of the Kolyma–Omolon Terrane (Table 2).

In Transbaikalia, stratigraphically succeeding the Zhidkhoshinsky Horizon are the Kizhiginskiy and Alentuiskiy horizons in ascending order, which are distinguished from the underlying horizon principally by possessing extensive volcaniclastic sediments and volcanics bearing macroplants of Artinskian to Kungurian age (Kotlyar et al., 2002). The next marine unit succeeding the nonmarine interval is the Antiinskiy Horizon, a succession of coarse-grained sandstone and conglomerate grading upwards into siltstone and tuff (Kotlyar et al., 2002). Brachiopods are sparse within this horizon, represented mainly by *Kaninospirifer* sp. (= '*Neospirifer* ex.gr. *neostriatus*' of Kotlyar et al., 2002), *Olgerdia* sp., *Rhynchopora lobjaense*, and *Terrakea* sp. The low diversity and particularly the lack of biostratigraphically characteristic species in this brachiopod assemblage hampers its correlation with any known Permian brachiopod faunas in the region. The bryozoan assemblage from the same horizon, on the other hand, is very distinctive, as it is marked by abundant *Dyscritella turbini*, a feature reminiscent of the middle and upper parts of the lower Omolonian Superhorizon of the Kolyma–Omolon Terrane (Kotlyar et al., in press-b). This correlation is also supported by the associated bivalve assemblage dominated by *Kolymia* cf. *inoceraformis* and *K. plicata* (Biakov, 2002), both being key elements of the *Kolymia plicata* and *K. inoceramiformis* zones of the Russco–Omolonian and Olynian horizons in the Kolyma–Omolon Terrane.

The Sosucheiskiy Horizon, conformably overlying the Antiinkiy Horizon, is characterized by an abundant fauna comprising mainly brachiopod, bivalve and bryozoan species (Kotlyar et al., 2002). Brachiopods are particularly common in this fauna and also varied stratigraphically, allowing the recognition of two main brachiopod assemblages: the *Magadania bajkurica–M. modotonensis* in the lower part, followed by the *Cancrinelloides obrutchewi–Attenuatella olexivi* assemblage, which can be correlated, respectively, with the *Magdania bakjurica* Zone and the lower part of the *Cancrinelloides obrutschevi–C. curvatus* Zone of the Kolyma–Omolon Terrane, or the *Tumarinia zavodovskyi* and *Cancrinelloides obrutschevi–C. curvatus* zones of the Verkhoyansk fold belt (Table 2).

In northeastern and central Mongolia, the stratigraphical interval broadly equivalent to the Antiinskiy and Sosucheiskiy horizons is represented by the Tasantemetian and Binder horizons (Manankov in Afanas'yeva et al., 2003). The Tsagantemet Horizon is defined by a succession of four brachiopod assemblages (Table 2). Interestingly, the lower three of these four assemblages have not been recognized from Transbaikalia, but they can be correlated directly with the lower four brachiopod zones of the Omolonian Superhorizon in the Kolyma–Omolon Terrane (Table 2). The uppermost part of the Tsagantemet Horizon can be compared directly with the lower part of the Sosucheiskiy Horizon, as both are characterized by the occurrence of *Magdania bajkurica–M. modotonensis* assemblage. The Binder Horizon tops the marine part of the Permian in central and northeastern Mongolia and is characterized by a brachiopod assemblage of *Cancrinelloides obrutschevi, C. licharewi, Baituganía duseevi* and *Neospirifer invisus* (Manankov in Afanas'yeva et al., 2003), which as a whole can be correlated with the *Cancrinelloides obrutchewi-Attenuatella olexivi* assemblage of Transbaikalia (Table 2).

Unlike central and northeastern Mongolia, marine deposition persisted into the late Guadalupian and even the Lopingian in Transbaikalia, as evidenced by two distinctive brachiopod assemblages, one characterizing the Togotuiskiy Horizon and the other defining the Zabaikalskiy Horizon—the highest marine unit for the entire Mongolian–Transbaikal region (Kotlyar et al., 2002). The lower brachiopod assemblage occurs in the upper part of the Togotuiskiy Horizon and is composed mainly of *Attenuatella olexivi, Cancrinelloides* cf. *curvatus, Penzhinella micluchomanclayi, Rhynchopora lobjaensis*, and some large but poorly preserved *Neospirifer* (Kotlyar et al., 2002), as well as some rare *Maitaia bella*, abundant *Polidevcia zaikalica* (Biakov, 2002), and rare *Timorites* sp. and *Neopronorites* sp. (Kotlyar et al., 1999). Clearly, both the brachiopod and bivalve assemblages are correlative with respective faunas of the Gizhigian Horizon of the Kolyma–Omolon Terrane or the Dulgalakhian Horizon of the Verkhoyansk fold belt (Table 2). The presence of *Timorites* in the Togotuiskiy Horizon suggests a Capitanian age for this horizon and for its associated brachiopod *Cancrinelloides curvatus* Zone and the bivalve *Maitaia bella* Zone (Table 2).

Marine fossils are rare in the Zabaikalskiy Horizon, represented by only one unidentified brachiopod species (*Attenuatella* sp.) and several bivalve species, including the dominant and endemic *Polidevcia zabaikalica* (Biakov, 2002). This much impoverished fauna therefore does not offer a conclusive age indication; however a general Late (but not latest) Permian, probably early Changhsingian, appears reasonable, in view of the fact that *Polidevcia magna*, a species closely comparable to *Polidevcia zabaikalica,* is a key element of the late Khivachian subhorizon in the Kolyma–Omolon Terrane (Biakov, 2000), of Changhsingian age.

### *3.5. Permian in the Bureya–Jiamusi Terrane and the Mongolia–Hinggan fold belt (SE Mongolia, NE China and the Amur area of SE Russia)*

The Permian marine successions of SE Mongolia, main parts of NE China (Inner Mongolia and parts of Jilin and Heilongjiang provinces) and the Amur area of SE Russia (Fig. 2) are sufficiently similar to one another in both lithostratigraphy and biostratigraphy that they are described together.

#### *3.5.1. SE Mongolia*

Among the three areas, perhaps the best exposed and also one of the best studied Permian marine successions is in SE

Mongolia along the border with China, where the Permian has been divided into five horizons (Pavlova et al., 1991; Manankov, 1998, 1999; Manankov et al., 2006) (Table 2). The Agui-Ula Horizon, at the base of the Permian succession, is a succession of mainly reefal limestone, intercalated with minor sandstone and siltstone. The horizon has yielded a very rich fusulinoidean fauna dominated by species of *Daixina, Pseudoschwagerina* and *Sphaeroschwagerina* (Solov'eva in Pavlova et al., 1991). This fauna has been compared closely with similar fusulinoidean faunas from the Asselian of the south Urals and also those from North China and South China. The Totoshan Horizon was supposed to lie stratigraphically above the Agui-Ula Horizon according to Solov'eva (in Pavlova et al., 1991), who characterized the horizon with the *Monodiexodina linearis* Zone of supposedly Sakmarian–Artinskian age (see also Manankov, 1999). However, Ueno (2006), after examining the SE Mongolian *Monodiexodina* species described by Solov'eva (in Pavlova et al., 1991), considered them to be referable to *Eoparafusulina* and assigned the '*Monodiexodina linearis*' Zone of Solov'eva to the Asselian (up to early Sakmarian), hence, being part of or equivalent to the Agui-Ula Horizon.

The Khovsgol Horizon is characterized by terrigenous marine sediments (sandstone and siltstone), with abundant brachiopods and some bryozoans and bivalves, but lacking fusulinoideans. Manankov (1998) established the brachiopod *Megousia aagardi-Paramarginifera nativa* Zone to represent this horizon and correlated it directly with the *Anidanthus aagardi* and *Megousia kuliki* zones of the Verkhoyansk fold belt and the Kolyma–Omolon Terrane in NE Asia (Table 2). The Tsagan-Ula Horizon occurs widely in SE Mongolia and is dominated by calcareous sandstone, siltstone and mudstone, with some intercalations of conglomerate and limestone (Manankov, 1999). Two brachiopod assemblages have been distinguished within the horizon: the *Liosotella decima-Waagenoconcha angustata* Zone in the lower part, and the *Alispiriferella lita-Kaninospirifer adressum* Zone in the upper. Both zones are dominated by species characteristic of the Boreal Realm, therefore allowing ready correlation between these two zones with their counterparts in the Verkhoyansk fold belt and the Kolyma–Omolon Terrane.

The last marine Permian unit in SE Mongolia is named the Solonker Horizon, a relative thin interval (about 23 m thick at its type locality; Manankov, 1999) of alternating limestone, calcareous siltstone, mudstone and sandstone. The horizon is characterized by the *Echinauris jisurensis* Zone, a brachiopod assemblage dominated by species of Boreal aspects, but also mixed with some elements of the palaeoequatorial Cathaysian Province such as *Compressoproductus* cf. *corniformis, Enteletes* sp. and *Prorichthofenia ussurica*. As will be discussed further below, this mixed nature of faunal characteristics appears to mark a regionally widespread and comparable stratigraphic horizon in East Asia, making it seemingly the most correlatable biostratigraphical interval for the region (Shi et al., 1995; Kotlyar et al., 2003). The age of the *Echinauris jisurensis* Zone cannot be decided in SE Mongolia, because of the lack of biostratigraphically diagnostic species associated with this zone; however, by its correlation with similar brachiopod zones in the Zhesi Formation of Inner Mongolia and the lower Chandalaz Horizon in South Primorye, where the age of the comparable zones is tightly constrained by the associated fusulinoidean, ammonoid and conodont faunas (see below), the *Echinauris jisurensis* Zone can be safely assigned to the Wordian (Table 2).

### 3.5.2. NE China

Permian marine sedimentary rocks of varying ages are distributed widely in NE China, occurring in both extensive, contiguous outcrop sections and also in deeply buried sections some 1700 m beneath the surface in the Daqing Oil Fields of the Songliao Basin (see for example, Liao and Wan, 2002); they have also been reported from an isolated outcrop (101°03′E, 39°40′N) in the Badain Jaran Desert near the southwestern end of Inner Mongolia in NW China (Zhang, 1990). As shown by Li and Gu (1984), and Shen et al. (2006), the Permian sedimentary rocks in the region exhibits considerable lateral and stratigraphic variations in both lithofacies and biofacies, implying a variety of depositional and tectonic settings during the Permian. Despite these variations, Shen et al. (2006) have been able to establish a stratigraphic framework in which the various locally named Permian rock units can be correlated with considerable consistency throughout NE China, due to their broad biostratigraphical similarities.

In general, both the lithostratigraphy and biostratigraphy of the Permian System in NE China can be closely compared with that of SE Mongolia; these similarities include the basal Permian (the Agui-Ula Horizon and the Amushan Formation or equivalents in NE China) and also the upper part of the Middle Permian (i.e. the Tsagan-Ula and Solonker horizons in SE Mongolia and the Zhesi and Yihewusu formations or equivalents in NE China) (Table 2). However, there also exist some significant differences that require some discussion. First, there seem to be no strata in SE Mongolia that can be compared with the Gegenaobao Formation of central Inner Mongolia, in which a characteristic *Jakutoproductus* fauna is found (Shi et al., 2002). Although the detailed taxonomy of the Inner Mongolian *Jakutoproductus* is yet to be documented, the general aspect of the brachiopod fauna may be compared with some or all of the *Jakutoproductus*-based zones of NE Asia and central and northeastern Mongolia (Table 2). Strata in SE Mongolia that is possibly equivalent, at least in age, to the Gegenaobao Formation is the 'Totoshan Horizon' in which the '*Monodiexodina linearis*' Zone was supposed to occur (Solov'eva in Pavlova et al., 1991), but, as pointed out above, the so-called *Monodiexodina* species could all prove, according to Ueno (in press), to be *Eoparafusulina* of Asselian (up to Sakmarian) age.

The second major difference between the Permian of SE Mongolia and NE China lies in the Kungurian strata and faunas. In the southern part of NE China (Sanmianjing Formation of southern Inner Mongolia and the Shoushangou Fomation of central Jilin Province), the Permian strata of this age is characterized by the *Misellina claudiae* Zone, like those from the Qixia Formation of South China, while in SE Mongolia this fusulinoidean fauna is absent and there instead occurs two cool-water brachiopod faunas (*Anidanthus aagardi–P. nativa* and *Kolymaella ogonorensis–Rhynoleichus dsilensis* assemblages), both comparable to coeval faunas of the Verkhoyansk and Kolyma–Omolon regions (Table 2).

The last major difference in the Permian biostratigraphy between NE China and SE Mongolia is concerned with the *Monodiexodina sutchanica* fauna. This fusulinoidean fauna, occurring in the upper part of the Baogete Formation in Inner Mongolia and several other localities in NE China (Shen et al., 2006; Ueno, 2006), has not been found anywhere in SE Mongolia, where coeval strata (i.e. the Tsagan-Ula Horizon) are instead characterized by brachiopod assemblages of predominantly Boreal aspects (Manankov, 1999).

### 3.5.3. The Amur area of SE Russia

Although Permian sedimentary rocks are known to occur in the southernmost part of the Khabarovsk Territory (Fig. 1), information on the stratigraphy of these rocks is extremely limited. Kotlyar et al. (1999) reported a Permian section (Oskhtinskaya Formation) from an open cut in the Bolshie Range in the Amur area near Birobidzhan (Fig. 2), which contains a 4.2 m interval of predominantly sandstone with subordinate limestone. Within this interval, a distinctive succession of faunal assemblages has been recognized, comprising in ascending order a *Waagenoceras* assemblage, a *Timorites–Waagenoceras* assemblage, and a biogeographically mixed brachiopod-dominated assemblage of *Yakovlevia mammata*, *Wimanoconcha wimani*, and *Leptodus nobilis.* Of most significance is the co-occurrence in the *Timorites–Waagenoceras* assemblage of *Leptodus nobilis* and *Maitaia bella*, the former is a key species of the overlying mixed brachiopod fauna, while the latter is a key species of the *Maitaia bella* Zone in NE Asia. These co-occurrences and stratigraphic close proximity with the overlying mixed brachiopod fauna thus suggest strongly that both the mixed brachiopod fauna and the bivalve *Maitaia bella* Zone are of Capitanian age, as suggested by Kotlyar et al. (1999).

### 3.6. Permian in the Xingkai Terrane and surrounding fold belts (eastern Jilin Province of NE China, northeastern Korea and South Primorye of Far East Russia)

Permian sedimentary rocks are distributed widely in the vicinity of the Xingkai Lake along the border between NE China and SE Russia and also along the border areas between China, Korea and SE Russia (Fig. 1). Among these adjoining areas, the Permian succession in South Primorye may be taken as a general reference as it is one of the best exposed and documented Permian sequences in the region. The Permian here comprises five horizons: Dunay, Abrek, Vladivostok, Chandalaz, and Lyudyanza, in ascending order (Likharev and Kotlyar, 1978; Kotlyar et al., 2003) (Table 2). The Dunay Horizon is a 1100–3500 m succession of volcanics and volcaniclastic rocks (breccia, conglomerates, sandstone and siltstones), with locally abundant plant fossils comparable to those from the Sakmarian–Kungurian floras of the Kuznetsk Basin in southern Siberia (Kotlyar et al., 2006-a) (Fig. 1). The overlying Abrek Horizon is a thick sequence of predominantly continental to marginal marine facies with abundant plant fossils, intercalated in the middle part with mudstone and siltstone containing a small but distinctive brachiopod fauna of *Rhynchopora* sp., *Primorewia reschentnikovi*, and *Tomiopsis atlanichus* (author's personal collection). Although differing in species composition, this brachiopod assemblage can be correlated with the *Kolymaella ogonerensis–Rhynoleichus dsilensis* Zone in the Khovsgol Horizon of SE Mongolia, as they both contain *Primorewia reschentnikovi,* and *Tomiopsis atlanichus*. The age of this brachiopod assemblage has been determined by a small but significant ammonoid fauna found in direct association with the brachiopod assemblage. The ammonoid fauna, dominated by *Epijuresanites pilnikovensis* (Zakharov et al., 1999), is of great interest not only for its significance in indicating a Kungurian age by comparison with similar faunas from the Urals (Bogoslovskaya et al., 1999; Grunt, 2005), but also for its wide correlation value for this part of the Permian in East and NE Asia, as the same genus has also been found from the Khovsgol Horizon in SE Mongolia (where it was identified as *Gobiceras elenae* by Bogoslovskaya in Pavlova et al., 1991), the Tumarian Horizon of the Verkhoyansk fold belt, and the Dzhigdalinian Horizon of the Kolyma–Omolon Terrane (Table 2). It is curious, however, that *Epijuresanites* has not been found in NE China.

In the neighbouring areas of Vladivostok and southwestern Primorye, the Abrek Horizon is conformably overlain by the Vladivostok Horizon, a succession of volcanic rocks and tuffaceous sediments of nearshore and continental origin (Burago, 1990). The marine portions of the horizon contain a brachiopod assemblage dominated by *Yakovlevia mammata*, *Liosotella decimana*, *Waagenoconcha angustata*, *Rhynchopora tchernyshae*, *Alispiriferella lita, Spiriferella keilhaviformis* and *Blasispirifer reedi* (author's own collection and identifications, see also Shi and Tazawa, 2001). This assemblage can be correlated directly with the *Liosotella decimana–Waagenoconcha angustata* and *Alispiriferella lita–Kaninospirifer addresum* assemblages of the Tsagan-Ula Horizon in SE Mongolia, the *Yakovlevia unsinuata–Waagenoconcha humboldti* assemblage of the Baogete Formation or equivalents in NE China and SE Mongolia (Table 2). The age of the Vladivostok Horizon is constrained by its possession of a small ammonoid fauna characterized by *Daubichites orientalis* (Zakharov and Pavlov, 1986). The ammonoid genus and related species also occur in the lower Kazanian of the Russian Platform and northern Urals, where it is associated with Roadian conodonts (Grunt, 2005; also see above).

The Chandalaz Horizon is perhaps the most securely dated Permian unit in the whole of East and NE Asia, because of its possession of, or in very close stratigraphic proximity with, several biostratigraphically important indicator fossils. The horizon, conformably overlying the Vladivostok Horizon, is characterized mainly by carbonate rocks, locally intercalated with siliciclastic and volcaniclastic rocks. Marine fossils abound, especially within the limestone units. At the type locality at Senkina Shapka in the Partizansk area in South Primorye, the horizon has been divided into three fusulinoidean zones: *Monodiexodina sutchanica–Metadoliolina dutkevitchi* Zone, *Parafusulina stricta* Zone and the *Metadoliolina lepida–Lepdoliolina kumanensis* Zone, in ascending order (Likharev and Kotlyar, 1978) (Table 2). The age of the first zone has been generally regarded to range from Wordian to possibly early Capitanian (Kotlyar et al., 2003), or early Midian in the Tethyan scale (Ueno et al., 2006). This age assignment is corroborated by the occurrence of *Roadoceras subroadense* from the lower Barabash Formation assigned to this horizon (Zakharov and Pavlov, 1986; Shen et al., 2004), and also by the recent discovery from the same level of the fusulinoidean zone of the conodont *Mesogondolella asserrata* (identified as *Jinogondolella asserrata* in Kotlyar et al., 2003). Directly associated with this fusulinoidean zone are numerous brachiopod and bryozoan species. The author's personal fieldwork and collection in 2000 in both the Senkina Shapka and Barabash sections of South Primoye indicate the following common brachiopods: *Kochiproductus* sp., *Leptodus* sp., *Liosotella* sp., *Substriatifera vladivostokensis*, *Compressoproductus corniformis*, *Yakovlevia mammatiformis*, *Spiriferella* sp., and *Kaninospirifer* sp. Up section at Senkina Shapka, the *Monodiexodina sutchanica–Metadoliolina dutkevitchi* Zone is replaced sharply by the *Parafusulina stricta* Zone with the first appearance of *Lepidoliolina*, abundant *Parafusulina* species and rare *Monodiexodina*. Brachiopods are scarce within this horizon and are represented mainly by *Transennatia* sp., *Spiriferella rajah,* and *Leptodus nobilis.* At Cape Grozny near Vladivostok (Fig. 1), this brachiopod assemblage is associated with *Timorites markevichi* (Kotlyar et al., 1999) and *Mesogondolella* cf. *bitteri* and *M. postserrata* (Kotlyar et al., 2003), both suggesting an unequivocal Capitanian age for the brachiopod fauna and hence, by correlation, also for the *Parafusulina stricta* Zone. The *Metadoliolina lepida–Lepidolina kumanensis* Zone, occurring in the upper part of the Chandalaz Horizon, again marks another major change in the fusulinoidean faunal succession, with the first appearance of many new genera, and the last occurrence of taxa that were dominant in the preceding two zones. This distinctive change in fusulinoidean species is paralleled by a similar turnover pattern in the brachiopod faunas, with a dramatic increase of warm-water Cathaysian elements and a scarcity of species characteristic of NE Asia. This brachiopod assemblage, named the *Prorichthofenia ussurica* Zone (Likharev and Kotlyar, 1978), is strikingly similar to the *Richthofenia cornuformis–Enteletes andrewsi–Notothyris nucleolus* Zone of the Yihewusu Formation of NE China, or the *Echinauris jisurensis* Zone of the Solonker Horizon in SE Mongolia (Table 2).

The highest Permian interval in South Primorye is represented by the Lyudyanza Horizon, which is composed of a succession of both marine and non-marine rocks. The marine components include calci-sponge reef buildups or bioherms of varying sizes in the lower part of the horizon, which have yielded a highly diverse reef-dwelling fauna consisting of foraminiferans, corals, brachiopods and bryozoans (Belyaeva et al., 1997). The brachiopods are characterized by an assemblage of exclusively warm-water elements characteristic of those from the Wuchiapingian of South China, including *Anidanthus sinosus*, *Chengxianoproductus nachodkensis*, *Peltichia nachodkensis,* and *Permophricodothyris grandis* (Kotlyar et al., 1989). Of the carbonate buildups, the best known and perhaps the largest is the 'Nakhodka Reef' (Belyaeva et al., 1997), from which *Cyclolobus kiselevae* (Zakharov, 1983) and *Clarkina* ex. gr. *orientalis* (Kotlyar et al., 2006-a) also occur, both of which would suggest an unequivocal Wuchiapingian age. The upper part of the Lyudyanza Horizon is typified by species of the *Colaniella parva* Zone of Changhsingian age (Vuks and Chedija, 1986). Although not directly associated with the foraminiferan assemblage, a late Changhsingian fauna comprising ammonoids, brachiopods and conodonts (*Clarkina* cf. *deflecta*) has also been reported from the uppermost part (the Kapreyev Formation) of the Lyudyanza Horizon (Zakharov et al., 1995; Kotlyar et al., 2006-a).

Comparing the Permian stratigraphy and biostratigraphy of the Xingkai Terrane between the Jilin Province of NE China and the western portion of South Primorye, two points are worth noting. First, the lowermost marine Permian (Asselian–?Sakmarian) appears to be missing in South Primorye portion of the Xingkai Terrane; however, this interval is possibly represented by part of the Shanxiuling Formation in the Yanbian fold belt of eastern Jilin Province, NE China. As noted by Shao et al. (1995) and Shi and Zhan (1996), the Shanxiuling Formation appears to represent a mélange of accreted rock bodies, including both in situ deposits of principally Guadalupian age as well as incorporated olistostromes of older carbonate rocks of Late Carboniferous to Early Permian age. Secondly, it is likely that the Chandalaz Horizon of South Primorye may be a lateral equivalent, either in part or in its entirety, to the Dasuangou (or Kedao) Formation in eastern Jilin Province of NE China (see Sun, 1988, 1990; also Shi and Zhan, 1996), or part of the Tumen Group of northeastern Korea (near the border with China and Russia), from which Om et al. (1996) have listed a fusulinoidean assemblage consisting of many of the species characteristic of the *Parafusulina stricta* and *Metadoliolina lepida–Lepidolina kumanensis* zones of the Chandalaz Horizon, as well as a few brachiopod species including *Yakovlevia*.

### *3.7. The Permian in Japan*

In general, the Permian rocks of Japan may be divided into three broad types according to the tectonic setting at their time of deposition: those deposited mainly on continental margins or microcontinents, including the South Kitakami Belt, the Hida Gaien Belt and the Kurosegawa Belt; one type attributable to seamount settings or large ocean plateaus such as the disrupted Akiyoshi Terrane, also including numerous relatively small-sized carbonate bodies of pelagic origin, now scattered within the Jurassic accretionary complexes such as the Mino Terrane; and the third type characteristic of the continental slope to ocean trench settings typified by the

Maizuru Belt. Except the Mino Terrane, which is dealt with in Section 3.7.1, the Permian stratigraphy and biostratigraphy of the other two types of Japanese terranes are summarized here.

### 3.7.1. Permian in the South Kitakami, Hida Gaien and Kurosegawa belts

The Permian stratigraphy, faunas and biostratigraphy of these three belts share many similarities, a feature that has led Tazawa (2004) to group them into a single composite terrane. Of these three belts, the Permian stratigraphy and biostratigraphy of the South Kitakami Belt is best known and well studied. Here, traditionally the Permian System has been divided into three series: Sakamotozawan (=Lower Permian), Kanokura (=Middle Permian) and Toyoman (=Upper Permian), in ascending order. The Sakamotozawan Series, typified by the Sakamotozawa Formation, unconformably overlying the Carboniferous, is a succession of sandstone, mudstone and limestone. Fusulinoideans recovered from the limestone beds of the Sakamotozawa Formation have been assigned to the *Robustoschwagerina schellwieni*, *Chalaroschwagerina vulgaris* and *Pseudofusulina fusiformis* zones, of Asselian to Kungurian age (Choi, 1973; Kimura, 1991). Although in general terms the fusulinoidean fauna as a whole resembles those from the Akiyoshi Terrane in SW Japan, the Sakamotozawa Formation lacks advanced forms of *Triticites* that characterize the basal Permian in the latter. This may imply that there is a significant hiatus at the base of the Sakamotozawan Series (Kimura, 1991).

The Kanokura Series, typified by the Kanokura Formation, is widely distributed in the South Kitakami Belt, but with considerable lateral and stratigraphic variations in both lithology and thickness, permitting the division of the series into two stages: the Kattisawan Stage in the lower part, followed by the Iwaizakian Stage. The former is predominantly a succession of conglomerate, sandstone, mudstone and shale, with abundant faunas, especially fusulinoideans, brachiopods, bivalves, some rugose corals and ammonoids. Of the fusulinoideans, two zones have been recognized: *Monodiexodina sutchanica* Zone (as revised by Ueno, 2006), followed by the *Lepidolina multiseptata* Zone. These two fusulinoidean zones, which may locally overlap with their nominal zonal species (e.g. Ehiro and Misaki, 2004), can be directly correlated with the *Monodiexodina sutchanica–Metadoliolina dutkevitchi* Zone in the lower Chandalaz Horizon of South Primorye (Table 2). Among the other marine invertebrate fossils within the Kattisawan Stage, brachiopods occur widely and have been extensively documented (e.g. Tazawa and Ibaraki, 2001; Tazawa, 2000, 2002). A notorious feature of the Kanokura brachiopod faunas as a whole is its conspicuously mixed palaeobiogeographical composition, featured by the co-occurrence of both warm-water Cathaysian elements (e.g. *Leptodus*, *Richthofenia*, *Meekella*, etc.) and cool-water Boreal and antitropical (or bipolar) forms (e.g. *Kochiproductus*, *Waagenites*, *Yakovlevia*, *Attenuatella* and *Spiriferella*). This feature is strikingly similar to the brachiopod faunas of the lower Chandalaz Horizon of South Primorye, or the Baogete Formation and Zhesi formations of NE China (Table 2). To a lesser extent, the mixed nature of the Kanokura fauna is also reflected among the ammonoids. For example, Ehiro (1998) was able to correlate, on the basis of the mixed ammonoid faunas, especially using such biostratigraphically important genera as *Cibolites*, *Timorites* and *Waagenoceras*, the Kanokura with the Maokouan of South China, the Guadalupian of southwest USA and the Chandalaz Horizon of Far East Russia. The Iwaizaki Stage, typified by the Iwaizaki Limestone at Cape Iwaizaki in NE Japan, is characterized by isolated carbonate buildups, which may change abruptly into conglomerates laterally. The carbonate buildups contain fusulinoidean fossils of the *Lepidolina multiseptata* Zone of Capitanian age, although locally *Monodiexodina* species belonging to the *M. sutchanica* Zone (Ueno, 2006) may also appear in its basal part. Kawamura and Machiyama (1995) have interpreted these carbonate buildups as coral reef complexes.

The Toyoma Series is mainly a succession of black mudstone and some sandstone beds in its upper part, attaining a thickness more than 1000 m (Tazawa, 1975). Locally (e.g. in the western part of South Kitakami), the series contains ‘Usiginu-type’ conglomerates at its base, which are usually constituted of large granitic as well as limestone boulders (Yoshida and Machiyama, 2004). In general, the Toyoma Series is poorly fossiliferous, but a few important ammonoid fossils have been found, including *Xenodiscus* cf. *carbonarius*, *Timorites intermedium*, and *Araxoceras* cf. *rotoides* from its lower part, and *Cyclolobus* sp. and *Paratirolites*? sp. from its upper part, which, according to Ehiro (1998), can be correlated with the Wuchiapingian and Changhsingian of South China, respectively. In addition to the ammonoids, Tazawa (1975) also established a foraminiferal *Colaniella parva* Zone from the upper Toyoma Series, along with a few brachiopods: *Eolyttonia* cf. *nakazawai, Megousia nakamurai* and *Paramarginifera japonica.* The presence of *Colaniella parva* Zone points to a direct correlation with the same zone from the upper Lyudyanza Horizon of South Primorye, where it is associated with a conodont species comparable to the Changhsingian *Clarkina deflecta* (Kotlyar et al., 2006-a) (Table 2).

The Permian in the Hida Gaien Belt in SW Japan is represented by the Moribu Formation, a more than 1430 m succession of sandstone, shale, conglomerate, and minor limestone intercalations (Tazawa, 2001a). Marine fossils are common, but confined to the lower and middle members of the formation. A rich brachiopod fauna, composed of 29 species in 27 genera, occurs in the lower part of the formation (Tazawa, 2001a). This fauna, much like the brachiopod fauna from the lower Kanokura Series of the South Kitakami Belt, is conspicuously mixed in biogeographical composition, with typical warm-water Cathaysian elements such as *Leptodus nobilis*, *Permundaria asiatica*, *Urushtenoidea crenulata*, and also cool-water Boreal taxa characteristic of NE Asia such as *Blasispirifer* cf. *reedi, Spiriferella lita* and *Yakovlevia kaluzensis*. The mixed nature of the Moribu brachiopod fauna clearly suggests a correlation with similarly mixed faunas of the South Kitakami Belt, NE China and South Primorye, all of which are assignable to the Wordian to Capitanian by means of their associated conodonts, fusulinoideans and/or ammonoids

(Table 2). This age interpretation based on the brachiopods is also in good agreement with the associated fusulinoidean fauna featured by a *Monodiexodina* species comparable to *M. sutchanica* from the Oguradani and Moribu formations (Ueno and Tazawa, 2004; Niwa et al., 2004; Ueno, 2006).

Permian rocks in the Kurosegawa Belt have been modified severely by subsequent accretionary tectonics, and therefore a reconstruction of their original stratigraphy is difficult. In general, three main rock types of Permian age are represented (Hada et al., 2001). The first is characterized by blocks, probably allochthonous, of varying sizes buried in tectonic mélanges. These blocks are of various lithologies, but are dominated by limestones. The second type is typified by accretionary complexes composed of mudstone, basaltic greenstone and reefal limestone. The third type are the 'covering sediments' of the Kurosegawa Belt, which are composed mainly of fairly well-bedded sandstone, mudstone and conglomerate intercalations (Kimura, 1991; Hada et al., 2001). Despite the fragmentary nature of their distribution, the limestone blocks in the mélange zones and limestone lenses (usually pebbles) scattered in the terrigenous rocks, have yielded a fairly consistent and highly abundant fusulinoidean faunal succession throughout this belt, characterized by the *Misellina–Cancellina–Colania–Lepidolina* lineage (Hada et al., 2001), ranging in age from Early Permian to late Middle Permian (Capitanian). In addition, Tazawa (2001b) has also indicated the presence of the Middle Permian *Neoschwagerina* and *Yabeina* zones in this belt, along with some rare *Monodiexodina* species assignable to *M. sutchanica* and *M. kumanensis* (Ueno, 2006).

### 3.7.2. Permian of the Akiyoshi Terrane (including the Maizuru Belt)

It has been widely accepted that the Akiyoshi Group of the Akiyoshi Terrane constitutes a classic example of the seamount stratigraphy composed of basaltic volcanic rocks in the basal part, capped by massive limestones in the upper (Sano and Kanmera, 1988; Yanagida et al., 1993b; Sano et al., 2004). The Permian portion of the group is represented by four main types of lithofacies: carbonate rocks (mainly limestone and limestone breccia), siliceous rocks of pelagic origin (radiolarian chert, siliceous mudstone and sandstone), terrigenous mudstone of continental margin origin, and siliceous tuff (Yanagida et al., 1993b). As reconstructed by Yanagida et al. (1993b), the present-day relative spatial disposition of these lithofacies clearly suggests an oceanic seamount palaeogeographical setting with a full spectrum of depositional environments, ranging from reef top through fore reef to reef toe environments. Both shallow and deep-marine fossils are present in the group. Among the former, fusulinoideans are particularly abundant, and have served as the basis for a very detailed biostratigraphical zonation scheme consisting of over 40 zones (e.g. Ozawa and Kobayashi, 1990; Ueno, 1996). According to the fusulinoidean biostratigraphy, marine deposition continued, almost uninterrupted, from Asselian to Capitanian. Of particular interest among the Permian fusulinoidean succession is the prevalence of the *Pseudoschwagerina–Pseudofuslina* fauna in the Early Permian and the dominance of the *Misellina–Cancellina–Colania–Lepidolina* faunal lineage in the Middle Permian (Ishii et al., 1985); the former has strong affinities with coeval faunas of South China, while the latter is more closely related, in generic and species composition, to contemporaneous faunas of the Kurosegawa Belt (Hada et al., 2001).

The Permian stratigraphy and faunal successions of the Maizuru Belt have been considered to resemble those of the Akiyoshi Terrane, especially for the pre-Capitanian rock units (Shimizu, 1961; Kobayashi, 2003). The Permian Maizuru Group is constituted by three unnamed formations, up to 3000 m in total thickness (Kobayashi, 2003). The lower formation is characterized by low-grade metamorphic basalts, tuff and radiolarian-bearing mudstone of Middle Permian age (Kobayashi, 2003). The middle formation consists mainly of radiolarian-bearing mudstone, sandstone, acidic tuff and some conglomerate lenses, with limestone clasts. The radiolarian assemblage indicates a Capitanian–Wuchiapingian age for this middle formation, which is also consistent with the age indicated by the foraminiferal fauna contained in the limestone clasts. The foraminiferal fauna is dominated by species of *Lepidolina*, *Metadoliolina* and *Colaniella* (Kobayashi, 2003). The upper formation is composed mainly of sandstone, mudstone, conglomerate and minor lenticular limestone. The limestone beds have yielded two foraminiferal assemblages: the *Codonofusiella–Colaniella* assemblage of Wuchiapingian age, and the *Palaeofusulina–Colaniella* fauna of Changhsingian age (Kobayashi, 2003).

## 3.8. Permian within the Jurassic accretionary belts (Sikhote Alin fold belt, Mino Terrane, Koryak-Kamachatka fold belt and Nadanhada Terrane)

Within the various Pacific-margin fold belts of East and NE Asia, and in Japan, there have been reported numerous discrete, usually metre to kilometre-scale, outcrops of Permian rocks within the strongly folded and thrust Jurassic accretionary complexes. These Permian rocks are almost invariably characterized by thin-bedded cherty units and/or limestone blocks free of terrigenous material. As already indicated, these rock bodies are generally regarded as displaced, far-travelled ocean-borne terranes accreted to the northwestern margin of the Pacific. With only a few exceptions, the Permian stratigraphy and biostratigraphy of these displaced terranes remain under-studied in comparison with the more inland areas of the region. One of the better documented case studies among these displaced terranes is the Mino Terrane in Japan. The Permian rocks here are represented by greenstone–limestone complexes and radiolarian-bearing bedded cherts, thought to, respectively, indicate seamount and pelagic ocean floor depositional environments (Sano et al., 1992; Kojima et al., 2000). Locally, the seamount reefal limestones contain rich marine invertebrate faunas, among which the brachiopods are of particular interest. Tazawa and Shen (1997) reported a Middle Permian brachiopod fauna from the Mino Terrane, in which both characteristic Tethyan (or South China-type) elements (*Eolyttonia*, *Compressoproductus*, *Peltichia*) and also North American forms (e.g. *Coscinophpora*, *Glyptosteges*, *Lepidospirifer, Cenorhynchia*) co-occur, featuring an unequivocal admixture of Cathaysian and North American faunas.

Across the Sea of Japan, possible counterparts of the Mino Terrane have been identified from both NE China and the Sikhote-Alin fold belt of SE Russia. The Nadanhada Terrane in the eastern part of the Heilongjiang Province of NE China is composed primarily of Permo-Carboniferous greenstone–limestone complexes and Triassic–Jurassic siliceous shale and chert (Shinjiro et al., 1989). The limestone units within the greenstone–limestone complexes have yielded a rich fusulinoidean fauna composed of two successive zones: the *Misellina claudiae* Zone in the lower and *Neoschwagerina* Zone in the upper, ranging in age from Kungurian to Wordian (Han, 1985). In the Sikhote-Alin fold belt, the possible northern extension of the Mino Terrane is represented by the Samarkinsky Terrane and also possibly the Taukha Terrane, both of which also strongly feature Permian greenstone–limestone complexes and radiolarian-bearing shale and bedded cherts (Rudenko and Panasenko, 1997; Kojima et al., 2000; Ishiwatari and Tsujimori, 2003). A total of 11 radiolarian zones have been recognized from the Sikhote-Alin fold belt, ranging in age from Asselian to Changshingian (Rudenko and Panasenko, 1997). Further to the north, another well-studied displaced terrane with distinctive Permian biotas is found in the Ekonay Terrane within the Koryak-Kamachatka fold belt in NE Russia (Fig. 1). Davydov et al. (1999) reported a highly diverse fusulinoidean fauna, represented by more than 65 species in 30 genera, from 12 separate limestone blocks (or olistostromes), all of which belong to the Ekonay Terrane (Sokolov, 1990). The diverse fusulinoidean fauna has been divided into five stratigraphic assemblages, respectively, representing the Asselian, Yakhotashian (or Artinskian), Bololrian (or Kungurian), Kubergandian (Roadian) and Midian (late Capitanian).

## 4. Biogeographical subdivisions of Permian marine faunas in East and NE Asia

It should be clear from the biostratigraphical synthesis above, that the Permian biotas in East and NE Asia not only demonstrate marked stratigraphical variations as reflected in the erection of numerous local stratigraphic assemblages or zones, but also exhibit considerable spatial variations. It is therefore necessary to comment on the palaeobiogeographical patterns of the marine biota of the entire region and also, where appropriate and possible, to elucidate the evolutionary processes of provincialism throughout the Permian. Several past studies have drawn attention to the Permian marine palaeobiogeography of this region (Ustritskiy, 1961, 1993; Nikitina, 1977; Durante et al., 1985; Ishii et al., 1985; Nakamura et al., 1985; Tazawa, 1991, 1998; Ustritskiy, 1993; Shi et al., 1995; Ganelin, 1997; Davydov et al., 1999; Kobayashi, 1999). In general, four distinctive biogeographical provinces have been recognized: the Verkolyman, Sino-Mongolian–Japanese, Cathaysian, and Panthalassan provinces (Fig. 3); and they are characterized in general terms below.

### 4.1. The Verkolyman Province

This provincial name was originally proposed by Shi and Archbold (1995) for the late Artinskian–Kungurian brachiopod faunas of the Verkhoyansk and Kolyma–Omolon regions; it is also adopted here as a general Permian biogeographical unit that covers all Permian marine invertebrate faunas of NE Asia, with the exception of the displaced terranes in the Koryak-Kamachatka fold belt (Fig. 3). Although its palaeogeographical extent may have varied through the Permian in relation to sea-level and climate changes and also changes in plate tectonic regimes, this province appears to have persisted throughout the Permian. The Verkolyman Province is most typical of the Late Palaeozoic Boreal Realm in that it lacks some major taxonomic groups that characterize the Palaeoequatorial Realm, such as fusulinoidean foraminifers, conodonts, compound rugose corals, calcareous algae, reef-building organisms, and certain brachiopod families such as Lyttoniidae, Meekellide, etc. In sharp contrast, on the other hand, the province is home to numerous families and genera that are either endemic to this and other Boreal provinces, or shared only with the Gondwanan Realm and/or Permian transitional biogeographical provinces in the form of antitropicality (Shi et al., 1995; Shi and Grunt, 2000). Taxa that are characteristic for the Verkolyman and other Boreal provinces are, for example, the *Verchojania–Jakutoproductus* lineage, Horridoniidae, Yakovleviidae and Licharewiidae among the brachiopods (Ganelin, 1997); Kolymiidae and some atomodesmatids among the bivalves (Astafieva, 1998; Biakov, 2000); *Sverdrupites*, *Tumaroceras,* and *Spirolegoceras* among the ammonoids (Kutygin, 2006), as well as many bryozoan genera and species such as *Permofenestella*, *Laxifenestella*, *Wjatkella* and *Timanodicta* (Gilmour and Morozova, 1999). The phenomenon of the Permian antitropicality (also described as bipolarity in some literature) between the Boreal Realm (including the Verkolyman Province) and the Gondwanan Realm has been referred to in several previous and recent studies, especially Ustritskiy (1974), Astafieva (1998), and Shi and Grunt (2000); so detailed accounts will not be repeated here. Although opinions remain varied as to the origin and development processes of this conspicuous Permian biogeographical feature of global scale, there is little doubt that intercontinental biotic exchanges between Eurasia and Gondwana must have occurred.

The overall relative low species diversity, relative high abundance of endemic taxa, coupled with the complete lack of fusulinoideans, conodonts and compound rugose corals of the Verkolyman marine faunas would suggest a cold to cool temperate climatic regime for NE Asia throughout the Permian. This inference is consistent with the palaeotemperatures obtained from the Permian bivalve shells by Astafieva-Urbaitis and Yasamanov (1986), who showed a general cool-water climatic condition for the marine Permian of NE Asia, with temperatures ranging from 19 to 22° in the Asselian to Artinskian, 16–20° in the Middle Permian, to 24–25° in the Late Permian.

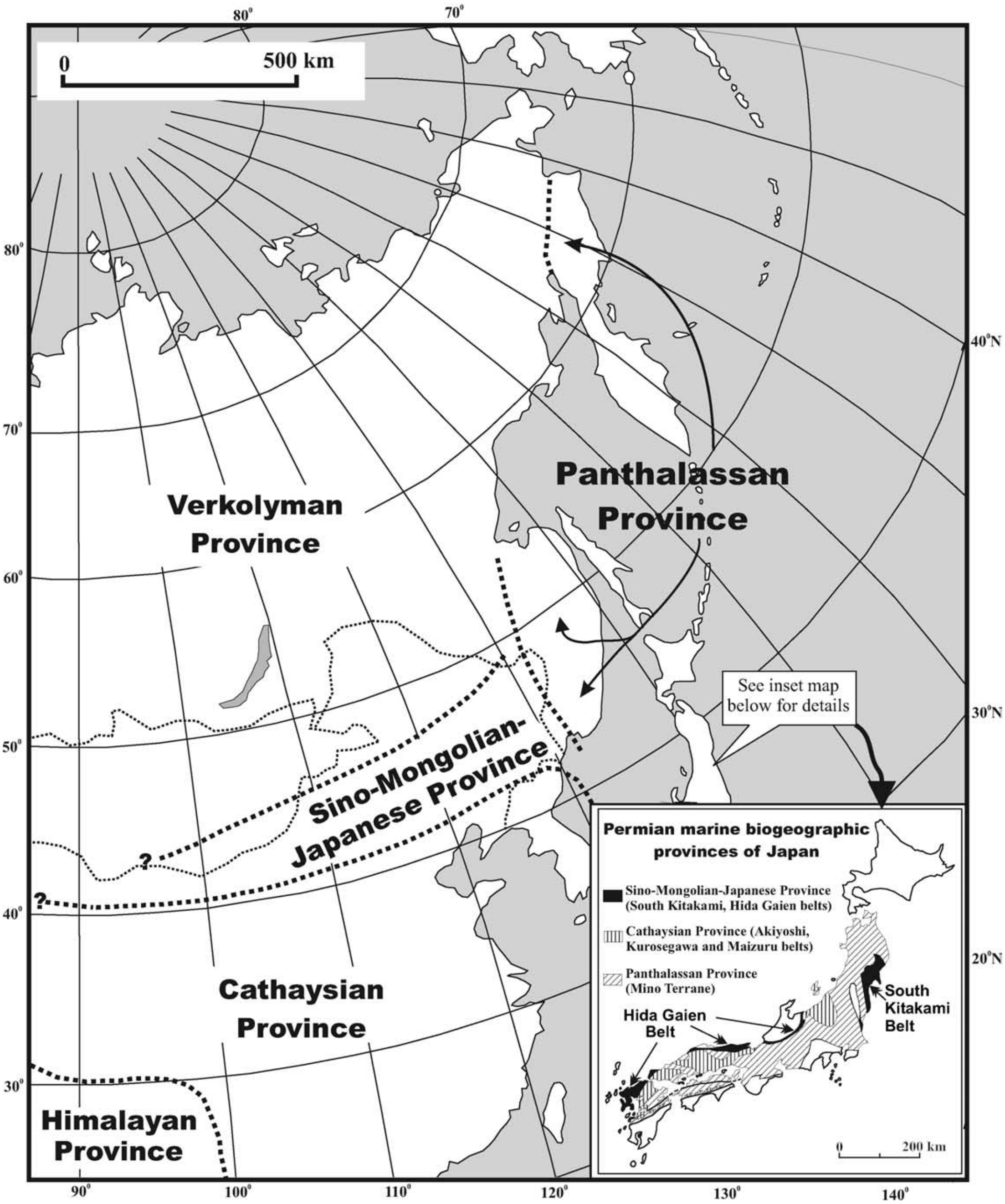


Fig. 3. Distribution of main Permian marine biogeographical provinces in present-day East and Northeast Asia (the inset map of Japan is based on Tazawa, 2001b). Question marks indicate uncertainty of the westward extension of the biogeographical boundaries due to lack of Permian exposures and fossil records.

### 4.2. The Cathaysian Province

This province (as amended by Shi and Waterhouse, 1990) of the Palaeoequatorial Realm in the study region includes the South China and Sino-Korea platforms and also the Akiyoshi and Kurosegawa terranes of Japan (Fig. 3), although the latter also exhibit some significant affinities with coeval faunas of the Sino-Mongolian Japanese Province (see below). In striking contrast to the Verkolyman Province, the Cathaysian Province is characterized by its high species diversity, abundant and widespread reef-building organisms in many of areas, abundant and highly diversified fusulinoidean faunas, compound rugose corals and ammonoids, and, at least in South China, also abundant and diverse conodonts. These faunas are widely associated with massive and extensive limestones. Both the biotic and abiotic features of this province would clearly point to a warm-water, palaeotropical setting.

### 4.3. The Sino-Mongolian–Japanese Province

Of all the provinces recognized here, this province is of particular interest because of its significance for Permian global correlations and palaeogeographical reconstruction models (see below). As a biogeographical entity, the province has been variably named (e.g. Nakamura et al., 1985; Tazawa, 1991; Shi et al., 1995). In this paper, the name Sino-Mongolian–Japanese Province of Shi and Tazawa (2001) is followed, referring to the broad areas of SE Mongolia, NE China, northeastern portion of the Korean Peninsula, the Amur area and southern Primorye of SE Russia, and the South Kitakami Terrane (as defined by Tazawa, 2004) of Japan (Fig. 3).

This province manifested itself most unequivocally during the Middle Permian when it flourished with a highly organized, broadly uniform, biogeographically mixed marine biota. The biogeographical admixture has been recognized in almost all marine invertebrate groups that existed within the province, but most notably among the brachiopods, bivalves, fusulinoideans, ammonoids and bryozoans (Shi et al., 1995). The detailed biogeographical features characteristic of this admixture may be summarized as follows:

(1) The biogeographical admixture of the marine biotas is primarily featured by the intermingling in the same biotic assemblages of taxa characteristic of both high-palaeolatitude cool-temperate Verkolyman and warm-water palaeoequatorial Cathaysian provinces.
(2) In addition to the Verkolyman and Cathaysian elements, the Sino-Mongolian–Japanese Province is also home to many endemic genera and species, as well as numerous genera of bitemperate and bipolar distributional aspects (terms of Shi and Grunt, 2000). For example, genera of bitemperate aspects are most notably represented by *Monodiexodina* (Fusulinoidea); *Daubichites*, *Paragastrioceras*, *Timorites* (Ammonoidea); *Waagenites*, *Spiriferella* (Brachiopoda); and those of a genuinely bipolar and bitemperate nature are exhibited mainly by brachiopods (e.g. *Attenuatella, Megousia*, *Spiriferella*, *Tomiopsis*, *Spirelytha*, etc.), bivalves (e.g. *Maitaia*, *Atomodesma*, *Myonia*, *Pyramus*, etc.) and ammonoids (*Uraloceras*). To this end, it is also of note that recent discoveries of a low-diversity but relatively high abundance conodont fauna from Inner Mongolia (Wang et al., 2004), Jilin Province of NE China (Wang et al., 2000), and South Primorye (Kotlyar et al., 2003) also point to a biogeographically mixed biota.
(3) These mixed Verkolyman and Cathaysian marine faunas are broadly coeval in age, ranging from Roadian to Capitanian, most likely with a climax at the Wordian. During the Early Permian, this mixed biogeographical province either did not exist or was at an incipient stage of development. During the Late Permian, the mixed Sino-Mongolian–Japanese Province vanished from most areas, where it was replaced by a distinctively mixed Angara-Cathaysian flora (Zhang, 1988; Huang, 1995). However, in the South Kitakami Terrane of Japan, this mixed marine biotic province seems to have persisted into the Late Permian, although considerably reduced in diversity and spread, as evidenced by a small marine fauna from the upper Toyoma Series described by Tazawa (1975). This fauna, of the *Colaniella parva* Zone, contains a small brachiopod fauna of five genera, one of which (*Eolyttonia*) suggests an unequivocal Cathaysian affinity, and the other (*Megousia*) an unequivocal bipolar origin.

The mixed nature of the Sino-Mongolian Japanese Province has made it difficult to classify this province in the context of Permian global marine biogeographical framework, as it really represents a palaeobiogeographical ecotone between the Boreal and Palaeoequatorial Realms. In this regard, it may be compared to Wallacea, a modern broad transitional biogeographical ecotone in the Indo-Australian region between the Australian biogeographical region and the Oriental biogeographical region (Wallace, 1999); its mixed biogeographical nature is also comparable to the Late Neogene marine faunas within the Sea of Japan (Tsuchi, 1990), the present-day marine biota of the Mediterranean Sea (Maldonado and Uriz, 1995), or the present-day marine fauna from the Sepetiba Bay (about 23°S) on the eastern coast of Brazil (Stevenson et al., 1998). These comparisons would suggest that the Sino-Mongolian–Japanese Province occupied a regionally extensive zone in East Asia during the Middle Permian, where a mesothermal (or warm-temperate) climatic condition prevailed. However, as noted by Shi et al. (1995), mixed Middle Permian marine faunas are succeeded by faunas of principally warm-water Cathaysian aspect, including the development of some reefal or reefoidal carbonate buildups, for example: the 'Nakhodka Reef' of South Primorye (Belyaeva et al., 1997), the Iwaizaki reefal limestone of the South Kitakami Terrane (Kawamura and Machiyama, 1995), as well as some calcisponge/algal bioherms from the Zhesi Formation of Inner Mongolia (Wang et al., 2002). This dramatic increase of Cathaysian elements in the Sino-Mongolian–Japanese Province has made it difficult to separate these two provinces for the Capitanian through to the Late Permian.

Additionally, some remarks are necessary in regard to the equivocal nature of the marine provinciality of two Japanese terranes: Akiyoshi (including Maizuru belt) and Kurosegawa. Yanagida (1996) reported a Capitanian brachiopod fauna from the siliceous mudstones (Tsunemori Formation) of the Akiyoshi Terrane. The biogeographical composition of this fauna is most interesting, as it is composed of almost equal numbers of warm-water Cathaysian-type (e.g. *Leptodus* sp., *Gubleria* sp., *Enteletes* cf. *wananensis*) and cool-water Verkolyman-type taxa (*Spiriferella qubuensis*, *Alispiriferella* sp. and *Megousia* sp.). This feature of biogeographical mixing is almost identical to the Middle Permian faunas of the South Kitakami and Hida Gaien belts of Japan and the Xingkai Terrane in NE China and South Primorye, hence implying that for the Capitanian the Akiyoshi Terrane could be a member of the Sino-Mongolian–Japanese Province. Likewise, the Late Permian (Lopingian) marine faunas from some localities of the Maizuru Belt demonstrate significant biogeographical affinities with the Sino-Mongolian–Japanese Province. Shimizu (1961) and Yanagida et al. (1993a) reported an unequivocally mixed Lopingian brachiopod fauna from rocks (Takauchi Limestone and Karita Formation, respectively) assignable to the *Colaniella–Codonofusiella* Zone, of Wuchiapingian age (Kobayashi, 2003). The mixed brachiopod fauna is characterized by the co-occurrence of *Spiriferella* (a bitemperate element) and *Spinomarginifera*, *Transennatia* and *Leptodus*, all being characteristic Cathaysian taxa. Also from the Maizuru Belt, Tazawa (2001b) has reported a small brachiopod fauna of exclusively Boreal biogeographical affinities, as evidenced by typical Verkolyman taxa (*Anemonaria* sp., *Kochiproductus* sp., *Yakovlevia* sp., *Attenuatella* sp. and *Spiriferella* sp.). The brachiopods are poorly preserved, rendering their specific taxonomy open and hence the age of the fauna uncertain; however, an Early to Late Permian age was suggested by Tazawa (2001b), based on correlations with brachiopod faunas from the Arctic and NE Asia.

At present, the Permian marine provinciality of the Kurosegawa Terrane also remains equivocal. On the one hand, its Permian marine faunas are dominantly Cathaysian-type, as summarized by Ishii et al. (1985), and Hada et al. (2001), but it has also yielded some rare *Monodiexodina* species assignable to *M. sutchanica* and *M. kumanensis* (Ueno, 2006). The occurrence of these two species, especially the former, would suggest a close biogeographical relationship of the Kurosegawa Terrane with the Sino-Mongolian–Japanese Province.

### *4.4. The Panthalassan Province*

This province, adopted from Tazawa (1998), refers to a number of Permian marine faunas believed to have originally inhabited offshore oceanic environments, such as seamounts or volcanic islands of oceanic origin. Most of the Permian marine faunas included in this province are today found in Jurassic accretionary complexes within the continental margins of East and NE Asia, including the Mino Terrane of Japan, the Nadanhada Terrane in the Heilongjiang Province of NE China, the Sikhote-Alin fold belt of Far East Russia and the Ekonay Terrane in the Koryak-Kamachutka fold belt of NE Asia. One of the better studied faunas from these displaced terranes is the 'Tethyan–North American mixed fauna' from the Mino Terrane (Tazawa and Shen, 1997). This fauna is characterized by an admixture of Cathaysian and North American elements, both of unequivocally warm-water palaeotropical origin. As a way of accounting for this unique mixture of biogeographical composition, and also in view of its Permian rock associations reminiscent of open ocean origin, Tazawa (1998, 2001b) has regarded the Mino fauna as having originated from a palaeotropical setting in the Permian Panthalassa ocean, probably with close proximity to both East Asia and southwest North America.

The faunal provinciality of the Ekonay Terrane through the Permian also appears to demonstrate a highly dynamic nature. According to Davydov et al. (1999), the Artinskian–Kungurian fusulinoidean fauna of this terrane showed neither significant similarity nor dissimilarity to any other coeval circum-Pacific faunas, implying a fairly independent (isolated) biogeographical position during this time. However, its Wordian–Capitanian fusulinoidean fauna exhibits significant similarities to those of the South Kitakami and Sikhote-Alin terranes, suggesting biotic exchanges among these terranes. The implications of this change of marine provinciality as demonstrated by the Ekonay Terrane are discussed in Section 5.

## 5. Significance of East Asia as a gateway for assisting Permian global correlations

Several recent studies have argued that the biogeographically mixed marine faunas of the Sino-Mongolian–Japanese Province in East Asia may have far-reaching global significance for Permian inter-continental correlations, especially correlations of Permian marine sequences between NE Asia and Gondwana (Shi, 2000; Kotlyar et al., 2003, 2006-a). The premise of this suggestion is based on the notion of the 'biostratigraphical gateway' concept, first proposed by the author in 1998 at the International Symposium on the Upper Permian Stratotypes of the Volga Region held at the Kazan State University, Russia (Shi and Archbold, 1999). In general, two broad Permian gateways exist in Asia, namely the 'Southern Transitional Zone' and the 'Northern Transitional Zone' of Shi et al. (1995). The former is essentially the same as the Permian Cimmerian biogeographical region consisting of Permian (especially Middle Permian) marine faunas of the Cimmerian Terrane (for details see Shi et al., 1995; Shi and Archbold, 1998; Ueno, 2003), while the latter coincides with the Sino-Mongolian–Japanese Province described above. The rationale of the Permian biostratigraphical gateway concept, as applied to East Asia, stems from the recognition and understanding of Permian mixed or transitional marine faunas in the Sino-Mongolian–Japanese Province. In essence, this new method explores the biostratigraphical potential of this province with mixed warm- and cold- to cool-water faunas as biostratigraphical bridges (or stepping stones) to correlate palaeotropical Permian sequences with those of the high palaeolatitude regions, as well as to correlate high-palaeolatitude Permian faunas and rock sequences between NE Asia and Gondwana. This is possible because, as discussed in Shi et al. (1995), the Sino-Mongolian–Japanese Province and its southern counterpart in the Cimmerian biogeographical region (Table 3) not only share some important cool-water taxa with those of high palaeolatitude Verkolyman and Gondwanan Permian marine biotas, some of which existed in the form of antitropical distributions, they also share some biostratigraphically important taxa (i.e. conodonts, fusulinoideans and important ammonoids) with some low palaeolatitudinal areas such as South China, South Urals and southwest USA from which the current international Permian chronostratigraphical scale has been derived (Jin et al., 1997; Wardlaw et al., 2004). Therefore, using the mixed warm- and cool-water biotas of the transitional Sino-Mongolian–Japanese Province and Cimmerian biogeographical region as bridges (or gateways), it should be practically possible to date some of the Permian faunas in the higher palaeolatitude regions of both hemispheres by aligning them with those of the lower palaeolatitudes.

Employing this scenario, I have attempted a correlation between some of the fossiliferous marine Permian formations

Table 3
Age assignment and correlation of selected Permian marine sedimentary rock formations (or horizons) between NE Asia and Gondwana by employing the 'biostratigraphical gateway' concept and also bipolarly and bitemperately distributed taxa (taxa shown in italics are the key genera shared either between NE Asia and Gondwana; between NE Asia, Gondwana and the two transitional zones; or between the transitional zones and the Palaeoequatorial provinces (see text for more information and discussion)

| Series | Stages | Gondwana (Indoralian, Austrazean and Westralian Provinces) | Southern Gateway (Southern Transitional Zone) (Himalayan & Sibumasu Provinces) | Palaeoequatorial Realm (Cathaysian, Iranian and Cisuralian Province) | Northern Gateway (Northern Transitional Zone) (Sino-Mongolian-Japanese Province) | Boreal Realm (Verkolyman Province) |
|---|---|---|---|---|---|---|
| | | Australia/Timor/ New Zealand/Timor | Tibet/Pakistan/ Himalaya/Yunnan | Tethyan region (South China. Indo-China, South Urals, central Iran) | South Primorye/ NE China/Japan | Verkhoyansk, Kolyma-Omolon, Transbaikal, North Mongolia |
| Lopingian | Chang. | Wairakian Stage (*Intomodesma, Kolymia, Pyramus, Myonia, Maitaia*) | Chhihidru Fm. (*Clarkina, Colaniella, Cyclolobus*) | Changhsingian (*Clarkina, Paleofusulina, Iranites*) | Lyudyanza Horizon (*Cyclolobus, Clarkina, Codonofusiella, Iranites, Araxoceras*) | Kolymian Superhorizon: Khivachian Horizon (*Marginalosia, Waagenoconcha/ Wimanoconcha; Intomodesma, Atomodesma, Kolymia, Vacunella, Pyramus, Myonia, Pachymyonia, Maitaia*) |
| | Wuchia. | Hardman Fm. (*Cyclolobus*) | Wargal Fm/ Xiukang Lst/ Qubuerga Fm. (*Roadoceras, Timorites; Clarkina, Codonofusiella*) | Wuchiapingian (*Clarkina, Codonofusiella, Araxoceras*) | | |
| Guadalupian | Capitan. | Amarassi & Basleo Beds (*Timorites*); Illawarra Coal Measures (part) | | Maokouan/Midian: Abadeh Fm (*Timorites*); Lengwuan (*Jinogondolella; Yabeina; Roadoceras*) | Chandalaz Horrizon (*Roadoceras, Timorites; Monodiexodina, Codonofusiella; Cancrinelloides; Maitaia; Jinogondolella, Mesogondolella*) | Gizhigian Horizon (*Timorites; Cancrinelloides; Maitaia*) |
| | Wordian | Broughton, Nowra, Berry Fms/Ingelara Fm. (*Terrakea*); Wandrawandian Slst. (*Megousia, Terrakea*) | Amb Fm (*Codonofusiella, Monodiexodina, Merrillina*) | Kuhfengian (*Neoschwagerina, Altudoceras*) | Vladivostok Horizon: *Waagenoceras-Timorites* Assemblage | Omolonian Superhorizon: Bocharian Horizon (*Terrakea; Myonia, Kolymia*); Olynian Horizon (*Terrakea; Kolymia; Sverdrupites*) |
| | Road. | Coolkilya Sst (*Daubichites*) | Ratburi Gp. (*Codonofusiella, Monodiexodina*) | Roadian (*Daubichites, Misellina*) | *Daubichites* | Russco-Omolonian Horizon (*Terrakea; Daubichites, Sverdrupites*) |
| Cisuralian | Kung. | Noonkanba Fm./ Upper Byro Gp. (*Paragastrioceras*) | Kaeng Krachang Group & equivalents (*Agathiceras, Metalegoceras; Spirelytha, Tomiopsis, Trigonotreta*) | Kungurian (*Paragstrioceras*) | Abrek Horizon (*Epijuresanites*) | Dzjigdalin. Superhor.: Khalalinian Horizon (*Epijuresanites; Megousia*); Koargychanian Horizon (*Paragastrioceras*) |
| | Asselian-Artinskian | Callytharra Fm./Lower Byro Gp./Wasp Head Fm. (*Metalegoceras, Agathiceras, Uraloceras; Costatumulus, Spirelytha, Tomiopsis; Astartella, Oriocrassatella, Palaeoneilo*) | | Asselian-Artinskian: *Metalegoceras, Uraloceras* | | Munugudzhak. Superhorizon: Ogonerian Horizon (*Metalegoceras, Agathiceras, Uraloceras; Costatumulus, Spirelytha, Tomiopsis; Astartella, Oriocrassatella, Palaeoneilo*, etc) |

Correlation via shared bitemperate taxa

Correlation via shared bipolar taxa and faunas and transitional zones

Dashed and dotted lines indicate possible age correlation of the concerned formations, horizons or fossil zones. The solid stars mark the position of the globally synchronous $N_1P$ Orthozone (or the 'Illawarra Reversal') of the Illawarra Hyperzone that has been found occurring in the various Permian biogeographical regions or provinces (Molostovskii, 2005).

between NE Asia and Gondwana using the mixed faunas of both the Sino-Mongolian–Japanese Province (i.e. the northern 'Gateway') and the Cimmerian biogeographical region (Himalayan and Sibumasu provinces) (the southern 'Gateway') as 'stepping stones' (Table 3). Although this new approach to Permian global correlation has not been applied to all Permian stages between NE Asia and Gondwana, it has proved successful for stratigraphically aligning at least some Permian faunas and rock formations between these two remote parts of the world, which otherwise would be difficult to reconcile. For example, joint occurrences of a number of Early Permian ammonoids (*Agathiceras*, *Metalegoceras*, *Uraloceras*) (Leonova, 1998), bivalves (*Astartella*, *Edmondia prichardi*, *Modiodus*, *Myophossa subarbitrata* and *Parallelodon bimodoliratus*) (Biakov, 2005), and brachiopods (*Costatumulus*, *Tomiopsis*, *Spirelytha*) between Australia and NE Asia in the form of bipolar distributions makes it possible to establish a broad correlation between the Farley Formation of eastern Australia and the Callytharra Formation and lower Byro Group of Western Australia, with the Munugudzhakian Superhorizon in NE Asia. Similarly, the Coolkilya Sandstone of Western Australia may be equated with the lower Vladivostok Horizon of South Primorye and the lower Omolonian Superhorizon of NE Asia, as all three units yield *Daubichites*, an ammonoid genus characteristic of the lower Kazanian (Roadian) in the Russian Platform (Bogoslovskaya et al., 1999; Grunt, 2005). It also seems reasonable to suggest an alignment between the upper Omolonian Superhorizon and its equivalents in NE Asia and the upper Shoalhaven Group (Nowra, Berry and Broughton formations) in the southern Sydney Basin of eastern Australia, as both areas yield a highly distinctive low-diversity, high-abundance fauna dominated by *Terrakea*. If this suggestion holds, these three eastern Australian formations could be assigned to the Wordian as its correlative, the upper Omolonian Superhorizon, has yielded a typical upper Kazanian (Wordian) ammonoid genus *Sverdrupites* (Grunt, 2005). This correlation also corroborates the revelation by Palmieri et al. (1994) that the Ingelara Formation of the Bowen Basin in Queensland of NE Australia, a lateral equivalent of the Broughton Formation in the southern Sydney

Basin, shares a significant number of small calcareous foraminiferal species with the Kazanian of the Russian Platform.

At present, direct biostratigraphical correlation between eastern Australia and NE Asia for post-Wordian strata is severely hampered by the lack of marine sediments and faunas in the former and the persistence of marine sedimentation in NE Asia, although this difficulty has been overcome to some extent by the recognition of a global magnetostratigraphic zone named the $N_1P$ Orthozone of the Illawarra Hyperzone, or better known as the 'Illawarra Reversal' (Jin et al., 2000; Molostovskii, 2005), in both high-palaeolatitude and also palaeoequatorial regions of the world, including the lower Tatarian of the Russian Platform, the middle Chandalaz Horizon of Russian Far East, the Bell Canyon Formation of Texas, in southwest USA, the upper Makouan of South China, the lower Wargal Formation in the Salt Range, the upper Gizhigian Horizon of NE Asia and the lower part of the Illawarra Coal Measures of the southern Sydney Basin in eastern Australia (Table 3). In the Guadalupian Mountains in southwest USA, the 'Illawarra Reversal' has been dated at $265.3 \pm 0.2$ Ma (Bowring et al., 1998), and is regarded as marking the boundary between the Wordian and Capitanian stages (Wardlaw et al., 2004). This age therefore clearly constrains the Broughton Formation of eastern Australia (and its lateral equivalents in the Bowen Basin of Queensland) and the Omolonian Superhorizon of NE Asia as no younger than Wordian.

Although Eastern Australia lacks Capitanian marine sequences, the Amarassi and Basleo Beds of Timor of Gondwana, and the Xiukang Limestone and Qubuerga Formation of southern Tibet in the Southern Transitional Zone, are certainly of Capitanian age because they contain *Timorites* and, in the case of southern Tibet, also *Roadoceras* (Shen et al., 2004). The presence of these two ammonoid genera would align the Timorese and southern Tibetan formations with the Chandalaz Horizon in Russian Far East, the Kanokura Series of Japan, the Togotuisky Horizon of Transbaikalia, and hence, by correlation using the 'biostratigraphical gateway' principle, also the Gizhigian Horizon of NE Asia (Table 3).

Marine Upper Permian is virtually missing from the whole of Australia except for the Hardman Formation of Western Australia. This formation contains a diverse marine fauna dominated by brachiopods and also *Cyclolobus* of mainly Wuchiapingian age. This ammonoid genus would suggest a direct correlation of this formation with the lower Lyudyanza Horizon of the Sino-Mongolian–Japanese Province in East Asia, through which it is also possible to correlate the former with at least part of the Khivachian Horizon of NE Asia. The likely correlation between the Hardman Formation and part of the Khivachian Horizon is also indicated by some shared brachiopods (e.g. large thick-shelled *Marginalosia* and *Wimanoconcha*) and, in particular, an atomodesmid species: *Atomodesma semplicata* Reed (Dickins, 1993). The marine Changhsingian of Gondwana is known only from New Zealand, a borehole sample from Western Australia (Thomas et al., 2004) and the peri-Gondwanan regions of the Salt Range of Pakistan, Nepal, Kashmir and southern Tibet. The correlation of this part of the Permian with NE Asia is difficult because of lack of common species, although Waterhouse (2002, p. 217) has suggested that a parallel in faunal development may be drawn between the faunas of the Wairakian Stage of New Zealand with those of the Khivachian Horizon of NE Siberia in terms of several bipolarly shared bivalve genera such as *Kolymia, Myonia, Pachymyonia, Myramusm* and *Intomodesma.*

## 6. Discussion

The plate tectonic configurations and palaeogeographical evolution of East and NE Asia through the Late Palaeozoic have attracted a number of studies, with a wide range of markedly different reconstruction models (Fig. 4). In this study, I have attempted to provide an alternative interpretation focused on the Middle Permian interval (Fig. 5) by integrating both published palaeomagnetic data (Table 4) and the marine biogeographical information outlined above. The former is used to indicate the palaeolatitude positions of major tectonic blocks, while the biogeographical data are employed to constrain palaeolatitude, palaeo-longitude (i.e. relative spatial relationships among the blocks) positions, as well as the nature and possible movement directions of palaeocean current systems. Superimposed on the palaeogeographical map is the relative distribution of the Middle Permian marine biogeographical provinces, recognized herein, in relation to the inferred palaeocean current systems and the palaeogeography of East and NE Asia.

There are a few significant features to be noted from the new reconstruction map. First, it is evident that the disposition of three of the four prevailing Middle Permian marine biotic provinces (Verkolyman, Sino-Mongolian–Japanese and Cathaysian provinces) is closely related to palaeolatitude zones, thus implying that the Middle Permian marine biogeography in East and NE Asia was controlled primarily by latitude-related climatic zonation patterns. However, climatic control alone could not explain the formation of the Panthalassan Province, which during the Middle Permian demonstrated significant faunal affinities to South China (Cathaysian Province) and North America, as well as with some of the terranes in the Sino-Mongolian–Japanese Province. These multi-dimensional biogeographical affinities of the Panthalassan Province may be best explained by a scenario that proposes that this province was located within the Permian equatorial belt in the open Panthalassa Ocean, with geographical proximities to both East Asia and North America, close enough to allow biotic interchanges during the Middle Permian. This interpretation also includes the assumption that the provinciality for some of the oceanic terranes included in the Panthalassan Province may have evolved in the course of the Permian. For example, the Ekonay Terrane demonstrated a highly dynamic nature in its provinciality through the Permian in that its Early Permian (Artinskian–Kungurian) fusulinoidean faunas showed neither significant similarity nor dissimilarity to any other coeval

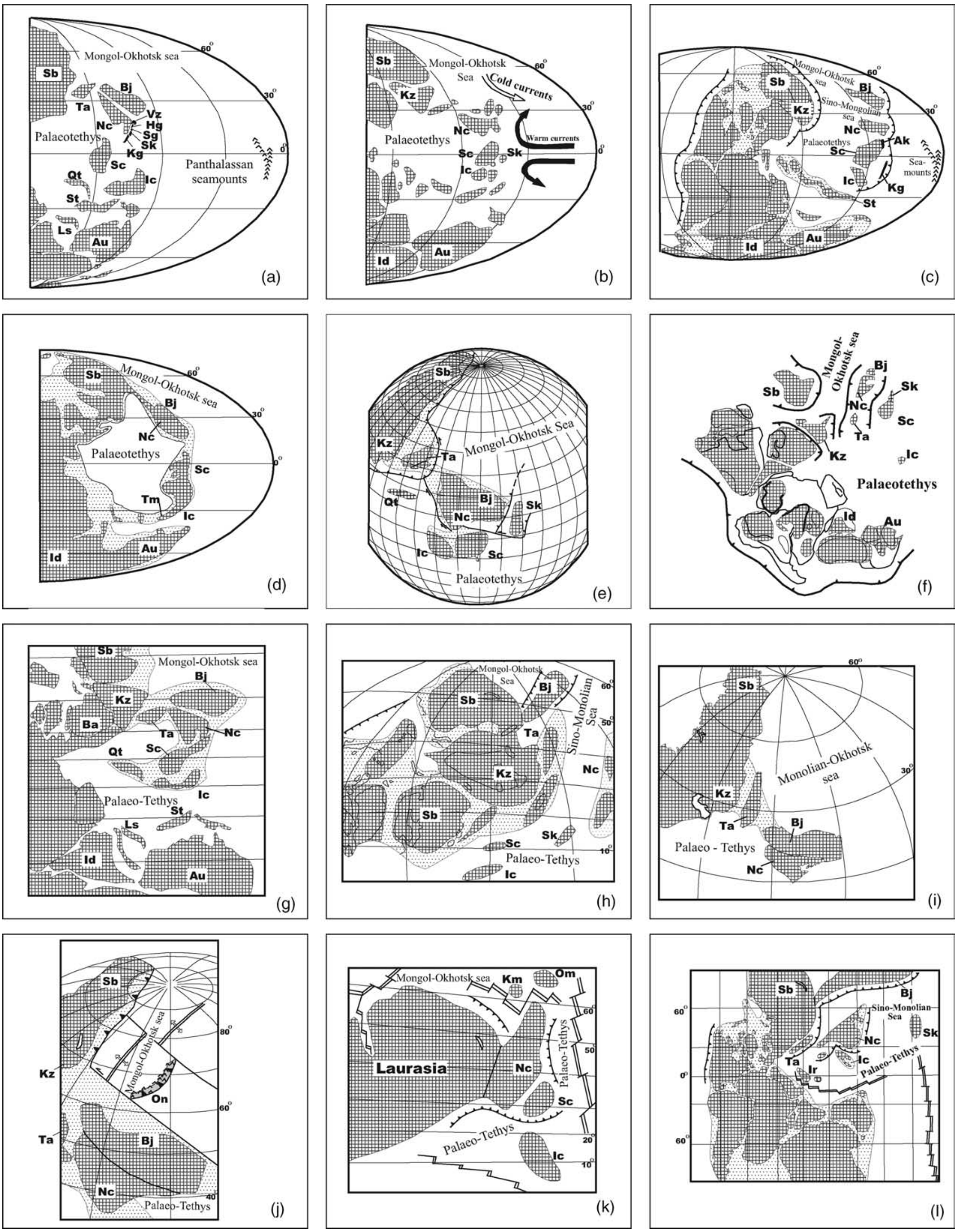

Fig. 4. Various schematic reconstruction models of Permian palaeogeography of East and Northeast Asia (note source for each map). (a) Tazawa (2001b); (b) Ehiro (2001); (c) Kobayashi (2003); (d) Kotlyar et al. (2003); (e) Enkin et al. (1992); (f) Maruyama et al. (1997); (g) Berzin and Dobretsov (1992); (h) Zonenshain et al. (1990); (i) Kravchinskiy et al. (2002a); (j) Zorin (1999); (k) Gordienko (1994); (l) Zonenshain et al. (1987). Crossed areas are land masses; dotted areas are continental shelves. Abbreviations of tectonic blocks are as follows, in alphabetical order: Ak, Akiyoshi Terrane; Au, Australia; Ba, Baltica; Bj, Bureya–Jiamusi Terrane (massif); Hg, Hida Gaien Belt (Terrane); Ic, Indochina Block; Id, India; Ir, Iran; Kg, Kurosegawa Belt (Terrane); Km, Kolyma Terrane; Kz, Kazakhstan Block; Ls, Lhasa Terrane; Nc, North China Platform (part of the Sino-Korean Platform); Om, Omolon Terrane; On, Onon Island Arc; Qt, Qiangtang Terrane; Sb, Siberian Platform; Sc, South China Platform; Sg, Sergeevka Terrane; Sk, South Kitakami Terrane; St, Shan-Thai (Sibumasu) Terrane; Ta, Tarim Block (Massif); Tm, Timor; Vz, Voznesensk Terrane.

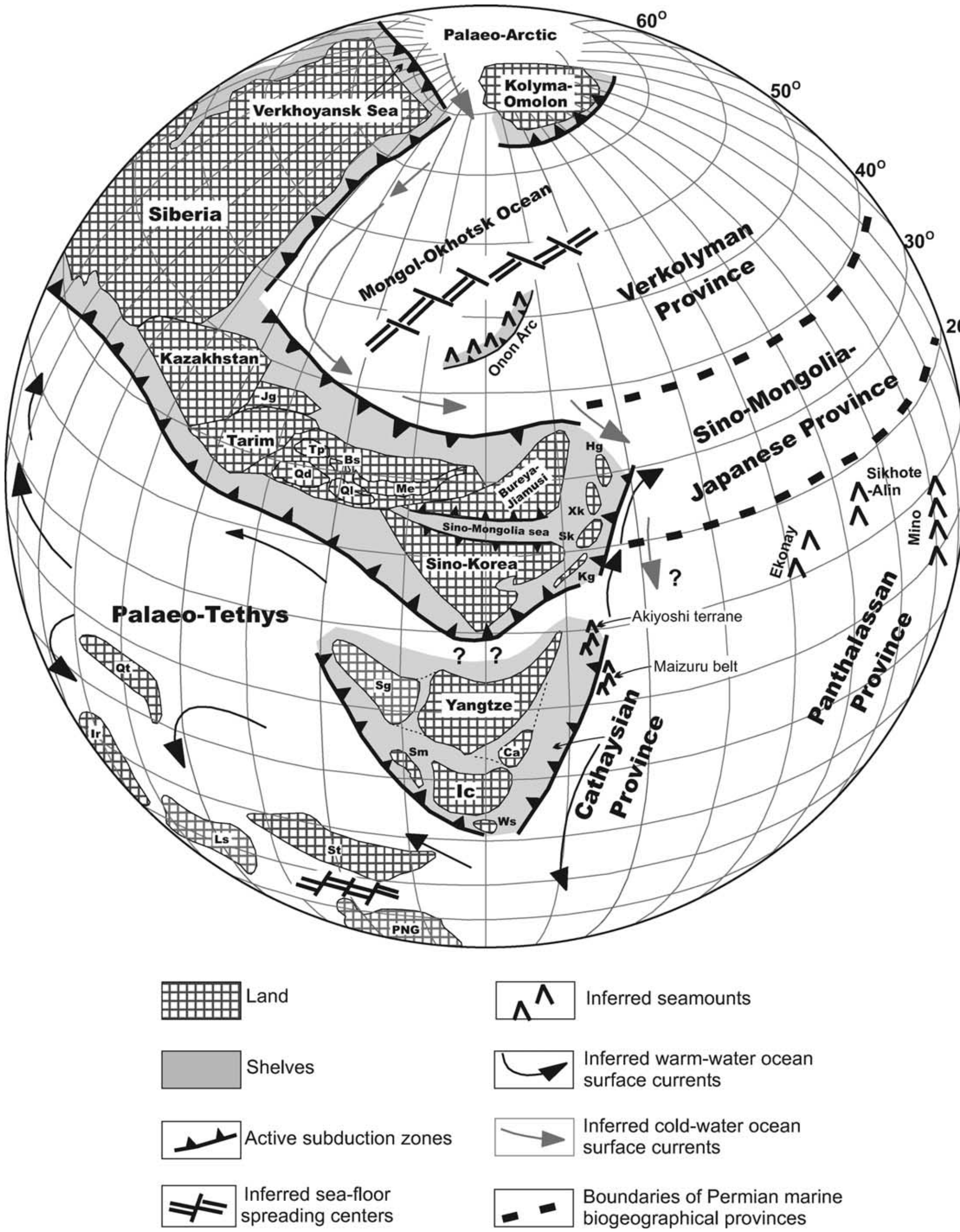


Fig. 5. A schematic palinspastic reconstruction of Middle Permian (Wordian–Capitanian; approximately 265 Ma) palaeogeography, marine biogeography and plate tectonic configuration of East and NE Asia. Symbols for tectonic blocks are as follows: Bs, Beishan area of NW China; Ca, Jiangnan oldland (Southeastern China); Hg, Hida Gaien Belt (Terrane); Ic, Indo-China Block; Ir, Iran; Jg, Junggar Block (massif); Kg, Kurosegawa Belt (Terrane); Ls, Lhasa Terrane; Me, Central Mongolia–Ergun Terrane; PNG, Papua New Guinea; Qd, Qaidam Terrane; Ql, Qilian Mountains; Qt, Qiangtang Terrane; Sg, Sanpang-Garze block (fold belt); Sk, South Kitakami Belt; Sm, Simao Terrane; St, Shan-Thai Terrane; Tp, Turpan Terrane; Xk, Xingkai (Khanka) Terrane; Ws, West Sumatra (based on Barber et al., 2005) (see text for more information and explanation). The question mark next to the arrow indicates a possible further southward intrusion of the northern cold-water ocean currents. The question marks between the Yangtze Block and Sino-Korea indicate a possibility of this area being shallow marine during the Middle Permian. The palaeo-position of the Onon Arc (in the Mongol–Okhotsk Ocean) is based on Zorin (1999).

circum-Pacific faunas, in sharp contrast to its late Middle Permian (Wordian–Capitanian) fusulinoidean faunas which exhibit significant similarities to those of the South Kitakami and Sikhote-Alin terranes. This change of biogeographical similarities with other terranes (areas) may suggest that the Early Permian marine provincialism of the Ekonay Terrane was either poorly defined, rendering its recognition difficult, or the terrane was so widely separated from all other regions of East and NE Asia at this time, that it belonged to an independent province. By Wordian–Capitanian, however, the Ekonay Terrane may have moved (i.e. drifted) geographically close enough to the South Kitakami and Sikhote-Alin terranes,

Table 4
Permian palaeolatitudes of major East and NE Asian tectonic blocks used for constraining their Permian palaeogeographical positions as shown in Fig. 5

| Main tectonic blocks | Age | Palaeolatitude | References |
|---|---|---|---|
| Kolyma–Omolon terrane | Permian | 75°N | Fujita and Newberry, 1982 |
| Verkhoyansk fold belt | Permian | 65°±2°N | Khramov and Utritskiy, 1990 |
| Siberian platform | Late Permian | 60°N | Smethurst et al., 1998 |
| | Latest Permian | 67.3°±9.4°N | Kravchinskiy et al., 2002b |
| Northern Mongol–Okhotsk fold belt | Late Permian | 63.8°N | Kravchinskiy et al., 2002a |
| Southern Mongol–Okhotsk fold belt | Early Permian | 24.4°N | Xu et al., 1997 |
| | Late Permian | 20.9°N | Kravchinskiy et al., 2002a |
| Junggar block (NW China) | Late Permian | 43.12°N | Sharps et al., 1992 |
| Southeastern Mongolia (Bureya–Jiamusi terrane) | Permian | 19°N | Pruner, 1987 |
| Inner Mongolia (Bureya–Jiamusi Terrane) | Middle Permian | 23.3°N | Tang, 1989 |
| Sikhote-Alin fold belt | Permian | 7.9°N | Zakharov and Sokarev, 1991 |
| North China (Sino-Korean Platform) | Permian | 15°±7°N | Khramov and Ustritskiy, 1990 |
| | Late Permian | 13.7°N | Zhu et al., 1998 |
| | Late Permian | 8.6°N | Huang et al., 2001 |
| Xingkai (Khanka) terrane | Early Triassic | 24.8°N | Tang, 1989 |
| | Middle Permian | 16.7°N | Shao and Tang, 1995 |
| Tarim block | Early Permian | 28.4°±4.4°N | Fang et al., 1990 |
| | Late Permian | 35.4°N | McFadden and McElhinny, 1988 |
| Mino terrane, Japan | Permian | 3.5°N | Hattori and Hirooka, 1979 |
| Yangtze block (South China Platform) | Middle Permian | 10°±5°N | Khramov and Ustritskiy, 1990 |
| | Late Permian | 12.1°N | Zhu et al., 1998 |
| | Late Permian | 10.5°N | Huang et al., 2001 |
| | Latest Permian | 2.6°N | Lin and Fuller, 1998 |

Data from Fujita and Newberry, 1982; Khramov and Ustritskiy, 1990; Smethurst et al., 1998; Kravchinskiy et al., 2002a,b; Xu et al., 1997; Sharps et al., 1992; Pruner, 1987; Tang, 1989; Zakharov and Sokarev, 1991; Zhu et al., 1998; Huang et al., 2001; Shao and Tang, 1995; Fang et al., 1990; McFadden and McElhinny, 1988; Hattori and Hirooka, 1979; Lin and Fuller, 1998.

to allow a significant increase of biotic interchanges. This explanation would imply that the Ekonay Terrane was on a constantly drifting mode throughout the Permian, causing its provinciality to evolve, rather than remaining static.

In fact, as already pointed out, the marine provinciality of at least two other East Asian terranes also appears to have evolved through the Permian. The Akiyoshi Terrane (including the Maizuru Belt) of Japan has strong Cathaysian affinities in the Early and early Middle Permian, but its Capitanian and Late Wuchiapingian brachiopod faunas (Yanagida, 1996; Yanagida et al., 1993a) exhibit some affinities with the Sino-Mongolian–Japanese Province. This changing pattern of marine provinciality may suggest that like the Ekonay Terrane, the Akiyoshi Terrane may have also been involved in a mode of active tectonic rafting across latitude zones in a general northerly direction. Alternatively, one can invoke a scenario involving the intrusion of cool-water ocean currents with Verkolyman species from the Mongol–Okhotsk Ocean southwards, passing through the Sino-Mongolian–Japanese Province into the eastern shelf of the Sino-Korean Platform, and even further south into the northeastern shelf areas of the South China Platform, where the Akiyoshi and Maizuru belts were situated (Fig. 5). In some respects, the Kurosegawa Belt may have behaved tectonically in a similar fashion to the Akiyoshi Terrane because, despite its overwhelming Cathaysian biogeographical aspects, it has also yielded some rare *Monodiexodina*, which elsewhere in East Asia are found only in the Sino-Mongolian–Japanese Province.

A second key feature of the tectono-biogeographical reconstruction, as depicted in Fig. 5, is its ability to explain the origin of the mixed Middle Permian marine faunas of the Sino-Mongolian–Japanese Province and its mechanism of biotic intermingling. Shi et al. (1995) noted that this province did not become fully established until mid-Permian. During the earlier Permian, marine faunas of the Bureya–Jiamusi Terrane and the northern margins of the Sino-Korean Platform were markedly different and belonged, respectively, to the Verkolyman and Cathaysian provinces. This marked biogeographical demarcation between the Bureya–Jiamusi Terrane and Sino-Korea in the Early Permian is probably an indication that there was a significant marine barrier between the two blocks, which, combined with considerable latitude differences and hence contrasting temperatures, prohibited the interchanges, if any, of marine biotas between the Verkolyman Province in NE Asia and the Cathaysian Province to the south. By Middle Permian, the Sino-Mongolia sea, due to continued subduction along both its northern and southern margins (Tang et al., 1995) (Fig. 5), had been considerably reduced in size. At the same time, the Sino-Korean Platform had advanced north to a position close to the Bureya–Jiamusi Terrane, as well as a few other continental terranes (or microcontinents) further to the east, such as the South Kitakami and Xingkai terranes, both of which are considered to be located in the lower middle latitudinal regions of the northern hemisphere, at the interface between the high palaeolatitude cool- to cold-water Verkolyman Province and the palaeotropical warm-water Cathaysian Province (Fig. 5). At this 'gateway' palaeogeographical position, the Sino-Mongolian–Japanese Province would have been influenced by both cold-water currents from the Mongol–Okhotsk Ocean in the north and the northward-deflected warm-water palaeoequatorial currents from the Palaeo-Tethys and Panathalassa to the south. It is probably, due to this unique tectono-palaeogeographical position, coupled with intermingled cold- and warm-water palaeocean currents, that a distinctively mixed cold- and warm-water marine biota became established in East Asia during the Middle Permian.

Towards the end of the Middle Permian marine sedimentation ceased across most parts of East Asia, except for the South Kitakami Belt, where localized marine deposition persisted into the Late Permian (Tazawa, 1975). The Upper Permian of NE China and South Primorye in Far East Russia is dominated by continental deposits, many of which feature mixed Angaran and Cathaysian floras. The timing of these mixed Late Permian floras has been widely interpreted to indicate the beginning of the final amalgamation of the Bureya–Jiamusi Terrane with Sino-Korea, and hence the complete closure of the Sino-Mongolian seaway (Zhang, 1988; Huang, 1995).

## 7. Conclusions

The marine Permian in East and NE Asia is characterized by a diverse array of sedimentary and volcanic-sedimentary rocks and faunas, representing a wide range of palaeo-latitudinal, palaeogeographical and plate tectonic settings. From NE Russia to Japan and North China, the marine Permian sedimentary rock sequences may be divided into four broad facies types and their marine faunas into four corresponding provinces. The northern facies, embracing the Kolyma–Omolon Terrane, the Verkhoyansk fold belt and the Transbaikal-northern Mongolia region, is characterized mainly by terrigenous sediments and an exclusively Boreal-type marine biota of the Verkolyman Province. The southern facies, including the Permian in the Sino-Korean Platform and some parts of Japan (e.g. the Akiyoshi Terrane including the Maizuru Belt), is distinguished by widespread carbonate rocks with a principally warm-water biota, characteristic of the palaeoequatorial Cathaysian Province. The marine Permian system in the intervening areas (i.e. SE Mongolia, NE China, South Primorye and the South Kitakami Terrane of Japan) is clearly transitional between the northern and southern facies, in that it is characterized by an abundance of both clastic and carbonate rocks, and, in particular, widespread and thick volcaniclastic successions. The Permian marine faunas in this broad transitional zone also demonstrate a transitional (i.e. mixed) nature between the cold-water Verkolyman Province in the north and the warm-water Cathaysian Province in the south, leading to the recognition of the Sino-Mongolian–Japanese Province. This transitional fauna is interpreted to have resulted from a combination of factors, including tectonic convergence between the Bureya–Jiamusi Terrane and the Sino-Korean Platform during the Permian, and the intermingling of both warm- and cold-water ocean currents off the eastern coast areas of the Bureya–Jiamusi Terrane and Sino-Korean Platform during the Middle Permian. The fourth type of Permian marine sedimentary and biogeographical facies (Panthalassan Province) of East and NE Asia is featured by seamount-type volcaniclastic and carbonate rocks of the Mino, Nadanhada, Sikhote-Alin and Ekonay terranes, most of which are today embedded within Jurassic accretionary complexes along the Pacific margin of East and NE Asia. The Permian biogeographical affinities of these displaced terranes, albeit primarily of warm-water palaeoequatorial origin, are nevertheless ‘multidimensional’ in that they exhibit varying degrees of close relationships with many other tectonic blocks and terranes in East Asia. The complex biogeographical signals of these displaced terranes are most likely a reflection of their changing palaeogeographical positions, hence changing palaeogeographical distances from other tectonic blocks in East and NE Asia during the Permian.

The ‘biostratigraphic gateway’ concept has been explored in some detail, with special reference to the Sino-Mongolian–Japanese Province. The mixed nature of its Middle Permian marine faunas of this province is regarded as a palaeobiogeographical feature of prime biostratigraphical significance. This is because the mixed marine faunas, with both warm- and cold-water elements, would make the province an ideal ‘biostratigraphical gateway’ for correlating high-palaeolatitude Verkolyman faunas and rock sequences with those of the palaeoequatorial Tethyan region, and further south, with the Gondwanan Realm. Using this principle, and in conjunction with some bipolarly or bitemperately shared Permian marine taxa and faunas, it has been possible to correlate Permian sedimentary rock formations of Australia, Tibet and Timor with those of NE Asia, and allow some of these high-palaeolatitude Permian formations and faunas in both hemispheres to be dated in terms of the international Permian chronostratigraphical scale with reasonable confidence.

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