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Journal of Asian Earth Sciences 26 (2006) 280–293
Journal of Asian Earth Sciences
www.elsevier.com/locate/jaes

South Primorye, Far East Russia—A key region for global Permian correlation

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Received 14 January 2005; received in revised form 6 June 2005; accepted 29 October 2005

Abstract

Significant differences between faunal and floral associations existing in different paleogeographic realms in the Kungurian–Late Permian interval make it difficult to correlate the Permian deposits of the world. Resolving this problem is one of the main tasks of Permian stratigraphy. The global significance of Permian strata of the Primorye region of Far East Russia is enhanced by the specific Middle Permian mixed Tethyan, Boreal and Gondwanan-type brachiopod fauna, mixed Angara-Euromerican-Cathaysian flora, and their close spatial and stratigraphical association with fusulinids, bryozoans, ammonoids, conodonts. These facts permit tracing of global correlational levels of some Permian sequences within the different paleobiogeographical realms: for example, the *Monodiexodina sutschanica-Metadoliolina dutkevichi* fusulinid zone of the Wordian age and *Parafusulina stricta* fusulinid zone of the Capitanian age. The Late Permian fauna of the Primorye is mainly Tethyan in origin and provides correlation with similar aged sequences from South China.

1. Introduction

The Kungurian–Late Permian interval was a time of increased paleoclimatic differentiation that led to strong biogeographic floral and faunal separation. Significant differences between these associations in different paleogeographic realms make it difficult to correlate Permian deposits. Resolving this problem is one of the main tasks of Permian stratigraphy.

Additionally, the Middle-Late Permian global scale is based on western Panthalassan and Tethyan faunas, which are comparable with the Boreal and Gondwanan ones only to a small degree. The problem of correlation of Permian age strata can be better understood by studying sequences in regions demonstrating mixed or alternating fossil associations derived from different paleobiogeographic realms. The Primorye region of Far East Russia promises possibilities for interprovincial correlation of Permian deposits due to its position bordering the Tethyan and Boreal realms.

In this paper, a description of the position of the Primorye within the Permian tectonic and paleogeographic framework is presented along with an overview of the regional Permian stratigraphy of this region. An interprovincial correlation based on the mixed faunal and floral associations is presented.

The Permian stratigraphy of the Primorye has been studied for many years. The presence of a succession of alternating continental and marine deposits permits the precise comparison of floral and faunal zonal sequences. Brachiopods, fusulinids, bryozoans, and ammonoids that compose the traditional basis for Permian biostratigraphy of the region are used to correlate these stratigraphic sequences to other regions of the Tethyan and Boreal realms (Sosnina, 1960; Burago et al., 1974; Nikitina, 1974; Kiseleva, 1982; Zakharov and Pavlov, 1986; Kotlyar et al., 1990). Additional data on conodonts has provided an improved correlation with the Permian global scale.

2. Tectonic framework

The region under consideration is located between Sino-Korean craton to the south and the Sikhote-Alin folded belt to

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doi:10.1016/j.jseaes.2005.10.010

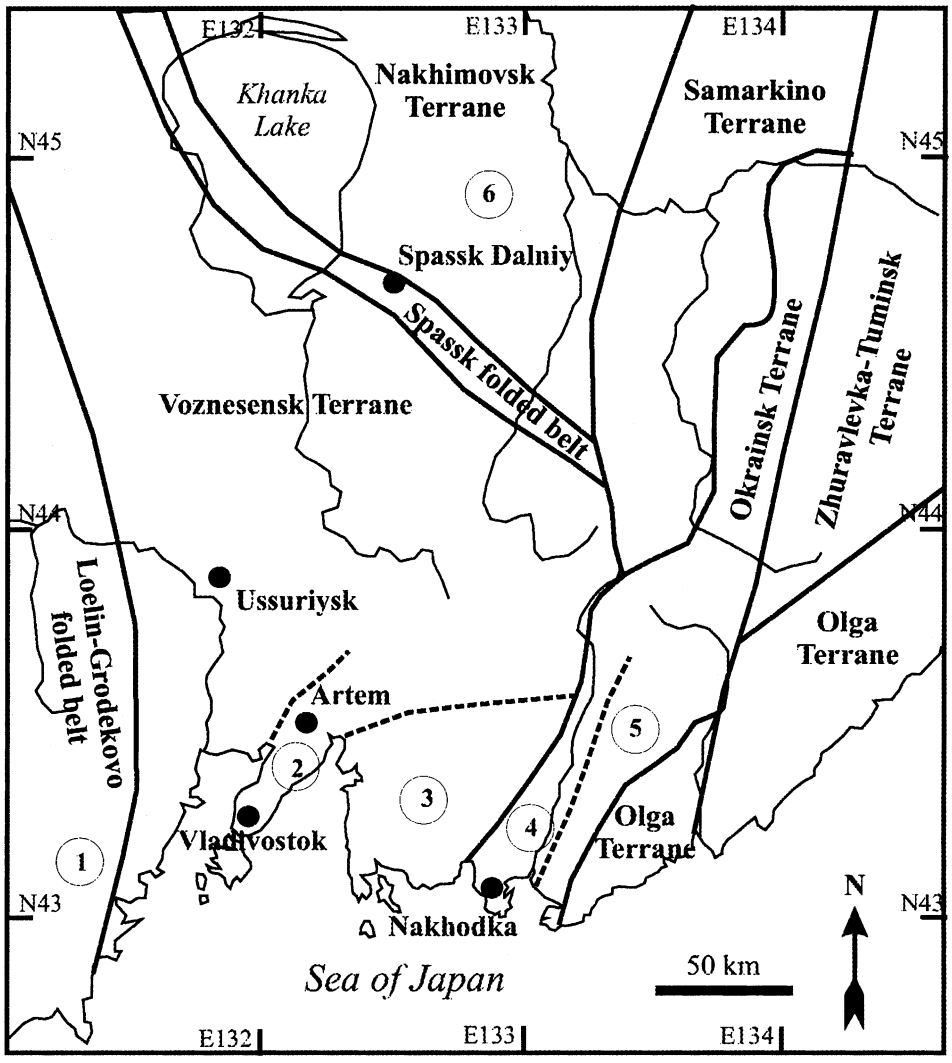

Fig. 1. Location of the terranes and areas under consideration: 1—Western Primorye area; 2—Muraviev area; 3—Dunay area; 4—Partizanka area; 5—Sergeevka area; 6—Malinovka area.

the east, and comprises the northeastern part of the Laoelin-Grodekovo folded belt and the Voznesensk, Nakhimovsk, and Okrainsk terranes (Fig. 1). These terranes compose part of the Burea-Khanka Palaeozoic continental superterrane (Khanchuk, 1992).

The northeastern part of the Laoelin-Grodekovo folded belt (Western Primorye area) is characterized by siliciclastic and carbonate Permian deposits containing a large amount of volcaniclastic and volcanic formations penetrated by Late Permian and Jurassic granitoids. Carbonate deposits are mainly of Late Permian age (Barabashevka Formation). The Early Permian and early Late Permian formations are composed mainly of siliciclastic sediments and volcanics. The Permian deposits overlie Pre-Cambrian and Early Paleozoic intrusive formations and are extensively faulted and folded.

The Muraviev and Dunay areas comprise the Voznesensk Terrane (Fig. 1). The Muraviev area is characterized by a siliciclastic Early-Late Permian formation overlain by a Late Permian siliciclastic and volcanigenic formation. The Latest Permian formation is composed of carbonate, siliciclastic, and volcanigenic formation. Permian deposits compose the core of the Muraviev anticline. The thickness of the Midian (Upper Wordian–Capitanian) part of this sequence is significantly less than the one in the Laoelin-Grodekovo folded belt (200–300 and 920–2900 m, respectively). However, the Upper Permian sequence is more complete (including Dorashamian) in the Muraviev area. This fact suggests significant subsidence of the area during the Late Permian.

The Dunay area is characterized by Lower Permian volcaniclastic, volcanic, and siliciclastic deposits representing an assemblage of formations of the volcanic arc that lie on the granite and gabbro basement. These deposits are penetrated by granite intrusions and folded.

The Nakhimovsk Terrane is located northeast of the Voznesensk Terrane (Fig. 1). The Malinovka area is characterized by Permian deposits similar to ones of the Voznesensk Terrane. A significant portion of the Permian sequence (Sakmarian–Changhsingian interval) lies on sialic

basement present in the Malinovka area. Volcanic and siliciclastic formations compose the Dunayan–Vladivostokian part of the sequence; siliciclastic and carbonate-silicaclastic formations represent the Chandalazian and Lyudyanzian.

The Partizanka and Sergeevka areas comprise the Okrainsk Terrane (Fig. 1). The Permian of the Partizanka area is represented by tectonic blocks of Kungurian and Upper Wordian–Changhsingian deposits. The Lower Permian formations are comprised of mainly siliciclastic deposits The Middle–Upper Permian formations are represented by carbonate buildup surrounded by shallow-water siliciclastic deposits containing volcanic and volcaniclastic material. The Sergeevka area is characterized by tectonic blocks composed of extensively faulted and folded fragments of Lower and Upper Permian siliciclastic deposits. Due to tectonic uplift of this area, only the upper part of the Permian sequence (Yastrebovka Formation) lies on the Proterozoc metamorphic basement.

The East Sikhote-Alin folded belt (Olga and Zhuravlevka-Tuminsk terranes, Fig. 1) is separated from the Okrainsk Terrane by Central Sikhote-Alin Fault and is represented by a complex group of tectonic sheets comprised of deep-water siliciclastic, carbonate, and cherty Palaeozoic deposits. All of the deposits are extensively faulted and folded. Sections containing various parts of the Permian sequence occur in separate tectonic blocks and olistoliths in the Mesozoic accretionary assemblage.

3. Biostratigraphy

The Permian deposits of the Primorye known in the south part of the Burea-Khanka Paleozoic superterrane are represented by shallow-water, shore, and continental facies (Fig. 2). Deep-water volcaniclastic, siliceous, and terrigenous Permian sediments are characteristic of the Samarka, Olga, and Zhuravlevka-Tuminsk terranes. Small depressions filled by the Permian volcanigenic and terrigenous deposits occur in the northern part of the Voznesensk terrane.

Continental and nearshore depositional environments were dominant in the Early Permian over the most part of the Primorye. Marine depositional environments were dominant in the Middle and Late Permian. Continental and nearshore deposits are characterized by abundant plant fossils. Nearshore sediments yield brachiopods and bivalves, and ammonoids are present. Rare conodonts and diverse invertebrates, including fusulinids, brachiopods, bryozoans, ammonoids, and radiolarians occur in the open-marine and carbonate buildup sequences.

Five horizons and biostratigraphic zones based on the guide groups of fauna compose the Permian regional stratigraphic framework of Primorye (Tables 1 and 2). The stratigraphic term ‘horizon’ is used here in Russian sense, namely as regional stratigraphic subdivision comprising isochronous formations or their parts.

The Dunay and Abrek horizons can be placed in the Cisuralian Series, the Vladivostok and Chandalaz—in the Guadalapian Series and the Lyudyanza in the Lopingian Series (Tables 1, 2).

3.1. Dunay Horizon

The Dunay Horizon corresponds to the Dunay Formation and occurs in the Voznesensk Terrane (Dunay area). The formation is represented by volcanics, volcanic breecia, conglomerates,, sandstones, siltstones, and tuffites (Fig. 2). Plant fossils are found only in the upper part of the horizon. The thickness of the Dunay Horizon varies from 1100 up to 3500 m.

Dunay plant fossils are the oldest known in the Permian of the Primorye (Table 2). Cordaites, especially of the morphological group ‘*Rufloria derzavinii–Cordaites singularis*’, dominate the plant associations (Meyen, 1969; Durante, 1976). Rare pteridosperms, ferns and sphenophyta occur as well. Two sub-associations can be recognized (Burago, 1979, 1983). The lower sub-association comprises: *Taeniaphyllum buragoae* Salmanov, *Cordaites batschatensis* (Radczenko) S. Meyen, *C. latifolius* (Neuburg) S. Meyen, *Rufloria aff. theodorii* (Tchirkova et Zalessky) S. Meyen, *Prynadaeopteris tunguscana* (Schmhausen) Radczenko, *Pursongia aff. ussaensis* Gorelelova, *Rufloria cf. derzavinii* (Neuburg) S. Meyen, *Xiphophyllum kulikii* Zalessky, *Gaussia relaxata* Radczenko and *Nephropsis integerrima* (Schmhausen) Zalessky. The upper one contains *Cardioneura* sp., *Cordaites cf. pseudoaequalis* (Radczenko), *Rufloria derzavinii* (Neuburg) S. Meyen, *R. sibirica* (Radczenko) S. Meyen, *R. aff. theodorii* (Tchirkova et Zalessky) S. Meyen, *Krylovia* sp., *Zamiopteris schmalhausenii* Schvedov, *Lepeophyllum acutifolium* Radczenko, *Samaropsis pusilla* Neuburg, *S. danilovii* Suchov and *Skokia elongata* (Tarasov) Suchov.

This association can be correlated with floras of the Promezhutochnaya (excluding the lower part) and the Ishan Formations of the Kuznetsk Basin (Gorelova et al., 1978; Zhuravleva and Il’ina, 1988); the lower part of Burgukli Formation of the Siberian Platform (Verbitskaya, 1973); the first sub-association of the ‘*Singularis-Derzhvinia*’ association of Mongolia (Durante, 1976); and the Lower Permian flora of the Okhotsk region (Radchenko, 1961). A Sakmarian (?)-Kungurian age for the Dunay Horizon is apparently established on the basis of correlation with similar age deposits in the Kuznetsk Basin (Glukhova, 1984; Naugolnykh, 1993; Durante, 1996; Esaulova, 1997).

3.2. Abrek Horizon

The Abrek Horizon comprises the Abrek and Pospelovka Formations of the Muraviev area (Voznesensk Terrane), the Kazachka and Reshetnikovo Formations of the Western Primorye area (Laoelin-Grodekovo terrane) and the Kostyukovka and Pospelovka Formations of the Malinovka area (Nakhimovsk Terrane) (Table 1). The type section of the horizon is located on the western and northern shore of the Strelok Bay (Muraviev area of the Voznesensk terrane). The Abrek Horizon is comprised mainly of siliciclastic deposits of continental, lagoon, and nearshore origin. Offshore

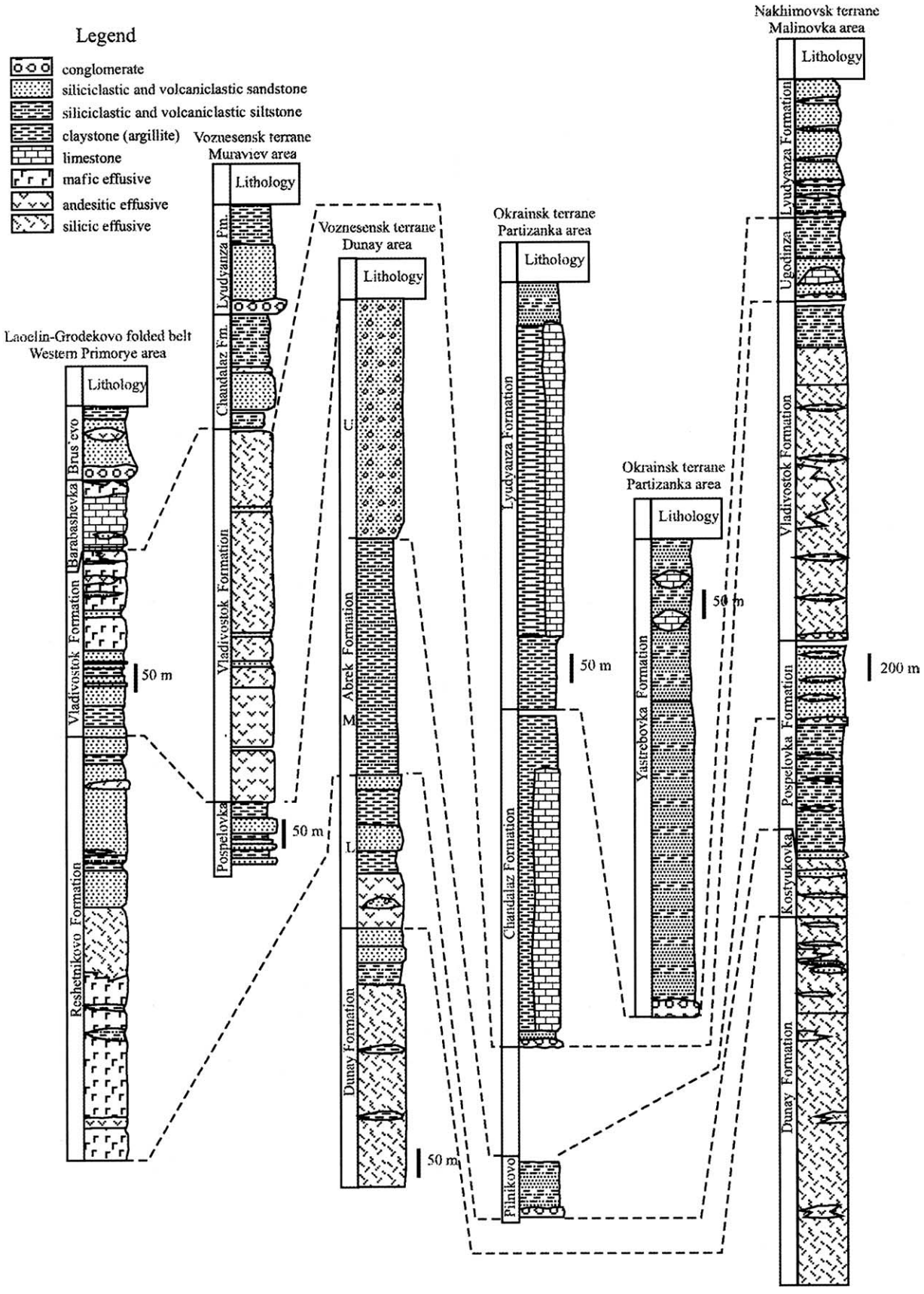

Fig. 2. Generalized lithological columns for the areas under consideration.

Table 1
Regional stratigraphic scheme of the Permian of South and Western Primorye

Global stratigraphic scale		Tethyan scale	Regional stratigraphic scale	Local stratigraphy					
Series	Stage	Stage	Horizon	Laoelin-Grodekovo folded belt	Voznesensk Terrane		Okrainsk Terrane		Nakhimovsk Terrane
				Western Primorye area	Muraviev area	Dunay area	Partizanka and Sergevka areas		Malinovka area
Lopingian	Changhsingian	Dorashamian	Lyudyanza		Kapreevka Beds			Kapreevka Beds	
				Brus'evo Fm.	Lyudyanza Formation		Lyudyanza Formation	Yastrebovka Formation	Lyudyanza Formation
	Wuchapingian	Dzhulfian		Barabashevka Formation					
Guadalupian	Capitanian	Midian	Chandalaz		Chandalaz Formation		Chandalaz Formation	? Sitsa Fm.	Ugodinza Formation
	Wordian								
		Murgabian	Vladivostok	Vladivostok Formation	Vladivostok Formation				Vladivostok Formation
	Roadian	Kubergandian							
Cisuralian	Kungurian	Bolorian	Abrek	Reshetnikovo Formation	Pospelovka Formation	Abrek Fm. U	?		Pospelovka Formation
						M	Pilnikovo Beds		
				Kazachka Fm.		L			Kostyukovka Formation
	Artinskian	Yakhtashian	Dunay			Dunay Formation			Dunay Formation
	Sakmarian	Sakmarian							
	Asselian	Asselian							

Table 2
Regional biostratigraphic units of the Permian of South and Western Primorye

Global Scale			Tethyan Scale		Regional scale	Regional biostratigraphical units							
System	Series	Stage	Series	Stage	Horizon	Foraminiferal zones	Ammonoid beds	Conodonts	Brachiopod zones	Bryozoan zones	Coral zones	Radiolarians	Plants
Permian	Lopingian	Changhsingian	Upper	Dorashamian	Lyudyanza	*Colaniella parva*	*Huananoceras quinjiangensis*	*Clarkina* cf. *C. deflecta*		*Arcticopora innae*			
							Iranites	*Clarkina* ex gr. *C. orientalis*					
		Wuchiapingian		Dzhulfian			*Cyclolobus kiselevae*						
							Xenodiscus subcarbonarius		*Anidanthus sinosus-Squamularia grandis*		*Pseudofavosites kotljarae-Calophyllum kabakovitchae*	*Follicucullus falx*	
	Guadalupian	Capitanian		Midian	Chandalaz	*Metadoliolina lepida-Lepidolina kumaensis*	*Stacheoceras orientale*	*Jinogondolella wilcoxi*	*Prorichthofenia ussurica*	*Girtypora regula*	*Szechuanophyllum kitakamiense-Wentzelloides (W.) ussuricus*	*Follicuculus porrectus F. scholasticus*	Late Sitsa plant assemblage
						Parafusulina stricta	*Timorites markevichi*	*Clarkina* cf. *C. bitteri Jinogondolella* cf. *J. postserrata*	*Leptodus nobilis-Spiriferella rajah*	*Ogbinopora perforata*	*Ufimia columoinum-Lophocarinophyllum chandalasicum*		
		Wordian				*Monodiexodina sutschanica Metadoliolina dutkevitchi*	*Tauroceras* sp.	*Jinogondolella* cf. *J. aserrata*	*Substriatifera vladivostokensis*	*Dyscritella bogatensis*			*Marratiopsis orientalis* beds / Early Sitsa assemblage
				Murgabian	Vladivostok		*Altudoceras subroadense*		*Muirwoodia mammata*	*Stenopora clara*			Vladivostok plant assemblage
		Roadian		Kubergandian			*Daubichites orientalis*						
	Cisuralian	Kungurian	Lower	Bolorian	Abrek Up.								Late Pospelovka plant assemblage
					Abrek Middle		*Epijuresanites pilnikovensis*		*Primorewia reshetnikovi-Tomiopsis atlanichus*			*Latentifistula* sp. *Tormentum narthecium Ruzhencevispongus* sp.	Early Pospelovka plant assemblage
					Abrek Lower								Konyushkov plant assemblage
		Artinskian		Artinskian	Dunay								Dunay plant assemblage
		Sakmarian		Sakmarian									
		Asselian		Asselian									

facies are only seen in the Western Primorye area. Volcanic deposits occur almost everywhere in the basal part of the horizon (Fig. 2). The Abrek Horizon can be subdivided into three parts (Burago, 1983).

The Lower Abrek includes the Lower Abrek Subformation, and the Kazachka and Kostuykovka Formations and is characterized by a Konyushkovo fossil plant association (Tables 1 and 2). The latter is composed mainly of cordaites similar to those present in the Late Balakhonian flora of the Kuznetsk Basin. The appearance of some elements of the Pechora flora is notable. Characteristic species are: *Annularia tenuifolia* Neuburg, *Prynadaeopteris tunguscana* (Schmhausen) Radczenko, *Sphenopteris batschatensis* Zalessky, *Cardioneura tebenjkovii* Schvedov, *Cordaites latifolius* (Neuburg) S. Meyen, *C. cuneifolius* Gorelova, *C. singularis* (Neuburg) S. Meyen, *Rufloria derzavinii* (Neuburg) S. Meyen, *R. ensiformis* (Neuburg) S. Meyen, *R. recta* (Neuburg) S. Meyen, *R.* ex gr. *theodorii* (Tchirkova et Zalessky) S. Meyen, *Vojnovskya paradoxa* Neuburg, *Zamiopteris longifolia* Schvedov, *Z. schmalhausenii* Schvedov, *Nephropsis rhomboidea* Neuburg, *Samaropsis danilovii* Suchov, *S. khalfinii* Suchov, *Cordaicarpus uralicus* Dombrovskaya and Pogorevich, *Cornucarpus kojimensis* Neuburg, *Skokia elongata* (Tarasov) Suchov and *Sylvella elongata* Suchov. The Konyushkovo Association is comparable with the flora of the Kemerovo and lower part of the Usyatsk Horizons of Kusnetsk Basin (Zhuravleva and Il'ina, 1988). Similar flora occurs in the Kungurian aged Ayachyaga Formation of the Pechora Basin (Pukhonto, 1998).

The Middle Abrek corresponds to the Middle Abrek Subformation Pilnikovo Beck and the lower parts of the Pospelovka and Reshetnikovo Formations (Table 1). This stratigraphic interval is characterized by Early Pospelovka plant fossils, bivalves, and brachiopods of the beds with *Primorewia reschetnikoviensis–Tomiopsis atlanichus* (Table 2). Cordaites of the Angaraland Province with '*Singularis-Derzhavinia-Latifolia*' leaf type dominate the plant association. The presence of the exotic genus *Wattia* and the appearance of the first Cathaysian elements at the top of the Lower Pospelovka mark a clear correlative level. *Wattia* is known in the Lower Permian Arroyo Formation in Texas (Mamay, 1967), in the Vorkuta Superformation and Eryaga Formation of the Pechora Basin (Pukhonto, 1999; Molin et al., 1983). This genus spread into the Eurasia arid belt in the Late Permian (Wang, 1996; Hill and El-Khayal, 1983). The most characteristic species are: *Paracalamites decoratus* (Eichwald) Zalessky, *Annulina neuburgiana* (Radczenko) Neuburg, *Prynadaeopteris tunguscana* (Schmalhausen) Radczenko, *Sphenopteris batschatensis* Zalessky, *S. tenuis* Schenk, *Glossopteris* sp., *Cordaites concinnus* (Radczenko) S. Meyen, *C. latifolius* (Neuburg) S. Meyen, *C. singularis* (Neuburg) S. Meyen, *Rufloria derzavinii* (Neuburg) S. Meyen, *R. ensiformis* (Zalessky) S. Meyen, *R. loriformis* (Neuburg) S. Meyen, *Nephropsis integerrima* (Schmhausen) Zalessky, *N. rhomboidea* Neuburg, *Vojnovskya elegans* Zimina, *Gaussia scutellata* Neuburg, *Zamiopteris longifolia* Schvedov, *Wattia neuburgiana* (Zimina) Burago, *W.* aff. *rara* Puchonto, *Samaropsis khalfinii* Suchov, *S. triguetra* Zalessky, *Skokia elongata* (Taras) Suchov, *Sylvella elongata* Suchov and *S. brevialata* Suchov. The assemblage is similar to the Late Kungurian and Early Solikamian flora of the Rudnik Formation of the Pechora Basin (Varyukhina et al., 1981; Molin et al., 1983; Pukhonto, 1998, 1999), and to the plant associations of the Usyatsk and Starokuznetsk horizons of the Kuznetsk Basin.

Nearshore deposits contain brachiopods (beds with the *Primorewia reshetnikovi-Tomiopsis atlanichus* assemblage) *Rhynchopora variabilis* Stuckenberg, *R. nikitini* Tschernyschew, *Rhynoleichus subglobosus* Abramov et Grigorjeva, *Primorewia reshetnikovi* Licharew ?t Kotlyar, *Fusispirifer* ex gr. *nitiensis* (Diener), *Tomiopsis atlanichus* Kotlyar, *T. taimyrensis* Tschernjak, *Spirelytha* sp., and *Cleiothyridina* sp. These brachiopods are associated with the ammonoid *Epijuresanites pilnikovensis* Zakharov in the Pilnikovo Beds (Zakharov et al., 1999). The brachiopods and ammonoid are typical of Boreal taxa stratigraphically restricted to the Late Kungurian–Solikamian interval and are widespread in the Boreal Realm (from the Kolyma-Omolon region to the Pai-Khoy) (Kotlyar et al., 2004). Bivalve species present include *Nuculana* sp. cf. *N. sinuata* (Dembskaja), *Aviculopecten* cf. *keyserlingi* Stuckenberg, *Streblopteria pusilla* (Schlotheim), *Schizodus* aff. *tabai* (Hayasaka), and *Praeundulomya petschorica* Muromzeva, which are characteristic of the Kungurian as well. The marine fossil assemblages can be correlated with the upper part of *Megousia kuliki* brachiopod zone of the Dzhigdali Horizon of Kolyma-Omolon region (Ganelin et al., 2001) and the Tumara Horizon of the Verkhnyaya Yana region (Klets, 2004).

The Upper Abrek consists of the upper part of the Abrek Formation (Voznesensk Terrane) and the Pospelovka (Voznesensk and Nakhimovsk terranes) and Reshetnikovo (Laoelin-Grodekovo folded belt) Formations (Table 1). The Upper Pospelovka plant association (Table 2) characteristic of the Upper Abrek reflects the early stage of development of the fern-pteridosperm-cordaite palaeoflora (Durante, 1995). Pteridosperms ('*Callipteris*', *Comia* and *Protoblechnum*) and the gymnosperm genus *Psygmophyllum* are present. *Glossopteris* and *Gangamopteris* demonstrate high diversity in the South Primorye (Zimina, 1967). Possibly an ingression of warm water masses leds to climatic changes favorable for immigrants from Cathaysia. Taxa present are: *Sphenopteris nystroemii* Halle, *S. cf. gothanii* Halle, *S.* aff. *tenuis* Schenk, *Cladophlebis manchurica* (Kaw.) Lee, *Protoblechnum*, *Pterophyllum eratum* Gu et Zhi, *Prynadaeopteris synica* (Zalessky) Burago, *Pecopteris anthriscifolia* f. *vorcutensis* Zalessky, *P. niamdensis* f. *makuchinae* Burago, *P. compta* Radczenko, *Sphenopteris nystroemii* Halle, *Rhachiphyllum orientale* (Zalessky) Burago, *R. ivancevia* Gorelova, *Comia latifolia* Tchalyshev, *C. latiloba* Burago, *Glossopteris tunguscana* (Neuburg) Zimina, *Pterophyllum eratum* Gu and Zhi, *Cordaites concinnus* (Radczenko) S. Meyen, *C. sylovaensis* (Neuburg) S. Meyen, *Rufloria derzavinii* (Neuburg) S. Meyen, *R. ensiformis* (Zalessky) S. Meyen, *Gaussia* sp., *Nephropsis (Sulcinephropsis) lampadiformis* Gorelova, *Psygmophyllum*

vesnjankianum Burago, *Samaropsis subelegans* Neuburg, *Tungussocarpus subtychtensis* Suchov and *Sylvella elongata* Suchov. This association is similar to plant assemblages of the Inta Formation and the lower part of the Seyda Formation of the Pechora Basin and Kuznetsk Formation of the Kuznetsk Basin, which is considered to be of Ufimian age (Durante and Puchonto, 1999; Pukhonto, 1998).

The Upper Abrek can be conditionally correlated with the *Kolymaella ogonerensis* Zone of North-East Russia based on the fact that both units are situated below beds containing *Daubichites* (Table 2).

The Tethyan Scale is traditionally used to correlate the overlying Permian deposits of the Primorye (Obyasnitelnaya zapiska k stratigraficheskoi shkale oblasti Tethys, 1980) (Table 2).

3.3. Vladivostok Horizon

The Vladivostok Horizon has its type section located on the right bank of the Pervaya Rechka River (Muraviev-Amurskiy Peninsula, Voznesensk terrane). The Vladivostok Horizon is dominated by volcanic rocks (andesitic and silicic), and by volcaniclastic and siliciclastic sediments of nearshore and continental origin (Fig. 2). The horizon corresponds to beds with the bryozoan *Stenopora clara*, which are correlated with the Omolon Horizon of the Kolyma-Omolon region, the Murgabian Stage of the Tethyan realm, and the Wordian Stage of the Guadalupian Series of the Global Scale (Kiseleva, 1986). Ammonoid beds with *Daubichites orientalis* reported in the lower part, and *Roadoceras subroadense* found in the upper part of the horizon (Zakharov and Pavlov, 1986), permit correlation of the Vladivostok Horizon with the Roadian-Wordian of the Global Scale or with the Kazanian and Lower Tatarian interval of the East-European Platform (Table 2). Brachiopod beds with *Yakovlevia mammata* contain rare *Waagenoconcha* sp., *Liosotella decimena* Manankov, *Rhynchopora tchernyshae* Koczyrkevicz, *Spiriferella keilhaviformis* Fredericks and *Alispiriferella litha* (Fredericks). The brachiopod assemblage is similar to the Tsaganul Association of South Mongolia (Pavlova et al., 1991).

The Abrek/Vladivostok boundary is marked by a significant turnover in the plant associations in the South Primorye probably caused by shift of the terranes into the subtropical belt. Wide expansion of Euramerican/Cathaysian floras was characteristic of the beginning of Vladivostok time. Maximum content of Cathaysian plants can be seen in the Western Primorye area (Laoelin-Grodekovo folded belt). Specific taxa of this area are: *Lobatannularia lingulata* Halle, *Schizoneura striata* Kawasaki and Kon′no, *Prynadaeopteris synica* (Zalessky) Burago, *Pecopteris tenuicoctata* Halle, *P. maritima* Zalessky, *Neuropteridium coreanicum* Koiwai, *Glossopteris mongolica* (Neuburg) Zimina, *Rhachiphyllum adzvense* (Zalessky) Naugolnykh, *R. sahnii* (Zalessky) Burago, *Comia enisejevensis f. petschorensis* Tchalyshev, *C. dobrolubovae* Tchalyshev, *Protoblechnum hallei* Yabe and Oishi, *Cordaites concinnus* (Radczenko) S. Meyen, *C. principalis* (Germar) Geinitz, *Nephropsis lampadiformis* Gorelova, *Pterophyllum* sp., *Tomia* sp. and *Psygmophyllum* sp. This assemblage is comparable with flora of the Kazankovo-Markino Horizon of the Kuznetsk Basin, the Kazanian–Lower Tatarian flora of the Changhi Formation of South Mongolia (Durante and Luwsanceden, 2002), and plant associations of the Sanczyoshuan Formation of the Maly Hingan (Huang, 1977, 1991). Similar plant assemblages are known in the Seyda Formation and in the lower part of the Talbey Formation of the Pechora Basin (Pukhonto, 1998). Characteristic Kazanian genera of this association are *Tschernovia*, *Prynadaeopteris*, *Rhachiphyllum* (=*Callipteris*), *Comia*, *Peltaspermum*, *Psygmophyllum*, *Sphenobaiera*, *Rhipidopsis*, *Rufloria* and *Cordaites*, etc.

3.4. Chandalaz Horizon

The Chandalaz Horizon comprises the Chandalaz Formation of the Voznesensk and Okrainsk terranes, the lower part of the Barabashevka Formation of the Laoelin-Grodekovo fold belt, and the Ugodinza Formation of the Nakhimovsk Terrane (Table 1). The Chandalaz Horizon is mainly represented by siliciclastic and carbonate deposits, but volcaniclastic deposits are also present. Siliciclastic sediments are of nearshore to offshore origin. Carbonate deposits are represented by bedded bioclastic and clastic limestone and some carbonate buildups. The buildups are mainly known in the Partizansk area. Their accumulation began in late Midian (*Metadoliolina-Lepidolina kumaensis* fusulinid Zone) and continued throughout the Late Permian (Fig. 2). The horizon contains abundant and diverse fossils of Midian (Late Wordian–Capitanian) age, which support biozonal sequences (Table 2). Widespread transgression is supposed during Chandalaz time. A prominent transgression maximum coincides with the *Parafusulina stricta* Zone (middle Midian or earliest Capitanian).

The basal part of the horizon is commonly represented by calcarenites or foraminiferal limestone yielding abundant *Monodiexodina*, *Metadoliolina*, *Pseudofusulina*, and *Parafusulina*. This part of the Chandalaz Horizon corresponds to the *Monodiexodina sutschanica-Metadoliolina dutkevitchi* Fusulinid Zone in the South Primorye (Voznesensk and Okrainsk terranes, lower part of the Chandalaz Formation) and beds with *Monodiexodina* in the Laoelin-Grodekovo folded belt (lower part of the Barabashevka Formation) (Table 2). *Sichotenella sutchanica* Toumanskaya, *S. sandalina* Sosnina, *Reichelina* aff. *changhsingensis* Sheng, *Minojapanella fusiformis* Sosnina, *Lantschichites delicata* (Colani), *Codonofusiella laxa* Douglas, *C.* aff. *kueichowensis* Sheng, *Pseudofusulina hupehensis* Chen, *Ps.* aff. *regularis* (Schellwien), *Parafusulina* aff. *tortilla* Sosnina, *M. sutschanica* (Dutkevich), *M. wanganensis* Sosnina., *M. shiptoni* (Dunbar), *M. kattensis* (Schwager), *Metadoliolina dutkevitchi* (Sosnina), *M. fecunda* Sosnina, and rare *Lepidolina* compose the association of this zone in the South Primorye. *Sichotenella maichensis* Sosnina, *Reichelina* sp., *Codonofusiella* sp., *Rauserella* aff. *pulchra* K. M.-Maklay, *Monodiexodina* cf. *sutschanica* (Dutkevich), *M.* cf. *wanganensis* Sosnina, *M. shiptoni* (Dunbar) and *M.* aff. *kattensis* (Schwager) are characteristic of the beds with *Monodiexodina* in the Laoelin-Grodekovo folded belt. An assemblage of the

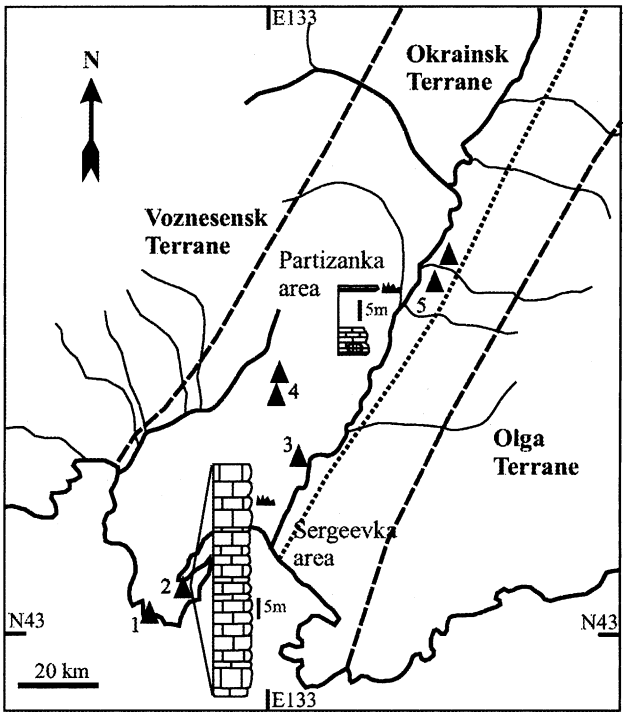

Fig. 3. Conodont localities in the Okrainsk Terrane: 1—Tungus Bay, Chandalaz Horizon, *Clarkina* cf. *bitteri*; 2—Nakhodka Reef, Lyudyanza Horizon, *Clarkina* ex gr. *orientalis*; 3—Ekaterinovka Quarry, Lyudyanza Horizon, *Clarkina* ex gr. *bitteri*, *Jinogondolella* cf. *postserrata*; 4—Chandalaz Range, lower part of the Chandalaz Horizon, *Jinogondolella* cf. *aserrata*; 5—Nikolaevka section, lower part of the Chandalaz Horizon, *Jinogondolella* cf. *aserrata*.

Dyscritella bogatensis Zone of bryozoans co-exists with the *Monodiexodina* fauna in both the South and Western Primorye. This zone is known in Gester Formation, USA (Gilmour and Snyder, 1977). A Wordian age of this interval is supported by the presence of the conodont *Jinogondolella aserrata* (Clark et Behnken)(Chandalaz Range and Nikolaevka section, Partizanka area, see Fig. 3) and typical Midian fusulinids.

Notable changes in the fusulinid associations can be seen at the base of the *P. stricta* Zone. The first *Lepidolina* multiseptata appears among abundant transient *Parafusulina*, *Chusenella*, *Yabeina*, and rare *Skinnerella.* The assemblage consists of *Sichotenella discoidea* Sosnina, *Reichelina* sp., *Lantschichites exilis* Sosnina, *Minojapanella* sp., *Chusenella pseudochihsiadensis* (Lee), *Chusenella* spp. and rare *Monodiexodina.*

Mixed Boreal and Tethyan brachiopod faunas characterize the early Chandalaz time (*Monodiexodina sutschanica-Metadoliolina dutkevitchi* and *P. stricta* Fusulinid Zones or *Substriatifera vladivostokensis* and *Leptodus nobilis-Spiriferella rajah* brachiopod zones). The brachiopod assemblage of the *Substriatifera vladivostokensis* Zone comprises mainly Boreal genera, such as *Yakovlevia*, *Wimanoconcha*, *Kochiproductus*, *Liosotella*, *Megousia*, *Anidanthus*, and *Spiriferella*. Rare *Leptodus* and *Transennatia* represent Tethyan forms. The most characteristic species are: *Derbyia grandis* Waagen, *Waagenites artemovskensis* Licharew et Kotlyar, *Wimanoconcha maliavkini* (Fredericks), *Waagenoconcha krishtofovichi* Fredericks, *Anidanthus ussuricus* (Fredericks), *Yakovlevia kaluzinensis* (Fredericks), *Y. mammata* (Keyserling), *Leptodus nobilis* (Waagen), *L. kaluzinensis* (Fredericks), *Transennatia gratiosa* Waagen, *Liosotella mongugaensis* (Maslennikov), *Alispiriferella litha* (Fredericks) and *Spiriferella saranaeformis* Fredericks.

The brachiopod assemblage of the *Leptodus nobilis-Spiriferella rajah* Zone contains fewer Boreal genera, but a significant number of Gondwanan forms and abundant Tethyan ones. *Kiangsiella*, *Tyloplecta*, *Haydenella*, *Bathymyonia*, *Collemataria*, *Leptodus*, *Gubleria*, *Leptodus*, *Spinomarginifera*, *Echinauris*, *Costiferina*, *Lamnimargus*, *Gefonia*, and *Rostranteris* appear in this zone (Kotlyar et al., 2003). This assemblage corresponds to the *Leptodus nobilis* Zone of the Kanokura Formation of Japan (Minato et al., 1978; Tazawa, 1996, 1999; Tazawa et al., 2000), the Solonker Horizon of the South-Eastern Mongolia (Manankov, 1999), the Wargal Formation (Waagen, 1884; Reed, 1944), and the Basleo Beds of Timor (Broili, 1916; Hamlet, 1928). The *Ogbinopora perforata* bryozoan zone corresponds to the *P. stricta* fusulinid and the *Leptodus nobilis-Spiriferella rajah* brachiopod zones (Table 2).

The ammonoid *Timorites markevichi* Zakharov had been found from Grozny Cape in association with brachiopods of the *Leptodus nobilis-Spiriferella rajah* Zone (Kotlyar et al., 1989). *Timorites* is a typical genus for the Capitanian of the North America. Capitanian conodonts *Clarkina* cf. *C. bitteri* (Kozur) and *Jinogondolella postserrata* (Behnken) also occur at this level in the buildups in the Tungus Bay and Ekaterinovka quarry (Fig. 3).

In the Laoelin-Grodekovo folded belt, beds with *Skinnerella* conformably overlie beds with *Monodiexodina* and correspond to the *P. stricta* Zone. *Minojapanella* cf. *exilis* Sosnina, *Codonofusiella* aff. *asiatica* K. M.-Maklay, *C. schubertelloides* Sheng, *C. ussuriensis* Toumanskaya, *Chusenella (Sosioella)* aff. *intermedia* Skinner and Wilde, *Skinnerella biturbinata* (King), *S. schucherti* Dunbar and Skinner, *S.* aff. *figueroai* (Thompson et Miller), *Eoparafusulina* sp. and *Parafusulin*a sp. are characteristic for these beds. Bryozoans are represented here by an association of the *Ogbinopora perforata* Zone, which is similar to one of the South Primorye (Chernysh and Kiseleva, 1971). Marine fossil assemblages of the upper part of the Chandalaz Horizon in the South Primirye (Partizanka area, Okrainsk terrane) are very diverse and abundant. They are the richest assemblages among the Late Midian ones of the Paleo-Tethys. Fusulinid associations are dominated by the East Tethyan genera *Metadoliolina* and *Lepidolina*. Their predominance marks the *Metadoliolina lepida–Lepidolina kumaensis* Zone (Table 2) and contains the following characteristic species: *Sichotenella discoidea* Sosnina, *S. ussurica* Sosnina, *Rauserella sphaeroidea* Sosnina, *R. erratica ussuriensis* Sosnina, *Reichelina cribroseptata* Erk, *Parareichelina mira* Sosnina, *P. rhomboides* Sosnina, *Minojapanella hainanensis* Sheng, *Lantschichites maslennikovi* Toumanskaya, *L. elegans* Sosnina, *L. tenuitheca* Sosnina, *Codonofusiella lipovensis* Sosnina, *C. parva* Sosnina, *Pseudofusulina* spp., *Chusenella cambodyensis*

(Gubler), *Ch. chihsiaensis* (Lee), *Parafusulina multiseptata* Schellwien, *P. suni* (Chen), *P.* aff. *rothi* (Dunbar and Skinner), *Kahlerina maxima* Sosnina, *K. crepida* Sosnina, *K. nautiloides* Sosnina, *Pseudokahlerina implexa* Sosnina, *Ps. compressa* Sosnina, *Pseudodoliolina* cf. *chinghaiensis* Sheng, *Ps.* aff. *oliviformis* (Thompson, Wheller et Danner), *Metadoliolina lepida* (Schwager), *M. ellipsoidalis* (Schwager), *M. gravitesta* (Kanmera), *Neoschwagerina* sp., *Yabeina sphaerula* Sosnina, *Lepidolina kumaensis* Kanmera, *L. ussurica* (Dutkevich), *L.(?) septulosa* I. Chedia and *Praesumatrina turgida* Sosnina. An abundant association of small foraminifers is known from the Upper Chandalaz as well (Sosnina, 1960; Kotlyar et al., 1990).

The Upper Chandalaz *Prorichthofenia ussurica* brachiopod zone is characterized by an association comprising only Tethyan species. They are typical for the carbonate buildup facies. The most common genera are: *Enteletes*, *Spinomarginifera*, *Haydenella*, *Transennatia*, *Tyloplecta*, *Leptodus*, *Collemataria*, *Richthofenia*, *Prorichthofenia*, *Cyrolexis*, *Hustedia*, *Hemiptychina*, *Permicola*, *Martinia*, *Rostranteris* and *Praeangustothyris.* This association is close to assemblages of the Iwaizaki Formation of the Kanokura Series of Japan (Minato et al., 1978).

Palaeontological characteristics of the Upper Chandalaz in the Laoelin-Grodekovo fold belt differ from the South Primorye ones. Biota is represented by only bryozoans of the *Girtypora regula* Zone containing species characteristic for associations of the Upper Maokou Formation of South China, the Amarassi bed of Timor and the Capitanian of USA (Kiseleva, 1982). Foraminifers are very sparse and represented by *Reichelina* sp., *Codonofusiella solida* Sosnina and *Abadehella coniformis* Okimura and Ishii, which are typical of the *Metadoliolina lepida-Lepidolina kumaensis* Zone. Characteristic warm-water forms, such as *Metadoliolina*, *Yabeina* and *Lepidolina*, are absent here. However, the Tethyan–Midcontinent North American conodont *Jinogondolella wilcoxi* (Clark et Behnken) co-exists with fusulinids and bryozoans (Rybalka, 1987).

The significant difference in the Upper Chandalazian fossil assemblages of the Western (Laoelin-Grodekovo folded belt) and Southern (Voznesensk and Okrainsk terranes) Primorye is probably caused by divergence in palaeogeographic position of these terranes. Probably the Laoelin-Grodekovo folded belt was shifted northward from the Voznesensk and Okrainsk terranes.

The continental and lagoonal facies of the Chandalaz Horizon in the Southern Primorye (Partizanka and Sergeevka areas, Okrainsk Terrane) are represented by the Sitsa Formation containing Sitsa plant fossil associations, which have been subdivided into lower and upper associations (Kotlyar et al., 1989). The Sitsa flora was formed in an environment of prominent transgression of warm Tethyan water masses and volcanic activity. The environment led to high diversity of plant biotopes in this region.

The Lower Sitsa plant assemblage corresponds to the *Monodiexodina sutschanica-Metadoliolina dutkevitchi* Zone (Table 2). Cordaites, ferns or pteridosperms dominate; rare conifers occur as well (Zimina, 1983). Angara type cordaites (*Rufloria*) occur in the Lower Sitsa association. *Annularia mucronata* Schenk, *Asterotheca primorskiensis* Burago, *Pecopteris arcuata* Halle, *Rhachiphyllum sahnii* (Zalessky) Burago, *Protoblechnum sp.*, *Cordaites ex gr. principalis* (Germ.) Geinitz, *C.* ex gr. *insignis* (Radczenko) S. Meyen, *Rufloria* sp., *Zamiopteris elongata* (Zalessky) S. Meyen and *Taeniopteris* sp. are specific forms of this association.

In the Western Primorye, beds with *Marattiopsis orientalis* corresponding to beds with *Monodiexodina*, and contain *Annularia mucronata* Schenk, *Schizoneura striata* Kawasaki and Kon′no, *Asterotheca primorskiensis* Burago, *Pecopteris anderssonii* Halle, *Cladophlebis mongolica* Durante, *Neuropteridium coreanicum* Koiwai, *Phylladoderma* sp., *Rhachiphyllum adzvense* (Zalessky) Naugolnykh, *Comia yichunensis* Huang, *Bicoemplectopteridium* aff. *longifolium* (Kodera) Asama, *Nilsonia* cf. *hongshanensis* Huang, *Cordaites principalis* (Germar) Geinitz, *Taeniopteris norinii* Halle and *Rhipidopsis panii* Chow. The genera *Mesocalamites*, *Bicoemplectopteridium*, *Flabellofolium* (=*Ginkgophytopsis*), *Phylladoderma*, *Nilssonia* and *Bardocarpus* appear in these beds.

The Upper Sitsa plant association occurs in the continental facies of the upper part of the Chandalaz Horizon, which is correlated with the *P. stricta* and *Metadoliolina lepida-Lepidolina kumaensis* Fusulinid Zones (Table 2). The Sitsa plant associations can be detected in the Western Primorye as well. An increase in humidity possibly caused changes in the plant association at this time. This climate change led to a restriction of area covered by thermophile forms and an expansion of the cordaite forests. The predominance of pteridospems and ferns is characteristic and cordaites were sub-dominants. There was a significant portion of Cathaysian forms accompanied by a smaller number of cordaites in the Western Primorye area.

Some genera characteristic of Euramerica (e.g. *Saaropteris* and *Mariopteris* (?)) appeared in the Late Sitsa plant association. The number of migrants from the East-European and Pechora provinces increased, and included taxa such as *Barakaria* (?) sp., *Annulina syrjagensis* Neuburg, *Prynadaeopteris tchernovii* (Zalessky) Fefilova, *Pecopteris niamdensis* Zalessky, *Pecopteris zalesskyi* Zalessky, *Protoblechnum salicifolium* (Zalessky) Burago, *Peltaspermum* sp., and *Cordaites* ex gr. *slovaensis* (Neuburg) S. Meyen.

The most characteristic species of the Upper Sitsa plant association are *Phylloteca turnaensis* Gorelova, *Annulina tajluganensis* (Radczenko) Burago, *Prynadaeopteris karpovii* Radczenko, *Pecopteris compta* Radczenko, *Pecopteris yabei* Kawasaki, *Cladophlebis melnikovii* Burago, *Rhachiphyllum sahnii* (Zalessky) Burago, *R. zeilleri* (Zalessky) Naugolnykh, Comia latifolia Tchalyshev, Pursongia sp., Peltaspermum sp., *Cordaites buragoi* Zimina, *Rufloria* sp., *Zamiopteris tajluganensis* Gorel., *Psygmophyllum demetrianum* (Zalessky) Burago, *Psygmophyllum klokii* (Zalessky) Burago, *Flabellofolium giganteum* (Burago) Jurina and Putjatina, *Rhipidopsis panii* Chow and *Tungussocarpus tychtensis* (Zalessky) Suchov. This association is comparable with plant

assemblages of the Upper Shihhotse Formation of North China (Yao and Ouyang, 1980), the Hongshan Formation of Hinggan (Huang, 1977, 1991), and the Tavantologoi Formation (Durante and Luwsanceden, 2002). In Late Sitsa time the region under consideration was located at the boundary of the Angaraland and Siberian palaeofloral provinces (Meyen, 1980).

3.5. Lyudyanza Horizon

The Lyudyanza Horizon comprises the Lyudyanza, Yasrtebovka and Brus'evo Formations represented mainly by terrigenous deposits, which contain carbonate bioherms at various stratigraphic levels (Fig. 2, Table 1). The horizon comprises biostratigraphic units based on different fossils (Table 2).

The Lyudyanza Formation occuring in the Okrainsk (Partizanka and Sergeevka area) and Nakhimovsk (Malinovka area) terranes is represented mainly by siliciclastic sediments, including an alternation of siltstone, sandstone, and argillite. There are thick bioherms among the siliciclastic deposits of the formation in the Okrainsk Terrane (Fig. 2).

The Yastrebovka Formation occurs only in the Sergeevka area (Okrainsk Terrane) (Table 1). It consists of siliciclastic, generally sandy and silty, deposits containing carbonate buildups in the upper part. Conglomerate composes the lower part of the formation (Fig. 2). Fusulinids of the *Colaniella parva* Zone and bryozoans of *Arcticopora innae* Zone support the Lyudyanza age of the Yastrebovka Formation (Table 2).

The Laoelin-Grodekovo fold belt typifies specific deposits of the Lyudyanza Horizon. Represented are coarse siliciclastic and volcaniclastic sediments of the Brus'evo Formation (Fig. 2) and characterized in the upper part by a fusulinid association of the *Colaniella parva* Zone.

Bryozoans of the Lyudyanza Horizon are represented by an association of the *Arcticapora innae* Zone (Table 2) and occur in the lower and middle parts of the Lyudyanza and Yastrebovka Formations (Kiseleva, 1982). Rare plant fossils (Burago, 1983) suggest an absence of cordaite flora and predominance of the Taeniopteridae.

Brachiopods of the lower part of the Lyudyanza Horizon are represented by *Peltichia nachodkensis* Kotlyar, *Chengxianoproductus nachodkensis* Kotlyar, *Anidanthus sinosus* (Huang), *Edriosteges poyangensis* (Kayser), and *Squamularia grandis* (Chao), which support correlation with the Wuchiapingian Stage of China (Sheng and Jin Yugan, 1994) and Chhidru Formation of Pakistan (Pakistan-Japanese Research Group, 1985). Additionally, the lower part of the horizon contains the ammonoid *Cyclolobus kiselevae* Zakharov, the fusulinid *Codonofusiella kwangsiana* Sheng, the conodont *Clarkina* ex gr. *C. orientalis* (Barskov et Koroleva) and sphinctozoans (Lyudyanza Formation, Nakhodka buildup, Partizanka area, Okrainsk Terrane) characteristic of the Dzhulfian or the Wuchiapingian Stages (Belayeva et al., 1997). In the Artemovka River Basin (Muraviev area) the lower part of the Lyudyanza Formation contains *Cyclolobus* (?) and *Eusanyangites bandoi* Zakharov (Zakharov et al., 1997).

The upper part of the horizon in the Trudnyi Peninsula (Partizanka area) and Malinovka area contains the advanced foraminifer *Colaniella parva* (Colani), *C. turris* G.Vuks, *C. pulchra* Wang, *C. xikouensis* Wang, *Shindella* sp. and *Staffella zisongzhengensis* (Sheng) of the Changhsingian Stage (Vuks and Chedija, 1986).

The occurrence of the Early and Late Changhsingian ammonoids (Zakharov and Pavlov, 1986; Zakharov et al., 1997) and the conodont *Clarkina* cf. *deflecta* (Wang et Wang) in Artemovka sequence, Muraviev area, Voznesensk Terrane permit correlation of the Upper Lyudyanza with the Changhsingian (Table 2). The Yastrebovka Formation (Orel Mountain, Sergeevka area) contains the radiolarian *Neoalbaillella optima* Ishiga and Imoto of Dzhulfian age (Rudenko, 1991) and *Palaeofusulina* cf. *prisca* Deprat of the Changhsingian (Table 2). A very diverse ammonoid assemblage is known from the Kapreevka beds (Zakharov et al., 1997). The latter lies at the top of the Permian sequences of Primorye in the Voznesenka (Artemovka River Basin) and Okrainsk (Partizanka area) terranes are represented by a siltstone unit about 40 m thick. The representatives of the ammonoids *Changhsingoceras* (?), *Liuchengoceras*, *Tapashanites* and *Sinoceltites* co-existing with brachiopods *Paracrurithyris pygmaea* (Liao), *Crurithyris flabelliformis* Liao and *Araxathyris minor* Grunt are typical for the uppermost Changhsingian of the South China. Therefore, according to ammonoid, fusulinid, and brachiopod evidence, the fauna of the uppermost part of the Lyudyanza and Yastrebovka Formations and the Kapreevka beds are Late Changhsingian (Table 1). The close similarity of the Late Changhsingian assemblages of the South Primorye (Okrainsk Terrane) and South China suggest that the Okrainsk Terrane was displaced southward and was located in Palaeoequatorial Realm near the South China Block (Shi et al., 2002).

4. Palaeobiogeography

Sedimentation in the Primorye in the Permian occurred on the depressed parts of the Bureya-Khanka Superterrane. Continental and nearshore environments dominated. Volcanic activity is characteristic for the Permian (especially in the Early Permian) of the territory. Siliciclastic sedimentation prevailed in the shallow-water marine environment. Carbonate sedimentation is characteristic of Chandalaz and Lower Ludyanza horizons.

Plant associations distributed through the enire Permian provide good information for climatic reconstructions. Additionally, diverse invertebrate fauna assemblages permit some palaeobiogeographic interpretations.

Paleofloral data support the following climatic subdivisions: two warm temperate climate belts (the Angara and Gondwana Realms); and subtropical and tropical belts (Euramerian and Cathaysian provinces in the Early Permian, and Cathaysian and Atlantic realms) in the Middle and Late Permian.

Biogeographic provinces based on the marine fauna are: Boreal, Tethyan, and Gondwanan.

The oldest known Permian (Dunay time) plant association in the Primorye was of Angara type. This association suggests a wet and relatively cool type of climate (warm temperate climatic belt). The Early Abrek plant associations, which followed the Dunay plant associations were composed mainly of cordaites and also suggests Angaran affinities.

The cordaites typical of the Angaran province predominate in the plant association of Middle Abrek time, however the appearance of the first Cathaysian forms in Late Abrek suggests some climate warming. This could have been caused by a possible ingression of warm water masses in Late Abrek time, which led to climatic warming favorable for immigrants from Cathaysia.

The Abrek/Vladivostok boundary marked by a significant turnover in the plant associations in the South Primorye, probably, was caused by a shift of the terranes into a subtropical belt. Wide expansion of Euramerian and Cathaysian flora characterized the beginning of Vladivostok time. Maximum abundance of Cathaysian plants can be seen in the Western Primorye area (Laoelin-Grodekovo folded belt). This type of plant association suggests a warm and dry climate.

A widespread transgression is suggested as occurring during the Chandalaz time. Mixed Boreal and Tethyan brachiopod faunas and an Angara type Cordaitean flora are specific for the Early Chandalaz time (*Monodiexodina sutchanica-Metadoliolina dutkevitchi* and *P. stricta* Fusulinid Zones or *Substriatifera vladivostokensis* and *Leptodus nobilis-Spiriferella rajah* Brachiopod Zones). The brachiopod assemblage of the *Substriatifera vladivostokensis* Zone comprises mainly Boreal genera. In the *Leptodus nobilis-Spiriferella rajah* Zone the Boreal genera gradually decrease in abundance, Gondwanan forms appear, and Tethyan elements are clearly more predominant. These facts suggest gradual climate warming coinciding with a wide exchange of faunas in the east Palaeotethyan realm caused by transgression.

Late Chandalaz time is characterized by differentiation between the faunal and floral affinities of the Laoelin-Grodekovo Terrane and the Voznesensk and Okrainsk terranes. In the Voznesensk and Okrainsk terranes the Late Chandalaz *Prorichthofenia ussurica* Brachiopod Zone is characterized by an association comprising only Tethyan species. Fusulinid associations of the *Metadoliolina lepida-Lepidolina kumaensis* Zone are also dominated by the East Tethyan genera *Metadoliolina* and *Lepidolina*.

Characteristic warm-water forms, such as *Metadoliolina*, *Yabeina* and *Lepidolina*, are practically absent in the Laoelin-Grodekovo Terrane. However, there were a significant portion of Cathaysian plant forms accompanied by fewer cordaites in this terrane. These data suggest transitional temperate to subtropical climate type.

A significant difference in the Late Chandalaz fossil assemblages of the Western (Laoelin-Grodekovo folded belt) and Southern (Voznesensk and Okrainsk terranes) Primorye is probably caused by divergence in palaeogeographic position of these terranes. Probably the Laoelin-Grodekovo folded belt was shifted northward from the Voznesensk and Okrainsk terranes.

Lyudyanza time (Late Permian) is characterized by the predominance of a Tethyan fauna (brachiopods, ammonoids, fusulinids, and conodonts). Close similarity of the Lyudyanza assemblages of the South Primorye and South China, accompanied by the absence of cordaite flora in the South Primorye suggest tropical climate type in the area under consideration.

5. Conclusions

The global significance of the Permian of the Primorye is enhanced by the characteristic Middle Permian mixed Tethyan, Boreal and Gondwanan-type brachiopod fauna, mixed Angara-Euromerican-Cathaysian flora, and their close spatial and stratigraphical association with fusulinids, bryozoans, ammonoids and conodonts. These facts allows tracing of several global correlational levels of Permian sequences within the different paleobiogeographical realms.

The Permian deposits of Primorye demonstrate that this region is unique in several different aspects. The Primorye region was located in the transitional belt between different palaeoclimatic and palaeobiogeographic provinces in the Permian. It was situated in a warm and wet temperate climatic zone in the Early Permian, then the Primorye terranes were shifted into a dry subtropical climatic zone in the Middle Permian, and at last, to a tropical climate in the Late Permian. Those unique positions of the region through Permian time allows for global correlation. The Early Permian horizons of the Primorye can be correlated with regional units of the Kolyma-Omolon, Verkhoyanye, Kuznetsk and Pechora Basins of the Boreal Realm. The main correlative interval is the Middle Abrek Subhorizon, containing Angara type plant fossils and brachiopod assemblages of Late Kungurian–Solikamian age (beds with *Primorewia reshetnikovi-Tomiopsis atlanichus* and *Epijuresanites*), widespread within the Boreal Realm.

The transitional location of the various Primorye terranes in the Middle Permian led to formation of a mixed brachiopod fauna. These associations provide correlation of mid-Permian units of the Primorye with both Boreal and Tethyan stratigraphic sequences. Some intervals show also the presence of a Gondwanan fauna. Several correlative levels, which can be traced globally, using ammonoids, conodonts, brachiopods and fusulinids, have been recognized: the *Monodiexodina suchanica-Metadoliolina dutkevichi* Fusulinid Zone of Wordian age and *P. stricta* Fusulinid Zone of Capitanian age.

The Late Permian fauna of Primorye is mainly Tethyan in origin and provides correlation with South China sequences.

It is notable that the Middle–Upper Permian sequence in the Primorye is exceptionally complete. It is possible to identify most global stages in the sections of the Okrainsk and Voznesensk terranes. The completness of the Permian

sequence of this region is comparable with the sequences of South China.

Acknowledgements

The authors are grateful to all geologists of the South-Primoryian expedition, who gave paleontological materials for a long time, to E. A. Dorukhovskaya for conodont collections from Muraviev and Partizanka areas. We are very thankful to Drs Marlynd Nestell and Galina Nestell for their valuable comments and help with English. NPO 'Konversia DVO' supported the conodont study of the Permian deposits in the Okrainsk terrane in 1992-1993. This work is supported by RFBR grant N 03-05-65118 and grant N GFEN 04-05-39005.

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