Fusulinids and Permian Scale of the Tethys

E. Ja. Leven

Geological Institute, Russian Academy of Sciences, Pyzhevskiĭ per. 7, Moscow, 119017 Russia
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Abstract—The curve depicting generic diversity of Permian fusulinids has two distinct peaks: the Asselian–Sakmarian and Midian. The in-between minimum corresponds to the end of the Bolorian Age. The most significant extinctions of fusulinids are recorded in the terminal Midian (71% of all genera), Bolorian (48%), Asselian (27%), and Sakmarian (23%) ages. A renewal of prime importance took place in the Kubergandian Age, when 52% of new genera appeared in fusulinid community. These data suggest that history of Permian fusulinids can be divided in two principal (Asselian–Bolorian and Kubergandian–Dorashamian) and four second-order periods of evolution (Asselian–Sakmarian, Yakhtashian–Bolorian, Kubergandian–Midian, and Dzhulfian–Dorashamian). Two main periods of evolution corresponding to the Lower and Upper Permian of traditional East European scale are suggested to be termed as the Cisuralian and Tethysian subsystems. The subsystems are divisible into the Uralian, Darvasian, Yangsingian, and Lopingian series corresponding to second-order periods of fusulinid evolution. The suggested scheme is consistent with traditional two-part subdivision of the Permian System. In distinction from the three-series global chronostratigraphic scale accepted recently, series in the suggested scheme are more proportional and better corresponding to the natural stages in evolution of marine biota. The global scale with its strict criteria used to define boundaries between series and stages is hardly applicable in the Tethyan region. This is evident from diverse opinions concerning position of the Guadalupian Series lower boundary in Tethyan sections.

Key words: fusulinids, diversity, evolutionary stages, Tethyan scale, Permian System, subsystems, series, stages.

INTRODUCTION

After long-lasted discussions, the new global chronostratigraphic scale of the Permian System was officially authorized at the beginning of 2001. The system was divided into three series (Cisuralian, Guadalupian, and Lopingian) and nine stages. The Asselian, Sakmarian, Artinskian, and Kungurian stages are included into the Cisuralian Series; the Roadian, Wordian and Capitanian stages are regarded as subdivisions of the Guadalupian Series, and the Lopingian Series is divided into Wuchiapingian and Changhsingian stages. The scale is primarily based on distribution of conodonts, which are rare and inadequately studied in Tethyan areas, where the scale can be hardly applied therefore. This problem has been considered in detail in earlier work (Leven, 2001). The other important problem concerning the new scale is an obvious disproportion between three series. The lower Cisuralian Series (23.5 m.y. long) is identical to the Lower Permian of the classical East European scale, the middle Guadalupian Series (12 m.y.) includes the Ufimian and Kazanian stages coupled with the greater lower part of the Tatarian Stage, while the third Lopingian Series (9.5 m.y.) corresponds to the rest of the latter (Menning, 2001). With such a disproportion, it is impossible to operate with the Guadalupian and Lopingian series in the Boreal and Notal regions.

At the congress "Permian System of the Earth" of 1991, I proposed a compromise stratigraphic scheme (Leven, 1992), in which two discriminated subsystems correspond to the Lower and Upper Permian of the classical scale and are divided in two series each. Series of the upper subsystem have been regarded therewith as corresponding to the Guadalupian and Lopingian series of the new scale, while the lower subsystem was divided into lower and upper series spanning the Asselian–Sakmarian and the Artinskian (Yakhtashian)–Kungurian (Bolorian) intervals, respectively. A similar four-member subdivision of the Permian has been suggested at the same congress by Ganelin and Kotlyar who based their conclusions on distribution of brachiopods in sections of the Boreal areas. There was no opposition to these proposals, but they have not been taken into account during the subsequent work on the new scale, because subdivision of the Lower Permian in two individual series has not been practically substantiated.

Obvious disadvantages of the new global scale are convincing that we need in a special scale for the Tethyan region, where application of the former is inconvenient. Such a scale tested in many sections of various Tethyan areas is already known (Leven, 1980a, 1981). This work is aimed to substantiate additionally the stages of that scale and their boundaries taking into consideration new data, which have been accumulated
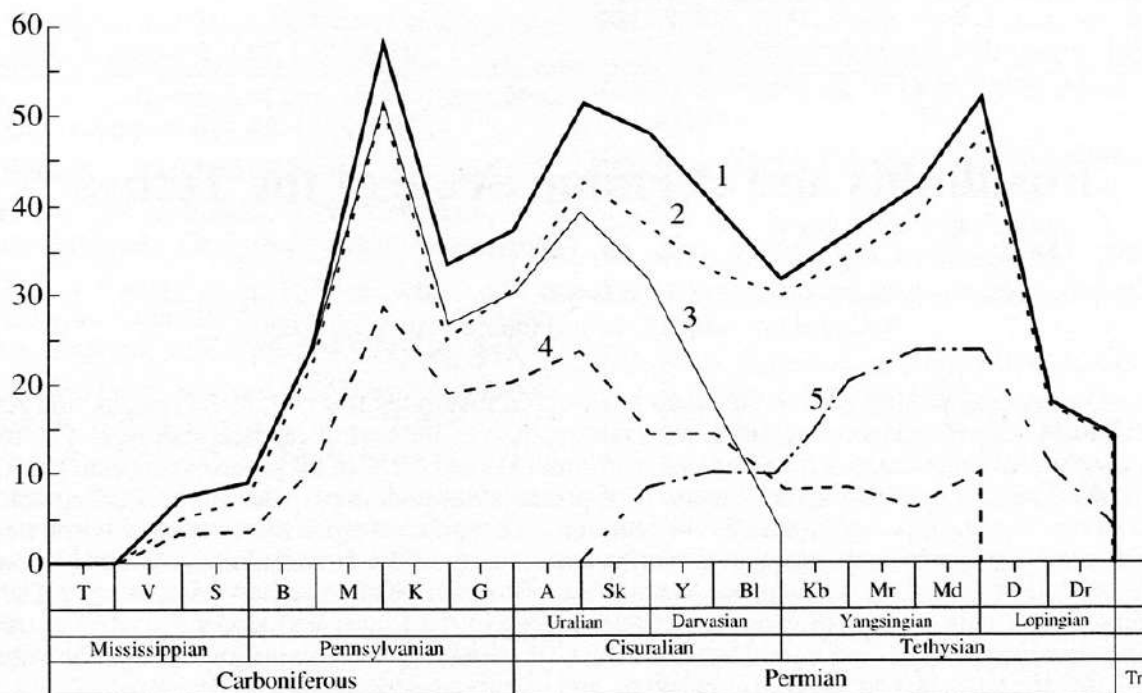
Fig. 1. Abundance rates of fusulinid genera calculated for the stage terminations: (1) quantity of genera worldwide; (2) Tethyan areas; (3) East Europe; (4) United States, Texas; (5) peri-Gondwanan part of the Tethys. Stage indices: (T) Tournaisian; (V) Visean; (S) Serpukhovian; (B) Bashkirian; (M) Moscovian; (K) Kasimovian; (G) Gzhelian; (A) Asselian; (Sk) Sakmarian; (Y) Yakhtashian; (Bl) Bolorian; (Kb) Kubergandian; (Mr) Murgabian; (Md) Midian; (D) Dzhulfian; (Dr) Dorashamian.

during the last two decades after the scale approval by the ISC. Simultaneously, the stage scale is coordinated with the suggested subdivision of the Permian System into subsystems and series.

DIVERSITY DYNAMICS OF FUSULINID GENERA

Fusulinids are most abundant, widespread and well-studied fossils characteristic of Permian deposits in Tethyan areas. Being of a high stratigraphic potential, they are used to elaborate the Permian stratigraphic scales, including the version considered below. Evolution of fusulinids was irregular, divisible into several stages of different orders. This is advantageous for hierarchic stratigraphic subdivision of the Permian System, beginning from zones to subsystems. Stages in evolution are recognizable based on various criteria, such as extinctions of different-rank taxa, diversity fluctuations, and successions of dominant fossil groups.

The presented diagrams illustrate the diversity variations of fusulinid genera beginning from their appearance in the Visean Age till the extinction at the end of the Dorashamian Age (Figs. 1, 2). The considered genera are classified in accord with "Guidebook to Systematics of Paleozoic Foraminifers" (Rauser-Chernousova et al., 1996). The abundance rates of Tethyan fusulinids are calculated for either the undivided stages or the lower and upper substages separately. The curves depicting the secular diversity variations of fusulinid genera in Tethyan areas or worldwide (Fig. 1) are very

similar, and this implies that Tethyan fusulinids define their general diversity.

In both curves, there are three diversity peaks, which took place in the Moscovian, Asselian–Sakmarian, and Midian periods. Accordingly, the entire history of fusulinid development can be divided in the Visean–Kasimovian, Gzhelian–Bolorian, and Kubergandian–Dorashamian periods of prime significance. The order Fusulinida was dominant during the first period. During the second one dominated fusulinids of the order Schwagerinida, while orders Neoschwagerinida, Staffellida and Schubertellida were the main taxa of the third period. The same conclusion is inferable from the histogram (Fig. 2) plotted based on calculations for the substage time spans. The only distinction is the two-peak character of the Asselian–Sakmarian maximum. The histogram also illustrates the abundance rates (in absolute values and percentages) of new and extinct genera for the each time span. Besides the Moscovian period of diversification, which is out the scope of this work, the appearance peaks of new genera are confined to the first half of the Kubergandian Age (52% of all genera) and to the second half of the Gzhelian Age (47%), i.e., to the commencement of second and third main periods of fusulinid development. Considerable renewals are also detectable in the early Yakhtashian (36% of new genera), Midian, and Asselian fusulinid assemblages. In addition to the complete extinction of fusulinids at the end of the Permian, catastrophic extinctions were characteristic of the terminal Midian (71% of all genera) and terminal Bolorian time (48%). Less significant extinctions were those signifying ter-
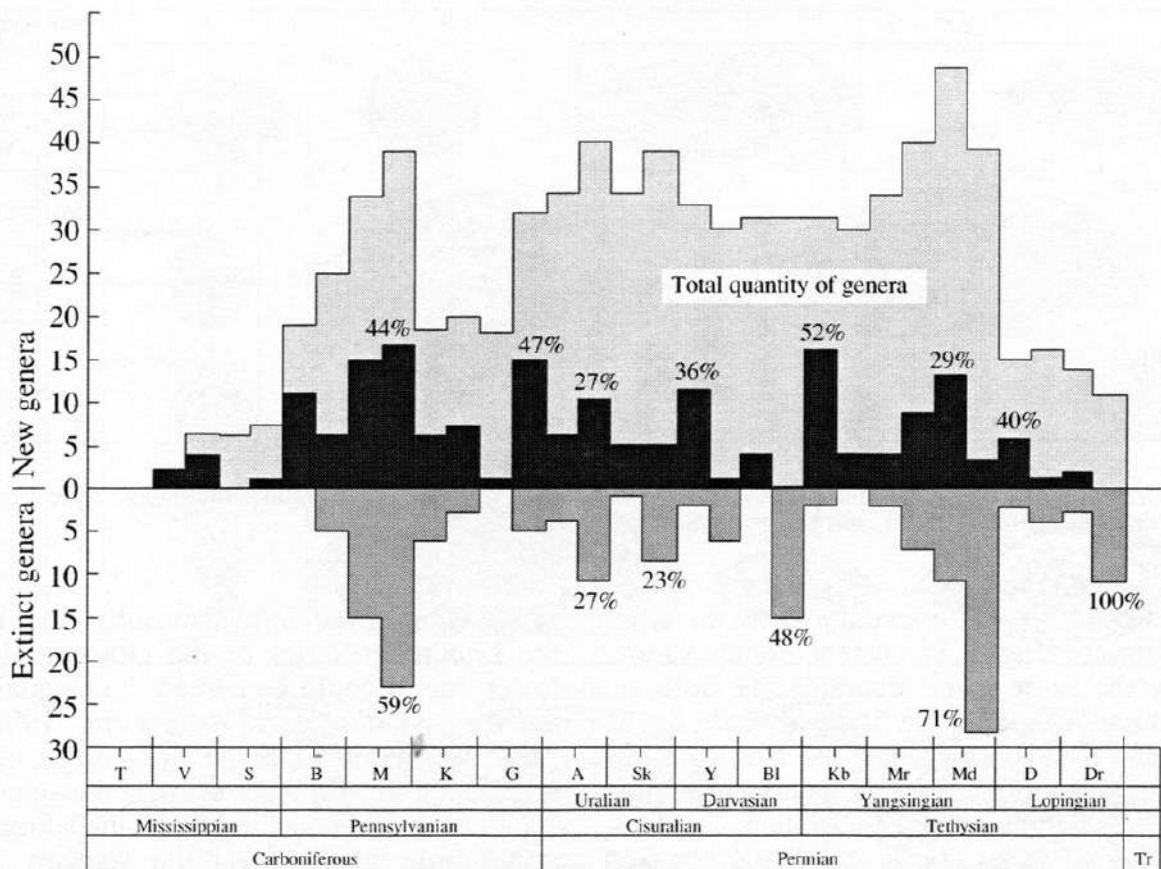
Fig. 2. Total quantity (shaded light gray) of fusulinid genera calculated per each half of an age; percentages of new (shaded black) and extinct (shaded dark gray) genera are calculated relative to the total quantity (stage indices as in Fig. 1).

minations of the Asselian and Sakmarian ages (27 and 23%, respectively). Consequently, the most abrupt and essential changes in Permian fusulinid assemblages are recorded across the Bolorian–Kubergandian and Midian–Dzhulfian boundaries.

The above data on distribution of fusulinids offer a possibility to substantiate subdivision of the Permian System into series and stages, at it is shown below.

BOUNDARIES OF THE PERMIAN SYSTEM

At present, the system lower boundary is placed officially at the base of the Asselian Stage in accord with the original idea of Ruzhentsev (1951) who recognized significance of this level based on distribution of ammonoids. In terms of fusulinid succession, this boundary marks the first appearance of the genus *Sphaeroschwagerina*. The genus that is widespread enables the boundary recognition in a vast territory from South and East European areas to Japan (Leven and Shcherbovich, 1978; *Guidebook...*, 1990; Davydov, 1995; Krainer and Davydov, 1998). In general, the fusulinid biota changed insignificantly across this boundary however. The more considerable changes are recorded in Gzhelian deposits. The changes were connected with diversification of the order Schwagerinida that appeared in the Kasimovian Age (47% of all genera) and gave rise to many new genera, the typical Lower Permian *Pseudofusulina*, *Rugosofusulina*, and *Dut-*

kevitchia included. Hence, it would be more reasonable to consider exactly this event as marking the Carboniferous–Permian boundary and to place this boundary somewhere in the Gzhelian Stage in its current understanding, or at the level separating the Gzhelian and Orenburgian stages, if the latter will be authorized. Such a viewpoint based on fusulinids complicates, however, the precise positioning of the boundary based on other fossils, e.g., on conodonts and ammonoids. The officially accepted boundary is more appropriate therefore.

According to decision of the International Stratigraphic Commission, the upper boundary of the Permian System is at the base of the *Hindeodus parvus* Zone of the conodont scale. The base of Bed 27c in the Meishan-D section (China) is selected for the GSSP of the boundary (*Vote on Meishan...*, 1999). Fusulinids disappear below this level and nowhere in the world attain it. In the indicated section, the last of them occur approximately 1 m below the Bed 27 (Zhao *et al.*, 1981). Thus, fusulinids do not fix precisely the upper Permian boundary that is placed slightly higher than the level of their final extinction.

SERIES OF THE PERMIAN SYSTEM

There are many variants of series discrimination in the Permian System. In the traditional East European scale, the system is divided in two main parts at the
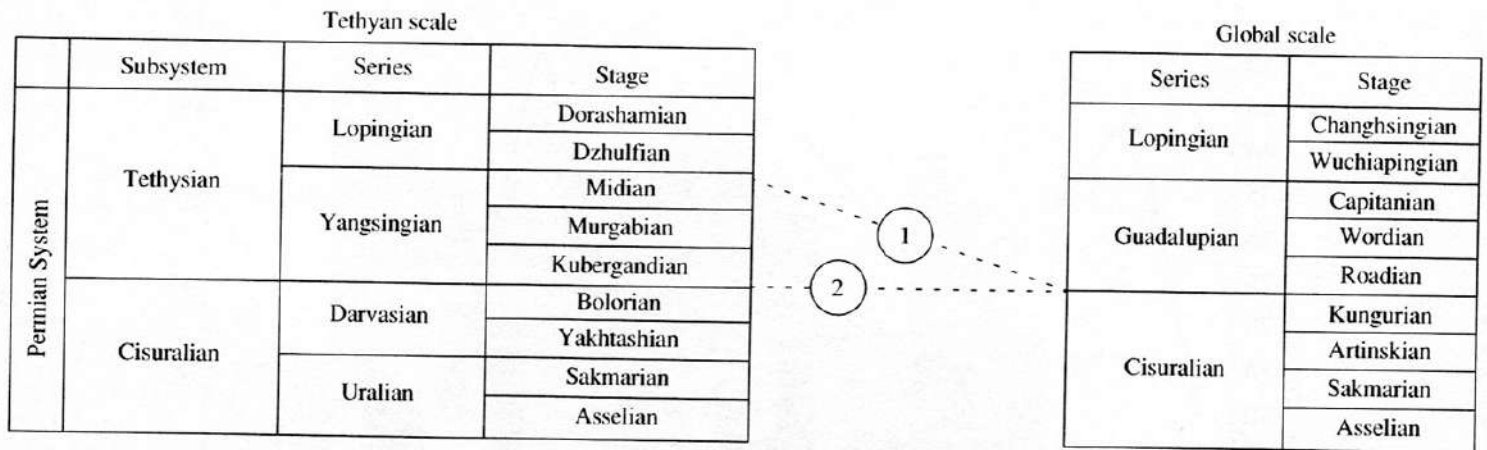
Tethyan scale

Permian System	Subsystem	Series	Stage
	Tethysian	Lopingian	Dorashamian
			Dzhulfian
		Yangsingian	Midian
			Murgabian
			Kubergandian
	Cisuralian	Darvasian	Bolorian
			Yakhtashian
		Uralian	Sakmarian
			Asselian

Global scale

Series	Stage
Lopingian	Changhsingian
	Wuchiapingian
Guadalupian	Capitanian
	Wordian
	Roadian
Cisuralian	Kungurian
	Artinskian
	Sakmarian
	Asselian

Fig. 3. Permian stratigraphic scale for Tethyan areas and its correlation with the global chronostratigraphic scale after Henderson et al., 1999 (1), and after Leven, 2001, and Kozur, 1998 (2).

level corresponding to the boundary between Kungurian and Ufimian stages. In current nomenclature, approximately the same level separates the Bolorian and Kubergandian stages of the Tethyan scale or the Cathedralian and Roadian stages of the North American scale. In the new global scale, the system is divided however into three main units: the Cisuralian, Guadalupian, and Lopingian series (Jin et al., 1997), the first and two second corresponding respectively to Lower and Upper Permian of the traditional East European scale.

From the viewpoint of main evolutionary periods of fusulinids, it is most reasonable to divide the Permian System in two parts corresponding to the second and third periods (Fig. 1), one characterizing the flourishing time of the order Schwagerinida, and the other one the prosperity time of orders Neoschwagerinida, Schubertellida, and Staffellida. Each of these periods can be divided then in two units of lower ranks spanning the Asselian–Sakmarian and Yakhtashian–Bolorian intervals of the Early Permian time and the Kubergandian–Midian and Dzhulfian–Dorashamian intervals of the Late Permian. In the global chronostratigraphic scale, the lower Cisuralian Series includes two former subdivisions, whereas the Guadalupian and Lopingian series correspond each to one of the latter subdivisions. The disproportion is obvious, and one can avoid it dividing the Cisuralian period in two individual series. As a result, the Permian System would be divided in two subsystems with two series in each (Fig. 3).

The name "Cisuralian" accepted in the new global scale can be given to the lower subsystem, and the upper subdivision of the same rank can be named the "Tethysian" Subsystem, because the most complete marine successions of this unit are known in Tethyan areas. Names "Uralian" and "Darvasian" appear to be appropriate for lower and upper series of the Cisuralian subsystem, since they have been formerly used for stratigraphic subdivisions of approximately the same ranges (de Lapparent, 1900; Schuchert, 1935; Stepanov, 1951; Miklukho-Maclay, 1958). The upper

subdivision of the Tethysian Subsystem is identical to the Lopingian Series of the global scale. As for the lower one, it could be named the Guadalupian Series, but the conodont dates (Mei et al., 1998; Henderson et al., 1999) imply that the unit's range, as I understand it (Fig. 3), corresponds only to the upper part of the standard series, and the name Guadalupian appears to undesirable therefore for the Tethyan successions. I propose to term it as the Yangsingian Series, because stratigraphic subdivision of nearly the same range is of a long-term usage under this name in China (Huang, 1932; Sheng and Jin, 1994).

Considered below are fusulinid assemblages characterizing four series outlined above, which correspond to second-order stages in evolution of the fossils under consideration (Plates I and II).

Cisuralian Subsystem

The Uralian Series spans the Asselian and Sakmarian stages of fusulinid peak diversities. The name "Uralian" was introduced for the so-called *"Schwagerina"* Horizon of the Ural region by de Lapparent (1900), who erroneously considered the horizon as a marine equivalent of the Stephanian Stage in the Upper Carboniferous succession of Western Europe. Ruzhentsev (1936) defined the *"Schwagerina"* Horizon as the Sakmarian Stage. He regarded the name "Uralian" as inappropriate for this stage, because different researchers used to be applying it for deposits of variable stratigraphic range. Following his argument, however, one should reject all the names of Permian stages, many of which are diversely understood even at present. The Sakmarian Stage distinguished by Ruzhentsev is not an exception, since its original range became reduced twice, when the lower half of the stage was attributed to the individual Asselian Stage.

The name "Uralian," approximately in its initial meaning, is suggested here for the lower series of the Cisuralian Subsystem. The series spans the Asselian and Sakmarian stages. Fusulinid assemblages of both
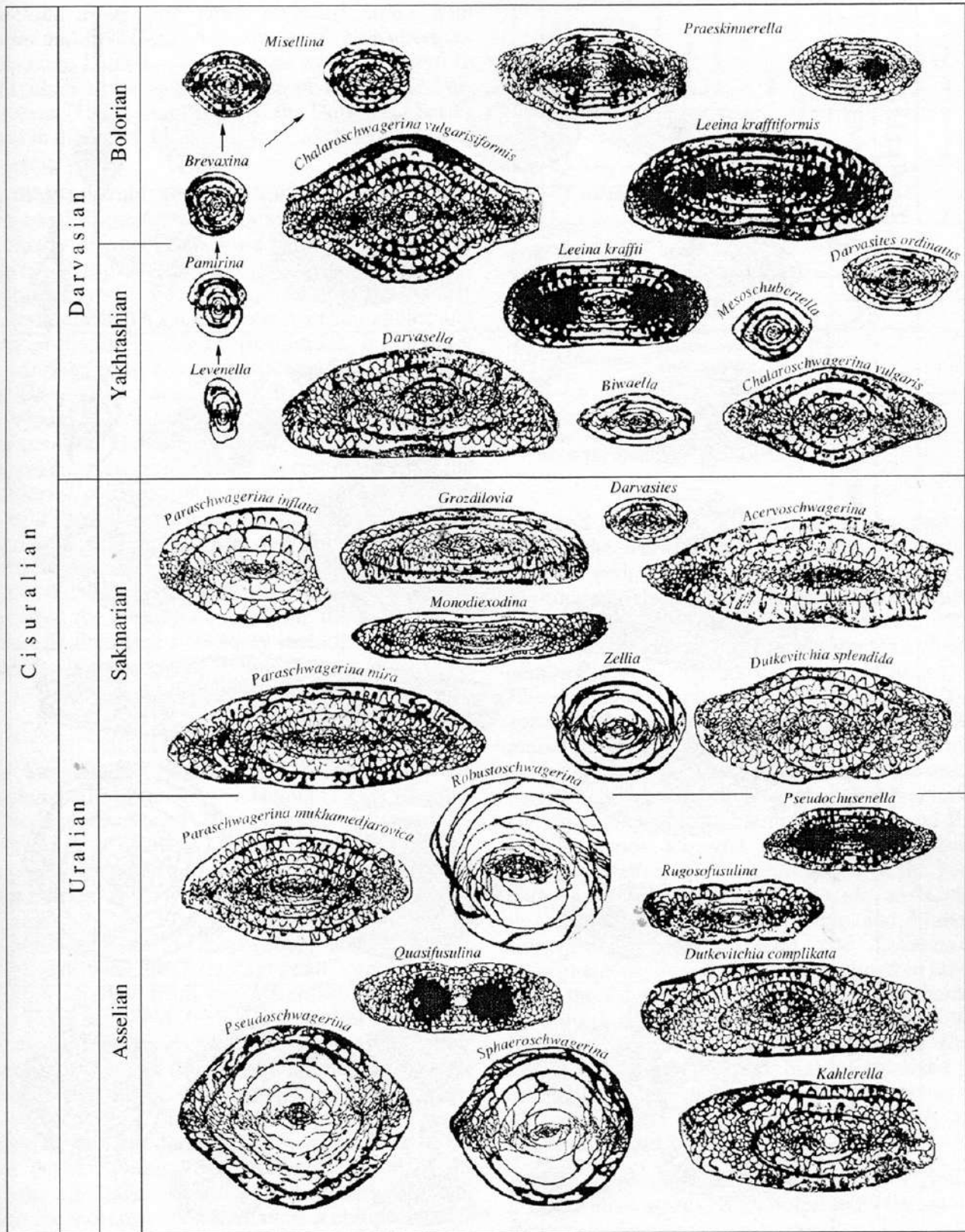
Plate I. Most characteristic fusulinid assemblages of series and stages of the Cisuralian Subsystem.

stages are similar and tightly connected with the Gzhelian ones. The order Schwagerinida is dominant. Genera *Rugosofusulina*, *Dutkevitchia*, *Kahlerella* (family Rugosofusulinidae), and *Pseudofusulina* (family Pseudofusulinidae), which appeared in the Gzhelian Age, are among the most abundant and characteristic.

Especially typical are genera with swollen and loosely coiled shells, such as *Sphaeroschwagerina*, *Pseudoschwagerina*, *Paraschwagerina*, *Zellia*, *Robustoschwagerina*, and some others, which are artificially attributed to the heterogeneous family Schwagerinidae. The genus *Quasifusulina* (order Fusulinida) is also
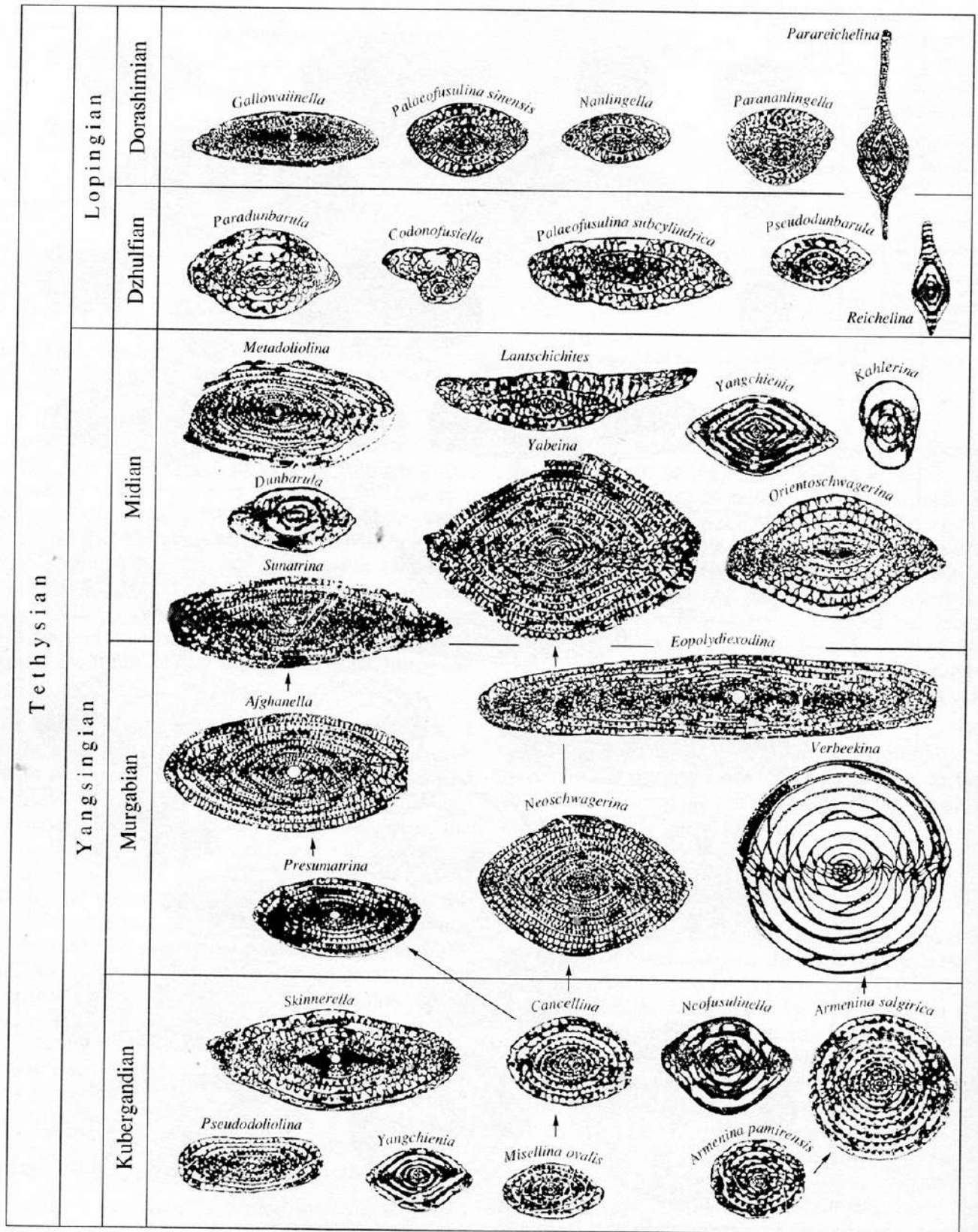
Plate II. Most characteristic fusulinid assemblages of series and stages of the Yangsingian Subsystem.

remarkable. Distinctions between Asselian and Sakmarian fusulinid assemblages are perceptible mostly at the species level, although the Sakmarian strata yield *Eoparafusulina* in association with first *Darvasites* and *Monodiexodina* forms, all unknown from the underlying deposits.

The Darvasian Series includes the Yakhtashian and Bolorian stages. Dutkevich (1937) introduced the series name to define an upper part of the Lower Permian in the Darvaz. Miklukho-Maclay (1958) distinguished under this name the stage corresponding to the *Parafusulina* and *Misellina* fusulinid zones. In addition

to *Misellina* Beds, the latter included strata with *Armenina* and first *Cancellina* forms of the Kubergandian Horizon. Later on, these strata were attributed to the individual Kubergandian Stage of the Upper Permian (Leven, 1963). Accordingly, the Darvasian Series accepted in this work is of a reduced range as compared to the primary one.

Fusulinid assemblages of the Yakhtashian and Bolorian stages of the series are very similar to each other, being clearly distinct from those of the previous Uralian Series. The boundary between two series marks extinction of most genera representing the family Schwagerinidae and a sharp decrease in abundance and diversity of the family Rugosofusulinidae. In the order Schwagerinida, most characteristic are *Chalaroschwagerina*, *Darvasites*, *Leeina* from the *L. krafti–L. fusiformis* group, *Praeskinnerella*, and first *Parafusulina* and *Skinnerella*. Genera *Biwaella*, *Mesoschubertella*, and *Toriyamaia* are remarkable representatives of the other orders. *Pamirina* that appeared in the Yakhtashian Age is of a special importance. At the beginning of the Bolorian Age, this genus gave rise to the first higher fusulinids of the order Neoschwagerinida (genus *Misellina*). The Darvasian fusulinid assemblages differ in general from the Uralian ones despite their successive character. At the same time, they include first taxa of the later Yangsingian Series.

Tethysian Subsystem

The Yangsingian Series spans the Kubergandian, Murgabian, and Midian Stages. Huang (1932) who distinguished the series attributed to it a part of the carbonate succession in southern China: the Chihsia Formation beginning from its transgressive base and the entire Maokou Formation up to the base of the next transgressive complex of the Lopingian Series. In the recent stratigraphic schemes of China (Sheng and Jin, 1994), the series is divided into four stages and corresponds to the section interval from the *Misellina* Zone to the *Yabeina* Zone inclusive. It should be noted that *Misellina* forms from the base of the Chihsia type section are represented by highly developed species *M. claudiae* and *M. ovalis* characteristic of the Kubergandian Stage. Their occurrence is indicative of the lower series boundary, which I understand as corresponding to the base of the *Armenina–Misellina ovalis* Zone of the Kubergandian Stage. Across this boundary, there is recorded the most remarkable change in composition of Permian fusulinid communities. *Chalaroschwagerina*, *Darvasites*, *Leeina*, *Biwaella*, *Mesoschubertella*, *Toriyamaia*, last *Quasifusulina*, *Robustoschwagerina*, and *Acervoschwagerina* characteristic of the Darvasian Series completely disappear here. The fusulinid assemblage of the Kubergandian Stage is entirely renewed. Higher fusulinids of the order Neoschwagerinida, newcomers among which are genera *Armenina*, *Pseudodoliolina* and *Cancellina*, grow in abundance. The last two genera are ancestors of families Pseudodoliolin-
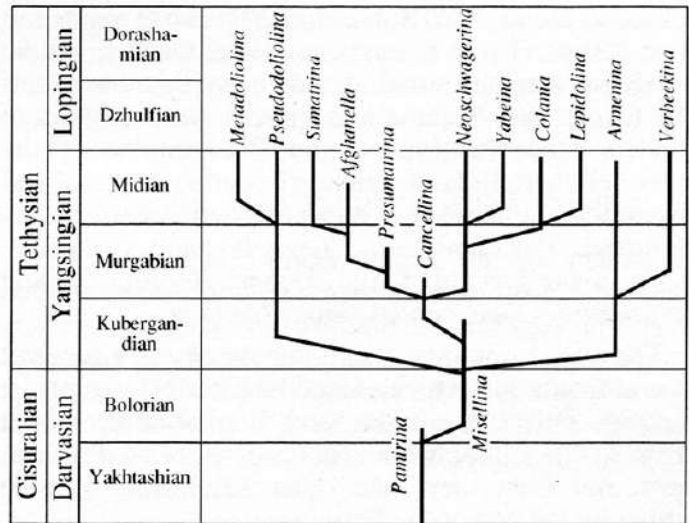

Fig. 4. Scheme illustrating phylogeny of the order Neoschwagerinida.

idae and Neoschwagerinidae, which became prosperous in the Murgabian and, especially, Midian ages together with representatives of Sumatrinidae and Verbeekinidae whose origin is recorded in the initial Murgabian time. A considerable renewal is characteristic of the order Schwagerinida, the leading taxa of which are genera *Parafusulina*, *Skinnerella*, and *Chusenella*. First *Eopolydiexodina* represented by subgenus *Bidiexodina* appear in the second half of the Kubergandian Age. The monotypic family Yanchienidae very characteristic of the entire Yangsingian Series appears in the order Schubertellida at the beginning of the Kubergandian Age. Generic composition of Schubertellidae and Boultoniidae becomes renewed because of *Neofusulinella*, *Codonofusiella*, and *Wutuella* origin in the Kubergandian Age and of *Russiella*, *Dunbarula*, and *Lantschichites* appearance in the Murgabian and Midian ages. Genera *Nankinella*, *Staffella*, and *Sphaerulina*, the newcomers of the order Staffellida, grow in abundance. Thus, the Yangsingian epoch in general is characterized by a quick diversification and prosperity of the order Neoschwagerinida at the beginning of the Kubergandian Age, by appearance of highly organized multiapertural Schwagerinida representatives (genus *Eopolydiexodina*), and by the growing diversity of other fusulinid orders.

The Lopingian Series includes the Dzhulfian and Dorashamian stages. Richthofen used the name "Lopingian" to determine the Upper Permian coal-bearing deposits in China (Kayser, 1883). Huang (1932) also considered these deposits in the rank of the upper series of the Permian System.

Fusulinid assemblages of the Lopingian Series are less diverse than the older ones because of a catastrophic extinction (71% of all genera) by the end of the Midian Age. Orders Neoschwagerinida and Schwagerinida completely disappeared across the Midian–Dzhulfian boundary, when families Yangchieniidae,

Schubertellidae, and Kahlerinidae became extinct in other orders. Three orders Staffellida, Ozawainellida, and Schubertellida crossed, however, this boundary. The former two became less diverse therewith, while families Palaeofusulinidae and Boultoniidae of the order Schubertellida experienced a certain renewal and diversification because of appearance of genera *Palaeofusulina, Paradunbarula, Tewoella,* and *Gallowainella* in the Dzhulfian Age. Genera *Nanlingella* and *Parananlingella* appeared somewhat later.

Thus, the Lopingian epoch in general was a survival time of fusulinids, which escaped the late Midian crisis. Families Palaeofusulinidae and Boultoniidae, which survived the crisis, were still in process of development, but even they, like other fusulinids, became extinct by the end of the Permian.

THE PROBLEM OF BOUNDARIES BETWEEN SUBSYSTEMS AND SERIES

If fusulinids are regarded as an orthostratigraphic group, the boundary between subsystems should be placed between the Bolorian and Kubergandian stages, since this level marks the most essential and quick changes in fusulinid assemblages. In the Kubergandian Stage stratotype and hypostratotype (the southeastern Pamirs), this level is at the base of the *Armenina–Misellina ovalis* Zone (Leven, 1981; Chediya *et al.*, 1986). In the Transcaucasia, the appearance level of abundant *Armenina* and highly developed *Misellina* is at the base of the Asni Formation (Leven, 1998). In southern China, deposits corresponding to the Bolorian Stage coupled with a greater part of the Kubergandian Stage are attributed now to the Loudinian Stage (Sheng and Jin, 1994), and the boundary under consideration is therefore inside the latter. I had a good opportunity to realize it personally when studied collections of thin sections, which characterize several very complete sections of southern China and are stored at the Nanking Institute of Paleontology and Stratigraphy and at the Guiyang Geological Survey, Guizhou Province. In the Luodian section for instance, first fusulinids undoubtedly belonging to the Kubergandian Stage (*Armenina, Parafusulina, Yangchienia*) appear in the Bed 25 (Excursion Guidebook, 1994; Leven, 2001). Immediately below, deposits are barren of fusulinids. In the Bed 21b, they belong to the upper Bolorian Substage (*Misellina termieri*). Conodonts *Mesogondolella saraciniensis* Gullo et Kozur, *M. phosphoriensis* (Younquist, Hawley et Miller) and *M. siciliensis* (Kozur), which coexist with fusulinids in the Bed 25, have been attributed by Kozur (1998) to the Roadian Stage of the Guadalupian Series. In sections of the Guizhou, Yunnan, and Guangxi provinces, which yield fusulinid assemblages, the boundary in question separates beds with diverse *Misellina, Chalaroschwagerina,* and *Darvasites* of the *Misellina termieri* Zone from beds with first *Armenina, Pseudodoliolina, Parafusulina,* and *Yangchienia* used to be included into the *Misellina*

claudiae or *M. ovalis* Zone (Xiao *et al.*, 1986; Zhou *et al.*, 1987; Zhang *et al.*, 1988). The Bolorian–Kubergandian boundary is also well traceable in the Akiyoshi section of Japan, where it corresponds to the base of the *M. claudiae* Zone (*Guidebook...*, 1990; Ueno, 1996). In Thailand, Bed B_2 yielding first *Armenina* and *Pseudodoliolina* definitely belongs to the lower Kubergandian Substage, whereas fusulinids from Bed B_1 are of the transitional type (Toriyama, 1975).

The above data show that outlined changes in fusulinid assemblages crossing the Lower–Upper Permian boundary are persistent and easily traceable throughout the Tethyan realm. Outside the Tethys, it is not a simple task to establish the same, because fusulinids become extinct across this boundary in the East European and Boreal regions, and this event may clearly indicate the boundary significance. Being based on ammonoids and conodonts, the Lower–Upper Permian boundary in the traditional East European scale separates the Kungurian and Ufimian stages (Leonova and Dmitriev, 1989; Kozur, 1995, 1998; Kozur *et al.*, 1994).

Because of fusulinid endemism, it is difficult to correlate the Tethyan and North American sections. In the project of the Global Chronostratigraphic Scale (Jin *et al.*, 1997), the boundary under consideration is placed at the base of the Roadian Stage, i.e., at the base of the Guadalupian Series. Such a decision is mostly based on distribution of ammonoids, as the ammonoid genera *Epiglyphioceras, Stacheoceras,* and *Paraceltites*, which are typical of the Roadian Stage in North America, are also known from the base of the Kubergandian Stage of the stratotype area in the southeastern Pamirs (Chediya *et al.*, 1986). In addition, the Bolorian ammonoids and conodonts are comparable with those of the Cathedralian Stage underlying the Roadian one (Leonova and Dmitriev, 1989). The suggested correlation seems doubtful however, because Chinese researchers reported that conodont species *Jinogondolella nankingensis*, the appearance of which marks by definition, the lower boundary of the Roadian Stage and of the Guadalupian Series as well, do not occur below Bed 46 of the Luodian section (Guizhou Province), i.e., below the upper third of the Murgabian Stage (Henderson *et al.*, 1999). One should remember also that Roadian conodonts coexist with Kubergandian fusulinids in the Bed 25 situated 150 m below in the Luodian section (Kozur, 1998).

The indicated contradiction in definition of the Cisuralian–Guadalupian boundary and in its correlation with the Cisuralian–Tethysian boundary are lacking explanations so far, as it has been formerly discussed in detail (Leven, 2001). Here I should mention only that the idea of Henderson and his Chinese colleagues who placed the boundary separating series or subsystems inside the Murgabian Stage is unacceptable in terms of fusulinids' evolution. Their idea excessively increases the range of the Cisuralian Subsystems and of

the upper stage of the Darvasian Series. Hence, it would be premature to use the name "Guadalupian" for the series spanning the Kubergandian, Murgabian, and Midian stages of the Tethyan scale.

Despite a considerable distinction between fusulinid assemblages of Uralian and Darvasian series of the Cisuralian Subsystem, it is difficult to establish precisely the level separating them. Since the changes are not abrupt but slightly progressing with time, the problem decision depends on formal criteria, which can be selected to fix the boundary. In Tethyan sections, the most convenient criterion is the appearance level of the *Pamirina* and approximately concurrent *Chalaroschwagerina* genera. With this criterion, the boundary coincides with the base of the Yakhtashian Stage (Leven, 1980б) and can be traced easily from the Carnic Alps on the west (Forke, 1995) to Japan on the east (*Guidebook...*, 1990; Ueno, 1996). The most clear transition from Sakmarian to Yakhtashian fusulinid assemblages is observable in the South Chinese sections, where it is recorded across boundary between the Zisongian and Longlinian regional stages (Sheng and Jin, 1994), the former of which spans the Asselian and Sakmarian stages, whereas the latter one is a younger synonym of the Yakhtashian Stage.

In opinion of Leonova (see in Leven *et al.*, 1992), ammonoids found near the top of the Yakhtashian Stage in its stratotype area are similar to the late Artinskian counterparts. The lower Artinskian conodonts (*Sweetognathus whitei*) appear in the section almost concurrently with first *Pamirina* forms. Accordingly, we may assume that Yakhtashian and Artinskian stages are approximately correlative, and hence the boundary between Uralian and Darvasian series of the Cisuralian Subsystem should be at the level separating the Sakmarian and Artinskian stages of the East European scale. Nothing more definite can be said about the issue based on the data available at present. Moreover, the boundary between these stages has not been officially fixed and present opinions about its positioning are very diverse. In North America, it used to be regarded as correlative with the boundary between the Lenoxian and Hessian stages (Ross and Ross, 1987), but its position is probably lower, inside the Lenoxian Stage or even at the base of the latter (Wardlaw and Davydov, 2000). The problem can be solved after additional research.

There is no problem concerning the boundary between the Yangsingian and Lopingian series, because it marks a catastrophic extinction of fusulinids and many other marine invertebrates by the end of the Midian Age (Jin, 1993). The GSSP of this boundary is suggested to be either at the base of the *Clarkina postbitteri* Zone in the conodont scale, or slightly higher, at the base of the *C. dukouensis* Zone (Henderson *et al.*, 2000). In the East European scale, its position is still unclear. Taking into consideration the paleomagnetic dates, one should seek for it inside the upper Tatarian

Substage (Burov, 1996), because the boundary between the Kiama and Illawarra superchrons corresponds here to the substage base, whereas in the Tethys it is near the base of the Midian Stage (Jin *et al.*, 2000).

STAGES AND THEIR BOUNDARIES

Except for two upper stages, all the others are defined in the Tethyan scale based on fusulinids. General characteristics of fusulinid assemblages have been used here to distinguish the Asselian and Sakmarian stages, while the other ones correspond to stages in evolution of fusulinids of the *Pamirina–Misellina–Cancellina–Neoschwagerina–Yabeina* phylogenetic lineage (Fig. 4, Plates I, II).

The Asselian Stage can be characterized based on fusulinid assemblages known from its type sections in the southern Urals. Most remarkable and typical of the unit are loosely coiled fusulinids, such as *Sphaeroschwagerina, Pseudoschwagerina, Zellia, Robustoschwagerina*, and some others. *Quasifusulina, Rugosofusulina, Dutkevitchia, Kahlerella*, and *Pseudofusulina* are also characteristic and abundant. Compositional peculiarities of Asselian fusulinid assemblages are persistent, though with some variations, throughout the Tethyan realm, and the stage is recognizable without difficulties everywhere from the Alps on the west to Japan and Indochina on the east.

The Sakmarian Stage yields fusulinids of a similar composition and can be discriminated from the Asselian Stage not everywhere. For instance, both subdivisions are regarded as the integral Zisongian Stage in stratigraphic schemes recently accepted in China (Sheng and Jin, 1994). Nevertheless, certain distinctions, even at the generic level, become evident after a careful analysis. Hence, the relative abundance of aforementioned Asselian genera, all occurring in the Sakmarian Stage as well, is different: *Quasifusulina, Sphaeroschwagerina, Pseudoschwagerina*, and *Dutkevitchia* are less abundant in the last case, while *Robustoschwagerina, Paraschwagerina*, and *Zellia* turn into leading taxa. Genera *Darvasites, Eoparafusulina, Monodiexodina* and *Acervoschwagerina* appear for the first time and become widespread. *Rugosofusulina* and *Pseudofusulina* are as abundant as before, but their species composition is considerably renewed. All these characteristics enable discrimination of the Sakmarian Stage, although its boundary with the Asselian Stage remains vague, especially if we take into consideration that it is imprecisely defined in the type sections of the southern Urals (Wardlaw *et al.*, 1999).

The Yakhtashian Stage is initial one in the Darvasian Series of the Cisuralian Subsystem. As is mentioned above, fusulinids of the stage differ from their Sakmarian assemblages as a consequence of the post-Sakmarian extinction, which decreased abundance rates of many genera typical of the Asselian–Sakmarian

community, namely of *Dutkevitchia, Sphaeroschwagerina, Pseudoschwagerina, Zellia, Paraschwagerina,* and some others. Newcomers characteristic of the Yakhtashian and Bolorian stages are genera *Pamirina, Pseudoreichelina, Mesoschubertella, Toriyamaia, Chalaroschwagerina, Darvasella, Leeina,* and *Praeskirnnerella. Darvasites* forms are still abundant like in the Sakmarian Stage, but their shells have more massive and wide chomata resembling those of the genus *Nagatoella.*

Deposits bearing Yakhtashian fusulinids are established in Turkey, Afghanistan, Darvaz, Pamirs, and Karakorum (Leven, 1967, 1980b, 1995, 1997; Leven *et al.,* 1992; Gaetani *et al.,* 1995). In China, the same interval of sedimentary successions corresponds to the Longlinian Stage (Sheng and Jin, 1994). The Yakhtashian Stage is also discriminated in the Akiyoshi section of Japan (*Guidebook…,* 1990; Ueno, 1996). Fusulinids characteristic of the stage are known from Thailand as well (Sakagami and Iwai, 1974).

The lower limitation of the Yakhtashian Stage has been discussed already in the section devoted to boundaries, which separate series of the Cisuralian Subsystem. It is problematic so far. At present, the boundary in question can be defined based on concurrent appearance of *Chalaroschwagerina* and first *Pamirina* forms of the subgenus *P. (Levenella).* The Yakhtashian Stage in my understanding approximately corresponds to the Artinskian Stage of the East European scale, as one can judge from distribution of ammonoids and conodonts. Because of biogeographic factors, a comparison between fusulinid assemblages from the Tethys and the Urals neither proves, nor discards that inference. Some Yakhtashian genera known from Texas (*Chalaroschwagerina, Praeskinnerella*) suggest that the unit under consideration may be correlative with the Lenoxian Stage (or with its upper substage) coupled with a basal interval of the Hessian Stage. Data on conodonts (Wardlaw and Davydov, 2000) are consistent with this conclusion. On the other hand, the Lenoxian Stage seem to be correlative with the Sakmarian one based on distribution of ammonoids (Kotlyar *et al.,* 1987).

The Bolorian Stage yields fusulinid assemblages, which are similar in general to the Yakhtashian counterparts. Distinctions are mainly recognizable at the species level. The principal distinctive feature is the appearance and subsequent flourishing of primitive higher fusulinids of the order Neoschwagerinida, which were represented first by subgenus *Brevaxina,* and then by subgenus *Misellina (Misellina)* (Fig. 4). A quick branching of *Brevaxina* from the ancestral genus *Pamirina* (Fig. 6) is recorded in many sections, and, based on this event, the Yakhtashian–Bolorian boundary is easily and confidently recognizable in all areas of the Tethys. Coexistence of *Brevaxina* and primitive *Misellina* with Yakhtashian–Bolorian genera *Mesoschubertella, Toriyamaia, Chalaroschwagerina, Darvasites, Leeina,* and *Praeskinnerella* enabled recognition

of the Bolorian Stage in many sections of the Transcaucasia and Iran on the west to Japan and Indochina on the east. The lower part of the Luodinian Stage in China (*Brevaxina dyhrenfurthi* and *Misellina termieri* zones) is correlative with the stage as well (Sheng and Jin, 1994).

Outside the Tethys, the Bolorian Stage is unrecognizable because of endemism of its fusulinid assemblages. Based on position in the sections and on distribution of ammonoids and conodonts, the unit is correlative with the Kungurian Stage of Eastern Europe and with the Cathedralian Stage of North America (Leonova and Dmitriev, 1989; Kozur, 1995, 1998; Kozur *et al.,* 1994). The correlation is problematic so far.

The Kubergandian Stage differs strongly from the Bolorian Stage and yields contrasting fusulinid assemblages. The distinctions have been outlined above by consideration of fusulinid evolution and boundaries separating the Permian Subsystems. Here, I should mention only that fusulinids from the lower *Armenina–Misellina ovalis* Zone of the stage are tightly connected with Bolorian assemblages, because the genus *Misellina* is well represented at this level. Accordingly, some experts, for instance, my colleagues in China, feel it appropriate to couple the Bolorian Stage and that zone into one stratigraphic subdivision such as the Luodinian regional stage (Sheng and Jin, 1994). However, the genus *Misellina* is represented in the *Armenina–M. ovalis* Zone by species, which are more developed, than their Bolorian counterparts. In addition, exactly this level marks the initial renewal of the entire community, i.e., the appearance of taxa, such as *Armenina, Pseudodoliolina, Yangchienia,* and *Neofusulinella,* which become widespread in the Yangsingian Series (Figs. 5, 6). The majority of taxa characteristic of the Yakhtashian–Bolorian period in fusulinid evolution do not cross the zone lower boundary. This is established not only in type sections of the Kubergandian Stage in the Pamirs (Leven, 1981; Chediya *et al.,* 1986), but also in most complete sections of southern China, where renewals in assemblages are recorded either at the base, or inside the beds corresponding to the *Misellina claudiae* or *M. ovalis* zones (Xiao *et al.,* 1986; Zhou *et al.,* 1987).

Deposits with Kubergandian fusulinids are established in numerous sections of a vast region, from the Mediterranean on the west to Japan and Indochina on the east. At present, there is no data, which may substantiate the direct correlation between the Kubergandian Stage and subdivisions of the East European scale. I accept conventionally the correlation between lower boundaries of this and Ufimian stages. My comments to correlation of the Kubergandian and Guadalupian lower boundaries are presented above.

The Murgabian Stage is tightly connected with the Kubergandian Stage as far as it concerns their fusulinid assemblages. Diversification of the order Neoschwagerinida is in progress at this level. Family Sumatrinidae with genera *Presumatrina, Afghanella,* and *Sumat-*

rina, Verbeekinidae (genus *Verbeekina*), and subfamily Lepidolininae (genera *Gifuella* and *Colania*) represent taxa first appeared in that order (Fig. 4). Genera *Yangchienia, Chusenella, Skinnerella*, and *Eopolydiexodina* of the Kubergandian origin become widespread. In distinction from the Kubergandian Age, the last taxon is represented by subgenus *E. (Eopolydiexodina)*. Orders Schubertellida and Staffellida also experience diversification.

The stage lower boundary is placed by definition at the appearance level of *Neoschwagerina, Presumatrina*, and *Verbeekina*, i.e., at the base of the *N. simplex* Zone. This is a very significant and remarkable level, and one should place the stage boundary exactly here, but not at the lower appearance level of the genus *Cancellina*, as it is done in some works by Chinese researchers (Sheng and Jin, 1994; Zhu and Zhang, 1994).

The Murgabian Stage and its lower boundary are easily traceable based on fusulinids from the Mediterranean to Indochina, i.e., over the entire Tethyan region. It is impossible so far to correlate directly the stage with subdivisions of the East European scale. As for the stage correlation with the North American scale, it seem to be very problematic because of controversial interpretations of conodont dates (Kozur, 1998; Henderson *et al.*, 1999; Leven, 2001).

The Midian Stage marks the third peak of fusulinid generic diversity (Figs. 1, 2). It was a prosperity time of the order Neoschwagerinida represented by taxa, which were highly organized, crowning the phylogenetic lineages of the Neoschwagerinidae, Sumatrinidae, Verbeekinidae, and Pseudodoliolinidae families (Fig. 4). Most remarkable among these taxa were genera *Yabeina* and *Lepidolina* first appeared at this level. Subfamily Chusenellinae with characteristic new genus *Orientoschwagerina* was of a greater significance in the order Schwagerinida. The Midian Age signifies as well the peak development of the orders Schubertellida, Staffellida, and Ozawainellida. Most remarkable representatives of these orders are the first appeared genera *Lantschichites, Paradoxiella, Eoverbeekina, Reichelina*, and *Rauserella*. One more taxon that appeared and became widespread in the Midian Age is family Kahlerinidae whose genetic roots are unclear.

According to original definition, the lower boundary of Midian Stage corresponds to the first occurrence level of *Yabeina* and *Lepidolina* whose geographic range is restricted by eastern areas of the Tethys, beyond which the boundary can be traced not so easily. Because of various criteria used to define the boundary on the west, it looks somewhat blurred here (Leven, 1996). Certainly, the boundary proper and its distinctive characters should be clarified and coordinated in the future. Paleomagnetic data may be important in this case, because preliminary (not very confident) research showed that boundary between the Kiama and Illawarra

superchrons is confined to the Midian Stage base (Jin *et al.*, 2000).

With certain reservations concerning the lower boundary, the Midian Stage is readily recognizable in the Tethyan realm. In China, it approximately corresponds to the Lengwuan Stage (Sheng and Jin, 1994). In East European sections, the Kiama–Illawarra boundary is detected inside the Tatarian Stage, and the Midian Stage may correspond therefore to the basal interval of the upper Tatarian Substage. In North America, the stage under consideration (or its greater upper part) is likely correlative with the Capitanian Stage. This is evident from the fact that conodonts *Jinogondolella postserrata*, the appearance of which marks the lower boundary of the Capitanian Stage, coexist with Midian fusulinids in the upper part of Maokou Limestone in China (Mei *et al.*, 1998). Typical Midian fusulinids (*Yabeina, Reichelina, Paradoxiella*) are known from the Lamar Limestone crowning the Capitanian Formation of Texas (Skinner and Wilde, 1955).

The Dzhulfian Stage is clearly distinct from the Midian Stage, because its fusulinid assemblages are of a low diversity. They are lacking fusulinids of the orders Schwagerinida and Neoschwagerinida, which dominated before and became extinct by the end of the Midian Age (Plate II). The other orders lost families Yangchieniidae, Schubertellidae, and Kahlerinidae. Families Boultoniidae and Palaeofusulinidae survived the late Midian crisis and, experiencing diversification, gave rise to new genera *Gallowaiinella, Tewoella, Paradunbarula*, and *Palaeofusulina*, which are most highly organized in corresponding families. Three of these genera used to be regarded not long ago as characteristic of the Dorashamian Stage only, but recently they were found in beds of southern China, which correspond to the lower part of the Dzhulfian Stage (Zhu, 1996).

The Dzhulfian Stage lower boundary (or boundary between the Yangsingian and Lopingian series), which is well detectable by changes in fusulinid assemblages, is now under verification based on distribution of conodonts (Henderson *et al.*, 2000). The GSSP of that boundary is supposed to be at the base of the Wuchiapingian Stage in the Penglaiten section of southern China (Henderson *et al.*, 2000). According to recent data (Sweet and Mei, 1999), the same level is recognizable at the base of the Ali Bashi Formation in the Kuhi Ali-Bashi section of northwestern Iran. The formation approximately corresponds to the lower part of *Reichelina–Codonofusiella* Beds in sections of Transcaucasia (Leven, 1998) and central Iran (*Iranian-Japanese...*, 1981). In North America, the boundary coincides with the top of the Capitanian Stage.

The Dorashamian Stage is unclearly characterized in terms of fusulinids' distribution. Characteristic of the stage are genera *Palaeofusulina, Nanlingella, Parananlinhella, Paradunbarula, Gallowaiinella, Tewoella, Nankinella, Sphaerulina, Staffella, Reiche-*

lina, and *Parareichelina*. Except for *Parananlingella* and *Parareichelina*, all other genera listed above are known also from the underlying Dzhulfian Stage. Accordingly, it is difficult to discriminate the Dzhulfian and Dorashamian stages based on fusulinids, but the problem can probably be solved with the help of conodonts and ammonoids (Jin *et al.*, 1997).

Outside southern China, where the local Changhsingian Stage is an equivalent of the Dorashamian Stage, fusulinids of the latter are well represented only in the Nikitinskaya and Urushten formations of the northern Caucasus (Kotlyar *et al.*, 1983). Based on conodonts, the stage is distinguishable in Transcaucasia (Kozur *et al.*, 1978) and in northwestern and central Iran (Sweet and Mei, 1999; Kozur *et al.*, 1975). The known finds of fusulinids and conodonts imply also that Dorashamian deposits are present in Greece, Turkey, Pamirs, the Salt Range, and Japan. Outside the Tethyan realm, deposits of the stage have not been established so far.

CONCLUSION

(1) The global chronostratigraphic scale is hardly applicable for Permian deposits in Tethyan areas, for which the alternative scale is suggested and characterized with due account for most recent data. The Permian System is divided therewith in two subsystems with two series in each. In general, these subdivisions and nine discriminated stages correspond to natural periods in evolution of fusulinids and other orthostratigraphic groups of marine fossils (Leven *et al.*, 1996). They reflect historical periods of the basin development and its biota evolution that progressed under influence of large transgressions and regressions, which increased or decreased the taxonomic diversity of organisms (Leven, 1993).

(2) The necessity to divide the Permian in two subsystems and four series is also implied by data on macrofauna distribution in Boreal sections. Accordingly, biostratigraphic regularities used to substantiate the Tethyan scale are of a global significance, being valid outside the Tethyan realm.

(3) The three-series global chronostratigraphic scale authorized recently is inconsistent with many biostratigraphic evidences considered in this work. Elaborators of the scale ignored the principle of natural history using instead the formal definition of stratigraphic boundaries based on conodonts' succession in a single phylogenetic lineage. As a result, stratigraphic ranges of series are disproportional in that scale and some boundaries, especially those of the Guadalupian Series and its stages, are traceable worldwide with difficulties. The series ranges in the scale proposed are more proportional, and the scale itself inherits advantages of the traditional two-part scale. The described subdivision scheme seems to be a better candidate for the global scale.

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