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THE PERMIAN STRATIGRAPHY AND FUSULINIDS OF THE TETHYS

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Abstract. The diversity curve of the Permian fusulinid genera shows two peaks corresponding to the Asselian-Sakmarian and the Midian times. The minimal generic diversity is recorded in the late Bolorian time. The most significant extinction events occurred at the end of the Midian (71% of the total amount of all genera), Bolorian (48%), Asselian (27%) and Sakmarian (23%) ages. The fusulinid assemblage was most notably changed by the appearance of new genera (52% of the total number) in the Kubergandian age. These data allow recognition of two main stages (Asselian-Bolorian and Kubergandian-Dorashamian) and four second-order stages (Asselian-Sakmarian, Yakhtashian-Bolorian, Kubergandian-Midian, and Dzhulfian-Dorashamian) in the Permian history of fusulinids. The main stages correspond to two Permian series of the East European scale, which can be considered as subsystems named Cisuralian and Tethysian, respectively. The latter are subdivided into the Uralian, Darvasian, Yangsingian and Lopingian series which corresponding to the second-order stages. The scale suggested does not contradict the traditional two-member subdivision and has an advantage over the accepted global three-member chronostratigraphic scale because the series suggested are more proportional to each other in scopes and reflect natural evolutionary processes of the marine biota. In addition, the application of the global scale to the Tethyan sequences is hampered by a limited number of criteria used in the drawing of series and stage boundaries, as evidenced by the existing different views on the position of the lower Guadalupian boundary in the Tethyan sections.

Riassunto. La curva della diversità dei generi di fusulinidi permiani mostra due massimi in corrispondenza dell'Asseliano-Sakmariano e del Midiano. Il minimo nella diversità generica si registra nel Boloriano superiore. Gli eventi di estinzione più significativi si verificarono alla fine del Midiano (71% di tutti i generi), Boloriano (48%), Asseliano (27%) e Sakmariano (23%). Le associazioni a fusulinidi ebbero il loro cambiamento più significativo con la comparsa di nuovi generi nel Kubergandiano (52% del totale). Questi fatti identificano due stadi principali (Asseliano-Boloriano e Kubergandiano-Dorashamiano) e quattro stadi di secondo ordine (Asseliano-Sakmariano, Yakhtashiano-Boloriano, Kubergandiano-Midiano e Dzhulfiano-Dorashamiano) nella storia dei fusulinidi permiani. Gli stadi principali corrispondono alle due serie della scala dell'Europa orientale, che possono venir considerate come sottosistemi, denominati rispettivamente Cisuraliano e Tethysiano. Gli stadi di secondo ordine possono venir suddivisi nelle Serie denominate Uraliano, Darvasiano, Yangsingiano e Lopingiano. La scala cronostrigrafica proposta non contraddice la tradizionale suddivisione in due parti del Permiano ed ha il vantaggio, rispetto alla scala globale attualmente accettata composta da tre parti, di serie più bilanciate in dimensioni e di riflettere meglio la naturale evoluzione dei biota marini. Inoltre, l'applicazione della scala globale alla Tetide è ostacolata dal limitato numero di criteri adottato nel definire i limiti delle serie e dei piani, come messo in evidenza dalle opinioni differenti a proposito della posizione del limite inferiore del Guadalupiano nelle successioni tetidiane.

Introduction. The generic diversity of fusulinids

Fusulinids are the most abundant, widespread and well-studied group of Permian marine fossils of the Tethys. For this reason, they have a major stratigraphic value and serve as the basis for all well-substantiated Permian stratigraphic scales. In the last years conodonts became increasingly important for the Permian stratigraphy of the Tethys. However, the application of the use of conodonts, as well as of another fossil group – ammonoids, is hampered by their sporadic occurrence.

The irregular evolution of Permian fusulinids is characterized by several different-order stages, which allow us to recognize corresponding stratigraphic units from zone to system, and to establish their hierarchy. The stages can be distinguished both by the appearance or extinction of different-rank taxa and by variations in the general diversity and changes in dominating groups.

The diagrams below show the generic diversity of fusulinids for the period from their appearance in the Visean to their extinction in the late Dorashamian (Fig.1, 2). The fusulinid system accepted is that presented in "The reference-book on the Paleozoic Foraminifera systematics" (Rauzer-Chernousova et al. 1996). Calculations

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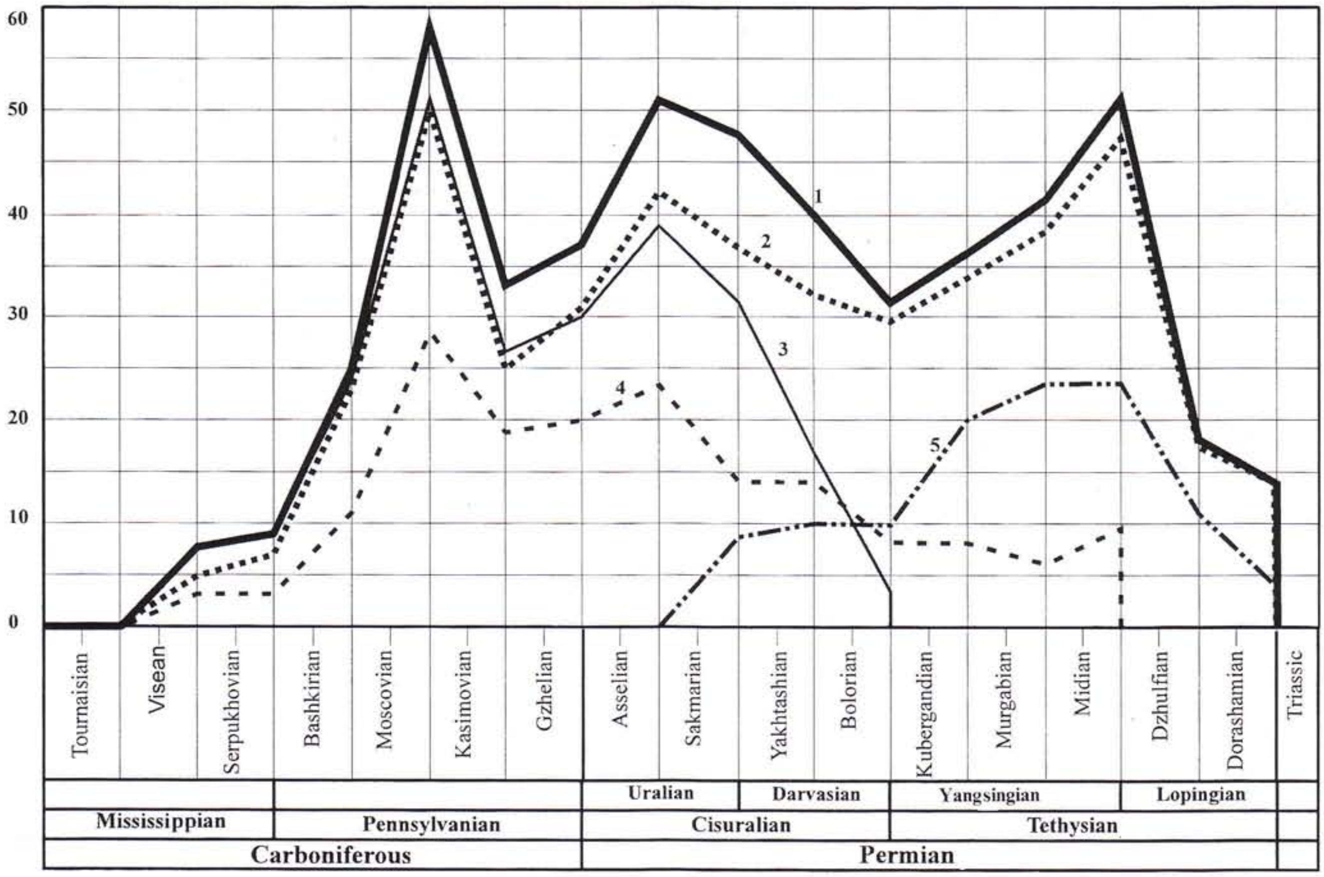

Fig. 1 - A number of fusulinid genera in the Carboniferous and Permian Stages.
1-a total member; 2- Tethys; 3-East European basin; 4 - USA; 5-peri-Gondwana part of Tethys (S. Afghanistan, S. Pamirs, Karakorum, S. Tibet).

were made either for every stage or independently for its lower and upper parts. Only the fusulinids of the Tethyan Realm were taken into account, but the diversity curve of the Tethyan fusulinids appeared to be coincident with that of the subglobal fusulinid fauna diversity (Fig. 1). It follows that the general fusulinid diversity was mainly determined by their diversity in the Tethys.

The general and Tethyan curves (Fig. 1) show three distinct peaks of diversity in the Moskovian, Asselian-Sakmarian and Midian times. Accordingly, the history of fusulinids comprises three large stages, i.e., Visean-Kasimovian, Gzhelian-Bolorian, and Kubergandian-Dorashamian with the orders Fusulinida, Schwagerinida, and Neoschwagerinida plus Schubertellida dominating, respectively. The histogram (Fig. 2) constructed for every half-stage shows the same pattern with the only difference that the Asselian-Sakmarian stage has a double diversity peak. Along with the general diversity curve, the histogram presents quantities and percentages of newly appeared and extinct genera. After the Moskovian peak the greatest number of genera appeared in the first half of the Kubergandian Age (52% of the total amount) and in the second half of the Gzhelian Age (47%), i.e., in the beginning of the second and third main stages of the fusulinid evolution. Noticeable renewals of fusulinid assemblages are also recorded also in the early Yakhtashian time (36%), as well as in the Midian and Asselian ages. Apart from the complete disappearance of fusulinids at the end of the Permian, a drastic catastrophic extinction (71%) occurred at the end of the Midian Age. The significant extinction events took place at the end of the Bolorian, Asselian and Sakmarian ages (48%, 27% and 23%, respectively). These data show that drastic and noticeable changes in the fusulinid associations happened at the Bolorian/Kubergandian and Midian/Dzhulfian boundaries. The problems of Permian boundaries and subdivision into series and stages with regard to the fusulinid evolution, are discussed below.

Boundaries of the Permian System

The formal lower boundary of the Permian System is drawn at the base of the Asselian Stage by using ammonoids and conodonts, as was suggested by Ruzhentsev (1951; Davydov et al. 1998). Based on fusulinids, this boundary is fixed by the first occurrence of the widespread genus *Sphaeroschwagerina* and can be easily traced from Southern and Eastern Europe to Japan (Krainer & Davydov 1998; Leven & Scherbovich 1978; Davydov 1995; Guidebook 1990). However, no significant change occurred in the fusulinid biota at this level. A

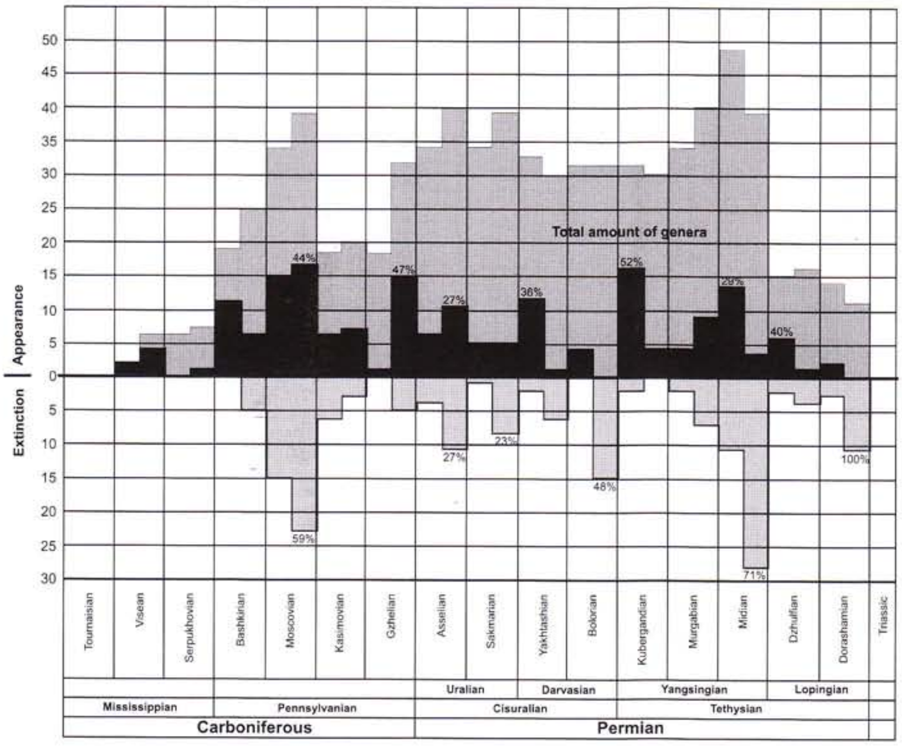

Fig. 2 - A total amount of the genera and a number of newly appeared and extinct genera of fusulinids in each half of ages (newly appeared and extinct genera shared in the general amounts are expressed in percent).

more essential change is recorded in Gzhelian time, when the Order Schwagerinida, which originated in the Kasimovian Age, increased in diversity, and a great number of new genera (47% of the total amount), including the typical Early Permian *Pseudofusulina, Rugosofusulina*, and *Dutkevitchia,* appeared. Based on the stages of fusulinid evolution, it would be natural to place the Carboniferous/Permian boundary inside the Gzhelian Stage, following its recent interpretation, or between the Gzhelian and Orenburgian stages, if the Orenburgian Stage is accepted. In this case, we shall face the problem of accurate fixation of the boundary and its tracing by means of fusulinids and other fossils including conodonts and ammonoids. In this respect, the formally accepted boundary seems preferable. The International Commission on Stratigraphy (ICS) approved the Permian/Triassic boundary at the base of the *Hindeodus parvus* conodont zone (Yin et al. 2001). The GSSP of this boundary is at the base of the Bed 27c of the section Meishan D (China). Fusulinids have completely disappeared worldwide below this level. Particularly, in the Meishan section, the latest forms were found one meter below the Bed 27 (Zhao et al. 1981). Thus, the upper Permian boundary cannot be accurately defined on the base of fusulinids, although it may be virtually related to their complete extinction.

The Permian series

There are many alternative schemes for the subdivision of the Permian System into series. In the East European scale, the system was traditionally subdivided into two parts with the boundary placed between the Kungurian and Ufimian stages. In its recent interpretation, this boundary corresponds to the Bolorian/Kubergandian boundary of the Tethyan scale and the Cathedralian/Roadian stages of the North American scale. Recently the ICS recommended subdividing the system into three series, i.e. Cisuralian, Guadalupian, and Lopingian series (Jin et al. 1997). The former series is a complete equivalent of the lower series of the traditional East European scale and the two others correspond to the upper one.

With regard to the fusulinid evolution, the Permian System can be divided into two parts related to the second and third main evolutionary stages (Fig. 1). As noted above, the second stage is characterized by the diversification and domination of the order Schwagerinida, and the third one by the diversification of the orders Neoschwagerinida, Schubertellida, and Staffellida. Each stage can be subdivided into two evolutionary second order stages, i.e., the Asselian-Sakmarian and Yakhtashian-Bolorian of the Early Permian and the Kubergandian-Midian and Dzhulfian-Dorashamian of the Late Permian. The Asselian-Sakmarian and Yakhtashian-Bolorian stages correspond to the Cisuralian Series of the Global Chronostratigraphic Scale (Jin et al. 1997). The Kubergandian-Midian and Dzhulfian-Dorashamian stages are likely equivalents of the Guadalupian and Lopingian series, respectively. Thus, the Cisuralian Series corresponds to two stages of the fusulinid evolution, whereas each of the other two series, corresponds to only one evolutionary stage. This evident disproportion can be avoided by dividing the Cisuralian Series into two independent series. In this case, the Permian System will comprise two subsystems and four se-

TETHYAN SCALE				GLOBAL SCALE	
	Subsystems	Series	Stages	Series	Stages
PERMIAN SYSTEM	TETHYSIAN	Lopingian	Dorashamian	Lopingian	Changhsingian
			Dzhulfian		Wuchiapingian
		Yangsingian	Midian	Guadalupian	Capitanian
			Murgabian		Wordian
			Kubergandian		Roadian
	CISURALIAN	Darvasian	Bolorian	Cisuralian	Kungurian
			Yakhtashian		Artinskian
		Uralian	Sakmarian		Sakmarian
			Asselian		Asselian

1 - C. M. Henderson & Mei Shilong (conodonts);
2 - H. Kozur (conodonts); M. F. Bogoslovskaya (ammonoids); E. Ja. Leven (fusulinids).

Fig. 3 - Proposed Permian scale for the Tethys and correlation of it with the Global Chronostratigraphic Scale.

ries (each subsystem consists of two series) based on the development of Tethyan fusulinids (Fig. 3).

I proposed this variant of subdivision of the Permian System at the Congress "The Permian of the World" held in Perm, 1991 (Leven 1992). V. G. Ganelin and G. V. Kotlyar (1991) suggested analogous schemes based on boreal sections with macrofaunal remains. However, later, Kotlyar approved the three-fold subdivisions of Jin et al. (1997). This indicates that the subdivision proposed reflects not only the evolutionary stages of fusulinids, but also some global processes of the Earth and biosphere. The scheme proposed is preferable over the three-member subdivision because it is more adequate to the processes of the Earth natural history, it agrees with the traditional two-member scale, and eliminates the evident disproportion in scope between the Cisuralian Series, on the one hand, and the Guadalupian and Lopingian series, on the other hand. The names Uralian and Darvasian are proposed for the series of the Cisuralian Subsystem. Lapparent (1900) and Miklukho-Maclay (1958) introduced these names for stratigraphic units of approximately equal scope. The upper subsystem of the Permian System can be called Tethysian because the most complete marine sections of this subsystem are located within the Tethys. The upper series of the Tethysian Subsystem is a complete equivalent of the Lopingian Series of the Global Chronostratigraphic Scale (Fig. 3, 4). Logically, the entire lower series of this subdivision should correspond to the Guadalupian Series. However, according to the conodont data (Mei et al. 1998; Henderson et al. 1999), only the upper part of the suggested series is equal to the Guadalupian. For this reason, the name "Guadalupian" is still undesirable when used for the Tethyan deposits. Instead, the name "Yangsingian", which has been long-used in China (Huang 1932; Sheng & Jin 1994) for the stratigraphic unit approximating in scope to the lower series, is suggested (Fig. 4).

Thus, the Permian stratigraphic scale for the Tethys takes the following form (Fig. 3). Fusulinid assemblages characteristic of each of the four series corresponding to the evolutionary stages of the second order are described below (Fig. 5, 6).

The Cisuralian Subsystem

The **Uralian Series** consists of the Asselian and Sakmarian stages and is characterized by the greatest fusulinid diversity. Lapparent (1900) used the name Uralian for the so-called "*Schwagerina* horizon" of the Urals, which he incorrectly considered to be a marine equivalent of the Stephanian Stage of the Upper Carboniferous of Western Europe. Ruzhentsev (1936) distinguished the "*Schwagerina* horizon" as the Sakmarian Stage. He rejected the name Uralian for this stage because of its ambiguous interpretation. However, building on this argument, we should abandon all traditional Permian stages, many of which have differently interpreted scopes. This is also true for the Sakmarian Stage, whose scope became two times smaller after Ruzhentsev had distinguished its separated half of it as the independent Asselian Stage (Ruzhentsev 1954).

Approximately, in accordance with Lapparent's view on the scope of the Uralian unit, this name is suggested for the lower series of the Cisuralian Subsystem composed of the Asselian and Sakmarian stages. Fusulinid assemblages in these stages are similar to each other and mostly inherited from the Gzhelian assemblage. Dominating forms belong to the order Schwagerinida. The most abundant and characteristic genera are those already appeared in the Gzhelian age: *Rugosofusulina, Dutkevitchia*, and *Kahlerella* of the family Rugosofusulinidae, *Pseudofusulina* (s. l.) of the family Pseudofusulinidae, and especially, inflated and loosely coiled forms with inflated tests, such as *Sphaeroschwagerina, Pseudoschwagerina, Paraschwagerina, Zellia, Robustoschwagerina* and some others, which are artificially combined into the heterogeneous family Schwagerinidae. The genus *Quasifusulina* of the order Fusulinida is also frequent. The Asselian and Sakmarian fusulinid assemblages differ mainly

Proposed Tethyan scale				China Sheng J. & Jin Y., 1994			
System	Subsystem	Series	Stage	System	Series		Stage
PERMIAN	TETHYSIAN	Lopingian	Dorashamian	PERMIAN	Lopingian		Changhsingian
			Dzhulfian				Wuchiapingian
		Yangsingian	Midian		Yangsingian	Maokouan	Lengwuan
			Murgabian				Kuhfengian
							Xiangboan
			Kubergandian			Chihsian	Luodianian
	CISURALIAN	Darvasian	Bolorian				
			Yakhtashian		Chuanshanian		Longlinian
		Uralian	Sakmarian				Zisongian
			Asselian				

Fig. 4 - Correlation of the Permian, Tethyan and Chinese scales.

at the species level. Only three genera (*Eoparafusulina*, *Darvasites* and *Monodiexodina*) are known to appear in the Sakmarian Stage.

The **Darvasian Series**. Dutkevich (1937) used the name "Darvasian" for the upper group of the Lower Permian deposits of Darvaz. This group was established by Miklukho-Maclay (1958) as the new Darvasian Stage. The fusulinid zones *Parafusulina*, *Misellina* and *Cancellina* were included into this stage. The *Cancellina* Zone was considered later as the Upper Permian Kubergandian Stage (Leven 1963). So, the scope of the Darvasian Series in this paper is slightly less shorter than the Darvasian Stage of Miklukho-Maclay.

The Darvasian Series comprises the Yakhtashian and Bolorian Stages. Fusulinid assemblages of these stages are very close to each other but are greatly different from those of the Uralian Series. At the series boundary, most genera of the family Schwagerinidae become extinct and forms of the family Rugosofusulinidae sharply decrease in abundance. The most characteristic genera of the order Schwagerinida are *Chalaroschwagerina*, *Darvasites*, *Leeina* of the *L. kraffti-fusiformis* group, *Praeskinnerella*, and the earliest *Parafusulina* and *Skinnerella*. Among representatives of other orders, *Biwaella*, *Mesoschubertella*, and *Toriyamaia* should be mentioned among the representatives of other orders. Of special significance is the occurrence of *Pamirina*, which appeared in Yakhtashian time and gave rise in Bolorian time to the genus *Misellina*, the earliest higher fusulinids of the order Neoschwagerinida. In general, the Darvasian fusulinid assemblage is easily distinguishable from the Uralian assemblage, although there are some common forms. In addition, the Darvasian assemblage contains the newly appeared elements (*Misellina*, *Yangchienia*) of the Yangsingian assemblage.

The Tethysian Subsystem

The **Yangsingian Series** consists of the Kubergandian, Murgabian and Midian stages. The Darvasian/Yangsingian boundary is marked by the most significant changes in the fusulinid assemblage. The characteristic Darvasian genera *Chalaroschwagerina*, *Darvasites*, *Leeina*, *Biwaella*, *Mesoschubertella*, and *Toriyamaia*, as well as the latest forms of *Quasifusulina*, *Robustoschwagerina*, and *Acervoschwagerina* completely disappeared. In Kubergandian time, the fusulinid assemblage appears fully renewed. Higher fusulinids of the order Neoschwagerinida increase in abundance and include the first appearances of the genera *Armenina*, *Pseudodoliolina*, and *Cancellina*. The two latter genera gave rise to the families Pseudodoliolinidae and Neoschwagerinidae, which, along with the families Sumatrinidae and Verbeekinidae, appeared in the early Murgabian, and then diversified in Murgabian and especially in Midian times. The order Schwagerinida was dominated by *Parafusulina*, *Skinnerella*, and *Chusenella*; the earliest *Eopolydiexodina*, represented by the subgenus *Bidiexodina*, appeared in the second half of the Kubergandian age. The monotypic family Yanchieniidae of the order Schubertellida appeared in the late Bolorian time and became characteristic of the entire Yangsingian Series. The generic compositions of the families Schubertellidae and Boultoniidae were renewed, owing to the appearance of the genera *Neofusulinella*, *Codonofusiella*, and *Wutuella* in Kubergandian time and the genera *Russiella* and *Lantschichites* in the Murgabian and Midian. The order Staffellida contained abundant forms of the genera *Nankinella*, *Staffella* and *Sphaerulina*. Thus, the Yangsingian Epoch is generally characterized by the rapid diversification of the order Neoschwagerinida, by the appearance of the highly developed multi-apertured genus *Eopolydiexodina* of the order Schwagerinida, and by the increased diversity of other fusulinid orders.

The **Lopingian Series** is subdivided into the Dzhulfian and Dorashamian Stages. Its fusulinid assemblage was noticeably impoverished by the catastrophic extinction (71% of all genera) in the late Midian. At the Midian/Dzhulfian boundary, the orders Neoschwagerinida and Schwagerinida as well as the families Yangchieniidae, Schubertellidae, and Kahlerinidae of other orders completely disappeared. Only the three orders Staffellida, Ozawainellida, and Schubertellida crossed this bounda-

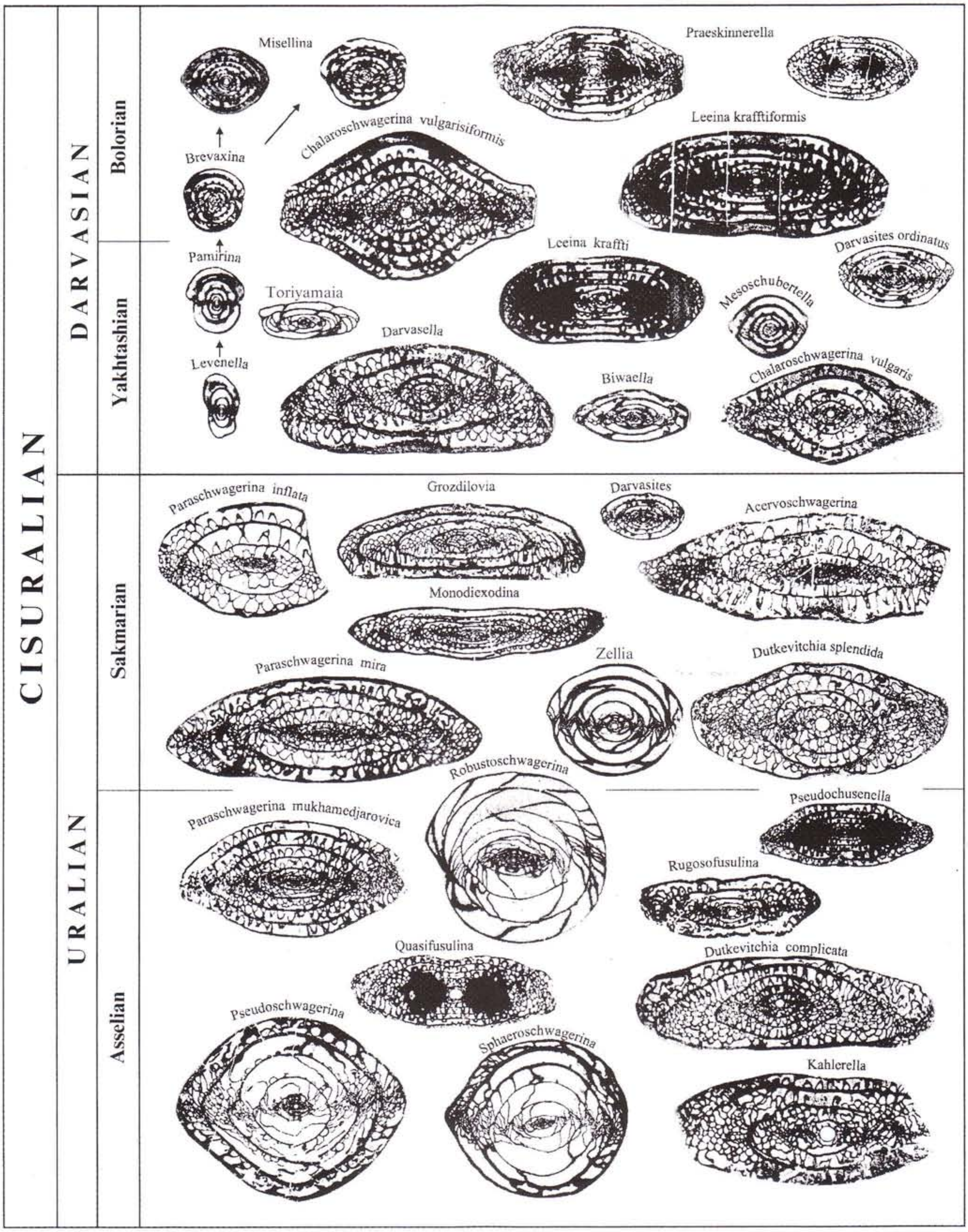

Fig. 5 - Characteristic fusulinids of the Cisuralian Subsystem subdivisions.

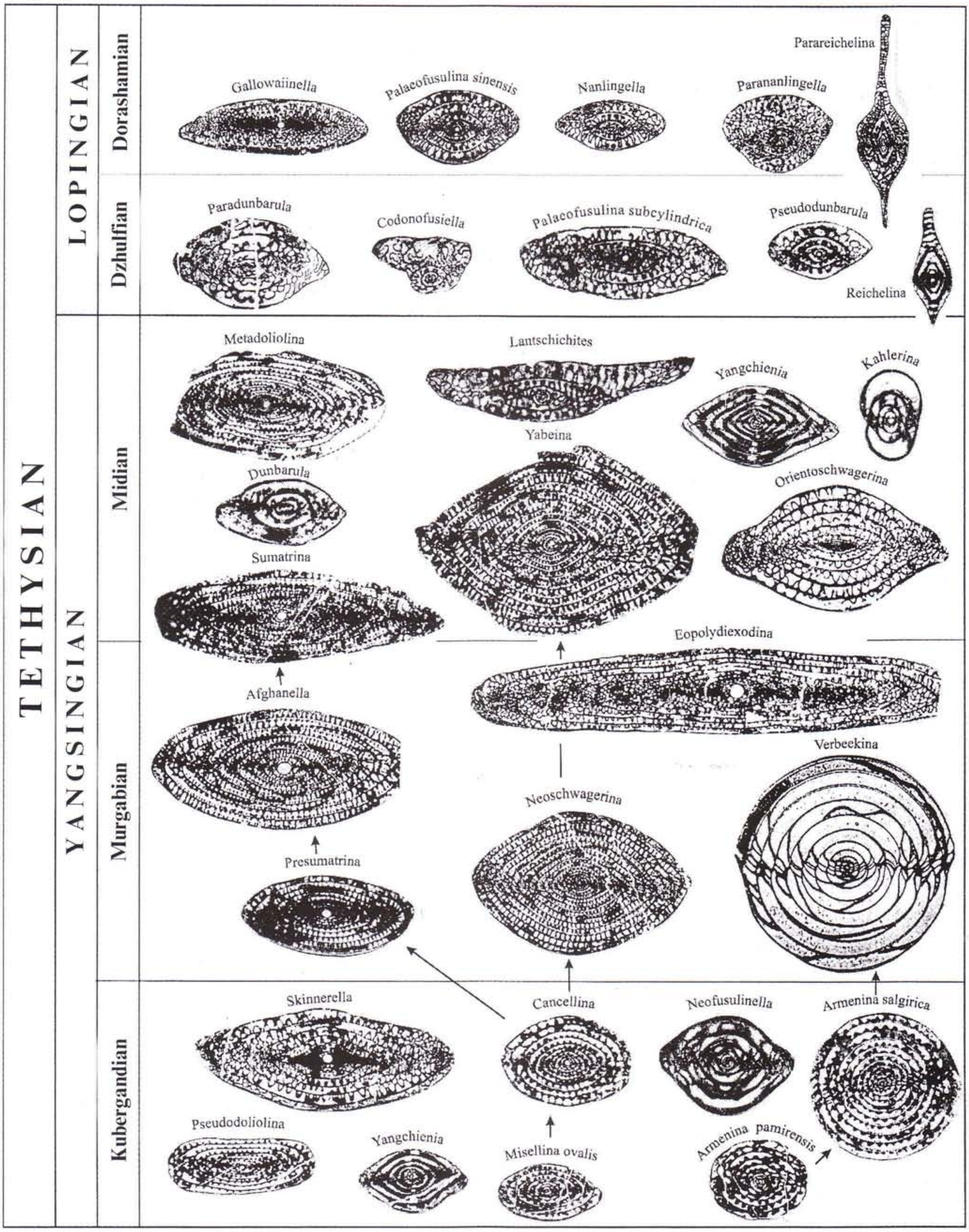

Fig. 6 - Characteristic fusulinids of the Tethysian Subsystem subdivisions.

ry. The two former orders show decreased diversity. The families Palaeofusulinidae and Boultoliidae of the order Schubertellida became more diverse at the expense of the appearance of the genera *Palaeofusulina, Paradunbarula, Tewoella*, and *Gallowaiinella* in the Dzhulfian Age, and *Nanlingella* and *Parananlingella* somewhat later.

Thus, the Lopingian Epoch can be characterized as the time of existence of fusulinids that survived the late Midian crisis. Only the families Palaeofusulinidae and Boultoniidae still continued to developed but became extinct by the end of the Permian.

The problem of subsystem and series boundaries

The fusulinid-based boundary of the subsystems coincides with the Bolorian/Kubergandian boundary, which is marked by the abrupt renewal of the assemblages. In the stratotype and hypostratotype sections of the Kubergandian Stage (SE Pamirs), the boundary lies at the base of the *Armenina-Misellina ovalis* Zone (Chedija et al. 1986; Leven 1981a, b). In Transcaucasia, the boundary is drawn at the base of the Asni Formation, where abundant *Armenina* and advanced *Misellina* appear (Leven 1998).

In South China, the deposits embracing the Bolorian Stage and most of the Kubergandian Stage are combined into the Luodianian Stage (Sheng & Jin 1994). Therefore, this boundary is set inside this stage. However it is easily recognized in the stage stratotype (the Luodian section, Excursion Guidebook 1994) by the first occurrence of early Kubergandian *Armenina, Skinnerella*, and *Yangchienia* in bed 25 (Leven 2001). According to Kozur (1998), the boundary beds of this section contain also conodonts of the Roadian, i. e., early Guadalupian Epoch. In other fusulinid-bearing sections of Guizhou, Yunnan and Guangxi provinces this boundary is placed between the beds with diverse *Misellina, Chalaroschwageina*, and *Darvasites* of the *Misellina termieri* Zone and the beds containing the earliest *Armenina, Pseudodoliolina, Parafusulina, Yangchienia*, which are usually assigned to the *Misellina claudiae*, or *M. ovalis* Zone (Xiao et al. 1986; Zhou et al. 1987).

In the Akiyoshi section of Japan, the distinct Bolorian/Kubergandian boundary lies at the base of the *M. claudiae* Zone (Guidebook 1990; Ueno 1996). In Thailand, the B2 Bed with the earliest *Armenina* and *Pseudodoliolina* is known to be of Kubergandian age. The B1 Bed bears the transitional fusulinid assemblage (Toriyama 1975).

These data show that the general change in the fusulinid assemblages at the boundary between the lower and upper Permian subsystems occurs everywhere in the Tethys and makes this boundary easily traceable. In contrast, in the East European and Boreal basins outside the Tethys, the boundary is characterized by the complete extinction of fusulinids, which makes this level extremely significant. The extinction happened at the end of the Kungurian, i. e., at the Early/Late Permian boundary of the traditional East European scale. The similar position of this boundary in the Tethys and East Europe is proved by ammonoid and conodont records (Leonova & Dmitriev 1989; Kozur 1995, 1998; Kozur et al. 1994).

Correlation between the sections of the Tethys and the western North America is hampered by the endemism of fusulinid assemblages. According to the draft of the Global Chronostratigraphic Scale (Jin et al. 1997), the boundary under discussion corresponds to the lower boundary of the Roadian Stage of the Guadalupian Series (Fig. 3). The correlation is mainly based on ammonoid records.

The ammonoids *Epiglyphioceras, Stacheoceras*, and *Paraceltites*, typical of the Roadian Stage of North America, were found in the basal beds of the Kubergandian stratotype in the SE Pamirs (Chedija et al. 1986). Bolorian ammonoids and conodonts are similar to those of the Cathedralian Stage preceding the Roadian Stage (Leonova & Dmitriev 1989; Kozur 1995). According to the Chinese data, however, the conodont species *Jinogondolella nankingensis*, whose first occurrence defines the lower boundary of the Roadian Stage and the Guadalupian Series, has not been found below the Bed 46 of the Luodian section (the Guizhou Province), i.e., the upper third of the Murgabian Stage (Henderson et al. 1999). According to Kozur (1998), the Roadian conodonts were found together with the Kubergandian fusulinids in the Bed 25 of the Luodian section, i.e., 150 m downsection.

The discrepancies in the position of the Cisuralian/Guadalupian series boundary and its correspondence to the Cisuralian/Tethysian subsystem boundary have not been explained yet (for details see Leven 2001). It should only be noted that to place the boundary between the series or the subsystems inside the Murgabian Stage, as it was suggested by Henderson and his Chinese colleagues (Henderson et al. 1999), is quite unacceptable in terms of fusulinid evolution. Furthermore, in this case, the Cisuralian Series (Subsystem) and its upper stage extremely increase in scope. Before these discrepancies are settled, it seems undesirable to call Guadalupian the series comprising the Kubergandian, Murgabian and Midian stages of the Tethyan scale.

In spite of the essential changes in the fusulinid assemblages at the Uralian/Darvasian series boundary of the Cisuralian Subsystem, its position is still difficult to define accurately. Because the changes were not simultaneous, the question arises as to what formal criteria should be chosen to fix the boundary. In the Tethyan sections, it is more convenient to draw the boundary at the almost simultaneous appearance of the genera *Pamirina* and *Chalaroschwagerina*. The boundary, so defined, coincides with the base of the Yakhtashian Stage (Leven

1982) and can be easily followed from the Carnic Alps in the west (Forke 1995) to Japan in the east (Guidebook 1990; Ueno 1996). The change from the Sakmarian fusulinid assemblage to that of the Yakhtashian one is best pronounced in the South China sections, where it marks the boundary between the regional Zisongian and Longlinian stages (Shen & Jin 1994). The former regional stage corresponds to the Asselian and Sakmarian stages (i. e., all Uralian Series) and the latter is a younger synonym of the Yakhtashian Stage (Fig. 4).

According to Leonova (Leven et al. 1992), ammonoids from the upper beds of the Yakhtashian stratotype section are similar to late Artinskian forms. The early Artinskian conodont *Sweetognathus whitei* occurs in some Chinese sections almost at the same level as the earliest *Pamirina*. All these data suggest that the Yakhtashian Stage approximately corresponds to the Artinskian Stage and, subsequently, the boundary between the Uralian and Darvasian series of the Cisuralian Subsystem may be coincident with that between the Sakmarian and Artinskian stages of the traditional East European scale. However, there are some data contradicting this conclusion. For example, *S. whitei*, whose first occurrence is suggested to be a marker of the lower Artinskian boundary, was found in the Upper Pseudoschwagerina Limestone of the Carnic Alps in association with Sakmarian fusulinids (Forke 1995). This species was also recorded in the Lenox Hills Formation (North America, Texas) (Wardlaw & Davydov 2000), which is usually correlated to the Sakmarian Stage of the Urals on the basis of fusulinids and ammonoids (Rauzer-Chernousova 1965; Furnish 1973). So, the problem of extending the Uralian – Darvasian boundary outside the Tethys remains open.

There is no problem about the boundary between the Yangsingian and Lopingian series because it is characterized by the catastrophic extinction of fusulinids and many other marine organisms in late Midian time (Jin 1993). The GSSP of this boundary was established at the base of the conodont *Clarkina postbitteri postbitteri* Zone (Jin et al. 2003). In the East European scale, the boundary position is still uncertain. According to paleomagnetic records, it lies inside the upper substage of the Tatarian stage (Burov 1996). In the North American scale it coincides approximately with the top of the Capitanian Stage (Henderson et al. 2000).

Stages and their boundaries

All stages of the Tethyan scale, except for the two upper ones, can be recognized by means of fusulinids. The Asselian and Sakmarian stages are established on the basis of the entire fusulinid assemblages, whereas the rest correspond to successive parts of the phylogenetic lines *Pamirina-Misellina-Cancellina-Neoschwagerina-Yabeina* and *Cancellina-Presumatrina-Afghanella-Sumatrina* (Fig. 5-7).

The Asselian Stage is characterized by the a fusulinid assemblage similar to that of the South Ural Asselian type sections. The loosely coiled forms, such as *Sphaeroschwagerina, Pseudoschwagerina, Zellia, Robustoschwagerina*, and others are typical and abundant. *Quasifusulina, Rugosofusulina, Dutkevitchia, Kahlerella, Pseudofusulinoides,* and *Pseudofusulina* are also frequent. Though varying, this assemblage is persistent throughout the Tethyan region and, consequently, the Asselian Stage can be readily recognized everywhere from the Alps in the west to Japan and Indo-China in the east.

It is difficult to separate locally the Sakmarian Stage from the Asselian Stage because of the similarity of their fusulinid assemblages. They are combined into the Zisongian Stage in the latest Chinese schemes (Shen & Jin 1994). However, accurate analysis reveals even generic distinctions between the Asselian and Sakmarian fusulinid assemblages. For instance, although the Sakmarian assemblage inherits all the Asselian genera listed above, their proportion is changed: *Quasifusulina, Sphaeroschwagerina, Pseudoschwagerina, Dutkevitchia* became less frequent, whereas *Robustoschwagerina, Paraschwagerina, Zellia* increase in abundance.

The newly appeared genera *Darvasites, Eoparafusulina, Monodiexodina*, as well as *Acervoschwagerina* were widespread. Still frequent *Rugosofusulina* (s.l.) and *Pseudofusulina* (s.l.) had essentially renewed species composition. These features allow the confident recognition of the Sakmarian Stage, although its boundary with the Asselian Stage is indistinct, particularly in the South Ural type sections (Wardlaw et al. 1999).

The Yakhtashian Stage is the lower unit of the Darvasian Series of the Cisuralian Subsystem. The Yakhtashian fusulinid assemblage is quite different from that of the Sakmarian one because the post-Sakmarian extinction resulted in the disappearance, or less diminished abundance, of many characteristic Asselian-Sakmarian genera, such as *Dutkevitchia, Sphaeroschwagerina, Pseudoschwagerina, Zellia, Paraschwagerina*, and others. They were replaced by the characteristic Yakhtashian and Bolorian genera, such as *Pamirina, Pseudoreichelina, Mesoschubertella, Toriyamaia, Chalaroschwagerina, Darvasella, Leeina* and *Praeskinnerella*. There are still many *Darvasites*, which, however, have more massive and wide chomata, resembling *Nagatoella*.

The deposits of the suggested Yakhtashian Stage characterized by this fusulinid assemblage are widespread in Turkey, Afghanistan, Darvaz, Pamirs and Karakorum (Leven 1967, 1982, 1995, 1997; Leven et al. 1992; Gaetani et al. 1995). In China, they characterize the Longlinian Stage (Shen & Jin 1994). The Yakhtashian Stage was established in the Akiyoshi section of Japan (Guidebook 1990; Ueno 1995). The characteristic fusulinid assemblage was found in Thailand (Sakagami & Iwai 1974).

The lower boundary of the Yakhtashian Stage was discussed above, when considering the boundaries of the

Cisuralian series. It needs to be more clearly defined, but at present it may be drawn by the almost synchronous appearances of *Pamirina*, the subgenus *P. (Levenella)* and *Chalaroschwagerina*. According to the ammonoid and conodont data, the Yakhtashian Stage approximates in scope to the Artinskian Stage of the East European scale. Comparative biogeographic analysis of the Tethyan and Uralian fusulinid assemblages can neither confirm nor reject this inference. Because some Yakhtashian elements (*Chalaroschwagerina, Praeskinnerella*) were found in the West Texas sections, the stage may be correlative to the Lenoxian Stage (or its upper half) and the lowermost part of the Hessian Stage. The correlation is supported by the conodont data (Wardlaw & Davydov 2000), but is in disagreement with the ammonoid records, which indicate the equivalence of the Lenoxian and Sakmarian stages (Bogoslovskaya in Kotlyar et al. 1987).

The fusulinid assemblage of the Bolorian Stage is generally similar to that of the Yakhtashian Stage in the generic composition, but differs at the species level. The main distinctive feature is the appearance and wide distribution of the earliest primitive higher fusulinids of the order Neoschwagerinida, which was represented at first by the subgenus *Brevaxina* and later by the subgenus *Misellina* of the genus *Misellina*. The rapid divergence of *Brevaxina* from the ancestor genus *Pamirina* is fixed in many sections, which makes the Yakhtashian/Bolorian boundary, which is defined by this event, easily and unambiguously recognizable and traceable throughout the Tethys. The occurrence of *Brevaxina* and primitive *Misellina* in association with the Yakhtashian-Bolorian genera *Mesoschubertella, Toriyamaia, Chalaroschwagerina, Darvasites, Leeina*, and *Praeskinnerella* and first *Skinnerella* provided the basis for establishing the Bolorian Stage in many sections, from the Transcaucasia and Iran in the west to Japan and Indo-China in the east. In China, the Bolorian Stage corresponds to the lower part of the Luodianian Stage (the *Brevaxina dyhrenfurthi* and *Misellina termieri* zones) (Sheng & Jin 1994).

The endemism of the Bolorian fusulinid assemblage prevents the identification of the stage outside the Tethys. Based on ammonoid and conodont data and the position in the section, the Bolorian stage is usually correlated to the Kungurian Stage of the East European scale and to the Cathedralian Stage of the North American scale (Leonova & Dmitriev 1989; Kozur 1995, 1998; Kozur et al. 1994). However, this correlation is still unreliable.

The fusulinid assemblage of the Kubergandian Stage sharply differs in taxonomical composition from the Bolorian assemblage. The differences were already discussed above in the sections dealing with the evolutionary stages of fusulinids and the boundaries of the Permian subsystems and there is no need to return to the problem. It should be only noted that the fusulinid assemblage of the lower zone (the *Armenina-Misellina ovalis* Zone) of the stage is similar to the Bolorian assemblage by the presence of the diverse *Misellina*. For this reason, some specialists, particularly the Chinese researchers, combined the deposits corresponding to the Bolorian Stage and the *Armenina-M. ovalis* Zone into a single stratigraphic unit, e.g., the Luodianian Stage (Sheng & Jin 1994). However, in the *Armenina-M. ovalis* Zone the genus *Misellina* is represented by more highly developed species than those of the Bolorian ones. In addition, this zone is characterized by the first occurrence of *Armenina, Pseudodoliolina, Yangchienia*, and *Neofusulinella* which are widespread in the Yangsingian Series. Most part of the Yakhtashian-Bolorian taxa did not cross the lower boundary of the zone, not only in the type sections of the Kubergandinian Stage in the Pamirs (Chedija et al. 1986; Leven 1981b), but also in the complete sections of South China, where the assemblage renewal occurred at the base or inside the *Misellina claudiae*, or *M. ovalis* Zone (Xiao et al. 1986; Zhou et al. 1987).

The deposits bearing the Kubergandian fusulinid assemblage were recognized in numerous sections from the Mediterranean in the west to Japan and Indo-China in the east. There is no direct evidence providing the correlation of the Kubergandian Stage to the East European units. We can conventionally correlate only the lower boundaries of the Kubergandian and Ufimian stages. The problem of correspondence between the lower boundary of the former stage with the Guadalupian base was considered above.

The fusulinid assemblage of the Murgabian Stage shows its close similarity to the Kubergandian assemblage. The diversification of the order *Neoschwagerinida* resulted in the development of the families Sumatrinidae (the genera *Presumatrina, Afghanella, Sumatrina* rapidly succeeding each other) and Verbeekinidae (the genus *Verbeekina*), as well as the subfamily Lepidolininae (the genera *Gifuella* and *Colania*). The Kubergandian genera *Yangchienia, Chusenella, Skinnerella, Eopolydiexodina* became widespread; the latter genus was represented by the subgenus *E. (Eopolydiexodina)*. The orders Schubertellida and Staffellida show increased diversity.

By definition, the lower boundary of the stage is drawn at the first occurrence of *Neoschwagerina, Presumatrina*, and *Verbeekina* at the base of the *N. simplex* Zone. This level seems to be more significant and suitable for establishing the stage boundary than the level of the *Cancellina* appearance below, as suggested in some Chinese publications (Shen & Jin 1994; Zhu & Zhang 1994).

The Murgabian Stage and its lower boundary are easily traceable throughout the Tethyan region from the Mediterranean to Indo-China. It is still impossible to directly correlate the stage to the units of the East European scale. The correlation to the North American scale is ambiguous due to the differences in dating of the conodont assemblages, as stated above (Kozur 1998; Henderson et al. 1999; Leven 2001).

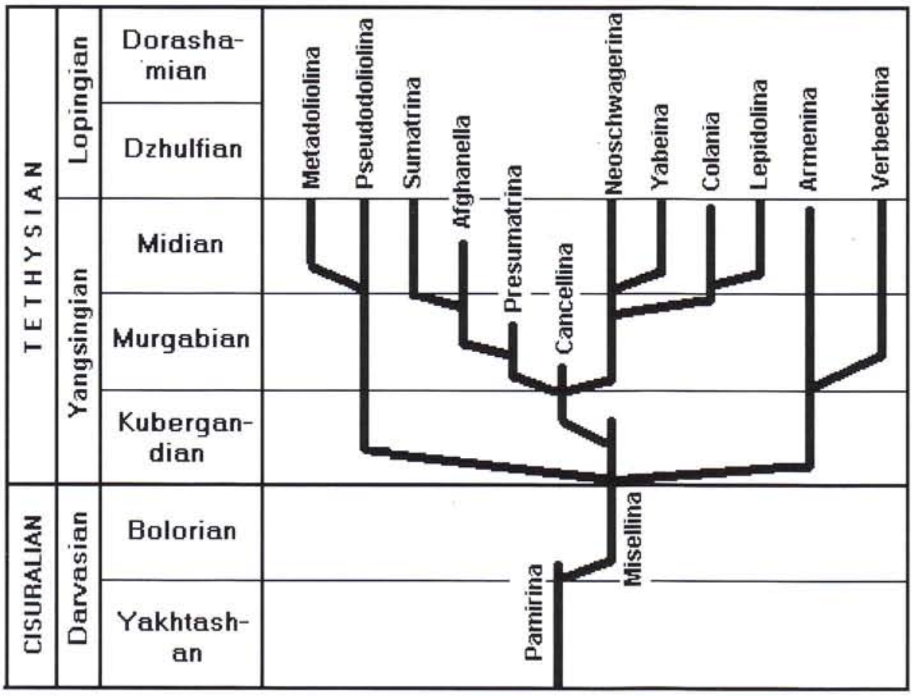

Fig. 7 - Phylogeny of the order *Neoschwagerinida*.

The Midian Stage corresponds to the third peak of the generic diversity of fusulinids (Fig. 1). The Midian Age is characterized by the diversification of the order Neoschwagerinida represented by the highly developed taxa that terminate the phylogenetic lines of the families Neoschwagerinidae, Sumatrinidae, Verbeekinidae and Pseudodoloilinidae. Among these taxa are the newly appeared genera *Yabeina* and *Lepidolina*. The order Schwagerinida shows the increased abundance of the subfamily Chusenellinae, which includes the newly appeared peculiar genus *Orientoschwagerina* and *Rugososchwagerina*. In the Midian Age, the orders Schubertellida, Staffellida, and Ozawainellida reached their highest development. Their characteristic representatives are the newly appeared genera *Latschichites, Paradoxiella, Eoverbeekina, Reichelina*, and *Rauserella*. The family Kahlerinidae of uncertain origin appeared and spread widely.

By definition, the lower boundary of the Midian Stage is drawn at the first occurrences of the genera *Yabeina* and *Lepidolina*. Because the index-genera are confined mainly to the eastern Tethys, it is difficult to recognize the boundary outside this region. In other regions, the boundary is defined by many factors and therefore it is indistinct (Leven 1996). Undoubtedly, the boundary and the criteria of its recognition need to be further specified.

With some assumptions concerning the lower boundary, the Midian Stage can be confidently recognized all over the Tethyan region. It corresponds approximately to the Lengwuan Stage of the Chinese scale (Shen & Jin 1994). Its lower boundary lies near the boundary between the Kiama and Illawarra paleomagnetic hyperzones (Jin et al. 2000). In the East European sections, the latter boundary occurs inside the Tatarian Stage and, hence, the Midian Stage corresponds to the lower part of the Upper Tatarian Substage. This stage or only its larger upper part is correlative to the Capitanian Stage of the North American scale, as suggested by the co-occurrence of the conodont *Jinogondolella postserrata*, which defines the lower boundary of the Capitanian Stage, and the Midian fusulinids in the upper part of the Maokou Limestones of China (Mei et al. 1998). The Lamar Limestone of the upper Capitan Formation of Texas contains the typical Midian fusulinids *Yabeina, Reichelina* and *Paradoxiella* (Skinner & Wilde 1955).

The fusulinid assemblage of the Dzhulfian Stage is considerably poorer than the Midian assemblage because the representatives of the orders Schwagerinida and Neoschwagerinida, as well as the families Yagchieniidae, Schubertellidae and Kahlerinidae, became extinct in late Midian time. In contrast, the diversity of the families Boultoniidae and Palaeofusulinidae increases, by due to the appearance of the highly developed genera *Gallowaiinella, Tewoella, Paradunbarula*, and *Palaeofusulina*. Up to recently, three of the genera listed were considered characteristic of the Dorashamian Stage, but they were found in the deposits corresponding to the lower Dzhulfian Stage in South China (Zhu 1996).

The lower Dzhulfian boundary (or the Yangsingian/Lopingian boundary), substantiated well by fusulinids, is being defined by the conodont data (Henderson et al. 2000). The GSSP of this boundary is suggested to be placed at the base of the Wuchiapingian Stage of the Penglaintan section of South China (Henderson et al. 2000). According to the latest data (Sweet & Mei 1999) this boundary lies at the base of the Ali Bashi Formation of the

Kuh-e-Ali Bashi section of northwestern Iran. This level corresponds to the lower part of the beds with *Reichelina-Codonofusiella* of the Transcaucasia (Leven 1998) and Central Iran (Iranian-Japanese Research Group, 1981). The boundary under consideration coincides with the top of the Capitanian Stage of the North American scale.

The Dorashamian Stage is not characterized by distinct fusulinid assemblage. The most characteristic genera are *Palaeofusulina, Nanlingella, Parananlinhella, Paradunbarula, Gallowaiinella*, and *Tewoella*, as well as *Nankinella, Sphaerulina, Staffella, Reichelina* and *Parareichelina*. Of the genera listed, only scarce *Parananlingella* and *Parareichelina* have not yet been found in the Dzhulfian Stage. For this reason, the Dzhulfian and Dorashamian stages cannot be sharply differentiated on the base of fusulinids, as it is done when by using the conodont and, partly, the ammonoid data (Jin et al. 1997).

The Dorashamian fusulinid assemblage was found in the Changhsingian Stage of South China, which fully corresponds to the Dorashamian Stage, and in the Nikitin and Urushten Formations of the North Caucasus (Kotlyar et al. 1983). Based on the conodont data, the Dorashamian Stage is recognized in the Transcaucasia (Kozur et al. 1978) and in northwestern and central Iran (Sweet & Mei 1999; Kozur et al. 1975). Discrete occurrences of fusulinids and conodonts indicate the presence of the Dorashamian deposits in Greece, Turkey, Pamirs, Salt Range and Japan. This stage has not yet been established outside the Tethyan region.

Conclusions

(1) The suggested Permian stratigraphic scale for the Tethys, which incorporates 2 subsystems, 4 series and 9 stages, is most adequate to the stages of the fusulinid evolution. In its turn, the fusulinid evolution reflects the history of the basin and marine biota. The main historical events were the extensive sea transgressions and regressions, which resulted in the increase and decrease in taxonomic diversity, respectively.

(2) Analysis of macrofauna of the Boreal region (Ganelin et al. 2002) supports the subdivision of the Permian System into two subsystems and four series. It shows the global character of the trends, on which the suggested Tethyan scale is based.

(3) The recently accepted three-member Global Chronostratigraphic Scale is not in agreement with these trends. The natural-historical principle was to a great extent substituted by the formal fixation of boundaries by the occurrence of successive conodont species of one phylogenetic line. This results in a disproportion among the stratigraphic scopes of the series, and in difficulties in tracing some boundaries, especially those of the Guadalupian Series and its stages.

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