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Peri-Tethys : stratigraphic correlations 2

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Peri-Tethys Programme

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Introduction

Le Programme international Péri-Téthys mène ses travaux en étroite connexion avec ceux développés dans le cadre du PICG Projet n° 343 « Stratigraphic correlation of Peri-Tethyan epicratonic basins » (1993-1996). Les résultats obtenus sur le Carbonifère supérieur-Permien inférieur sont particulièrement remarquables. Le présent volume est la synthèse de ces données, coordonnées par Alain Izart (Université de Nancy) et Denis Vaslet (BRGM, Orléans).

Il compile les découvertes les plus récentes avec les données précédemment acquises et propose des corrélations stratigraphiques entre la plate-forme Nord péri-téthysienne [bassins ouest européens (France, Allemagne, Grande-Bretagne, Pays-Bas), bassins d'Europe de l'Est (Pologne, République tchèque, Slovaquie), CEI (Russie, Ukraine, Kazakhstan), Turquie], le domaine Téthysien [Espagne, Italie, Autriche, Iran] et la plate-forme Sud péri-téthysienne [Afrique du Nord (Algérie, Maroc, Tunisie), Moyen-Orient (Égypte, Syrie), Arabie (Arabie Saoudite, Oman) et enfin Pakistan].

Ce volume s'intègre dans la série des publications du Programme international Péri-Téthys :

Roure F. (ed.) 1994. — *Peri-Tethyan Platforms: Proceeding of the IFP Peri-Tethys Research Conference held in Arles, France, March 23, 1993.* Technip, Paris, 275 p.

Ziegler P. A. & Horwath F. 1996. — Peri-Tethys Memoir 2 : Structure and prospects of Alpine Basins and Forelands. *Mémoires du Muséum national d'Histoire naturelle,* Paris 170, 547 p.

Crasquin-Soleau S. & De Wever P. 1997. — Peri-Tethys : stratigraphic correlations 1. *Geodiversitas,* 19 (2) : 169-499.

Crasquin-Soleau S. & Barrier É. 1998. — Peri-Tethys Memoir 3 : Stratigraphy and evolution of Peri-Tethyan Platforms. *Mémoires du Muséum national d'Histoire naturelle,* Paris, 177, 262 p.

Crasquin-Soleau S. & Barrier É. 1998. — Peri-Tethys Memoir 4 : Epicratonic basins of Peri-Tethyan margins. *Mémoires du Muséum national d'Histoire naturelle,* Paris, 179, 294 p.

The International Peri-Tethys Programme carries on its works in close relationship with the IGCP project No. 343 "Stratigraphic correlation of Peri-Tethyan epicratonic basins" (1993-1996). The results obtained on the Late Carboniferous-Early Permian are particularly outstanding pieces of work. This volume is a synthesis of these data co-ordinated by Alain Izart (Université de Nancy) et Denis Vaslet (BRGM, Orléans).

It compiles the most recent discoveries with data previously established and introduce stratigraphic correlations between Peri-Tethyan Northern platform [western European basins (France, Germany, Great Britain, Netherlands), eastern European basins (Poland, Czech Republic, Slovak Republic), CIS (Russia, Ukraine, Kazahkstan), Turkey], Tethys domain (Spain, Italy, Austria, Iran) et Peri-Tethyan Southern platform [North Africa (Algeria, Morocco, Tunisia), Middle east (Egypt, Syria), Arabia (Saudi Arabia, Oman) and Pakistan].

This volume fits within publications of the Peri-Tethys Programme.

Roure F. (ed.) 1994. — *Peri-Tethyan Platforms: Proceeding of the IFP Peri-Tethys Research Conference held in Arles, France, March 23, 1993.* Technip, Paris, 275 p.

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We want to express our gratefulness to:

– the Muséum national d'Histoire naturelle which

Nous tenons à exprimer notre gratitude :
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– l'équipe de cartographie du Programme Péri-Téthys (Bruno Vrielynck, CNRS et Christophe Turcq, UPMC, Paris) pour leur aide dans la finalisation de certains documents ;
– les scientifiques ayant assuré les rapports sur les différents articles (J. F. Becq-Giraudon, BRGM, Orléans ; J. Broutin, UPMC, Paris ; J. Clermonté, Université H.-Poincaré, Nancy ; D. Massa, Suresnes ; I. D. Somerville, University College, Dublin, Irlande ; D. Vachard, USTL, Lille ; G. B. Vai, Université de Bologne, Italie).

give us the opportunity to publish this second thematic volume in Geodiversitas*;*
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Sylvie Crasquin-Soleau and Patrick De Wever

Stratigraphic correlations between the continental and marine Tethyan and Peri-Tethyan basins during the Late Carboniferous and the Early Permian

Alain IZART [1], Denis VASLET [2], Céline BRIAND [1], Jean BROUTIN [3], Robert COQUEL [4], Vladimir DAVYDOV [5], Martin DONSIMONI [2], Mohammed El WARTITI [6], Talgat ENSEPBAEV [7], Mark GELUK [8], Nathalya GOREVA [9], Naci GÖRÜR [10], Nayyer IQBAL [11], Geroi JOLTAEV [7], Olga KOSSOVAYA [12], Karl KRAINER [13], Jean-Pierre LAVEINE [4], Maria MAKHLINA [14], Alexander MASLO [15], Tamara NEMIROVSKAYA [15], Mahmoud KORA [16], Raissa KOZITSKAYA [15], Dominique MASSA [17], Daniel MERCIER [18], Olivier MONOD [19], Stanislav OPLUSTIL [20], Jörg SCHNEIDER [21], Hans SCHÖNLAUB [22], Alexander STSCHEGOLEV [15], Peter SÜSS [23], Daniel VACHARD [4], Gian Battista VAI [24], Anna VOZAROVA [25], Tuvia WEISSBROD [26], Albin ZDANOWSKI [27]
(see appendix 2 for addresses)

343 IUGS UNESCO IGCP

Izart A. *et al.* 1998. — Stratigraphic correlations between the continental and marine Tethyan and Peri-Tethyan basins during the Late Carboniferous and the Early Permian, *in* Crasquin-Soleau S., Izart A., Vaslet D. & De Wever P. (eds), Peri-Tethys: stratigraphic correlations 2, *Geodiversitas* 20 (4) : 521-595.

ABSTRACT

The compilation of detailed stratigraphic, sedimentologic and paleontologic data resulted in stratigraphic correlations of marine and continental areas outcropping today in the Tethyan and Peri-Tethyan domains: (1) the base of the Moscovian would correspond to the base of the Westphalian C in the Peri-Tethyan domain and to the base of the Westphalian B in the Tethyan domain; (2) the Kasimovian, the Gzhelian and the Orenburgian would correspond in the northern Peri-Tethyan domain and Tethyan domain (Carnic Alps) respectively to the early Stephanian, the late Stephanian and the Autunian *p.p.*, in the southern Peri-Tethyan domain to an undifferentiated time interval. The boundary between the Stephanian and the Autunian was recognized in the Donets Basin with some doubts; (3) the Asselian, Sakmarian, Artinskian and Kungurian would correspond in all the domains to the Autunian *p.p.* and the Saxonian that remain difficult to separate.

KEY WORDS
Peri-Tethys, biostratigraphy, Carboniferous, Permian, Tethys, stratigraphic correlations.

RÉSUMÉ
Corrélations stratigraphiques dans les bassins téthysiens et péri-téthysiens au Carbonifère supérieur et au Permien inférieur. Des corrélations sont proposées entre les domaines marins et continentaux du Paléozoïque supérieur affleurant aujourd'hui dans le domaine téthysien et sur les plate-formes qui le bordent au nord et au sud: (1) la base du Moscovien correspondrait dans le domaine péri-téthysien à la base du Westphalien C et dans le domaine téthysien à la base du Westphalien B ; (2) le Kasimovien, le Gzhélien et l'Orenburgien correspondraient dans le domaine nord péri-téthysien et dans le domaine téthysien (Alpes carniques) respectivement au Stéphanien inférieur, supérieur et Autunien *p.p.*, dans le domaine sud péri-téthysien à un intervalle de temps indifférencié, la correspondance n'étant pas établie précisément. La limite entre le Stéphanien et l'Autunien a été reconnue dans le bassin du Donetz avec incertitudes ; (3) l'Assélien, le Sakmarien, l'Artinskien, le Kungurien correspondraient dans tous les domaines à l'Autunien *p.p.* et au Saxonien, qui restent difficile à différencier.

MOTS CLÉS
Péri-Téthys, biostratigraphie, Carbonifère, Permien, Téthys, corrélations stratigraphiques.

INTRODUCTION

In the frame of the IGCP 343, a synthesis of the published and original data from eastern and western Europe, northern Africa and Arabia is presented. Three litho- and chronostratigraphic cross-sections (location Fig. 1) show the results in three domains outcropping nowadays in the northern Peri-Tethyan domain (Fig. 2, Inset Fig. 1), in the Tethyan domain (Fig. 3, Inset Fig. 2) and in the southern Peri-Tethyan domain (Fig. 4, Inset Fig. 3). Biostratigraphic correlations are proposed in the northern Peri-Tethyan domain (Fig. 5) between the marine eastern basins (Russia, Ukraine) and the continental western basins (France, Germany), and are extended to the other domains (Figs 6, 7). Moreover, the latitudinal correlations between the continental basins and the correlations based on the sequence stratigraphy allow to test the climatic, eustatic and tectonic factors. The radiochronologic data chart of Hess & Lippolt (1986) and of Menning (1995) are chosen for the Late Carboniferous and for the Permian respectively.

BIOSTRATIGRAPHIC CORRELATIONS BETWEEN THE MARINE AND CONTINENTAL DOMAINS

Correlations are proposed for the Bashkirian-Moscovian and Namurian-Westphalian time intervals in the northern Peri-Tethyan domain (Fig. 8). Sinitsyn *et al.* (1978), Yablokov *et al.* (1978), Aisenverg *et al.* (1978), Makhlina *et al.* (1979), Solovieva (1985), Solovieva *et al.* (1985a, b), Kagarmanov & Donakova (1990), Izart *et al.* (1996), Izart *et al.* (1998), Makhlina *et al.* (1997), Vachard & Maslo (1996), Einoir *et al.* (1996), Briand *et al.* (1998), Zhamoida (in press), Ensepbaev *et al.* (this volume) described the Carboniferous of the Ural, Moscow, Donets and Precaspian (Kazakhstan) Basins. The Bashkirian and Moscovian show thin and medium bedded limestones in the Moscow and Ural Basins. During this time, the Donets was a paralic basin with thick alternations of fluvial sandstone, paleosol, coal, marine limestone and claystone, deltaic siltstone and sandstone. In eastern Europe, fusulinid, conodont and coral

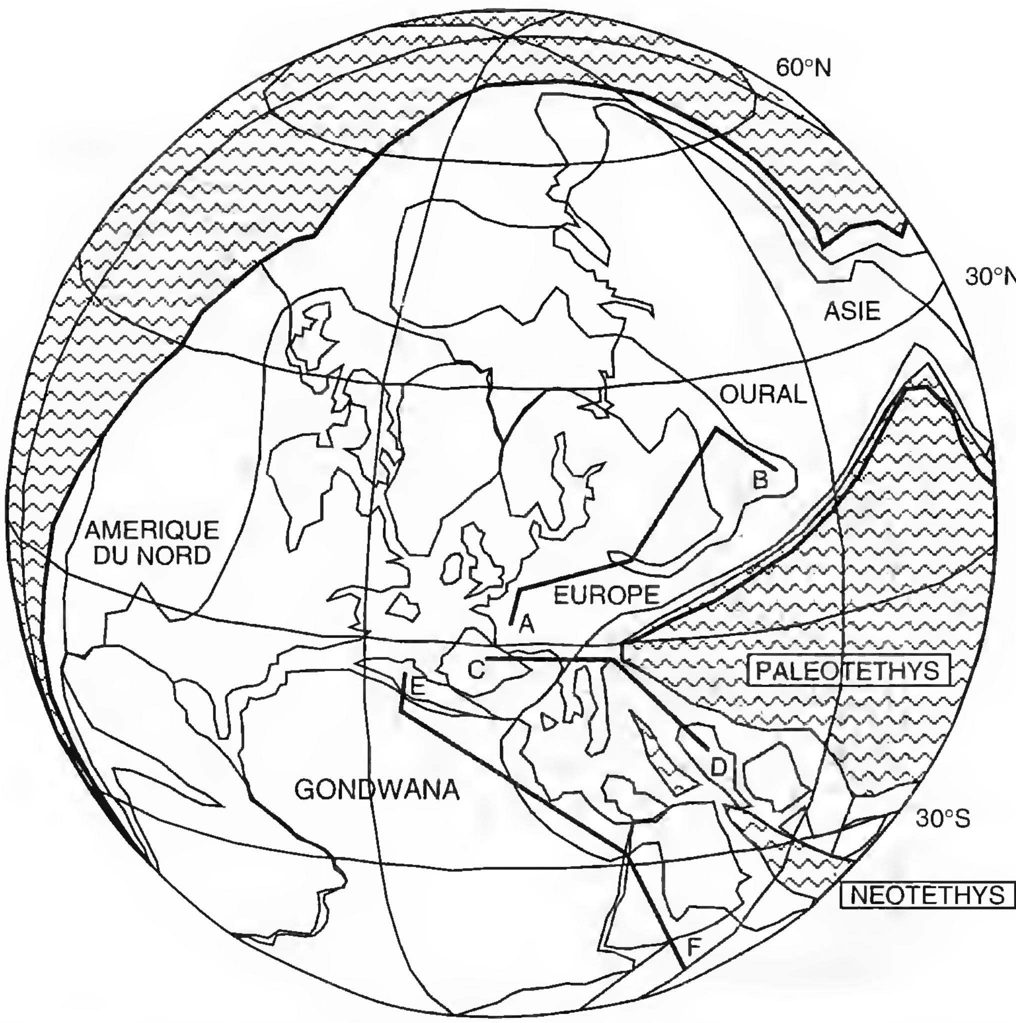

FIG. 1. — Location of cross-sections on the paleogeographic map of the North Hemisphere during the Lower Permian modified after Scotese & Langford (1995). Land in white, shallow sea in stipple, ocean in waves, active plate boundaries in bold lines. **AB**, cross-section of the northern Peri-Tethyan Basins; **CD**, cross-section of the Tethyan Basins; **EF**, cross-section of the southern Peri-Tethyan Basins.

biozones were defined for the Bashkirian, Moscovian, Kasimovian, Gzhelian and marine Early Permian (Fig. 5). See also for the fusulinids, Davydov (1996) and the table in Krainer & Davydov (this volume) and for the corals Kossovaya (1996) and Kossovaya (this volume). In the paralic basins of western Europe, the Namurian and the Westphalian present thick alternations of fluvial sandstone, paleosol, coal, marine, lagoonal and lacustrine claystone, deltaic siltstone and sandstone. The flora allows to define a biostratigraphy and a chronostratigraphy framework (Fig. 5). The distribution of flora for the North France coal basin (Laveine 1987) and microflora for western Europe (Clayton *et al.* 1977) are presented for the Namurian and Westphalian. The basins of Lorraine (Donsimoni 1981), the Netherlands (Geluk), the Ruhr (Fiebig 1969; Josten 1991), Poland (Zdanowski & Zakowa 1995), the Czech (Oplustil & Pesek this volume) and Slovak (Vozarova this volume) Republics, the Caucasus (Chernyavsky *et al.*

AGE (Ma)	Continental STAGES	FRANCE	GERMANY	DONETS	MOSCOW	URAL	Marine STAGES	
274–277	Saxonian					Irensk Philippovsk	Kungurian	LOWER PERMIAN
277–283			SAALE Hornburg			Saraninsk Sarginsk Irginsk Burtsevsk	Artinskian	
283–290		AUTUN Millery Surmoulin		Kramatorsk		Sterlitamak Tastubsk	Sakmarian	
290–296	Autunian	Muse Igornay Epinac	Sennewitz Halle	Slavjansk Nikitovsk Kartamysh	Sokolvesarsk	Shikansk Kholodnolozk	Asselian	
296–300		SAINT-ETIENNE Couronnement Janon	Mansfeld	Mironovsk Kalinovsk	Melekhovo Noginsk Pavlov-Posad Amerevo Rechitsy	Zianchurinsk	Orenburgian	UPPER CARBONIFEROUS
300–302							Gzhelian	
302–305	Stephanian	Gier	Grillenberg	Torezk	Dorogomilovo Khamovnichi Krevyakino	Abzanovsk	Kasimovian	
305–308	Westphalian D	N FRANCE Assise de Bruay	RUHR Ibbenburen	Sanjarovsk Sabovsk	Myachkovo Podolsk	Bolshekynsk	Moscovian	
308–311	Westphalian C		Lembeck Dorsten	Marievsk Kamensk	Kashira Vereia	Kirovsk		
311–313	Westphalian B	A. d'Anzin	Horst Essen	Krasnodonsk	Upper Aza	Asatausk	Bashkirian	
313–315	Westphalian A	A.de Vicoigne	Bochum Witten	Makeevsk Zuevsk		Tashatinsk		
315–317	Namurian C	A. de Flines	Sprockhövel	Blagodatnensk Manullovsk	Lower Aza	Askynbashsk		
317–319	Namurian B		Vorhalle Hagen	Feninsk		Akavask Siuransk		

FIG. 2. — The formations of the northern Peri-Tethyan Basins.

1978) and North Turkey (Zonguldak; Kerey *et al.* 1985; Görur *et al.* 1997) are also considered in this study. The Donets Basin is the only northern Peri-Tethyan Basin, where the correlation between the marine and continental domains has been attempted. In this basin, the

AGE (Ma)	Continental STAGES	SPAIN: PALENCIA	SPAIN: PICOS DE EUROPA	ITALY	CARNIC ALPS	IRAN	Marine STAGES	
274–277	Saxonian						Kungurian	LOWER PERMIAN
277–283					Goggau Tressdorf		Artinskian	
283–290		unnamed			Trogkofel Upper Pseudo-Schwagerina	Dorud	Sakmarian	
290–296	Autunian			Rio Marina	Grenzland		Asselian	
296–300		Villablino Sabero			Lower Pseudo-Schwagerina Carnizza Auernig Corona Pizzul	Gheselghaleh	Orenburgian	UPPER CARBONIFEROUS
300–302	Stephanian						Gzhelian	
302–305		Barruelo	Puentelles	Spirifer			Kasimovian	
305	Cantabrian	Branosera	Gamonedo		Meledis Bombaso			
305–308	Westphalian D	Central ASTURIAS Sama	Picos de Europa	San Antonio			Moscovian	
308–311	Westphalian C	Lena						
311–313	Westphalian B			Carpineta				
313–315	Westphalian A							
315–317	Namurian C	Valdeteja	Valdeteja				Bashkirian	
317–319	Namurian B							

FIG. 3. — The formations of the Tethyan Basins.

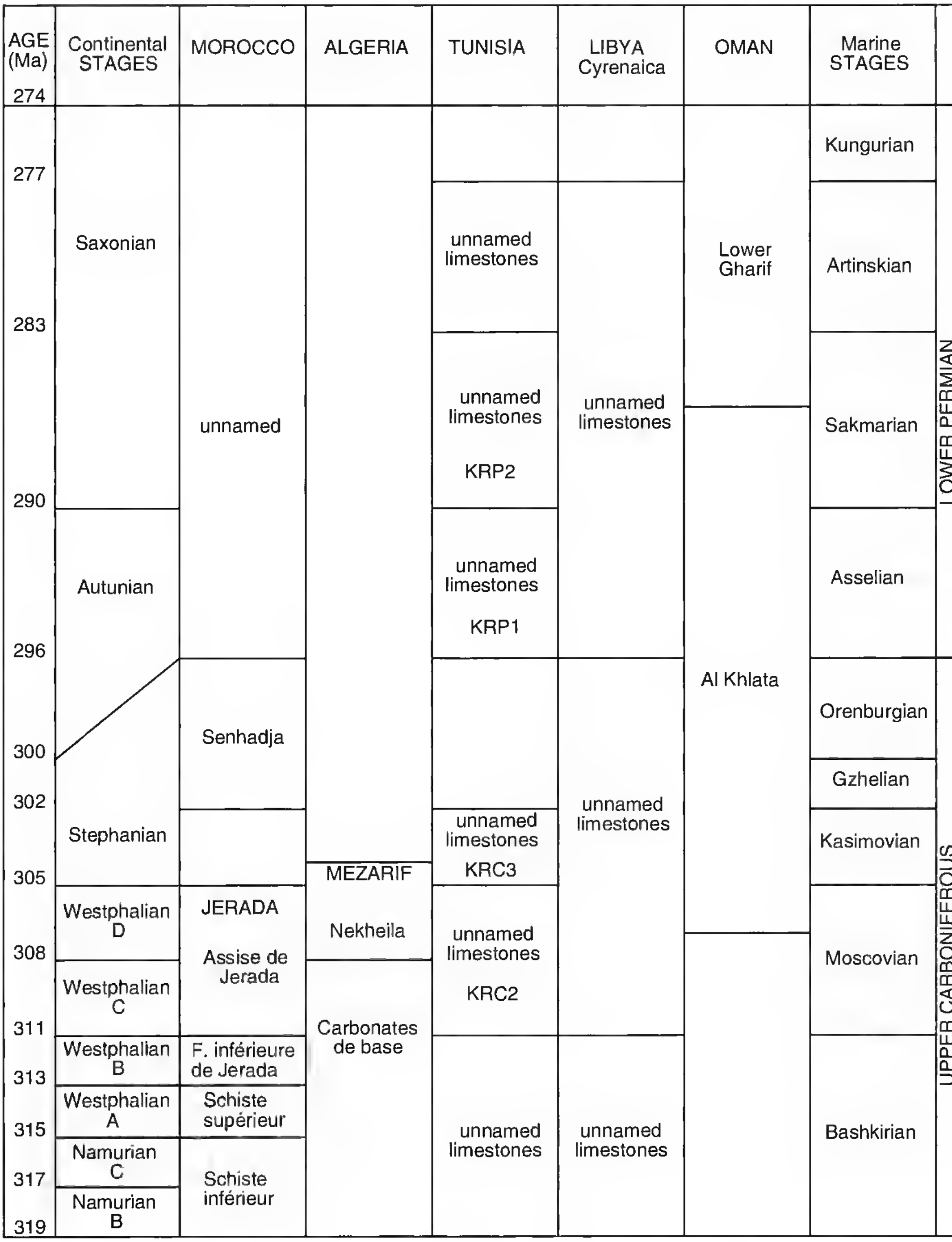

FIG. 4. — The formations of the southern Peri-Tethyan Basins.

flora are closed to western Europe ones (Fissunenko & Laveine 1984), but some differences could be sometimes noted. The microflora presents a local biozonation (Coquel *et al.* 1984). At the boundary between the Westphalian B and C, a disharmony is observed in the appearance of species more precocious or later in the Donets Basin than in western Europe. The base of the Moscovian would be inside the Westphalian B or at the base of the Westphalian C (Fig. 8).

Correlations are proposed for the Kasimovian-Gzhelian-Orenburgian and the Stephanian-Autunian in the northern Peri-Tethyan domain. The Kasimovian, the Gzhelian and the Orenburgian show thin limestones in the Moscow Basin and thick paralic facies in the Donets Basin. The Kasimovian, the Gzhelian and the Orenburgian (Fig. 5) present fusulinid, conodont and coral biozones in the Moscow, Ural and Donets Basins. Davydov (1990, 1992) moved the *Ultradaixina bosbytauensis* biozone from the Asselian to the late Gzhelian. The boundaries of this biozone present an uncertainty, because Davydov defined this biozone in the carbonated marine facies of the pre-Donets Basin in Russia, whereas the Donets Basin in Ukraine shows lagoonal facies without fusulinids. Then, Davydov (1996) put the *Daixina sokensis* and *Ultradaixina bosbytauensis* biozones in the Orenburgian, between the Gzhelian and the Asselian. The boundary between the Carboniferous and the Permian is located at the top of the Orenburgian. The Stephanian, defined in the limnic basin of Saint-Étienne, was subdivided by Doubinger *et al.* (1995) into a early Stephanian (Barruelian) corresponding to the Stephanian A and an late Stephanian (Forezian) corresponding to the Stephanian B and C with a precise biozonation of flora (Fig. 5). The Stephanian presents breccia along the sides of the basin and lacustrine claystone and coal in the center (Becq-Giraudon *et al.* 1995, Mercier this paper). The early Stephanian exhibits hygrophytic Lycophytes and Filicophytes (*Pecopteris* sp., *Astherotheca lamuriana*, Fig. 5) and presents Westphalian affinities. The late Stephanian shows hygrophytic Pteridosperma-phytes and Lycophytes (*Odontopteris* sp., *Pecopteris* sp., *Sphenopteris* sp., *Alethopteris zeilleri*, *Sphenophyllum angustifolium*) and some occurrences of xerophytic plants (*Autunia conferta*, *Lodevia nicklesii*). The biozonation of Clayton *et al.* (1977) applies in Saint-Étienne with some occurrences of xerophytic spores with *Potonieisporites novicus* and *Vittatina* sp. Alternation of hygrophytic and xerophytic floras and microfloras are observed through the late Stephanian in numerous basins (Broutin *et al.* 1986, 1990). The basins of Lorraine (Donsimoni 1981), the Saale (Schneidert & Gebhardt 1993), Poland (Zdanowski, this paper), the Czech (Oplustil this paper) and Slovak (Vozarova this paper) Republics, the Caucasus (Chernyavsky *et al.* 1978) and North Turkey (Kerey *et al.* 1985) are also considered. In the Donets Basin (Fig. 8), the biozonation of flora is local (Boyarina, in press; Izart *et al.* 1998) with some common plants as *Astherotheca lamuriana* in the late Stephanian. There were alternations of hygrophytic and xerophytic flora and microflora (*Lodevia nicklesii*, *Potonieisporites novicus*) in the Orenburgian (Stschegolev *in* Aisenverg *et al.* 1978; Stschegolev & Kozitskaya 1984; Izart *et al.* 1998). The Kasimovian (Fig. 8) would be equivalent to the early Stephanian. The Gzhelian (Fig. 8) would be the equivalent of the late Stephanian, the Orenburgian of the early Autunian *p.p.* if we refer to the appearance of the xerophytic plants, or of the late Stephanian if we refer to the acme of the xerophytic plants. The beginning of the sedimentation in the Stephanian and Autunian Basins that depends on their tectonic opening will be heterochronous in western Europe.

Correlations are proposed between the marine and continental Early Permian in the northern Peri-Tethyan domain. The marine Early Permian was defined in the Ural Basin (Chuvashov 1993). The Asselian, the Sakmarian, the Artinskian Stages have a carbonate facies whereas the Kungurian is evaporitic. Biozones of fusulinids, conodonts and corals were defined (Fig. 8). The new Permian chronostratigraphic subdivisions (Yugan 1996; Yugan *et al.* 1997) were utilized. In the Moscow Basin, the Asselian is carbonated and in the Donets Basin, the Asselian and the Sakmarian exhibit red claystone and evaporites. The Autunian, defined in the limnic basin of Autun (Fig. 5), shows fluvial sandstone and

WESTERN EUROPE (FRANCE - GERMANY)							EASTERN EUROPE (DONETS - MOSCOW - PERM)							
Age (Ma)	Sequences (1)	Goniatites (2)	Flora (3)	Microflora (4)		CONTINENTAL STAGES	Sequences (1)	Flora (5)	Microflora (6)	Foraminifera (7)	Conodonts (8)	Corals (9)	MARINE STAGES	
274							KU			*Nodosaria sexangulata Parafusulina solidissima*			KUNGURIAN	LOWER PERMIAN
										Nodosaria pugioidea				
277	SA						AR			*Hemigordius saranaensis*	*Neostreptognathodus pequoppensis*		ARTINSKIAN	
						SAXONIAN				*Parafusulina solidissima*		*Lophophyllidium sp.*		
										Pseudofusulina juresanensis	*Sweetognathodus whitei*	*Protolonsdaleiastraea juresanensis*		
										Pseudofusulina pedissequa				
283							S3			*Pseudofusulina urdalensis*	*Sweetognathodus primus*	*Protolonsdaleiastraea longiseptata*	SAKMARIAN	
							S2			*Pseudofusulina verneuili* *Pseudofusulina uralica*	*Neogondolella lata*	*P. bisaplata* *Timania schmidti*		
							S1			*Pseudofusulina moelleri*	*Neogondolella uralensis*	*Kleopatrina magnifica*		
290							A3			*Sphaeroschwagerina sphaerica*	*Streptognathodus postfusus*	*Kleopatrina pseudoelegans*	ASSELIAN	
	AU		*Autunia conferta* *Rhachiphyllum schenkii*	*Disaccites striatiti* *Potonieisporites spp.* *Vittatina spp.*	DS	AUTUNIAN	A2	*Autunia conferta*	*Potonieisporites "novicus-bhardwajii"* *Vittatina spp.*	*Sphaeroschwagerina moelleri*	*Streptognathodus fusus* *Streptognathodus constrictus*	*Tschussovskenia caespitosa*		
							A1			*Sphaeroschwagerina fusiformis*	*Streptognathodus cristellaris*	*Ferganophyllum uralicum*		
296														

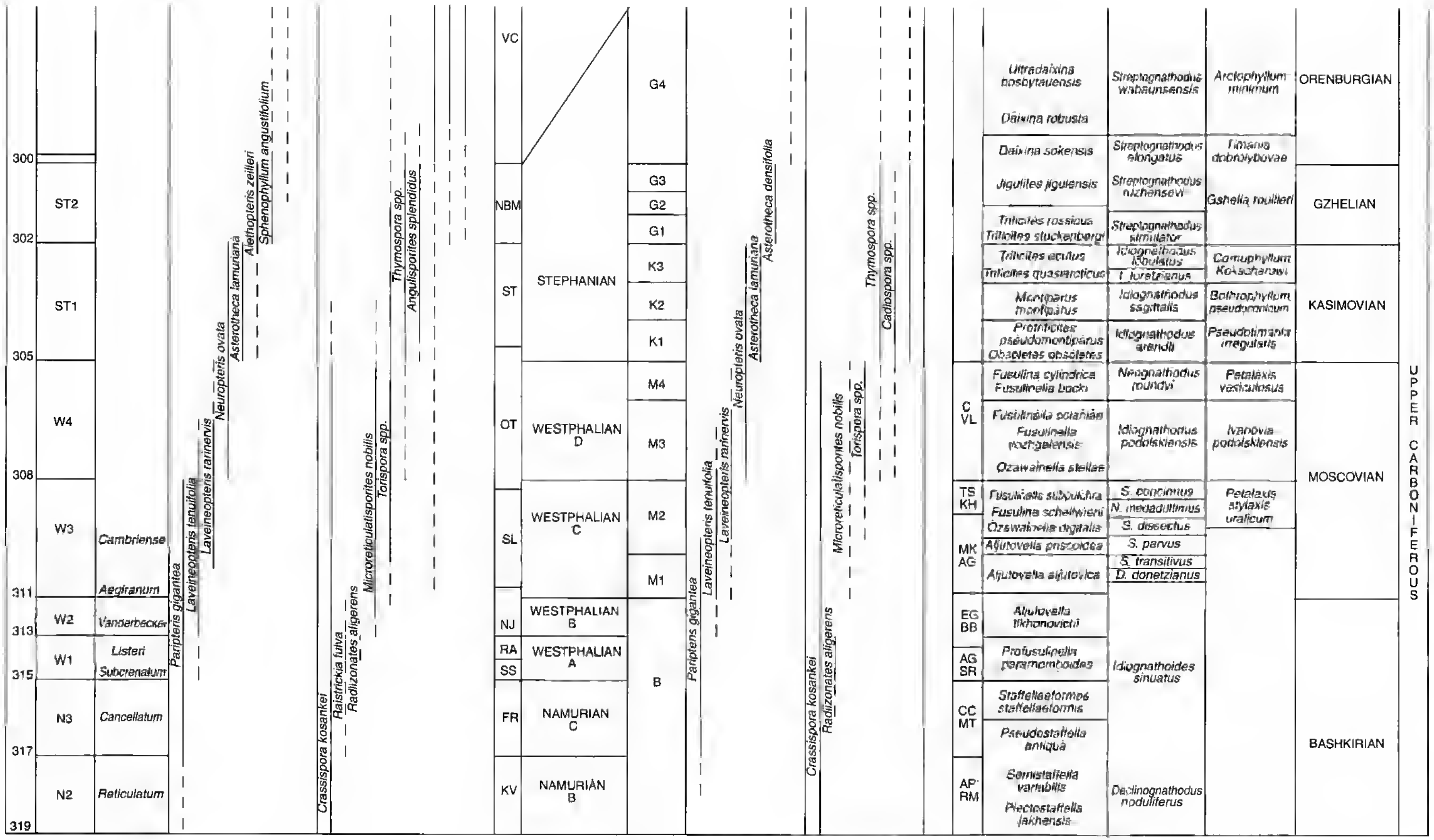

FIG. 5. — Biostratigraphy and chronostratigraphy of the northern Peri-Tethyan Basins. 1, Izart (this paper); 2, Bouroz *et al.* (1978); 3, Laveine (1987), Broutin (this paper); 4, Clayton *et al.* (1977), Coquel & Broutin (this paper); 5, Fissunenko & Laveine (1984), Stschegolev & Broutin (this paper); 6, Coquel *et al.* (1984), Inosova *et al.* (1976), Broutin (this paper); 7, Solovieva *et al.* (1985a, b), Davydov (1990, 1992), Chuvashov (1993), Vachard & Maslo (this paper); 8, Alekseev, Goreva, Kozitskaya & Nemirovskaya (this paper); 9, Kossovaya (this paper).

SPAIN (PALENCIA-CENTRAL ASTURIAS)							SPAIN (PICOS DE EUROPA)			CARNIC ALPS				
Age (Ma)	Sequences (1)	Flora (2)	Microflora (3)	CONTINENTAL STAGES	Foraminifera (4)	MARINE STAGES	Sequences (1)	Foraminifera (5)	MARINE STAGES	Sequences (1)	Foraminifera (6)	Flora (7)	MARINE STAGES	
274													KUNGURIAN	LOWER PERMIAN
277	SA			SAXONIAN										
											Schwagerina vulgaris			
											Praeparafusulina lutugini		ARTINSKIAN	
283														
											Paraschwagerina inflata			
										S				
											Schwagerina moelleri		SAKMARIAN	
290														
	AU	*Autunia conferta*		AUTUNIAN						A	*Sphaeroschwagerina glomerosa*	*Autunia conferta*	ASSELIAN	
296														

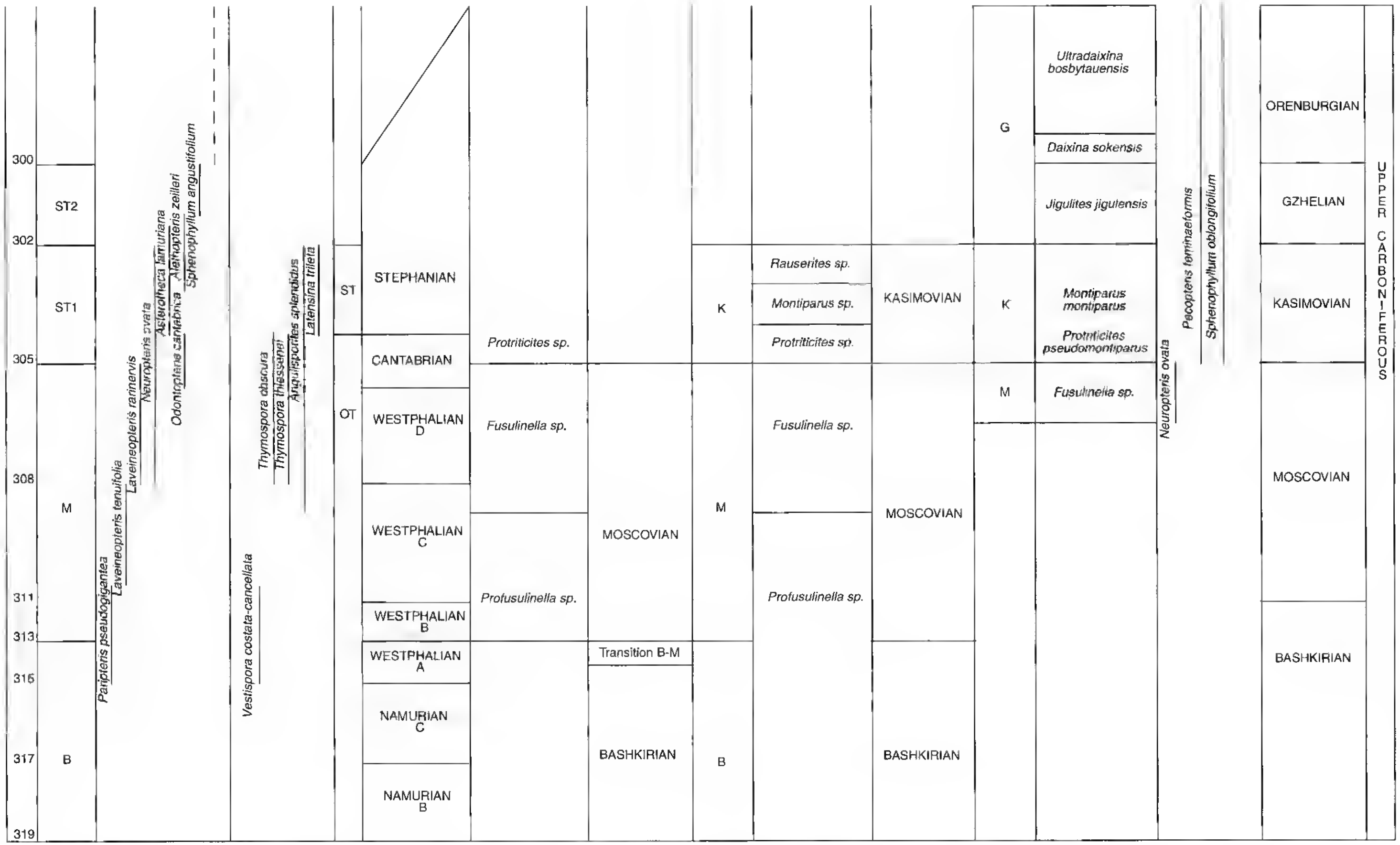

FIG. 6. — Biostratigraphy and chronostratigraphy of the Tethyan Basins. **1**, Izart (this paper); **2**, Wagner & Winkler-Prins (1985), Martinez Garcia (1991); **3**, Leyva *et al.* (1985), Coquel & Rodriguez (1995); **4**, Lys (1988), Granados *et al.* (1985); **5**, Villa (this paper); **6**, Krainer (1992, 1993), Vai & Venturini (1997); **7**, Krainer (this paper).

MOROCCO - ALGERIA - TUNISIA - LIBYA - EGYPT									SAUDI ARABIA	OMAN			
Age (Ma)	Sequences (1)	Goniatites (2)	Flora (3)	Microflora (4)	CONTINENTAL STAGES	Sequences (1)	Foraminifera (5)	MARINE STAGES	Sequences (1)	Microflora of Arabia (6)	Microflora of Oman (7)	STAGES	
274								KUNGURIAN				KUNGURIAN	
277					SAXONIAN								
	SA							ARTINSKIAN				ARTINSKIAN	
283											*Kingiacolpites subcircularis*		LOWER PERMIAN
						S	*Schwagerina sp.* *Staffellidae*	SAKMARIAN	S			SAKMARIAN	
290													
	AU		*Lodevia nicklesii* *Rhachiphyllum schenkii*	*Potonieisporites "novicus bhardwaji"* *Vittatina spp.*	AUTUNIAN	A	*Sphaeroschwagerina sp.*	ASSELIAN	A		*Cycadopites cymbatus* *Protohaploxypinus spp.* *Vittatina spp.*	ASSELIAN	
296													

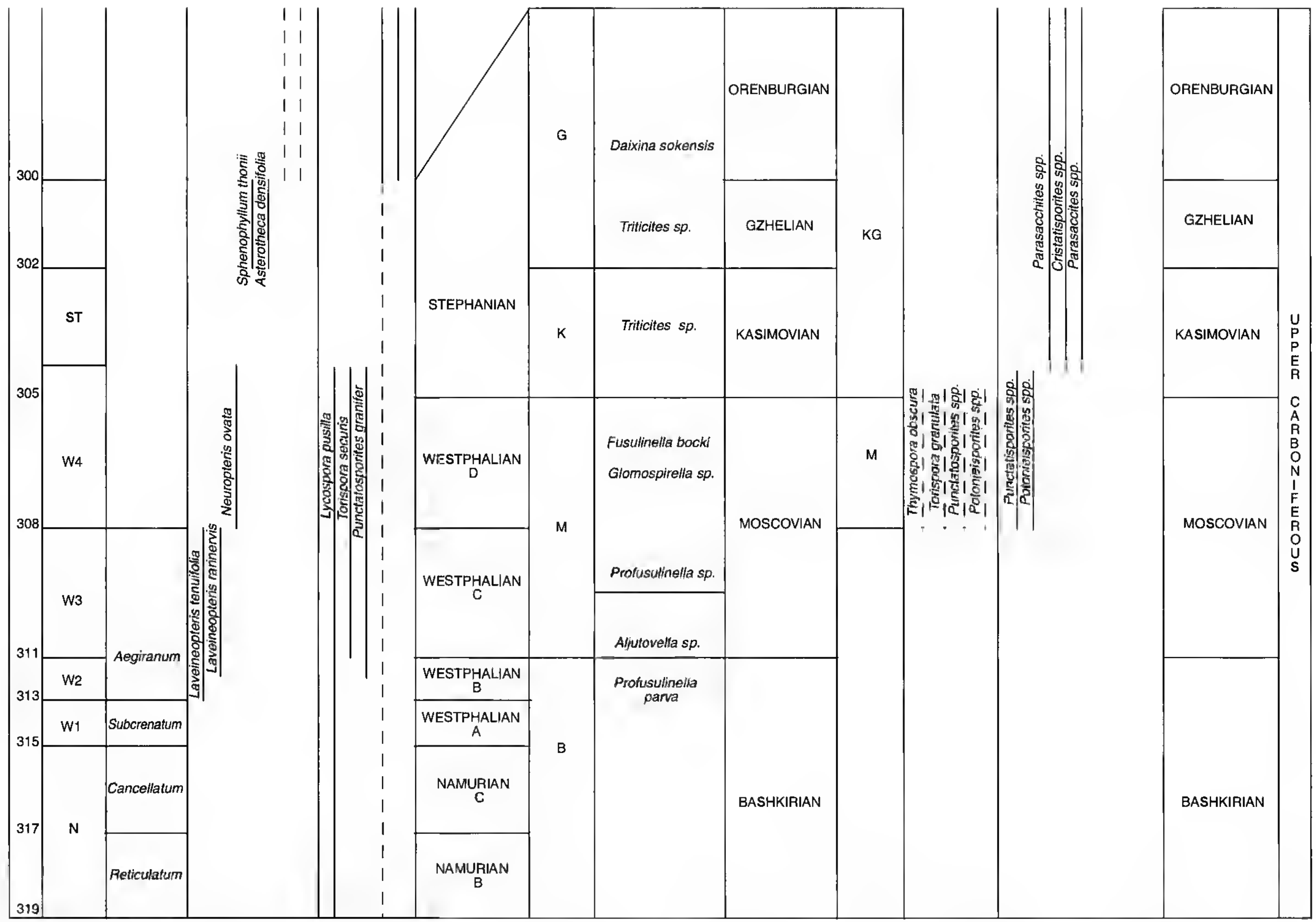

FIG. 7. — Biostratigraphy and chronostratigraphy of the southern Peri-Tethyan Basins. **1**, Izart (this paper); **2**, Deleau (1951), Owodenko (1976); **3**, Deleau (1951), Nedjari (1982), Desteucq *et al.* (1988), Broutin & El Wartiti (this paper); Aassoumi (1994); **4**, Doubinger & Fabre (1983), Aassoumi (1994); **5**, Lys (1988), Nedjari (1982), Massa & Vachard (1979), Kora (this paper); **6**, Owens & Turner (1995); **7**, Love (1994).

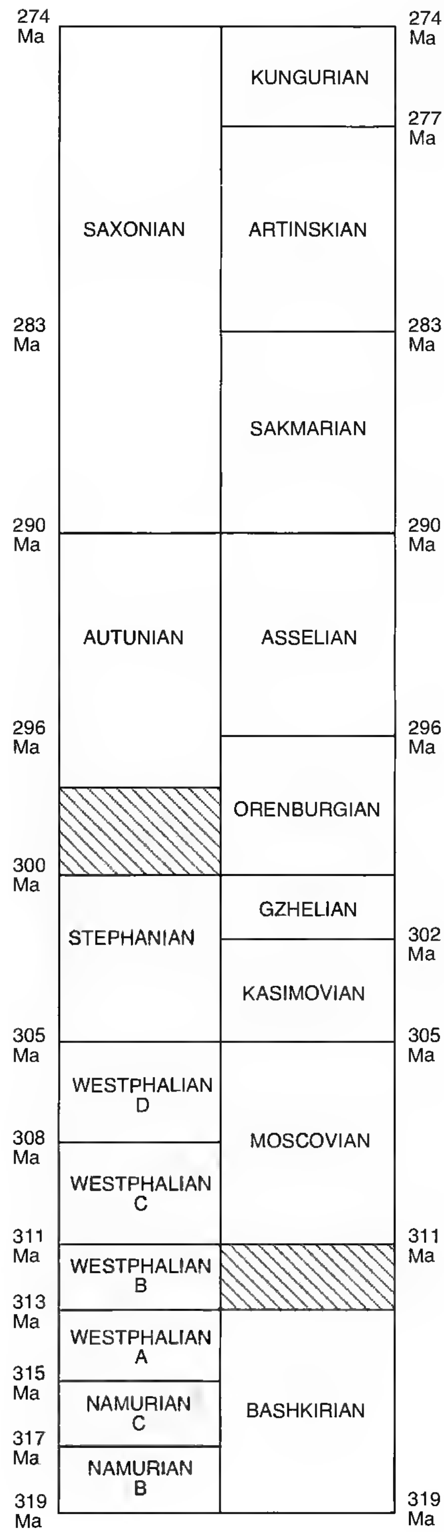

FIG. 8. — Correlations of the continental and marine Late Carboniferous and Early Permian of the Tethyan and Peri-Tethyan Basins. Oblique lines: uncertainty.

lacustrine claystone with xerophytic flora and microflora (*Autunia conferta, Rhachiphyllum schenkii, Potonieisporites* sp., *Vittatina* sp.). The Saar-Nahe Basin presents red fluvial sandstone and lacustrine black shale (Stapf 1997). The Saale Basin in Germany (Schneider & Gebhardt 1993; Schneider *et al.* 1994, 1995; Schneider 1996; Schneider & Rössler in press) exhibits two informal lithological units named early and late "Rotliegend". The early "Rotliegend" includes grey conglomerates and sandstones that would be dated to the Autunian by plants (*Autunia conferta*) and the late "Rotliegend" red conglomerates and sandstones that would be dated to the Saxonian by tracks of reptile. The boundary of these units presents an incertitude between the basins of North Germany and the Saale (Menning 1995). The basins of Poland (Zdanowski this paper), the Czech (Oplustil this paper) and Slovak (Vozarova this paper) Republics are also considered. In the Donets Basin (Fig. 5), the flora and microflora of the Asselian and Sakmarian Stages are xerophytic (Inosova *et al.* 1976) with *Autunia conferta, Potonieisporites* sp. and *Vittatina* sp. The climate changed from a humid tropical to a dry tropical climate (Parrish 1995). According to Schneider *et al.* (1994, 1995), the Kartamysh, Nikitovsk and Slavjansk formations would be equivalent to the early "Rotliegend" and the Kramatorsk formation to the late "Rotliegend" with some incertitudes. The Asselian would correspond to the Autunian *p.p.* and the Sakmarian, Artinskian and Kungurian to the Saxonian (Fig. 8).

Correlations are proposed in the Tethyan (Fig. 6) and southern Peri-Tethyan domains (Fig. 7). The Bashkirian and Moscovian are dated by fusulinids in the paralic basin of the Cantabrian zone in Palencia (Lys 1988a) and in the central Asturias (Granados *et al.* 1985), the limestones of the Picos de Europa (Villa 1985; Villa *et al.* 1993), Tuscany (Vai 1991, 1994; Pasini & Vai 1997), eastern Elbourz (Jenny *et al.* 1978; Jenny-Deshusses 1983), Mezarif, Algeria (Nedjari

1982; Lys 1988a), Tunisia (Lys 1988b), Turkey (Monod 1977; Lys 1988a), Libya (Massa & Vachard 1979; Vachard *et al.* 1993), Egypt (Kora 1995), Syria (Al Youssef & Ayed 1992). The Carnic Alps (Schönlaub 1992; Krainer 1993; Vai 1991; Vai & Venturini 1997; Krainer & Davydov, this volume) present only the late Moscovian. Some marine bands dated to the Moscovian are known in Morocco, Jerada (Owodenko 1976) and in Algeria, Bechar (Deleau 1951). The Kasimovian is found everywhere except in Algeria (Bechar, Mezarif). The Gzhelian and the Orenburgian are found everywhere except in Spain, Algeria (Bechar, Mezarif) and southern Tunisia (Lys 1988b). The marine Early Permian is found everywhere except in Spain, Algeria (Bechar, Mezarif) and Libya (Ghadames). The marine facies of the Late Carboniferous and Early Permian are unknown in Saudi Arabia. In Oman, the Early Permian presents marine and continental levels (Broutin *et al.* 1995; Angiolini *et al.* 1997).

The Westphalian is paralic in central Asturias, in Jerada (Morocco) and in Bechar (Algeria). The hygrophytic flora and microflora are dated the Westphalian A to D in central Asturias (Leyva *et al.* 1985a, b, c; Granados *et al.* 1985; Saenz de Santa Maria *et al.* 1985; Wagner & Alvarez 1991) and in Jerada (Owodenko 1976; Desteucq *et al.* 1988; Izart 1991), the Westphalian C and D in Bechar (Deleau 1951; Coquel *et al.* 1988). Elsewhere the base of the Moscovian could be located in Spain inside the Westphalian A or B (Wagner & Bowman 1983; Granados *et al.* 1985; Leyva *et al.* 1985a, b, c; Martinez Dias *et al.* 1985; Ginkel & Villa 1996), and in Algeria at the base of the Westphalian C (Lys 1988a) as in eastern Europe, but there is an objection: an eustatic event is synchronous everywhere in the world, or the appearance of plants in the Westphalian of Spain presents a disharmony. In Libya (Massa *et al.* 1980; Coquel *et al.* 1988), in Saudi Arabia (Owens & Turner 1995), in Oman (Love 1994) as in Gondwanaland, a xerophytic microflora with *Potonieisporites* sp. is known in the Westphalian D.

In the Cantabrian zone in Palencia, Bouroz *et al.* (1972), Wagner & Winkler-Prins (1985, 1991, 1993) defined the Cantabrian and the Stephanian in the interval attributed by Lys (1988a) to the late Moscovian (Myachkovian) and the Kasimovian. The comparison between the flora and microflora (Coquel & Rodriguez 1995) does not allow to differentiate the Cantabrian and the Stephanian. The precocious tectonic opening of the basin of the Cantabrian zone in Palencia would explain the presence of the Cantabrian in this basin and its absence in the Saint-Étienne Basin. The lower part of the Cantabrian could be connected with the Westphalian D and the upper part with the early Stephanian. In the Carnic Alps, Krainer (1993) reported in the Kasimovian and the Gzhelian hygrophytic flora dated to the Stephanian (*Pecopteris* sp., *Sphenophyllum* sp.). In Morocco, hygrophytic plants dated to the late Stephanian exist in the High Atlas (Beauchamp *et al.* 1986; Doubinger & Roy-Dias 1985, 1986; Aassoumi 1994). In Oman, Love (1994) described microflora *Microbaculispora* known in the Gondwanaland. The equivalence between the Kasimovian-Gzhelian and the Stephanian is established in the Tethyan domain, but not in the southern Peri-Tethyan domain.

The Autunian presents xerophytic plants (*Autunia conferta*) in the Carnic Alps (Krainer 1993) and in Spain where in addition the Saxonian exists (Martinez-Garcia 1991). The Autunian and the Saxonian exhibit xerophytic flora and microflora with *Lodevia nicklesii*, *Rhachiphyllum schenkii*, *Potonieisporites* sp. and *Vittatina* sp. in central Morocco (Broutin *et al.* 1987; El Wartiti *et al.* 1986, 1990; Aassoumi 1994). Doubinger & Fabre (1983) attributed to the Autunian a microflora with *Torispora* sp., *Potonieisporites* sp. at the top of the Bechar Series. In Oman, Love (1994) distinguished the biozone *Cycadopites* dated to the Asselian and Sakmarian and the biozone *Kingiacolpites* dated to the late Sakmarian to Kungurian, known in Gondwanaland. In the Salt Range (Pakistan), the biozone *Cycadopites* (Iqbal 1993 and this volume) was found at the base of the Warcha Formation, corresponding to the Sakmarian-Artinskian interval. Everywhere, the correlations are imprecise between the marine and continental Permian.

LATITUDINAL CORRELATIONS

The stratigraphic correlations provided by the plants of the continental domain will depend on the latitudinal location of each domain. Following the position of the continents according to Scotese & McKerrow (1990), this hypothesis can be tested on the basis of the relations between the hygrophytic plants and the equatorial-humid tropical climate and between the xerophytic plants and the dry tropical-desert climate. The geographic zonation of climate has been described in term of floral biomes for the Early Permian (Sakmarian) and Late Permian (Kazanian) by Ziegler (1990) and Ziegler *et al.* (1997). The biomes are: (1) equatorial and tropical everwet, (2) tropical and subtropical summerwet, (3) coastal and inland tropical desert, (4) winterwet, (5) western and eastern warm temperate, (6) western and eastern cool temperate, (7) midlatitude desert, (8) cold temperate, (9) arctic and (10) glacial. This approach has been adapted from a climate study of the Recent. The sediments gave also informations about the climates: coal in various climates (cold to tropical), reef in tropical climate, evaporite in dry tropical or desert climate, tillites in cold climate. Numerous paleoclimate studies exist for the Permian: Parrish (1995), Kutzbach & Gallimore (1989), Kutzbach & Ziegler (1993), Barton & Fawcett (1995); Crowell 1995. All these studies exhibit from Late Carboniferous to Trias an increase of the aridity in the humid tropical zone, that was explained by the perfect symmetry of the continental surfaces at the equator, that implied a warm and dry climate with monsoons. In the northern Peri-Tethyan domain, the location of western and eastern Europe was between the equator and 5°N during the Westphalian, between 5°N and 10°N during the Early Permian (Fig. 1). All the basins were located inside the same latitudinal zone and the latitudinal correlations are excellent. The Westphalian presents hygrophytic plants and coal in the everwet biome, the Stephanian alternation of hygrophytic and xerophytic plants (Saint-Étienne, Saale, Donets) and alternation of red beds and grey beds with coal (Lorraine, Saale, Czech Republic, Slovakia, Donets) explained by period of monsoon in the summerwet biome. The Autunian exhibits xerophytic plants growing on the slopes of basins and alternation of red beds and lacustrine black shale (Autun, Lorraine, Saar-Nahe, Saale, Czech Republic and Slovakia) or coal (Donets) in the summerwet biome. The Saxonian presents xerophytic plants, red beds, calcretes and evaporites (Saale, Czech Republic, Slovakia, Donets, Russian platform) in the subtropical desert biome.

In the Tethyan domain (Fig. 1), Spain, Italy and the Carnic Alps were located at 5°S during the Westphalian and Stephanian and at the equator during the Early Permian. The Westphalian and Stephanian present hygrophytic plants and coal in the everwet biome, the Autunian xerophytic plants growing on the slopes of basins and red beds in the summerwet biome, the Saxonian xerophytic plants and red beds in the subtropical desert biome in spite of its location at the equator. The presence of this subtropical biome at the equator can be explained by the perfect symmetry of the continental surfaces at the equator (Parrish 1995). The correlations are excellent between the northern Peri-Tethyan and Tethyan domains. The presence of two opposite climates at the equator during the Westphalian and the Early Permian makes the correlations easier.

In the southern Peri-Tethyan domain (Fig. 1), North Africa was located at 10°S during the Westphalian and at the equator during the Early Permian. Libya, Egypt and Saudi Arabia were located at the 25°S during the Westphalian and 20°S during the Early Permian; Oman and the Salt Range were located at 50°S during the Westphalian and at 40°S during the Early Permian. In North Africa, the Westphalian and the Stephanian present hygrophytic plants and coal in the everwet biome, the Autunian xerophytic plants growing on the slopes of basins and red beds in the summerwet biome, the Saxonian xerophytic plants and red beds in the subtropical desert biome in spite of its location at the equator and for the same reason as the Tethyan domain. In Libya, Egypt and Saudi Arabia, the plants were xerophytic during the Westphalian and the Early Permian. In Oman and the Salt Range as in all Gondwanaland, the plants lived in a cool to temperate climate. These different latitudinal locations make the correlations difficult between Europe and Gondwanaland.

During the Late Carboniferous and Early Permian, three realms are defined (Ziegler 1990): the tropical Cathaysian (biome 1) in China and Euramerican-Atlantic in Europe and North America (biome 1 during Carboniferous and biomes 2 and 3 during Permian) realm, the North temperate Angaran realm (biomes 4 to 8) in Siberia and the southern temperate Gondwanan realm (biomes 5 to 10) in Gondwana. Biome 1, represented by tropical rainforests populated by arborescent hygrophytic flora, was known in China during the Carboniferous and Permian and in Europe and North America during the Late Carboniferous. Biome 2 was represented by *Callipteris* and primitive conifers (*Walchia*) during the Early Permian in Europe, North Africa and North America. Biome 6 was represented by *Glossopteris* and Biome 8 by *Gangamopteris* in Gondwana.

CORRELATIONS FOUND ON THE SEQUENCE STRATIGRAPHY

A sequence stratigraphy of the Carboniferous and Permian was built by Ross & Ross (1987, 1994, 1995). Second order, third order (Figs 5-7), fourth order and high frequency sequences were defined in eastern Europe in Moscow Basin (Briand *et al.* 1998), the Donets Basin (Izart *et al.* 1996 and 1998) and the Central Ural Basin (Izart *et al.* 1998), and in the western Europe in paralic and limnic basins (Izart & Vachard 1994), in the foreland basin of Asturias and in the rift basin of the Carnic Alps (Samankassou 1997; Vai & Venturini 1997; Krainer & Davydov, this volume), in the intracontinental basins or the marine platform of North Africa (Izart 1991).

For the Late Carboniferous, the same number of third order and second order sequences was found in the Moscow and Donets Basins and a different number in western Europe. In the Moscow and Donets Basins, the Moscovian, Kasimovian and Gzhelian-Orenburgian deposits each form a second order sequence, the Moscovian is subdivided into four third order sequences, the Kasimovian into three or four sequences and the Gzhelian-Orenburgian into four or five sequences. In western Europe, the Westphalian presents four third order sequences, the Stephanian two, the Autunian one, the Saxonian one. The number of sequences is different from Ross & Ross (1987), who used fourth order sequences. In eastern Europe, they resulted from the eustacy that produced synchronous sequences and tectonics. In western Europe, the sequences are tectonically controlled and heterochronous with eastern Europe.

For the Late Carboniferous, the fourth order sequences (FOS, 400 000 y.) and high frequency sequences (HFS, 40 000 y. to 250 000 y.) are variable everywhere, as shown by Izart & Vachard (1994) and these results: for Moscovian, eleven FOS and forty HFS in Moscow and eighteen FOS and one hundred HFS in Donets; for Kasimovian, eight FOS and twenty HFS in Moscow, seven FOS and twenty-six HFS in Donets; for Gzhelian-Orenburgian, nine FOS and twenty-four HFS in Moscow, sixteen FOS and fifty-two HFS in Donets; for Westphalian, ten FOS in western Europe and for Westphalian C, four FOS and sixteen HFS in England; four FOS and forty HFS in North France and Germany. The number of FOS is different from Ross & Ross (1987) and the number is variable everywhere. In the Moscow Basin, eustacy prevails certainly over tectonics and in the Donets and western Europe Basins, tectonics prevail over eustacy. The average duration of HFS in the Moscow and western Europe Basins is near the periodicity of eccentricity (100 000 y.) and in the Donets Basin near the periodicity of obliquity (40 000 y.). However, a better accuracy of time by radiochronology is needed to calibrate these sequences.

The Early Permian deposits in Central Ural form two second order sequences, one during Asselian and one during the Sakmarian and Artinskian, five third order sequences for the Asselian, three for the Sakmarian, two composite for Artinskian and one composite for the Kungurian. The Early Permian deposits in the Donets Basin form one second order sequence during the Asselian and the Sakmarian, three third order sequences during the Asselian and one during the

Sakmarian. The number of sequences is weakly different from Ross & Ross (1987, 1994, 1995): five for Asselian, four or five for the Sakmarian, three or four for the Artinskian and one composite or two for the Kungurian. These sequences are controlled by eustacy and tectonics in the Ural foreland Basin and the Donets Basin.

For the Early Permian, the fourth order sequences (FOS) and high frequency sequences (HFS) are variable everywhere: for the Asselian, eleven FOS and eighteen HFS in Donets and a number superior to twenty-four HFS in Central Urals; for Sakmarian, ninety-two HFS in Central Urals; for the early Artinskian (Bursevkian-Irginian), seventeen HFS in Central Urals. These sequences are controlled by eustacy and tectonics. The average duration of HFS is near the periodicity of eccentricity (100 000 y.).

The tectonic control was important in the Asturias and the eustatic control rules over in the Carnic Alps. The sequences are heterochronous in the Asturias and synchronous with eastern Europe in the Carnic Alps. The tectonics prevails in the continental basins of Morocco, the eustacy in the marine basins in Morocco, Algeria, Tunisia, Libya and Egypt. These sequences of the southern Peri-Tethyan domain are heterochronous in the intracontinental basins and synchronous with eastern Europe in the marine basins. The beginning of the sedimentation in the continental stages of the Late Carboniferous and Early Permian are heterochronous according to the tectonic phases affecting each basin, even though it is synchronous in the marine stages that are under the control of the eustacy.

CONCLUSION

Stratigraphic correlations (Fig. 8) are proposed between the marine and continental facies in the northern Peri-Tethyan, Tethyan and southern Peri-Tethyan domains. The base of the Moscovian would be located between the late part of the Westphalian B and the base of the Westphalian C in the northern Peri-Tethyan domain, between the bases of the Westphalian A and C in the Tethyan domain, at the base of the Westphalian C in the southern Peri-Tethyan domain. The Moscovian would be equivalent to the Westphalian C and D in the northern and southern Peri-Tethyan domains and to an imprecise time interval (Westphalian A to Cantabrian *p.p.*) in the Tethyan domain. The Kasimovian would correspond to the early Stephanian in the northern Peri-Tethyan domain, to the Cantabrian *p.p.* and the early Stephanian in the Tethyan domain. The equivalence between the Kasimovian and the early Stephanian is not established in the southern Peri-Tethyan domain. The Gzhelian would be equivalent to the late Stephanian and the Orenburgian to the lower part of the Autunian in the northern Peri-Tethyan domain with an uncertainty, because we can choose either the appearance of xerophytic plants, or the acme for the definition of the base of the Autunian. In the Carnic Alps, the Gzhelian would be equivalent to the late Stephanian. The equivalence between the Gzhelian and the late Stephanian is not established in the southern Peri-Tethyan domain. The marine Early Permian would be equivalent to the continental Early Permian in all the domains, the Autunian and the Saxonian remain difficult to separate. A latitudinal good correlation is observed on the continents except near Gondwanaland. A good correlation linked with the eustacy is observed in the marine domain and a heterochrony in the beginning of the sedimentation linked with the tectonics is reported in the continental domain.

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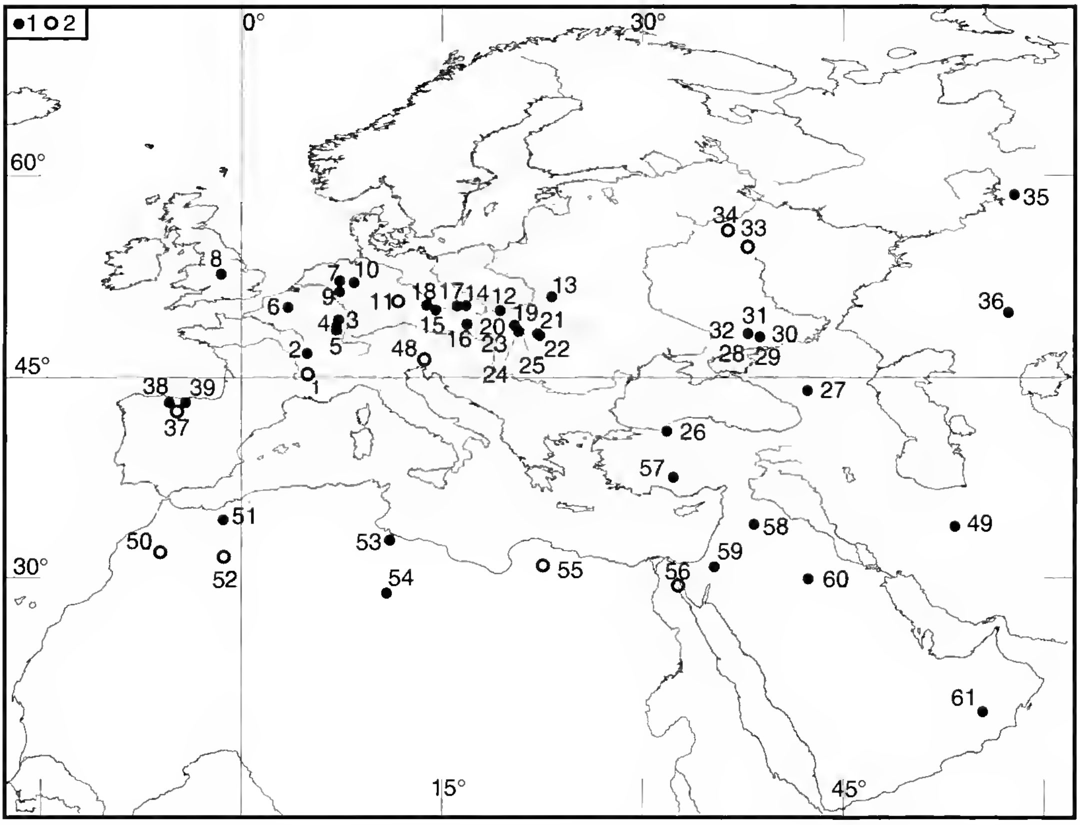
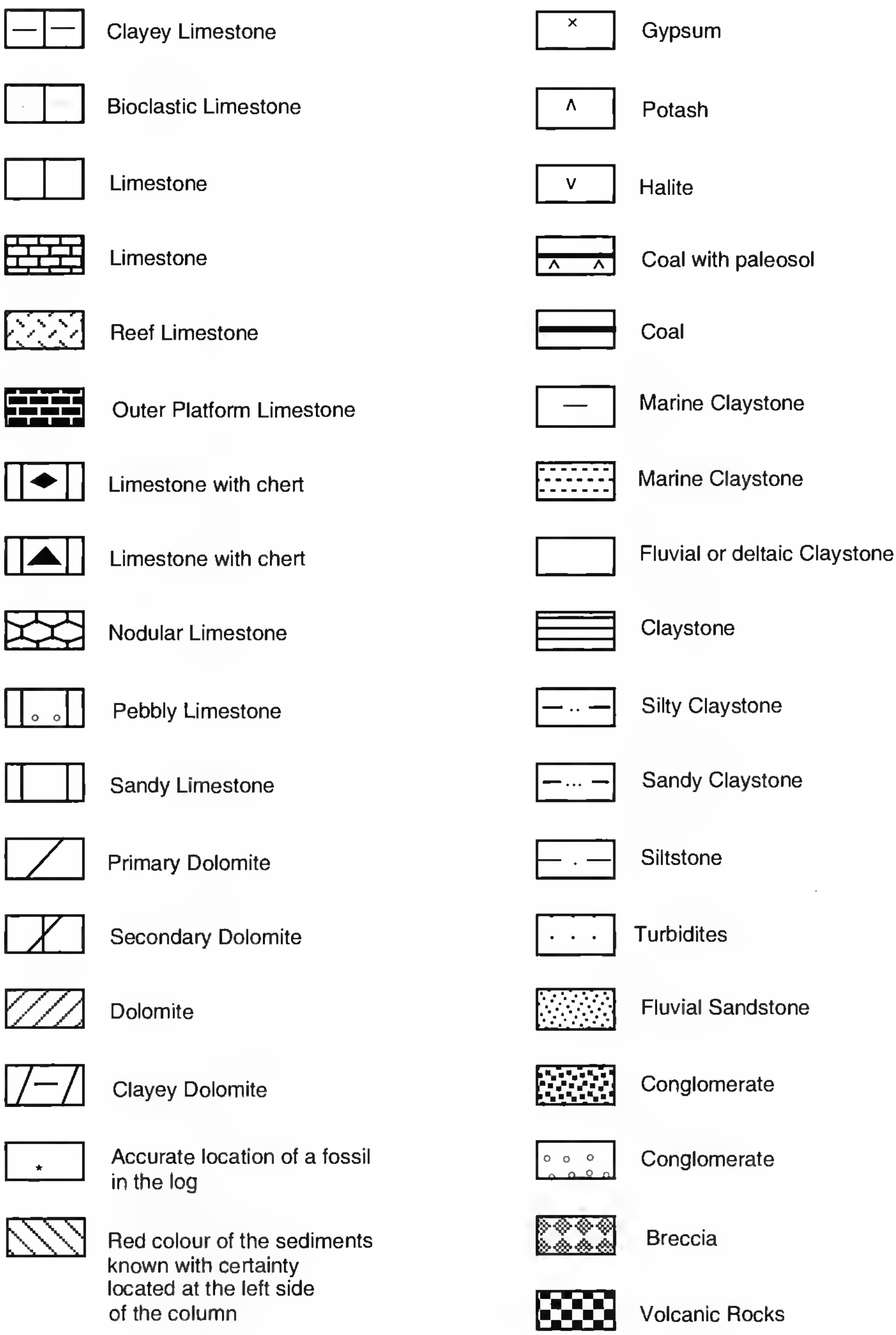
APPENDIX 1

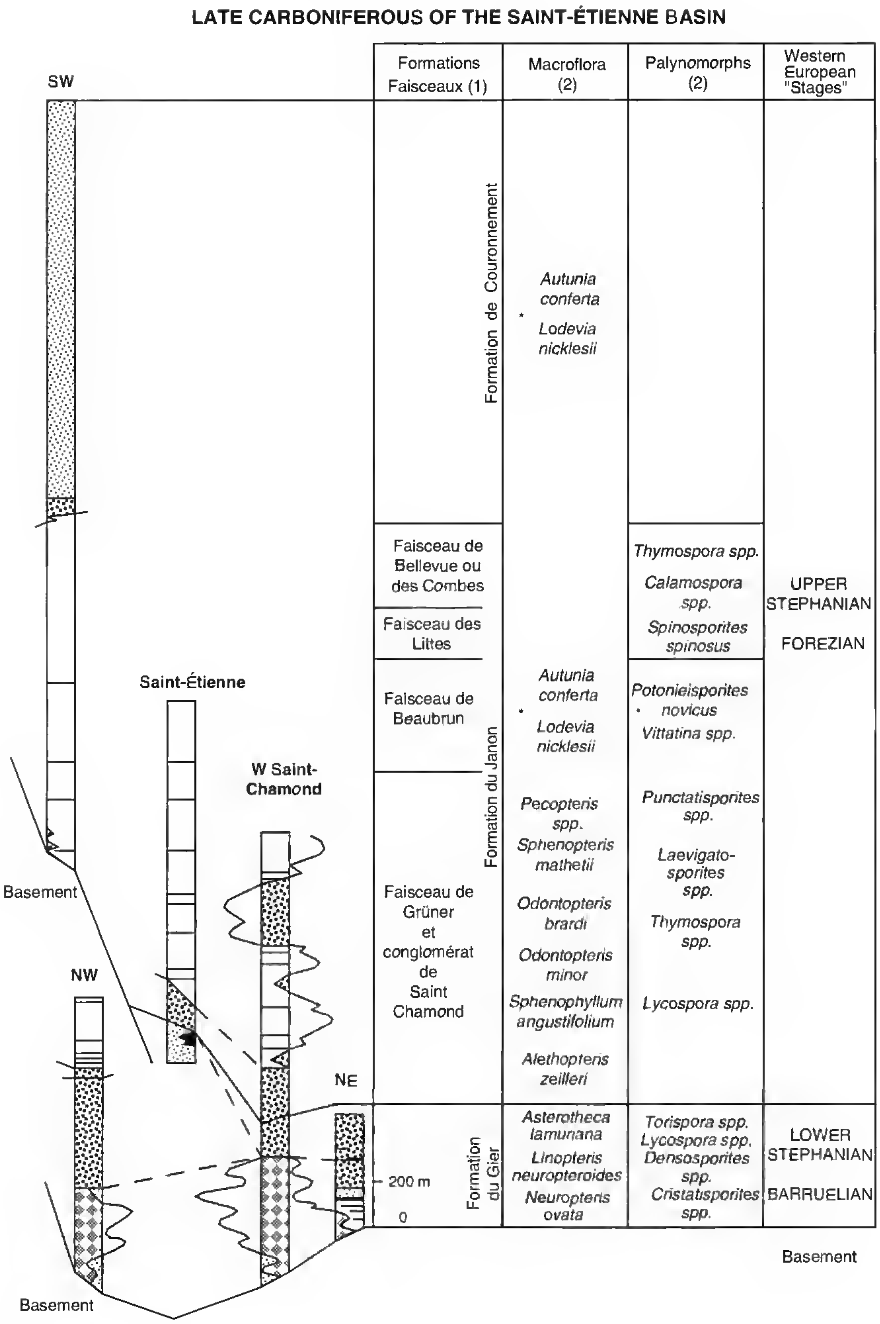
Late carboniferous and Early Permian logs and tables. Northern Peri-Tethyan Basins (logs 1-36); Tethyan Basins (logs 37-49); Southern Peri-Tethyan Basins (logs 50-62).



Map. — Location of the logs or sections presented in the appendix 1. Map realized by the Peri-Tethys cartographic team. Pakistan table (62) is not located on the map. **1**, log or section; **2**, synthetic log or section.

LEGEND


Clayey Limestone
Bioclastic Limestone
Limestone
Limestone
Reef Limestone
Outer Platform Limestone
Limestone with chert
Limestone with chert
Nodular Limestone
Pebbly Limestone
Sandy Limestone
Primary Dolomite
Secondary Dolomite
Dolomite
Clayey Dolomite
Accurate location of a fossil in the log
Red colour of the sediments known with certainty located at the left side of the column
Gypsum
Potash
Halite
Coal with paleosol
Coal
Marine Claystone
Marine Claystone
Fluvial or deltaic Claystone
Claystone
Silty Claystone
Sandy Claystone
Siltstone
Turbidites
Fluvial Sandstone
Conglomerate
Conglomerate
Breccia
Volcanic Rocks

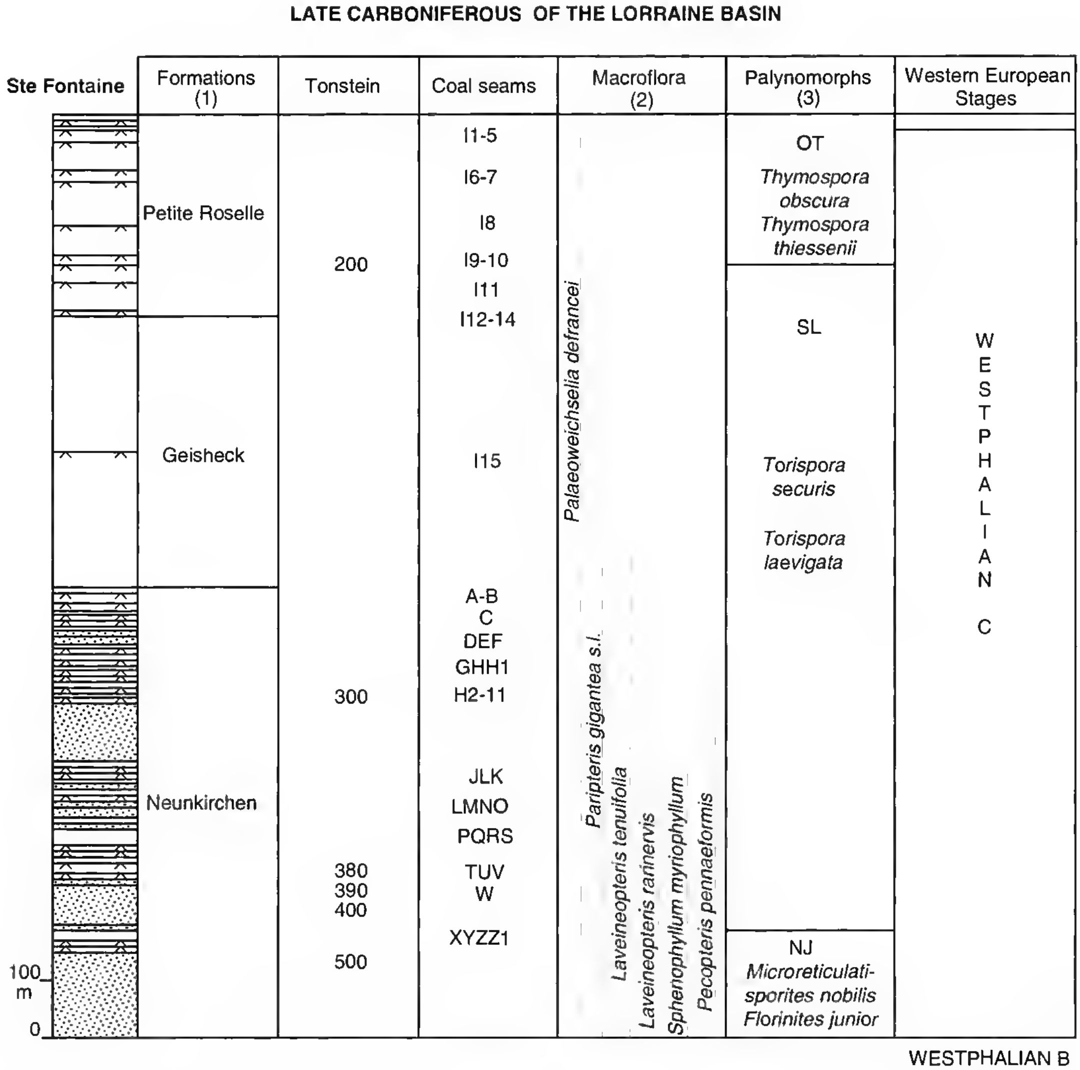


LOG. 1. — Late Carboniferous of the Saint-Étienne Basin, coordinated by Mercier and Broutin. 1, Mercier (this paper); 2, Broutin (this paper). Saint-Étienne, France, 4°24'E - 45°27'N; Firminy, ex-SW, 4°15'E - 45°24'N; La Fouillouse, ex-NW, 4°19'E - 45°30'N; W Saint-Chamond, 4°30'E - 45°29'N; Rive-de-Gier, ex-NE, 4°37'E - 45°31'N.

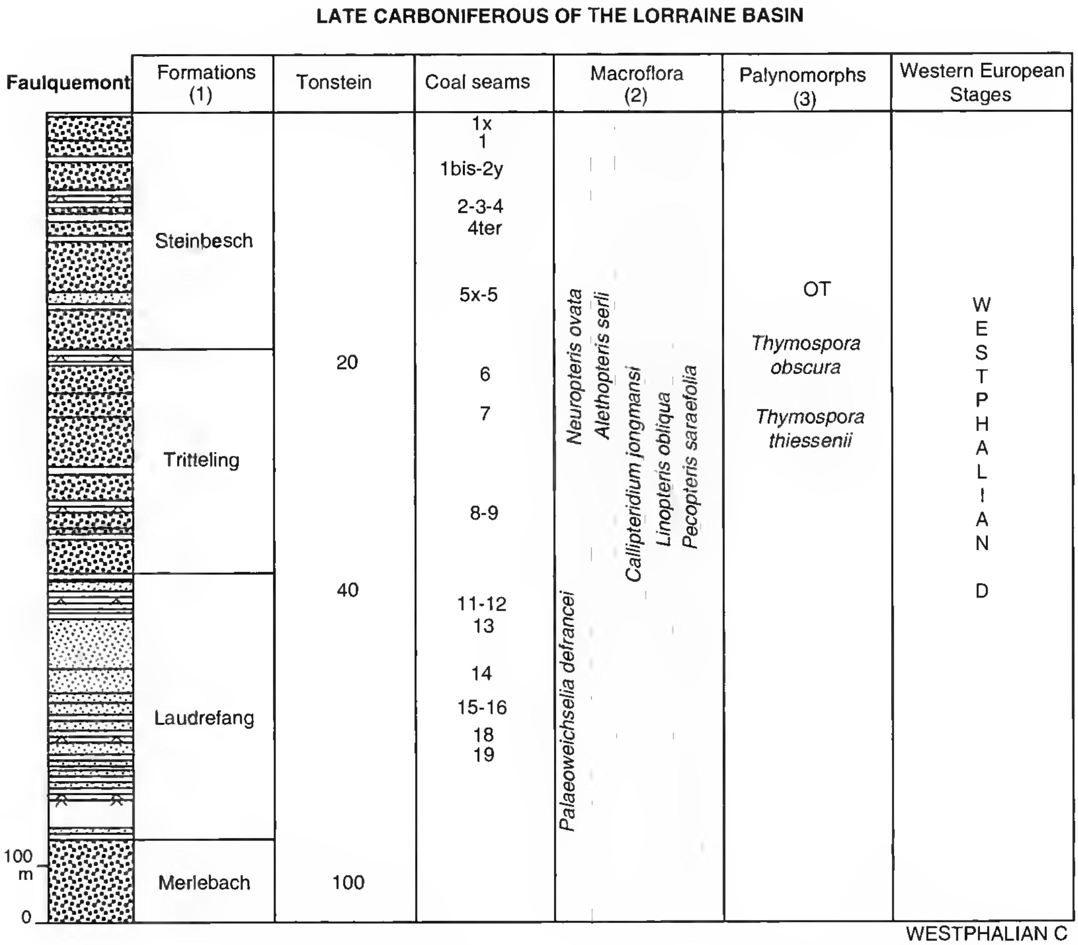
AUTUNIAN OF THE AUTUN BASIN

Formations	Beds	Macroflora	Palynomorphs	Western European Stages	
Millery	Les Télots bituminous beds (10 beds)	*Rhachiphyllum schenkii* *Rhachiphyllum pellatii* *Lodevia bibractensis*		UPPER AUTUNIAN	AUTUNIAN
Surmoulin	Surmoulin bituminous bed	*Gracilopteris raymondii* *Baiera raymondii*			
Muse	Muse bituminous bed Lally bituminous bed	*Autunia conferta* *Autunia naumanii* *Walchia piniformis* *W. goeppertiana* *Culmitzschia frondosa*	*Disaccites striatiti* *Vittatina spp.* *Disaccites non-striati* *Potonieisporites novicus-bhardwaji complex*	LOWER AUTUNIAN	
Igornay	Igornay bituminous bed Moloy bituminous bed	*Sphenophyllum angustifolium* *Alethopteris zeilleri*	*Vesicaspora spp.* *Vittatina costabilis* *Florinites spp.*		
Epinac		*Pecopteris plumosa* *Odontopteris brardii*	*Monoletes spores* *Trilete spores*	UPPER STEPHANIAN	
				BASEMENT	

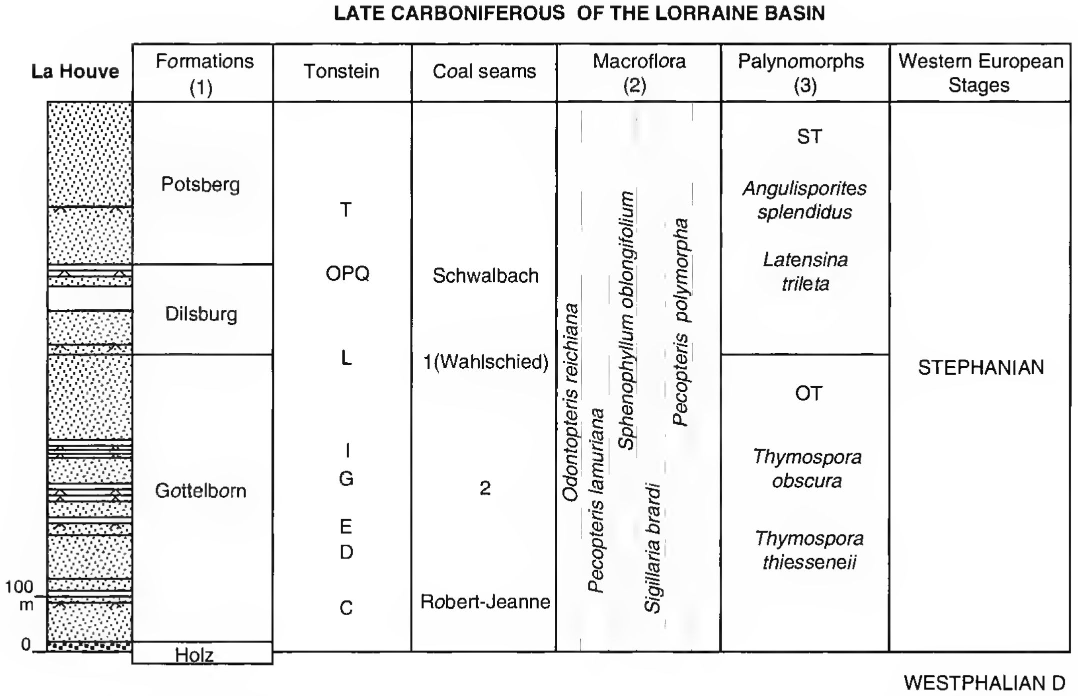
LOG. 2. — Autunian of the Autun Basin, coordinated by Broutin, after Broutin *et al.* (1996). Autun, France, 4°30'E - 47°N.



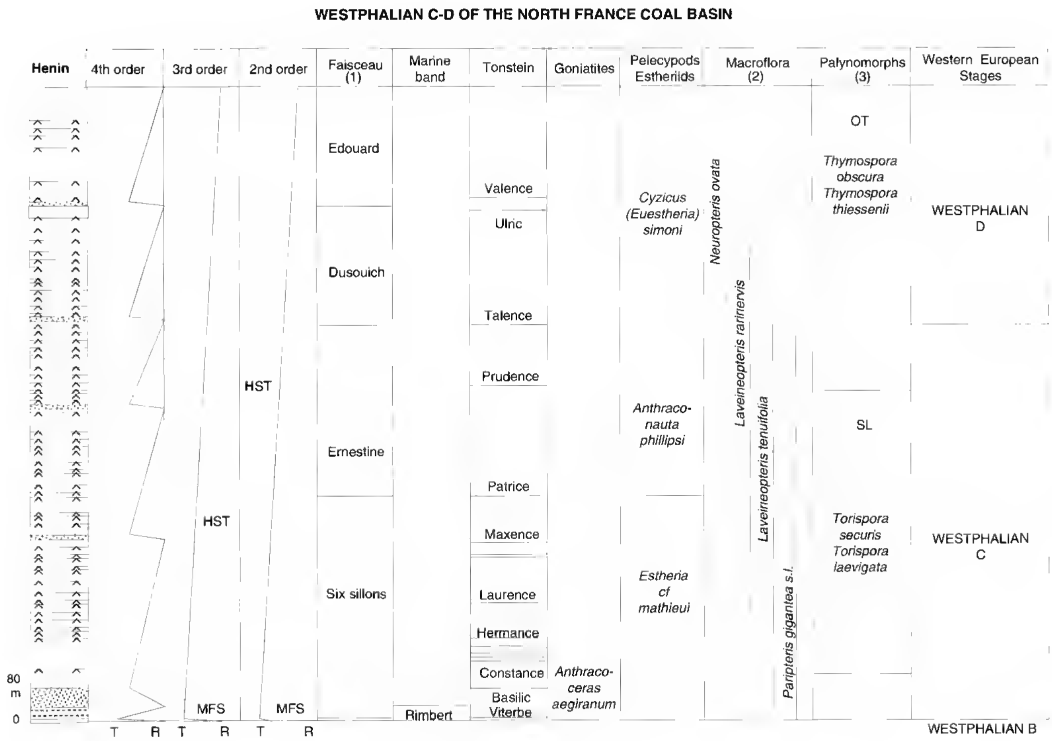
LOG. 3. — Late Carboniferous of the Lorraine Basin, coordinated by Donsimoni, Laveine and Coquel, Sainte-Fontaine, 6°48'E - 49°30'N. **1**, Donsimoni (this paper); **2**, Laveine (this paper); **3**, Coquel (this paper).



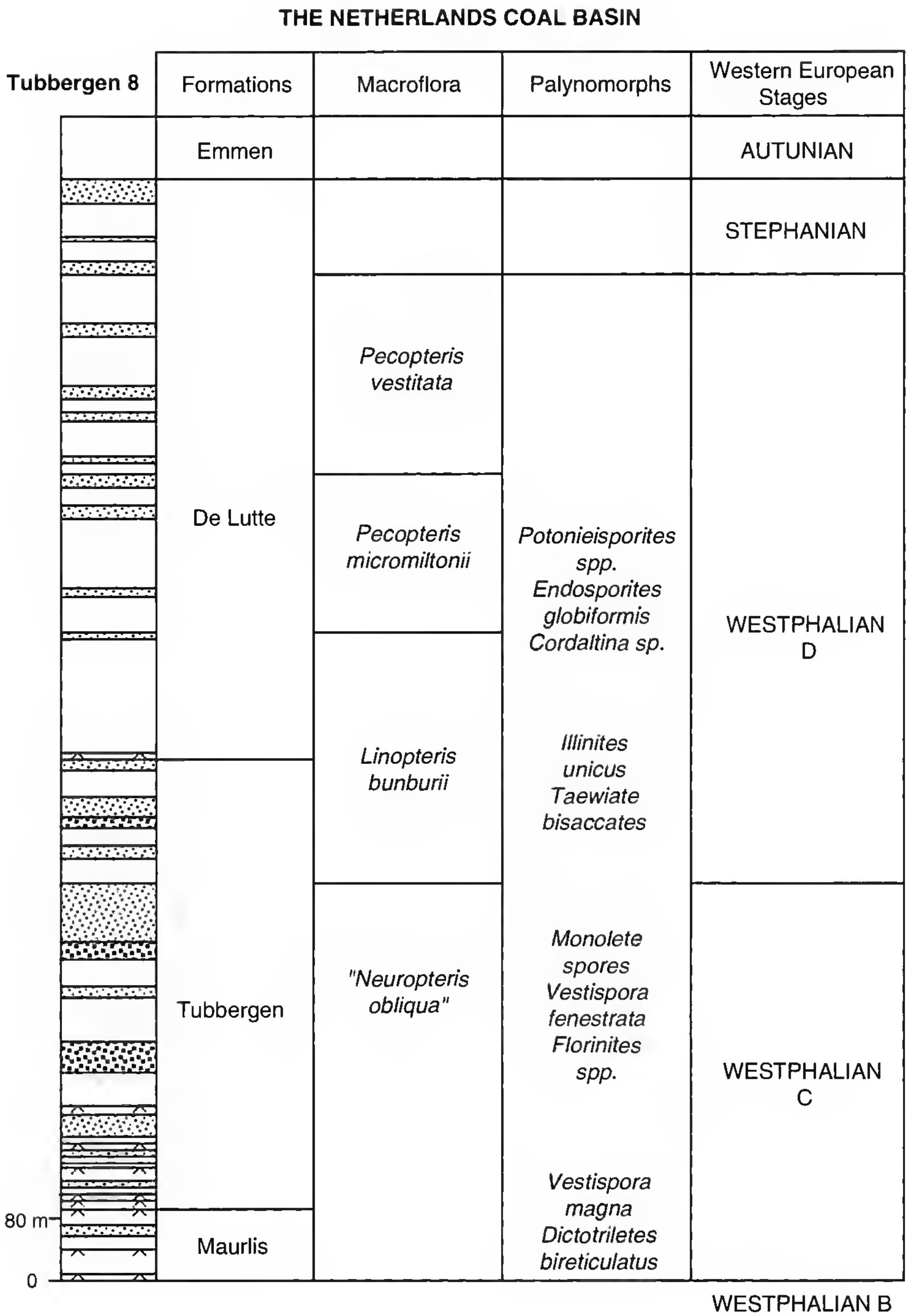
Log. 4. — Late Carboniferous of the Lorraine Basin, coordinated by Donsimoni, Laveine and Coquel, Faulquemont, 6°38'E - 49°02'E. **1**, Donsimoni (this paper); **2**, Laveine (this paper); **3**, Coquel (this paper).



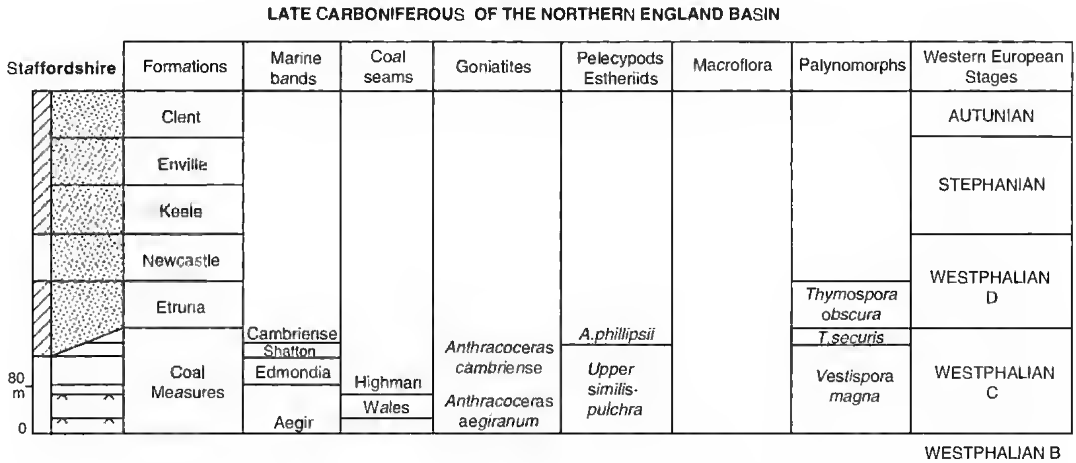
LOG. 5. — Late Carboniferous of the Lorraine Basin, coordinated by Donsimoni, Laveine and Coquel, La Houve, 6°38'E - 48°45'N. **1**, Donsimoni (this paper); **2**, Laveine (this paper); **3**, Coquel (this paper).



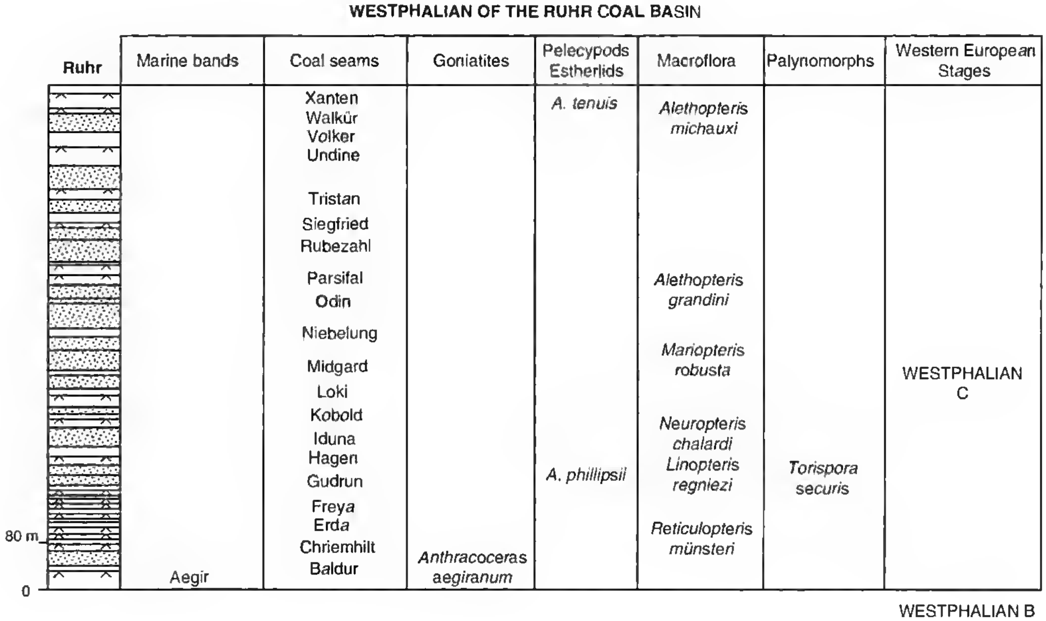
LOG. 6. — Westphalian C and D of the North France Basin, coordinated by Izart, Laveine and Coquel. **1**, Izart after Bouroz *et al.* (1964); **2**, Laveine (this paper); **3**, Coquel (this paper). Hénin, North France, 3°E - 50°30'N.



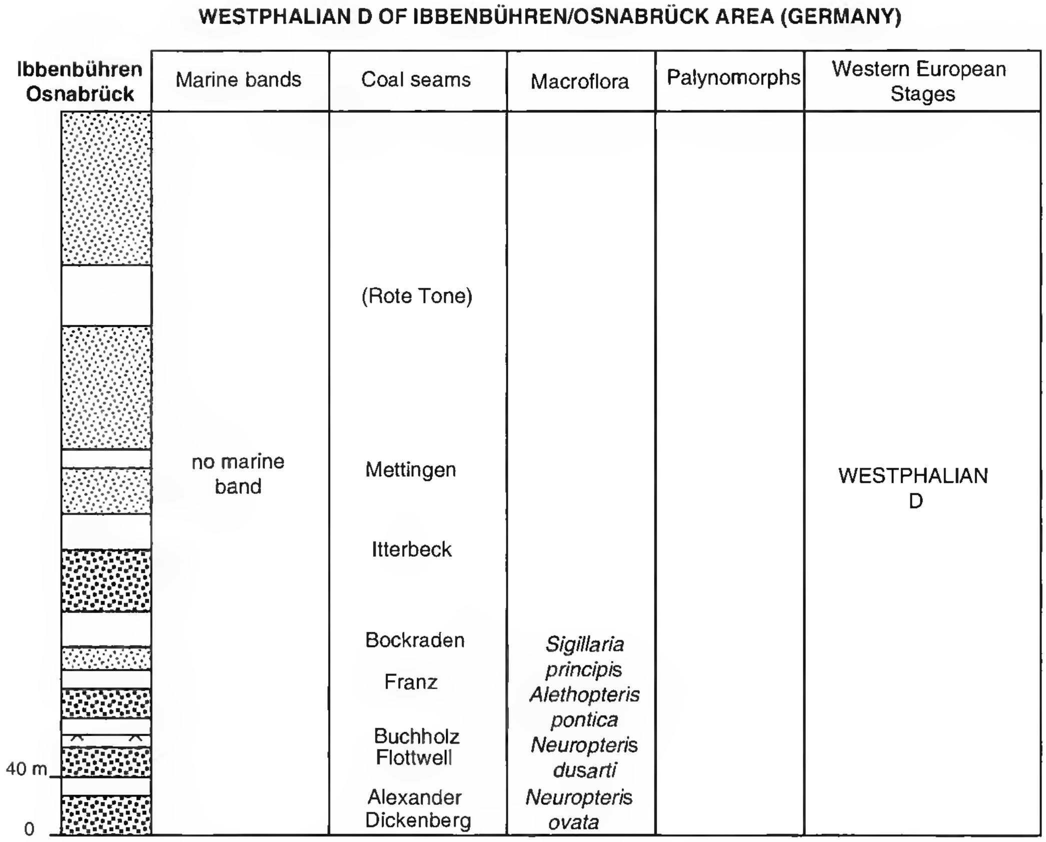
Log. 7. — The Netherlands coal Basin, coordinated by Gelük, after Gelük (1997). Tubbergen-8, 6°53'E - 52°26'N.



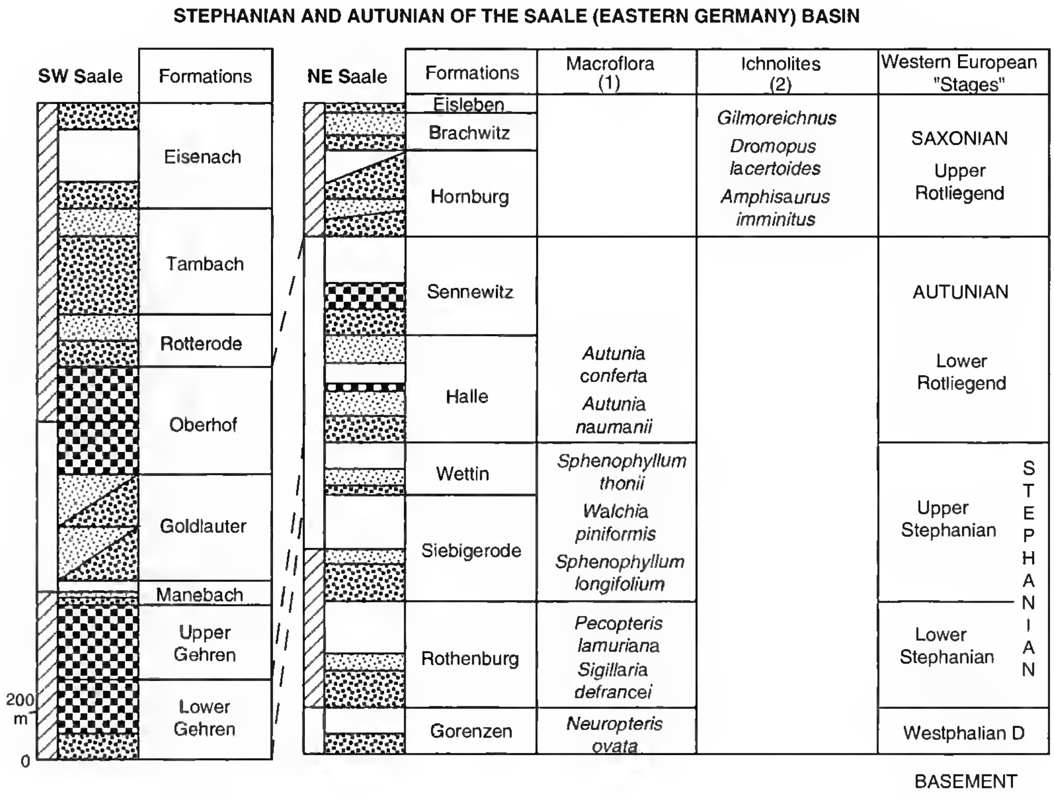
Log. 8 — Late Carboniferous of the Northern England Basin, coordinated by Izart, Izart (this paper) after Ramsbottom *et al.* (1978). Stafford, North England, 2°W - 52°50'N.



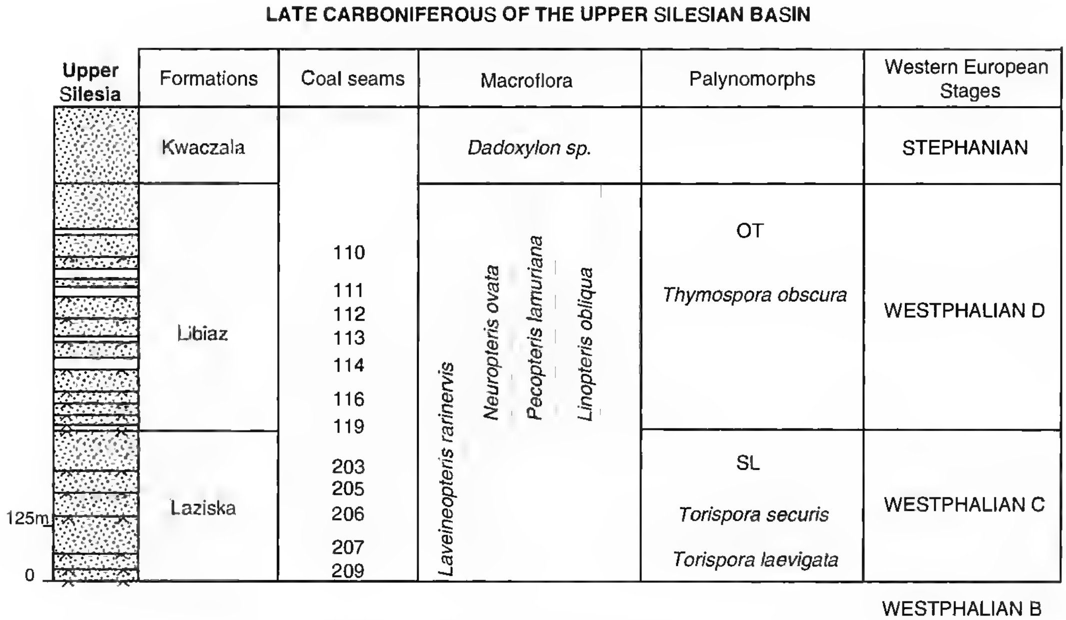
Log. 9. — Germany Basins. Westphalian of the Ruhr coal Basin, coordinated by Süss after Fiebig (1969) and Josten (1991). Lippermulde 1, Ruhr, Germany, 6°52'E - 51°37'N.



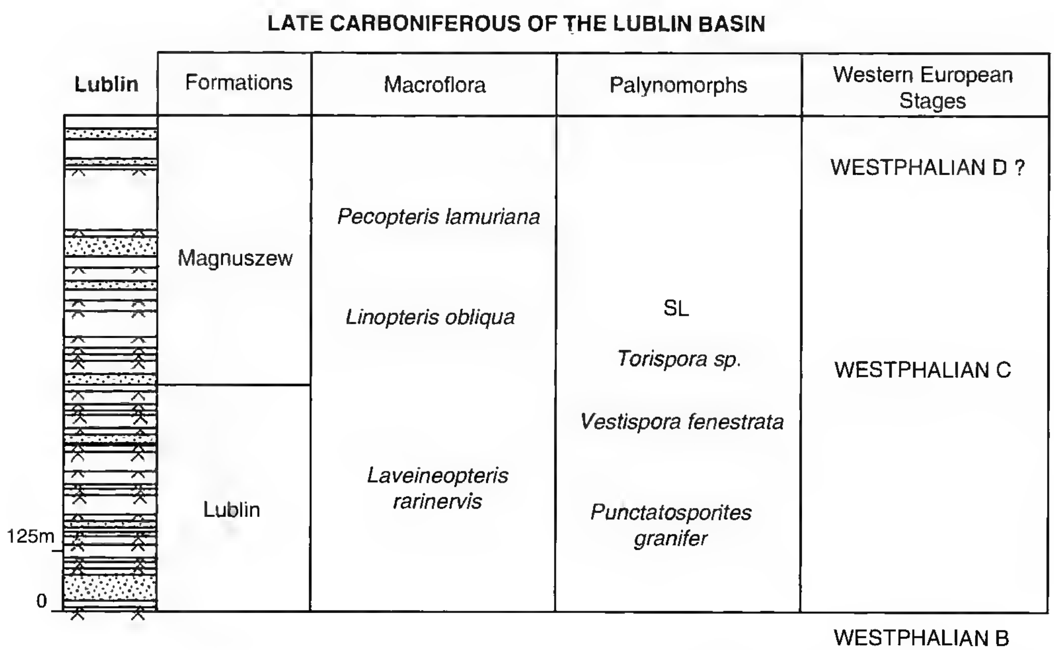
LOG. 10. — Germany Basins. Westphalian of the Ibbenbühren/Osnabrück area coordinated by Süss, after Josten (1991). Ibbenbühren, Osnabrück, 8°E - 52°20'N.



LOG. 11. — Germany Basins. Stephanian and Autunian of the Saale (eastern Germany) Basin, coordinated by Izart, Izart (this paper) after Schneider & Rossler (in press); **1**, Broutin (this paper); **2**, Lützner (1987). Halle, NE Saale, 12°E - 51°30'N; Tambach, SW Saale, 10°36'E - 50°48'N.



LOG. 12. — Poland Basins, coordinated by Izart. Late Carboniferous of the upper Silesian Basin, Izart (this paper) after Zdanowski & Zakowa (1995). Katowice, Poland, 19°E - 50°15'N.



LOG. 13. — Poland Basins, coordinated by Izart. Late Carboniferous of the Lublin Basin, Izart (this paper) after Zdanowski & Zakowa (1995). Lublin, Poland, 22°45'E - 51°15'N.

LATE CARBONIFEROUS AND EARLY PERMIAN OF THE LOWER SILESIAN BASIN CZECH REPUBLIC

Brou-1

100m

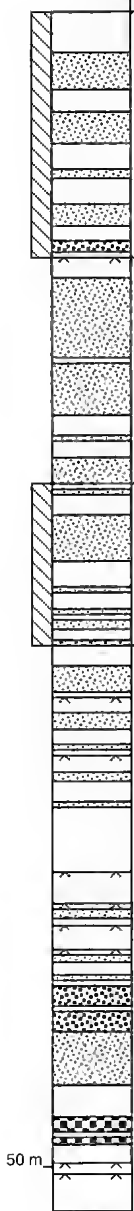
0

Formations (1)	Macroflora (1)	Palynomorphs (1)	Western European Stages (1)	Western European Stages (2)
Broumov	*Autunia conferta* *Autunia naumanii* *Walchia piniformis*	*Potonieisporites novicus* *Florinites*	AUTUNIAN	AUTUNIAN
Chvalec	*Autunia naumanii* *Alethopteris zeilleri* *Odontopteris brardii*	*Cadiospora magna* *Angulisporites splendidus*	C	
Odolov	*Sphenophyllum oblongifolium* *Sphenophyllum thoni v. minor*	*Potonieisporites novicus* *Verrucosisporites grandiverrucosus*	STEPHANIAN B	UPPER STEPHANIAN
			A	LOWER STEPHANIAN
	Sphenophyllum emarginatum *Pseudomariopteris ribeyroni*	*Vestispora fenestrata* *Vestispora quaesita*	CANTABRIAN	
			WESTPHALIAN D	
Zacler	*Sphenophyllum myriophyllum* *Sphenophyllum cuneifolium*	*Torispora securis* *Westphalensisporites striatus*	WESTPHALIAN C	
	Laveineopteris tenuifolia *Paripteris linguaefolia*	*Dictyotriletes bireticulatus* *Savistrisporites camtotus*	WESTPHALIAN B	

LOG. 14. — Czech Republic Basins, coordinated by Oplustil, Pesek, Martinek, Simunek & Drabkova. Late Carboniferous and Early Permian of the lower Silesian Basin. **1**, Oplutil *et al.* (this volume); **2**, this paper. Broumov, Czech Republic, 16°21'E - 50°35'N.

LATE CARBONIFEROUS IN THE CENTRAL AND WESTERN BOHEMIA

OB-1



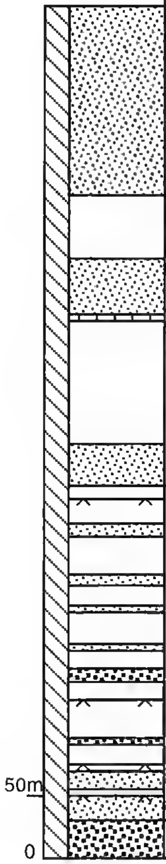
Formations		Macroflora	Palynomorphs	Western European Stages (1)		Western European Stages (2)
Line		*Sphenophyllum angustifolium*, *Sphenophyllum thoni v. minor*, *Pecopteris densifolia*, *Ernestiodendron filiciforme*, *Callipteridium pteridium*, *Odontopteris brardii*, *Odontopteris osmundaeformis*		C	STEPHANIAN	UPPER STEPHANIAN
Slany	Otruby	*Sphenophyllum oblongifolium*, *Sphenophyllum longifolium*	*Granulatisporites granifer*	B	STEPHANIAN	UPPER STEPHANIAN
Slany	Malesice	*Sphenophyllum thoni v. minor*, *Pseudomariopteris ribeyroni*	*Verrucosisporites grandiverrucosus*	B	STEPHANIAN	UPPER STEPHANIAN
Slany	Jelenice	*Odontopteris intermedia*	*Kosankeisporites elegans*	B	STEPHANIAN	UPPER STEPHANIAN
Tynec		*Sigillaria brardii*, *Sphenophyllum thoni v. minor*, *Nemejcopteris feminaeformis*		A	STEPHANIAN	LOWER STEPHANIAN
Kladno	Nyrani	*Sphenophyllum emarginatum*, *Dicksonites pluckeneti*, *Ptychocarpus unitus*	*Vestispora fenestrata*, *Vestispora quaesita*	CANTA-BRIAN		LOWER STEPHANIAN
Kladno	Nyrani	*Praecallipteridium rubescens*, *Sphenophyllum emarginatum*	*Torispora securis*, *Punctatosporites minutus*, *Microreticulosporites nobilis*, *Laevigatosporites minimus*	WESTPHALIAN D		
Kladno	Radnice	*Laveineopteris tenuifolia*, *Sphenophyllum cuneifolium*	*Knoxisporites*, *Pustulatisporites pustulatus*, *Dictyotriletes*	WESTPHALIAN C		

BASEMENT

Log. 15. — Czech Republic Basins, coordinated by Oplustil, Pesek, Martinek, Simunek & Drabkova. Late Carboniferous in the central and western Bohemian. **1**, Oplustil *et al.* (this volume); **2**, this paper. Otruby, Czech Republic, 14°06'E - 50°15'N.

LATE CARBONIFEROUS AND EARLY PERMIAN OF THE BOSKOVICE FURROW

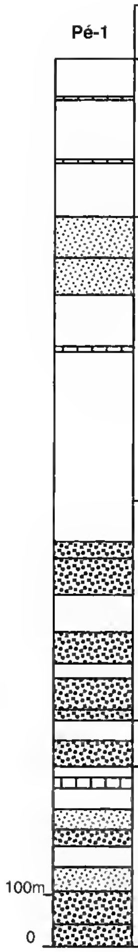
Boskovice



Formations	Macroflora	Palynomorphs	Western European Stages
Upper red	*Walchia piniformis* *Autunia conferta* *Autunia naumanii* *Lodevia nicklesii* *Dichophyllum flabellifera* *Odontopteris minor* *Odontopteris osmondaeformis*	*Potonieisporites novicus* *Florinites minutus*	AUTUNIAN
Rosice-Oslavany	*Odontopteris brardii*		AUTUNIAN
Rosice-Oslavany	*Sphenophyllum angustifolium*		UPPER STEPHANIAN
Basal red			STEPHANIAN C
			BASEMENT

LOG. 16. — Czech Republic Basins, coordinated by Oplustil, Pesek, Martinek, Simunek & Drabkova. Late Carboniferous and Early Permian of the Boskovice Furrow, after Oplustil *et al.* (this volume). Boskowice, Czech Republic, 16°25'E - 49°10'N.

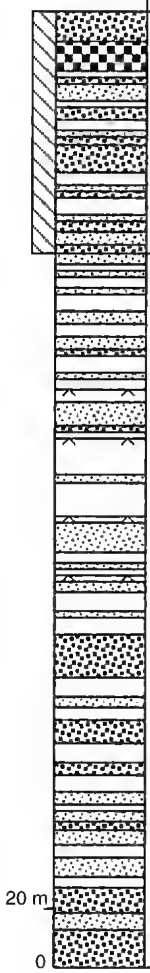
CARBONIFEROUS AND EARLY PERMIAN OF THE KRKONOSE BASIN



Formations	Macroflora	Palynomorphs	Western European Stages (1)	Western European Stages (2)
Prosecne	*Autunia conferta*	*Vesicaspora spp.* *Vittatina costabilis* *Gardenaisporites glomus* *Knoxisporites glomus* *Endosporites formosus*	AUTUNIAN	AUTUNIAN
Vrchlabi	*Autunia conferta* *Ernestiodendron filiciforme*	*Potonieisporites novicus* *Vittaina costabilis* *Protohaploxipinus spp.* *Hamia pollinites*		
Semily	*Ernestiodendron filiciforme* *Callipteris pteridium* *Alethopteris zeilleri* *Odontopteris osmudaeformis*	*Cadiopora magna* *Spinisporites spinosus* *Potonieisporites novicus*	C — STEPHANIAN	UPPER STEPHANIAN
Semily / Syrenov / Kumburk	*Pecopteris unita* *Annularia stellata* *Sphenophyllum emarginatum* *Sphenophyllum oblongifolium*	*Cadiospora magna* *Endosporites formosus* *Verrucosisporites sinensis* *Gillespieisporites spp.*	B, A	LOWER STEPHANIAN
Kumburk	*Alethopteris sp.* *Pecopteridium costei* *Nemejcopteris feminaeformis*	No microflora	CANTABRIAN	
			WESTPHALIAN D	

LOG. 17. — Czech Republic Basins, coordinated by Oplustil, Pesek, Martinek, Simunek & Drabkova. Carboniferous and Early Permian of the Krkonose Basin. **1**, Martinek *et al.* this volume; **2**, this paper. Prosecne, Czech Republic, 15°41'E - 50°34'N.

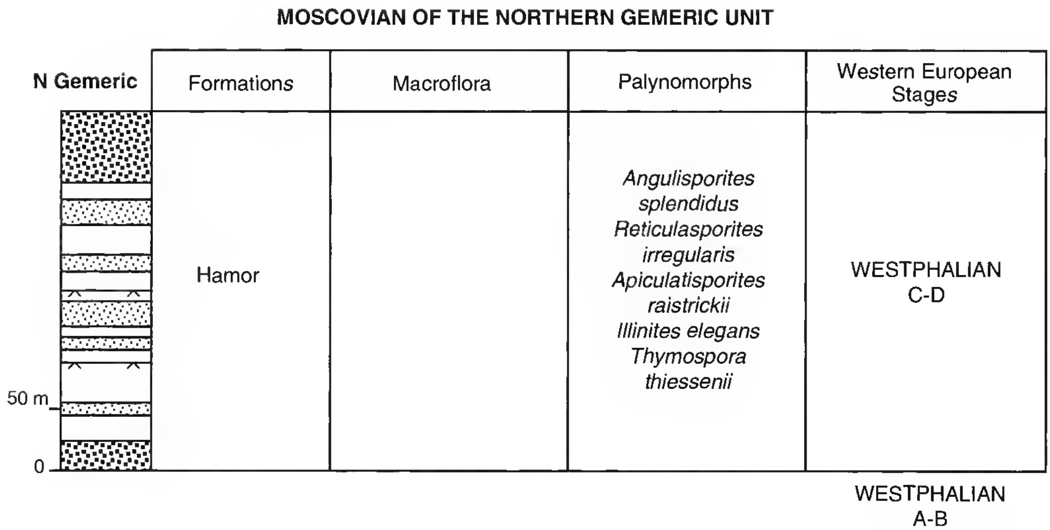
LATE CARBONIFEROUS AND EARLY PERMIAN OF THE KRUSNE HORY MOUNTAINS



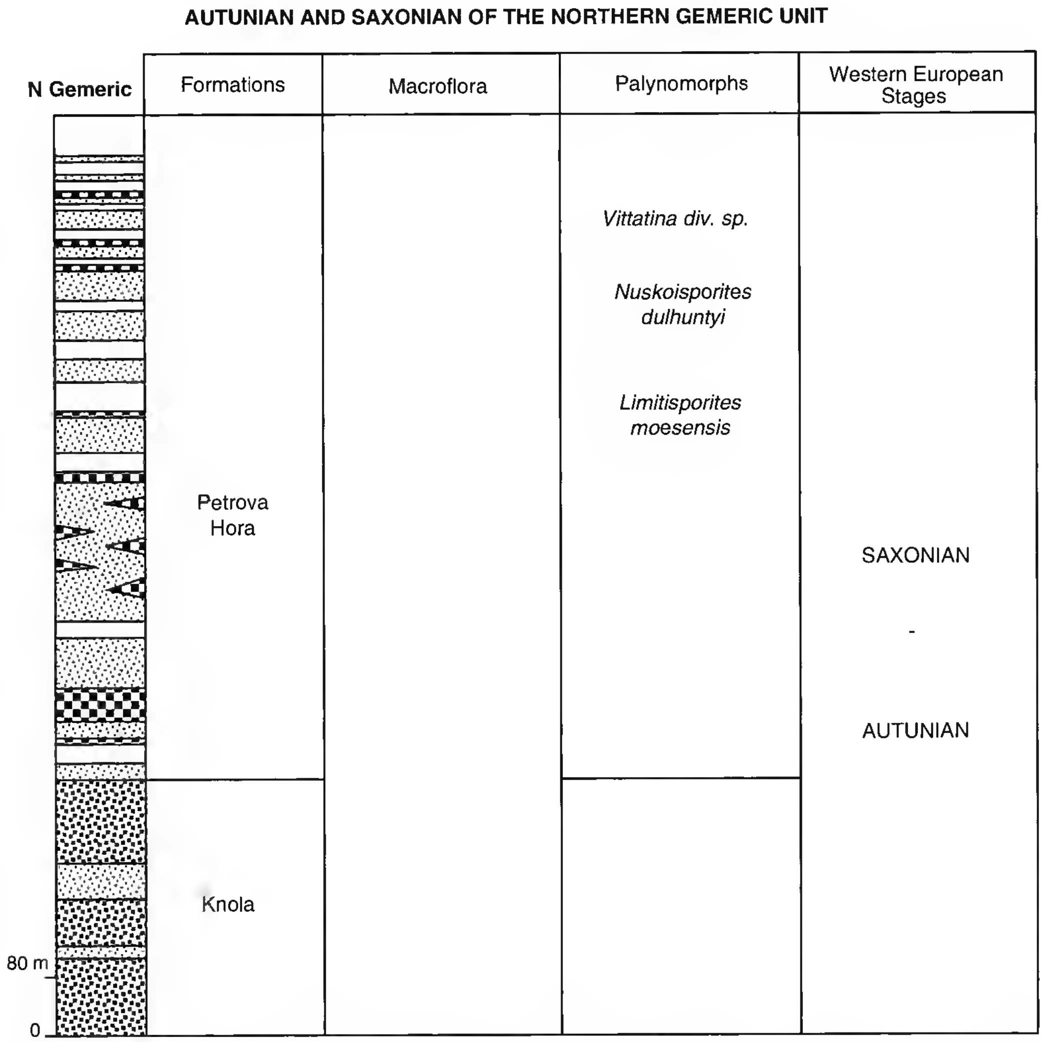
Krusne hory	Formations	Macroflora	Palynomorphs	Western European Stages
	Red			AUTUNIAN - UPPER STEPHANIAN ?
	Grey	*Sphenopteris nummularia* *Paripteris gigantea* *Sphenophyllum cuneifolium* *Corynepteris angustissima* *Senptenbergia pennaeformis*		WESTPHALIAN B-C

BASEMENT

Log. 18. — Czech Republic Basins, coordinated by Oplustil, Pesek, Martinek, Simunek & Drabkova. Late Carboniferous and Early Permian of the Krusne hory Mountains, after Oplustil *et al.* (this volume). Krusne Hory, Czech Republic, 13°24'E - 50°37'N.



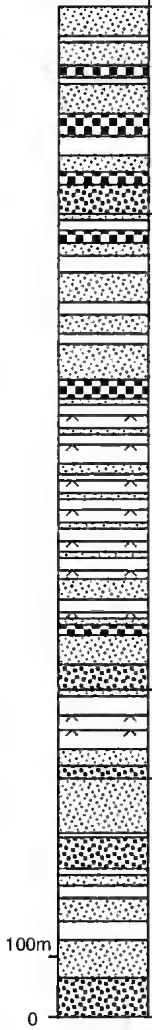
LOG. 19. — Slovak Republic Basins, coordinated by Vozarova. Moscovian of the northern Gemeric unit (Slovak Republic), after Vozarova (this paper). Northern Gemeric, Slovak Republic, 20°30'E - 48°55'N.



LOG. 20. — Slovak Republic Basins, coordinated by Vozarova. Autunian and Saxonian of the northern Gemeric unit (Slovak Republic), after Vozarova (this paper). North Gemeric, Slovak Republic, 20°30'E - 48°55'N.

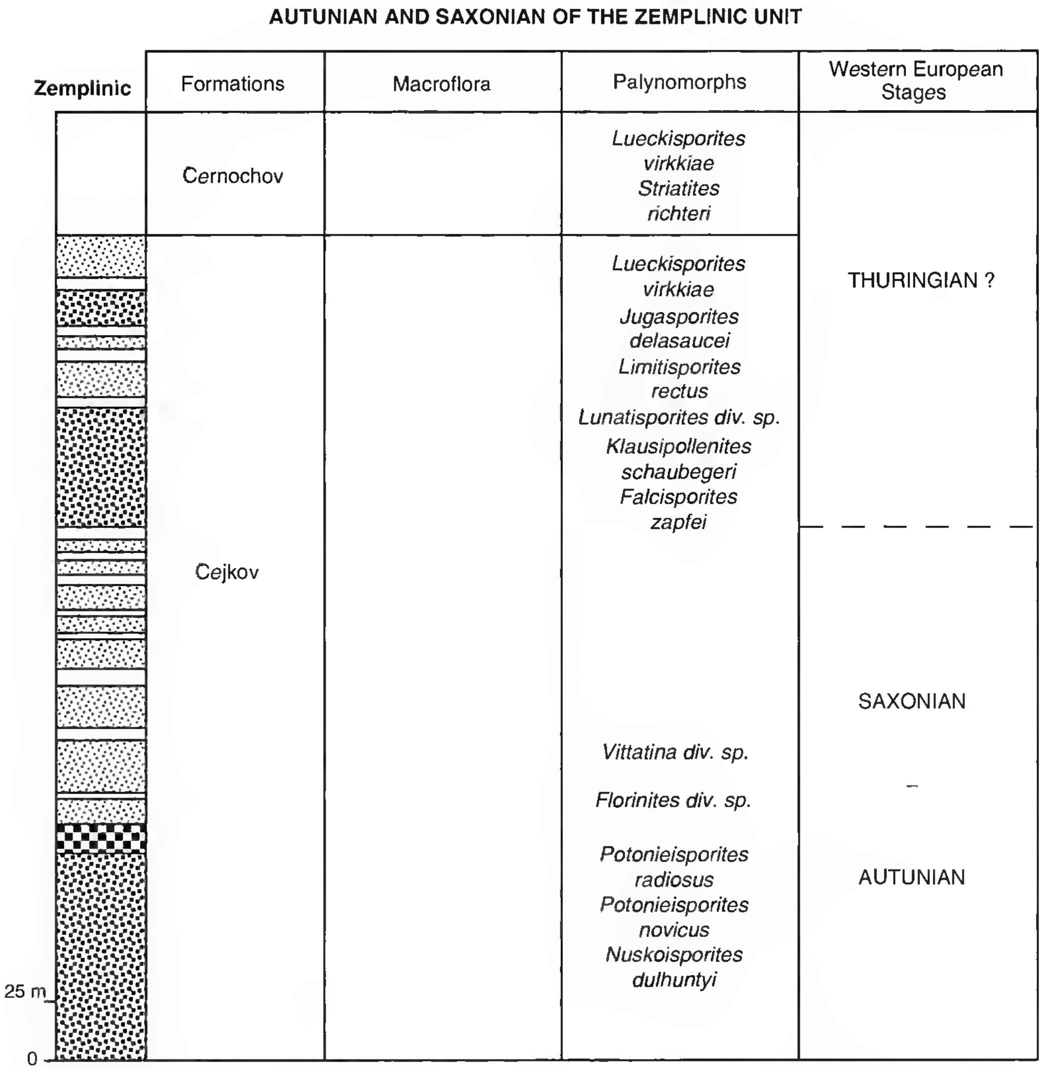
LATE CARBONIFEROUS OF THE ZEMPLINIC UNIT

Zemplinic

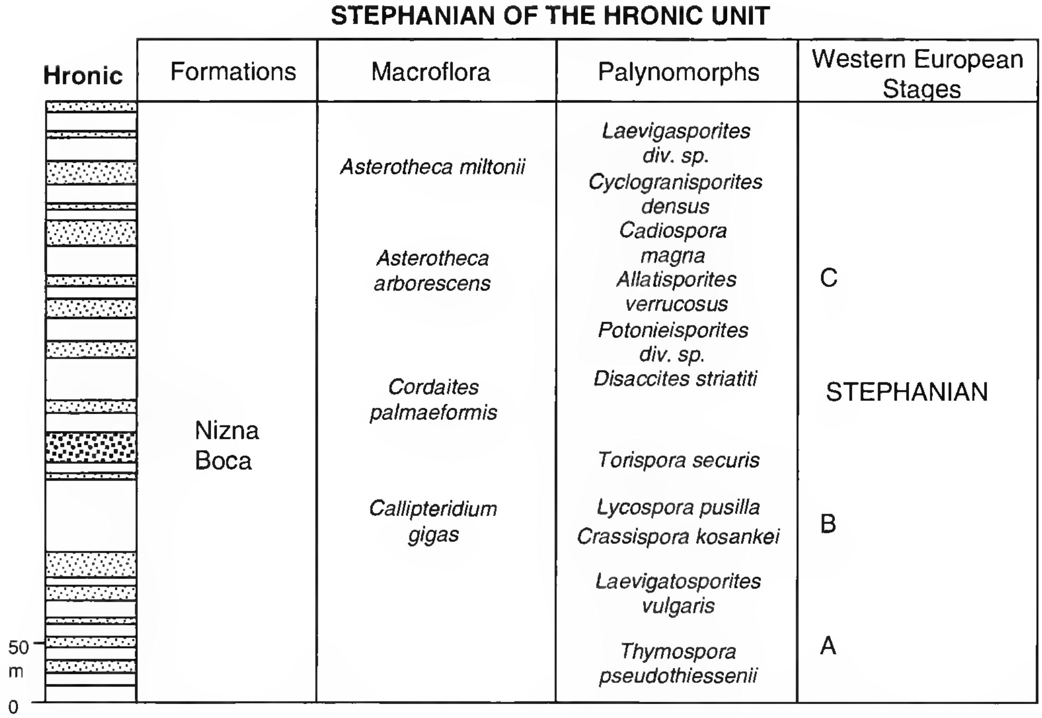


Formations	Macroflora	Palynomorphs	Western European Stages
Kasov	*Dadoxylon sp.*	*Columinisporites ovalis* *Thymospora perverrucosa* *Vestispora fenestrata* *Cyclogranisporites pergranulus*	C
Trna	*Stigmaria ficoides* *Pecopteris cyathea* *Cordaites borrassifolius* *Asterotheca arborescens* *Alethopteris bohemica* *Sphenophyllum oblongifolium* *Annularia pseudostellata*	*Columinisporites* *Lycospora granulata* *Torispora laevigata* *Densosporites plicatus* *Endosporites div. sp.* *Torispora securis* *Thymospora thiessenii* *Thymospora perverucosa*	STEPHANIAN B
Luhyna	*Calamites cistii* *Pecopteris cf miltonii* *Asterophyllites trichomatosus*	*Lycospora pusilla* *Laevigatosporites sp.* *Dendosporites div. sp.*	A
Cerhov		*Triquitres tricuspis* *Microreticulatisporites sulcatus* *Cyrratriradites trizonarius*	WESTPHALIAN C-D

Log. 21. — Slovak Republic Basins, coordinated by Vozarova. Late Carboniferous of the Zemplinic unit (Slovak Republic), after Vozarova (this paper). Zemplinic, Slovak Republic, 21°44'E - 48°30'N.

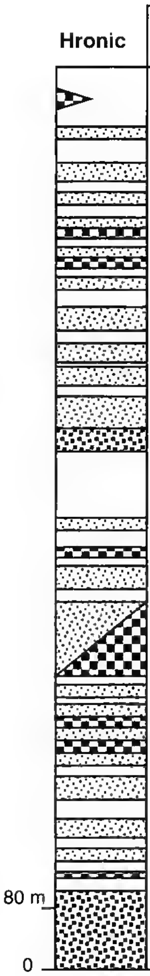


LOG. 22. — Slovak Republic Basins, coordinated by Vozarova. Autunian and Saxonian of the Zemplinic unit (Slovak Republic), after Vozarova (this paper). Zemplinic, Slovak Republic, 21°44'E - 48°30'N.



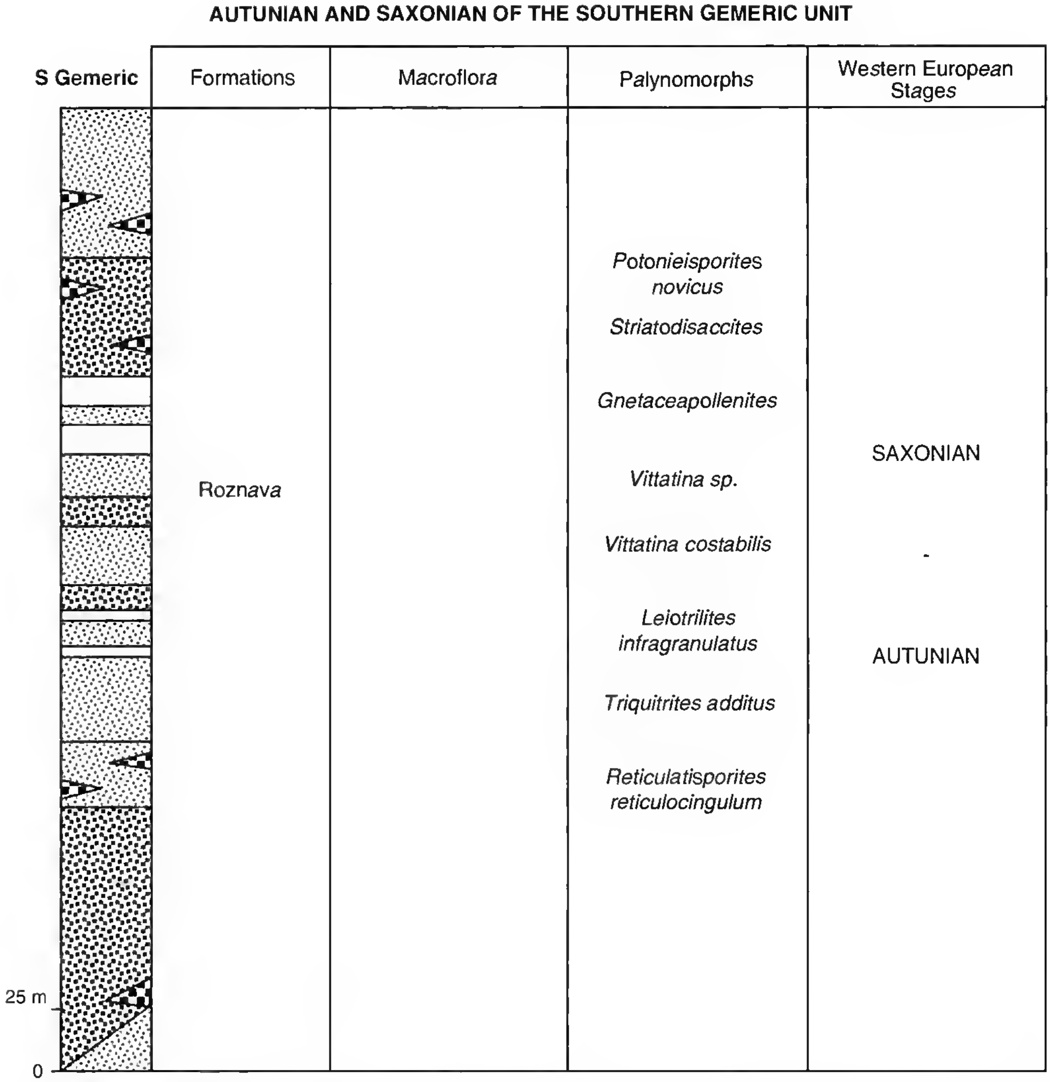
LOG. 23. — Slovak Republic Basins, coordinated by Vozarova. Stephanian of the Hronic unit (Slovak Republic), after Vozarova (this paper). Hronic, Slovak Republic, 19°58'E - 49°03'N.

AUTUNIAN AND SAXONIAN OF THE HRONIC UNIT

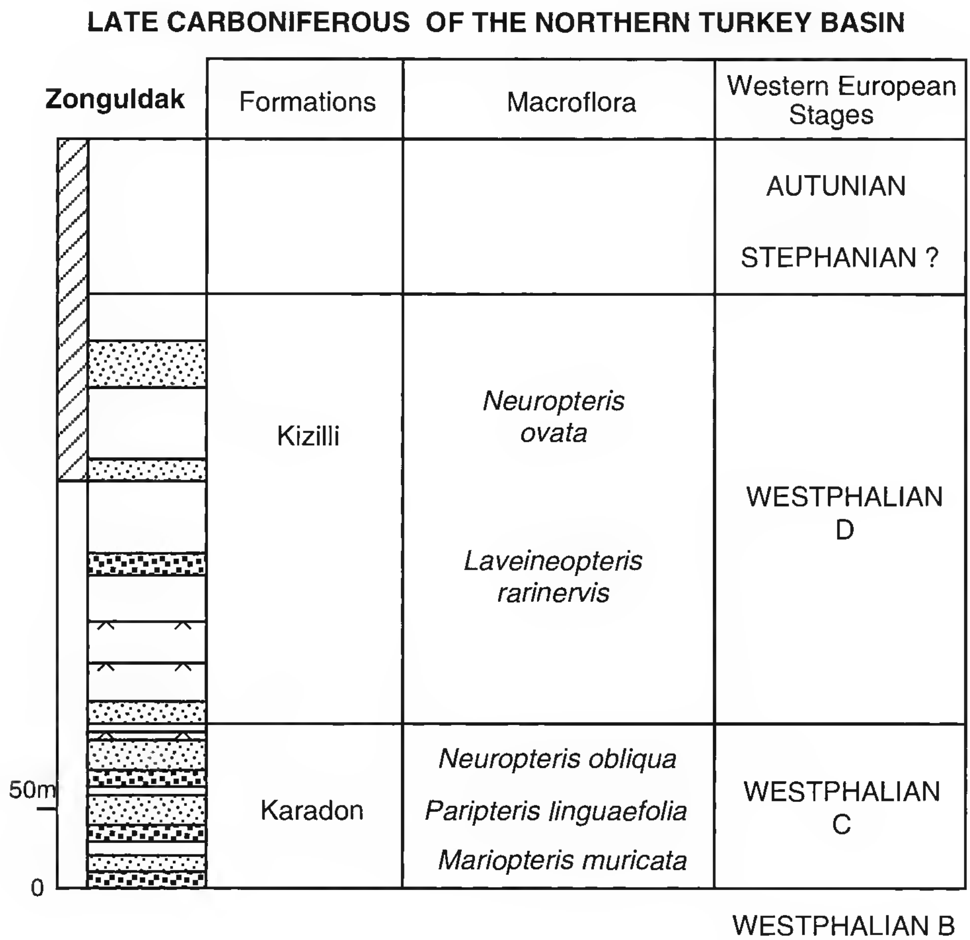


Formations	Macroflora	Palynomorphs	Western European Stages
Maluzina		*Latensina trileta* *Potonieisporites radiosus* *Potonieisporites novicus* *Limitisporites rectus* *Jugasporites delassaucei* *Vittatina ovalis* *Spinosporites exiguus* *Cordaitina sp.* *Vittatina div. sp.* *Punctatisporites speciosus* *Columinisporites ovalis* *Florinites luberae* *Latensina trileta* *Potonieisporites div. sp.* *Illinites unicus* *Disaccites striatiti* *Nuskoisporites dulhuntyi*	SAXONIAN – AUTUNIAN

LOG. 24. — Slovak Republic Basins, coordinated by Vozarova. Autunian and Saxonian of the Hronic unit (Slovak Republic), after Vozarova (this paper). Hronic, Slovak Republic, 19°58'E - 49°03'N.



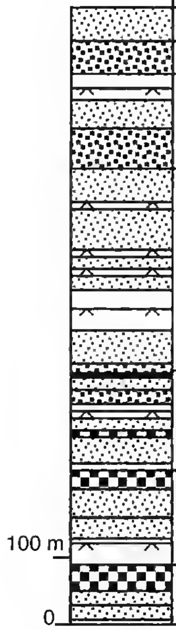
Log. 25. — Slovak Republic Basins, coordinated by Vozarova. Autunian and Saxonian of the southern Gemeric unit, after Vozarova (this paper). Southern Gemeric, Slovak Republic, 20°18'E - 48°40'N.



LOG. 26. — Late Carboniferous of the Northern Turkey Basin, coordinated by Izart, Izart (this paper) after Görur *et al.* (1997) and Kerey *et al.* (1985). Zonguldak, North Turkey, 31°30'E - 41°15'N.

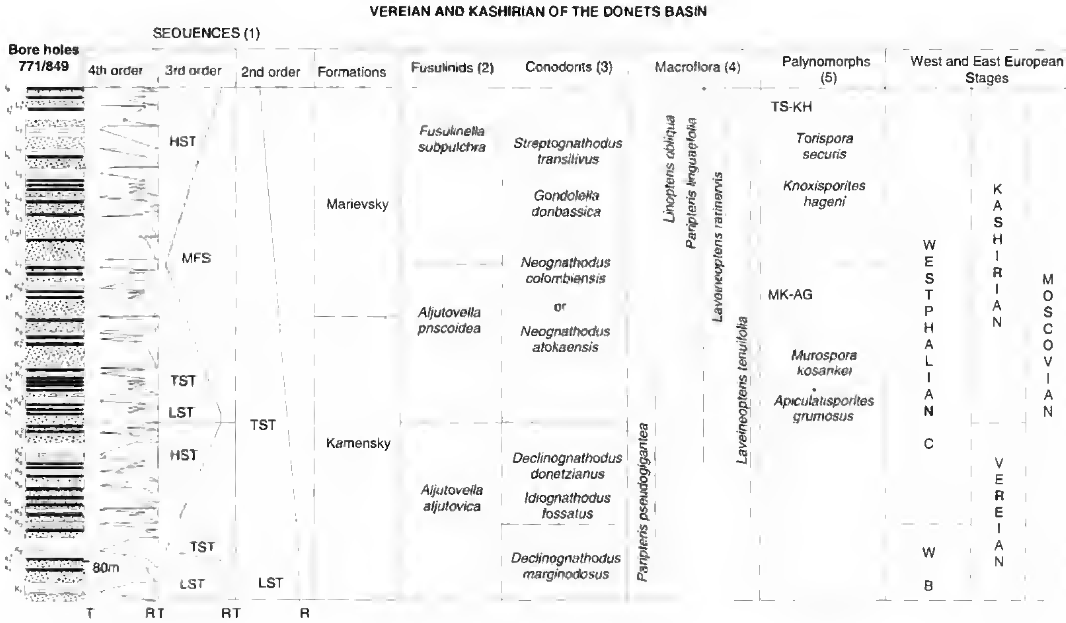
LATE CARBONIFEROUS OF THE CAUCASUS BASIN

N Caucasus

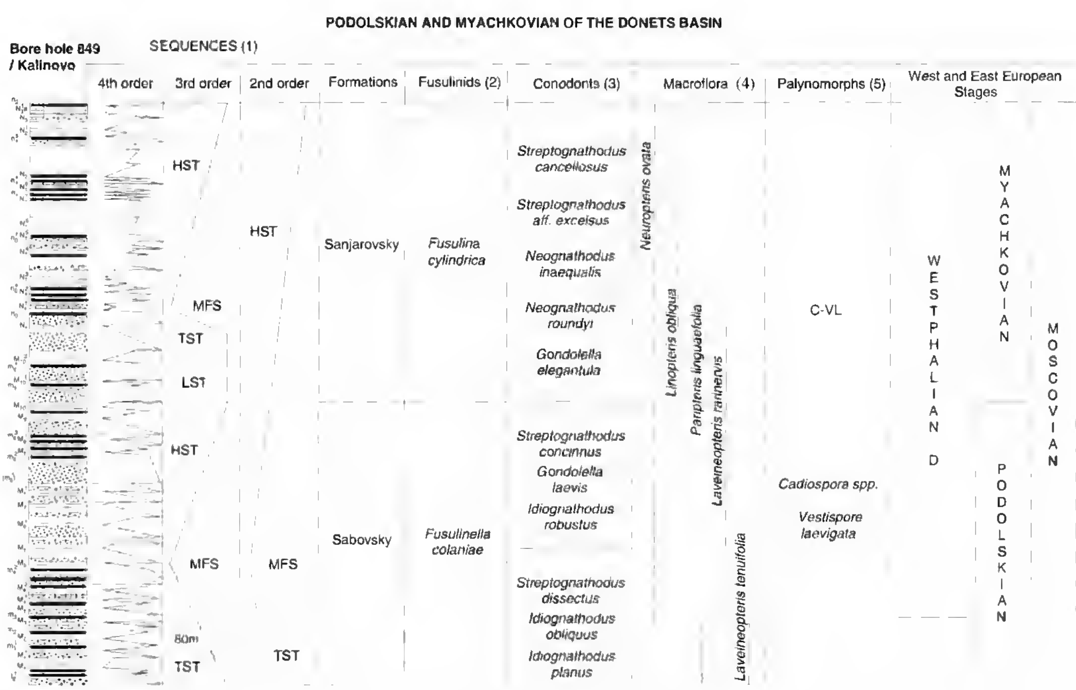


Formations	Macroflora	Western European Stages	Eastern European Stages	
	Walchia piniformis	AUTUNIAN	PERMIAN ?	
		UPPER STEPHANIAN	GZHELIAN	
	Asterotheca hemitelioides *Annularia stellata* *Sigillaria brardii*	LOWER STEPHANIAN	KASIMOVIAN	
	Sphenophyllum emarginatum	WESTPHALIAN D	Myachkovian Podolskian	MOSCOVIAN
	Sphenophyllum majus *Linopteris obliqua* *Neuropteris gigantea*	WESTPHALIAN C	Kashirian	MOSCOVIAN
			Vereian	MOSCOVIAN

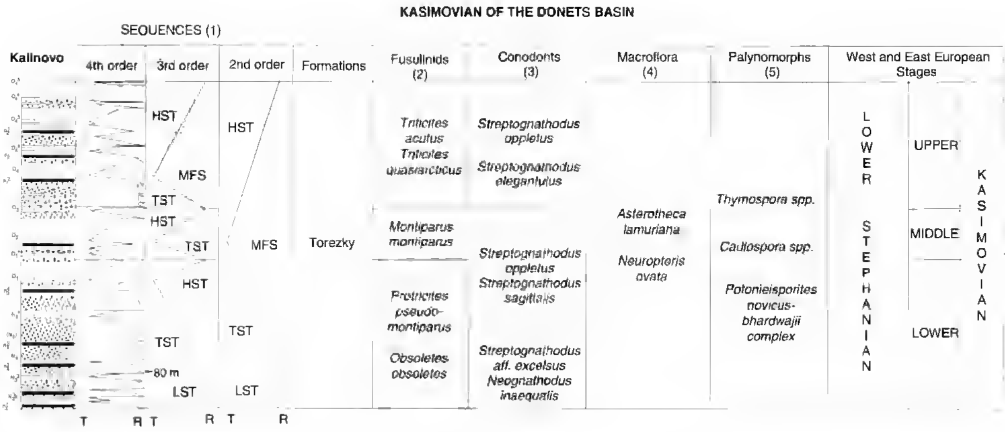
Log. 27. — Late Carboniferous of the Caucasus Basin, coordinated by Izart, Izart (this paper) after Chernyavsky *et al.* (1978). Labinskoe, Russia, 42°E - 44°N.



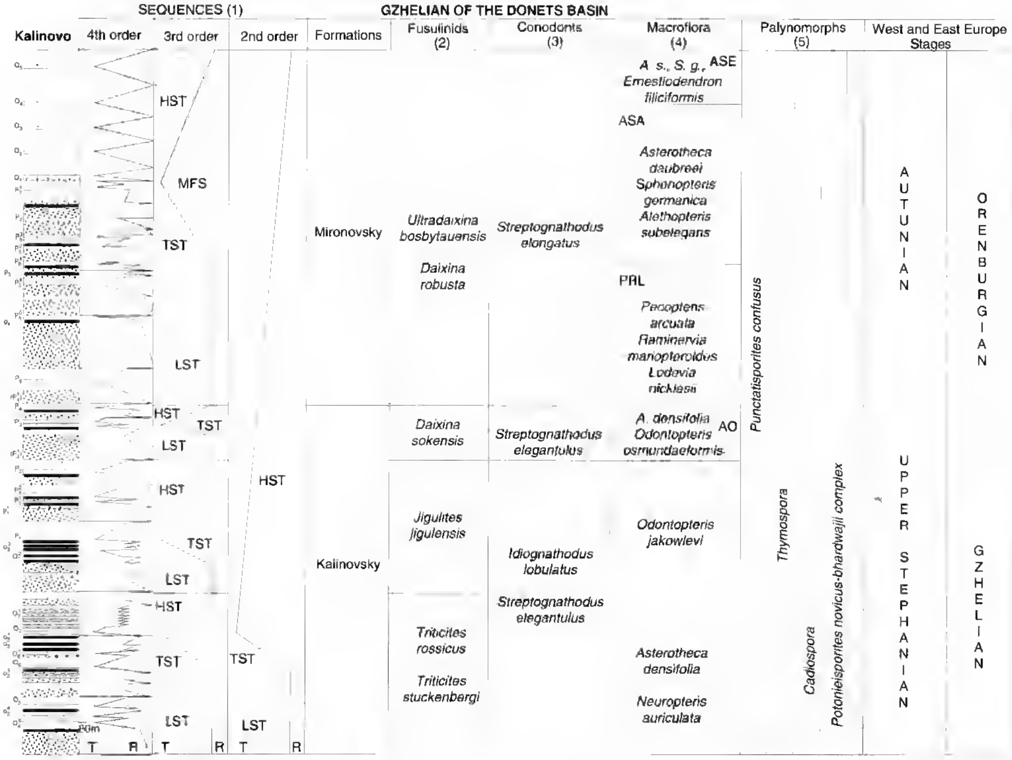
Log. 28. — Donets Basin (Ukraine), coordinated by Izart *et al.* (1996, 1998). Vereian and Kashirian of the Donets Basin. **1**, Izart *et al.* (1996); **2**, Vachard & Maslo (this paper); **3**, Kozitkaya (this paper); **4**, Laveine (this paper); **5**, Coquel (this paper). Boreholes 771/849, 38°30'E - 48°12'N.



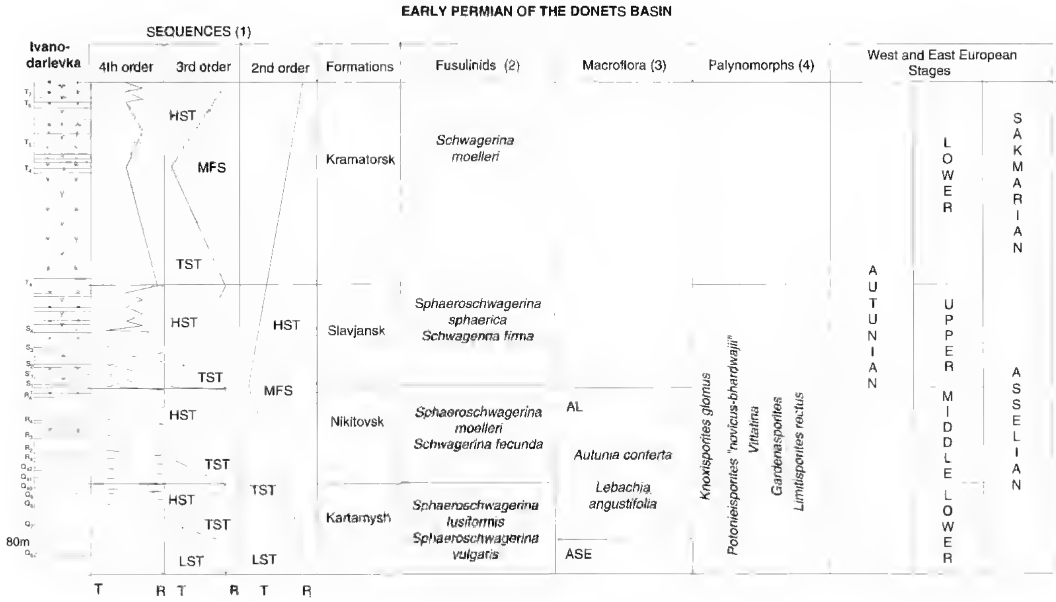
Log. 29. — Donets Basin (Ukraine), coordinated by Izart *et al.* (1996, 1998). Podolskian and Myachkovian of the Donets Basin. **1**, Izart *et al.* (1996); **2**, Vachard & Maslo (this paper); **3**, Kozitkaya (this paper); **4**, Laveine (this paper); **5**, Coquel (this paper). Boreholes 771/849, 38°30'E - 48°12'N.



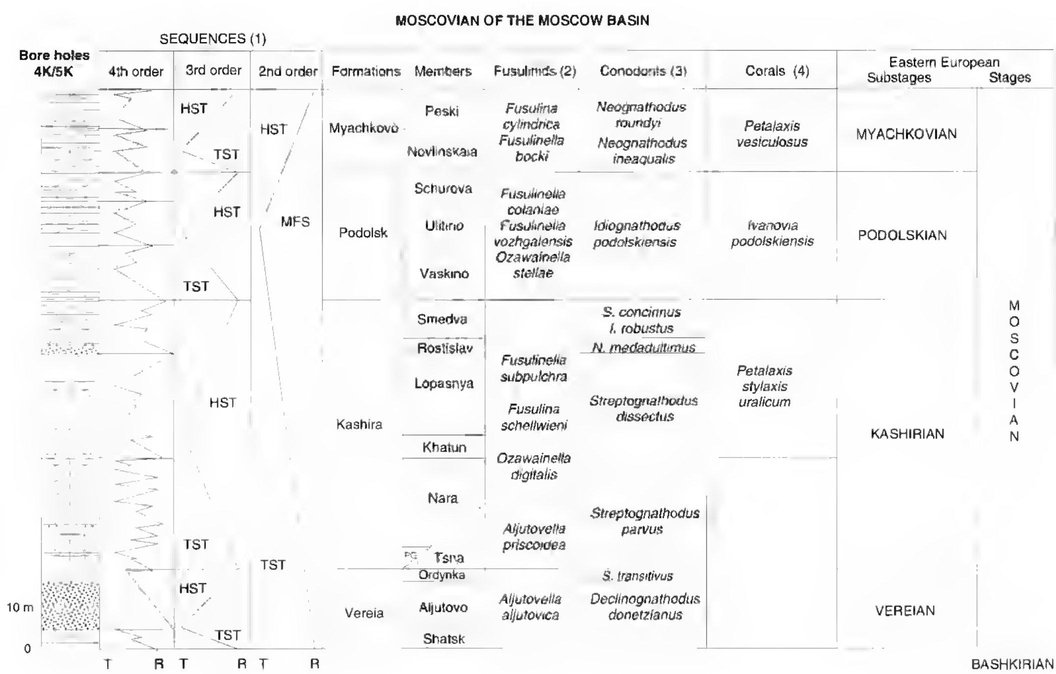
LOG. 30. — Donets Basin (Ukraine), coordinated by Izart *et al.* (1996, 1998). Kasimovian of the Donets Basin. **1**, Izart *et al.* (1996); **2**, Vachard & Maslo (this paper); **3**, Kozitkaya (this paper); **4**, Stchegolev (this paper); **5**, Broutin (this paper). Kalinovo cross-section, 38°48'E - 48°36'N.



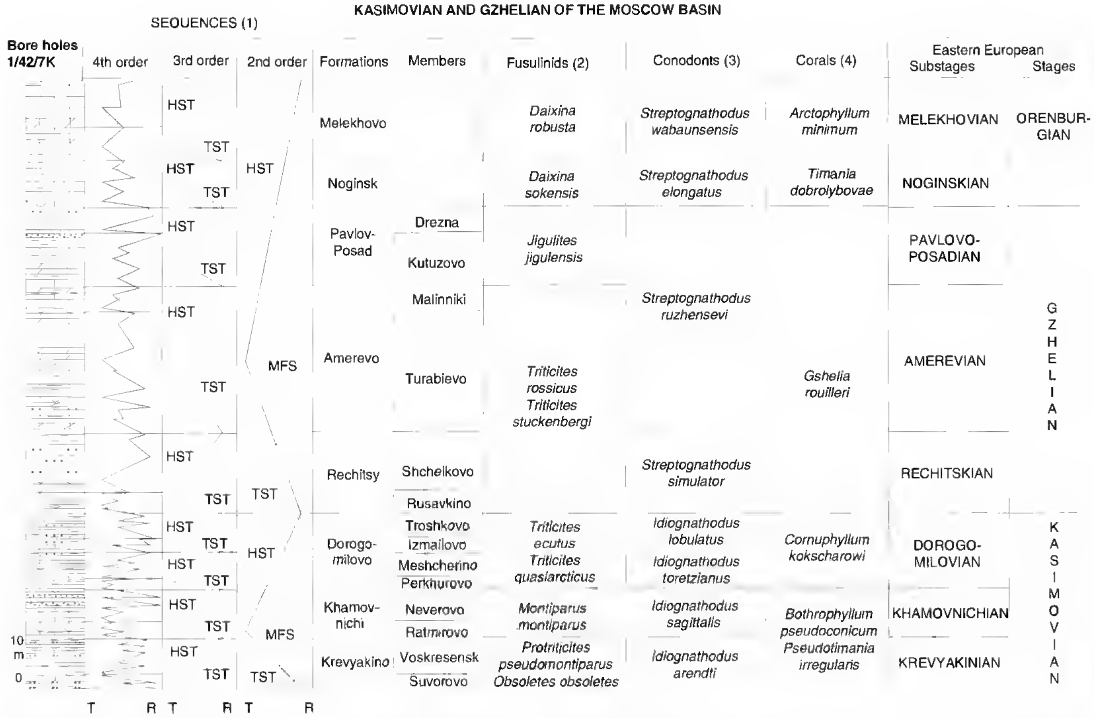
LOG. 31. — Donets Basin (Ukraine), coordinated by Izart *et al.* (1996, 1998). Gzhelian and Orenburgian of the Donets Basin. **1**, Izart *et al.* (1996); **2**, Vachard & Maslo (this paper); **3**, Kozitkaya (this paper); **4**, Stchegolev (this paper); **5**, Broutin (this paper). Kalinovo cross-section, 38°48'E - 48°36'N.



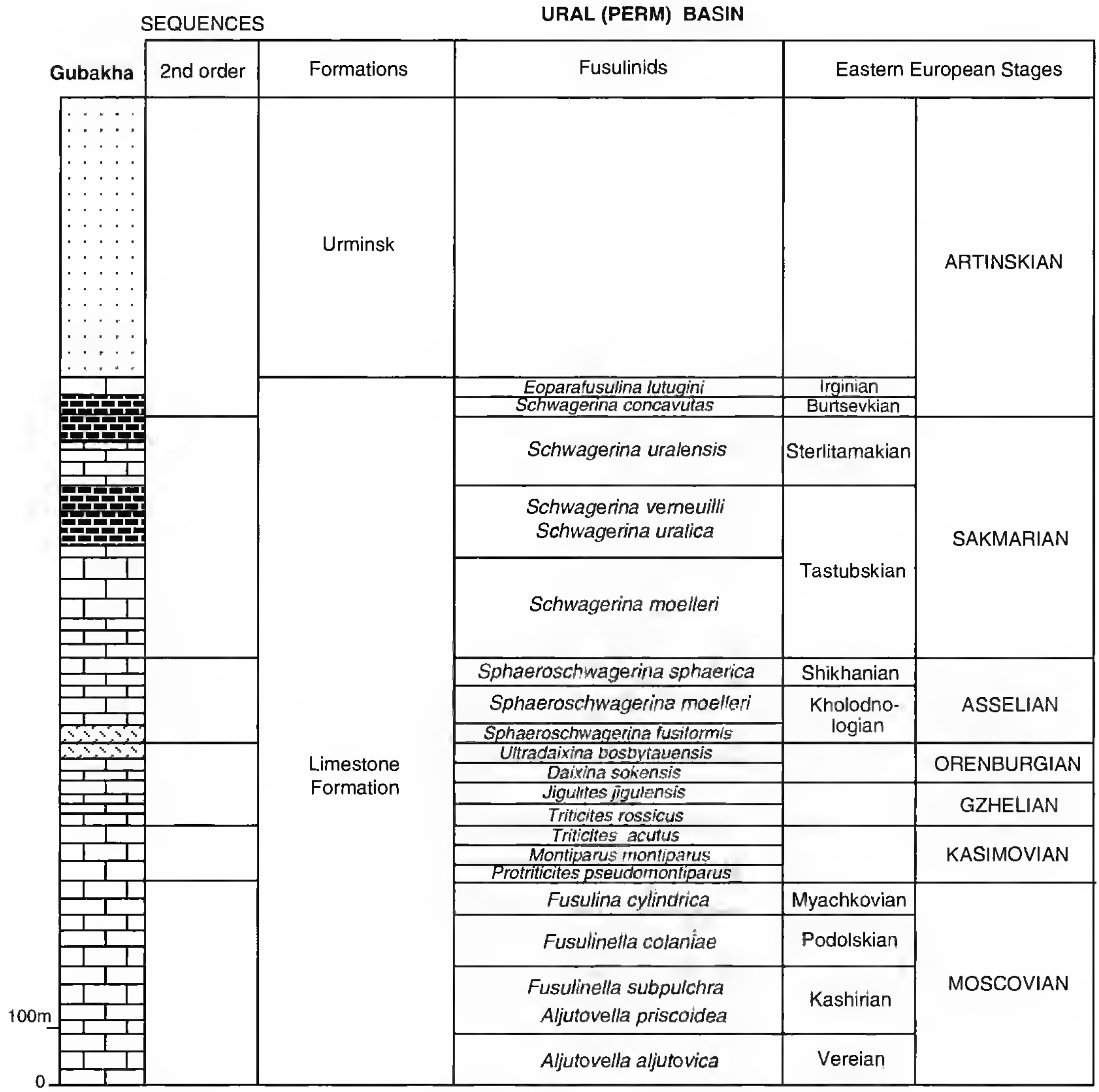
Log. 32. — Donets Basin (Ukraine), coordinated by Izart *et al.* (1996, 1998). Early Permian of the Donets Basin. **1**, Izart *et al.* (1996); **2**, Vachard & Maslo (this paper); **3**, Stchegolev (this paper); **4**, Broutin (this paper). Ivanovo-Darievka cross-section, 37°30'E - 48°30'N.



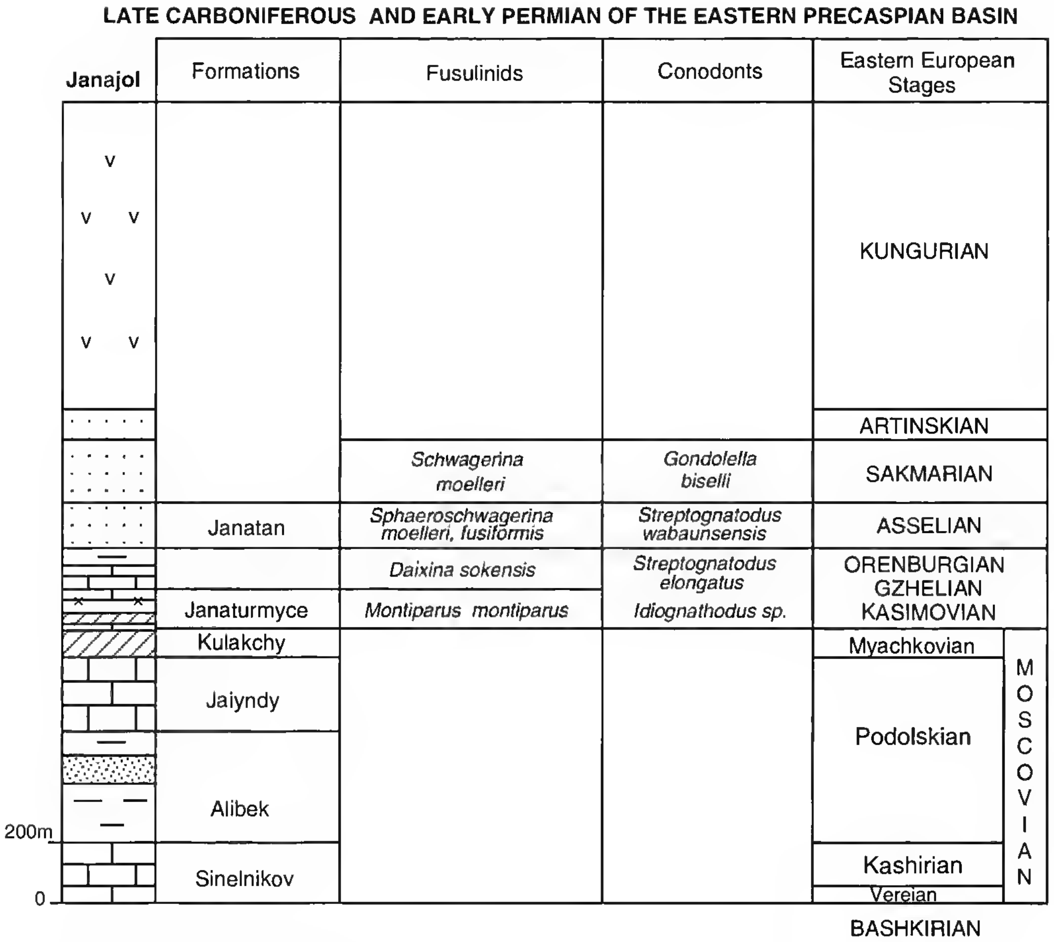
Log. 33. — Moscow Basin, coordinated by Briand *et al.* Moscovian of the Moscow Basin. **1**, Briand *et al.* (1998); **2**, Makhlina *et al.* (1997); **3**, Goreva (this paper); **4**, Kossovaya (this paper). Borehole 4K, 37°30'E - 55°N; Borehole 5K, 38°E - 55°45'N.



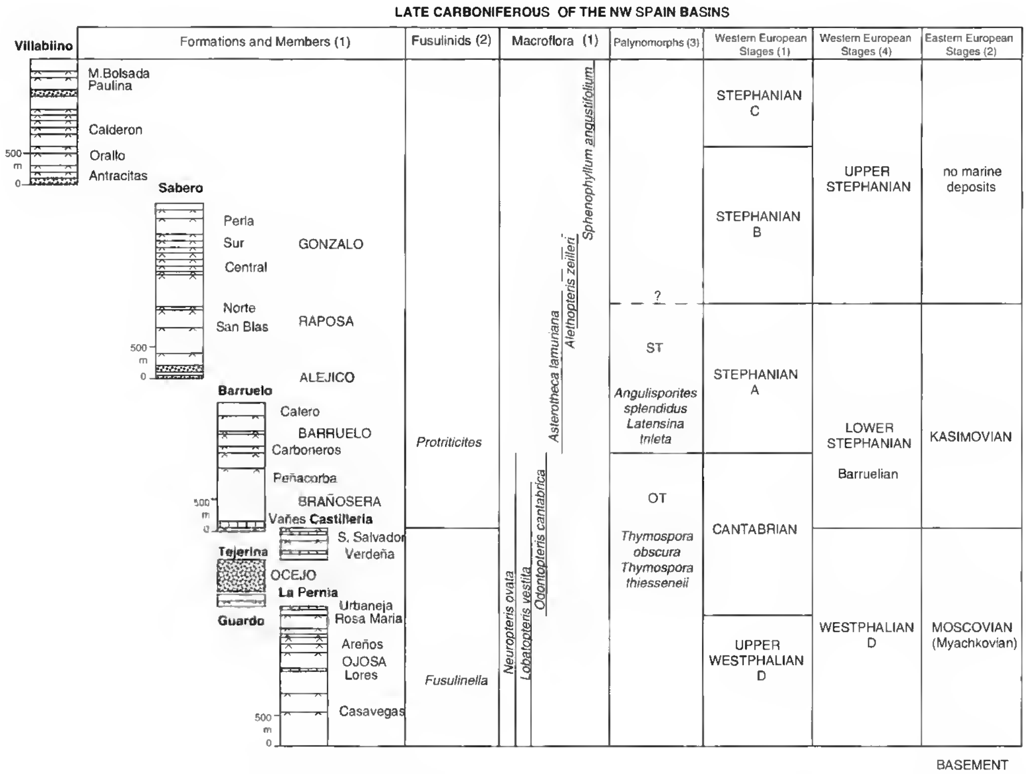
Log. 34. — Moscow Basin, coordinated by Briand *et al.* Kasimovian and Gzhelian of the Moscow Basin. **1**, Briand *et al.* (1998); **2**, Makhlina *et al.* (1997); **3**, Goreva (this paper); **4**, Kossovaya (this paper). Boreholes 1/42, 35°50'E - 56°42'N; Borehole 7K, 38°30'E -56°N.



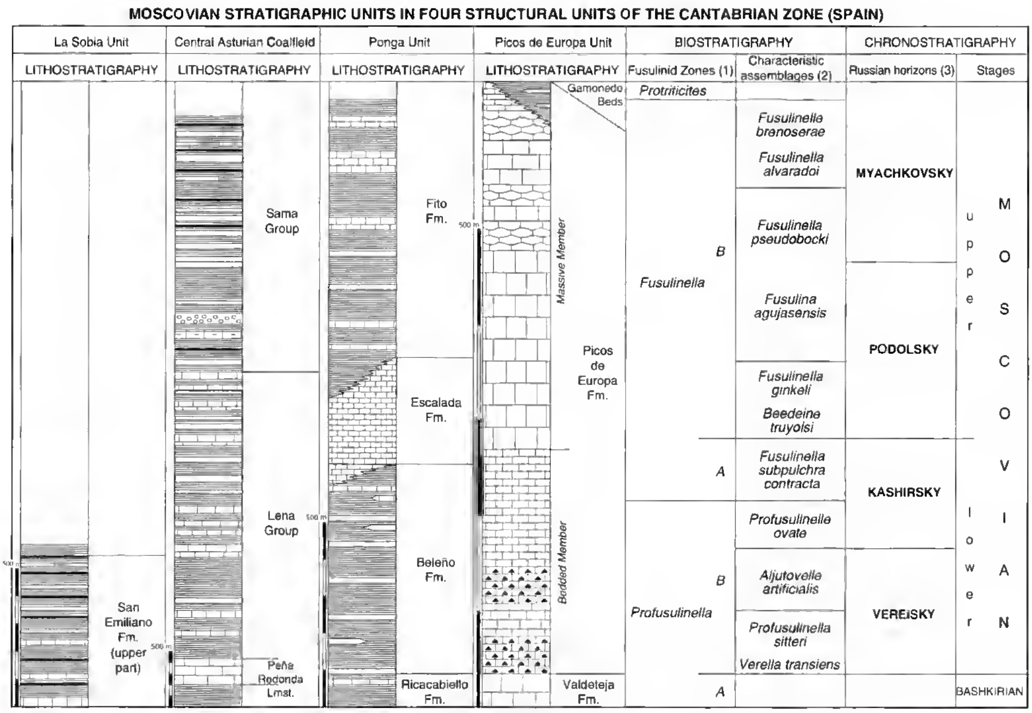
LOG. 35. — Moscovian to Artinskian in Central Ural Basin (Perm), coordinated by Izart *et al.*, after Chuvachov (1993). Gubakha, Russia, 57°30'E - 58°50'N.



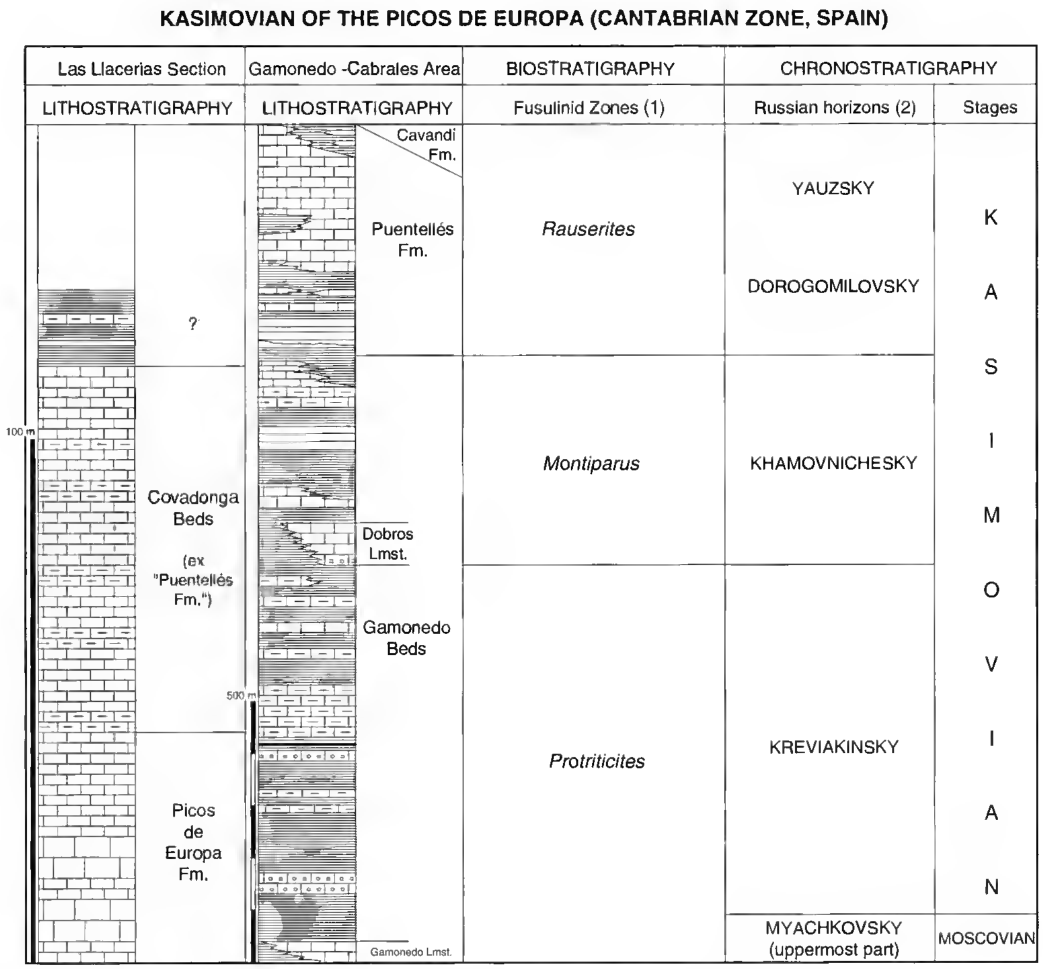
LOG. 36. — Late Carboniferous and Early Permian of the Eastern Precaspian Basin (Kazakhstan), coordinated by Ensepbaev, after Ensepbaev (this paper). Janajol, Kazakhstan, 57°E - 50°N.



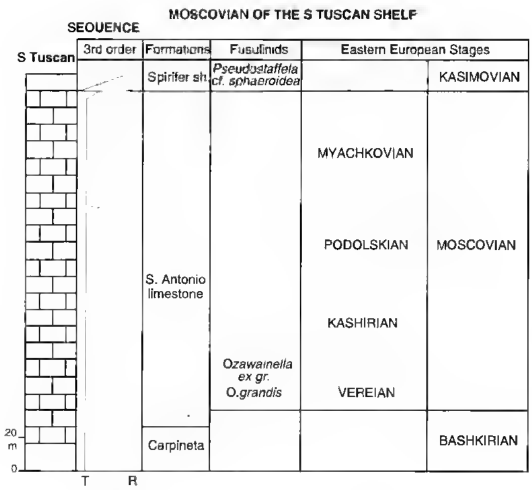
LOG. 37. — Late Carboniferous of northwestern Spain Basins, coordinated by Izart. **1**, Bouroz *et al.* (1972), Wagner & Winkler-Prins (1985); **2**, Lys (1988a); **3**, Coquel (this paper); **4**, this volume. La Pernia, Spain, 4°30'W - 43°N; Guardo, Spain, 4°50'W - 42°53'N; Tejerina, Spain, 5°01'W - 42°55'N; Castilleria, Spain, 4°28'W - 42°56'N; Barruello, Spain, 4°16'W - 42°53'N; Sabero, Spain, 5°10'W - 42°50'N; Villablino, Spain, 6°10'W - 42°58'N.



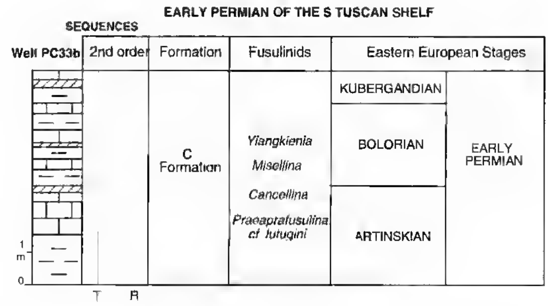
LOG. 38. — Cantabrian Basin (Spain), coordinated by Villa. Moscovian stratigraphic subdivisions in four structural units of the Cantabrian zone (Spain). **1**, after van Ginkel (1965); **2**, **3**, Villa (this paper). Mieres, Spain, 5°47'W - 43°16'N.



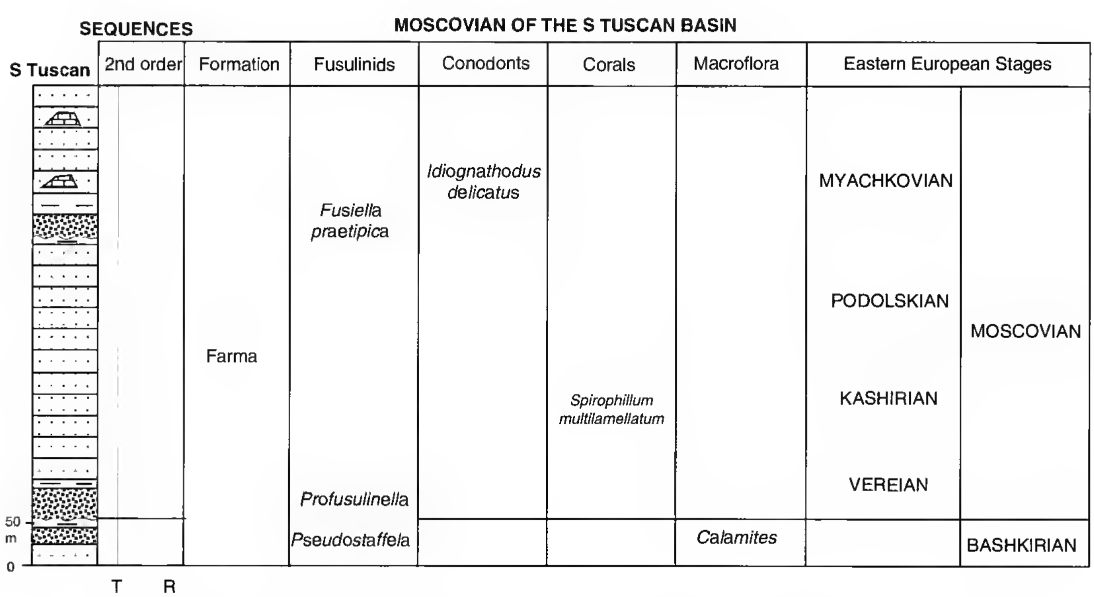
LOG. 39. — Cantabrian Basin (Spain), coordinated by Villa. Kasimovian of the Picos de Europa (Cantabrian zone, Spain). **1**, according to Villa (1985, modified); **2**, Villa (this paper). Picos de Europa, Spain, 4°50'W - 43°15'N.



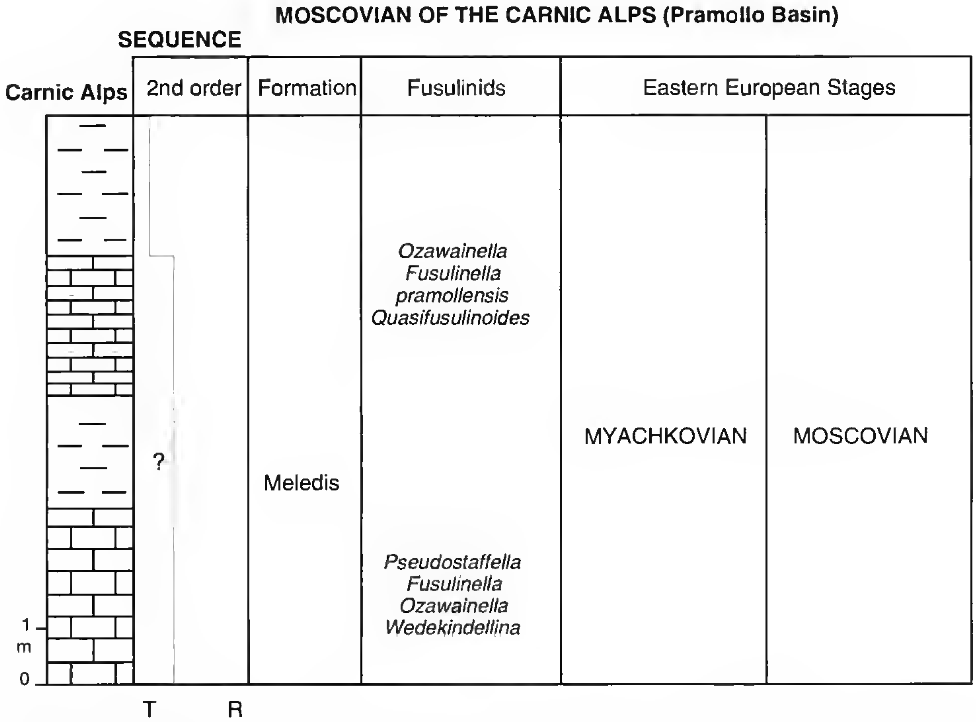
Log. 40. — Italy Basins, coordinated by Pasini & Vai. Moscovian of the southern Tuscan Shelf, Pasini & Vai (1997).



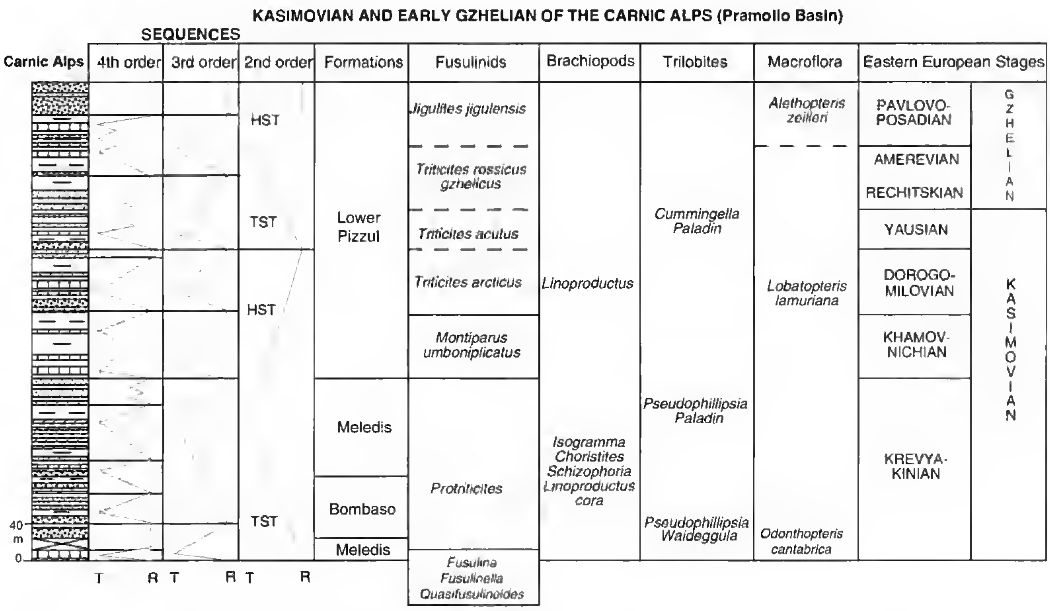
Log. 41. — Italy Basins, coordinated by Pasini & Vai. Early Permian of the southern Tuscan shelf, Pasini & Vai (1997).



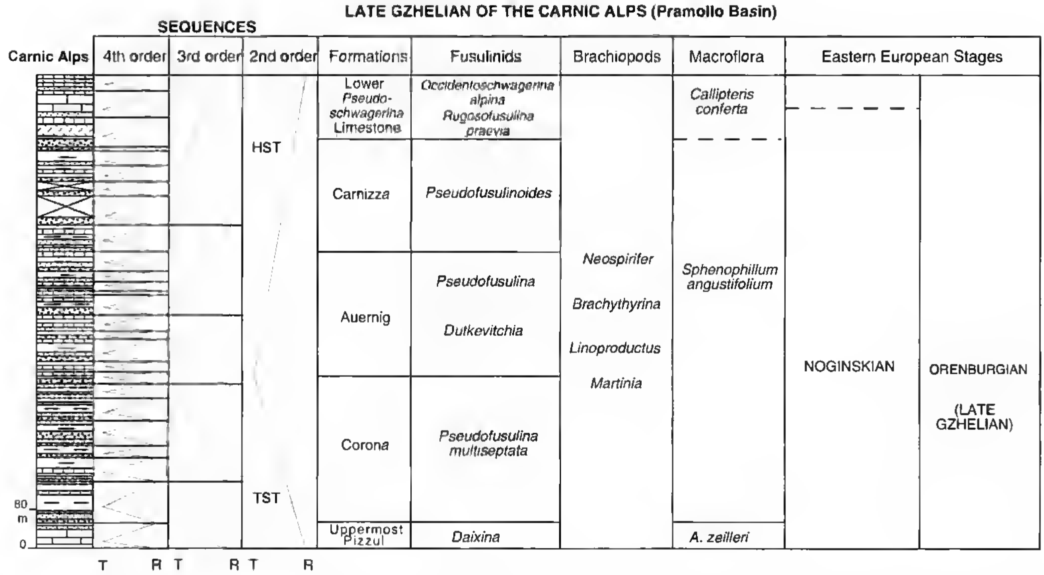
Log. 42. — Moscovian of the southern Tuscan Basin, Pasini & Vai (1997), Borehole PC33b (Tuscany, Italy).



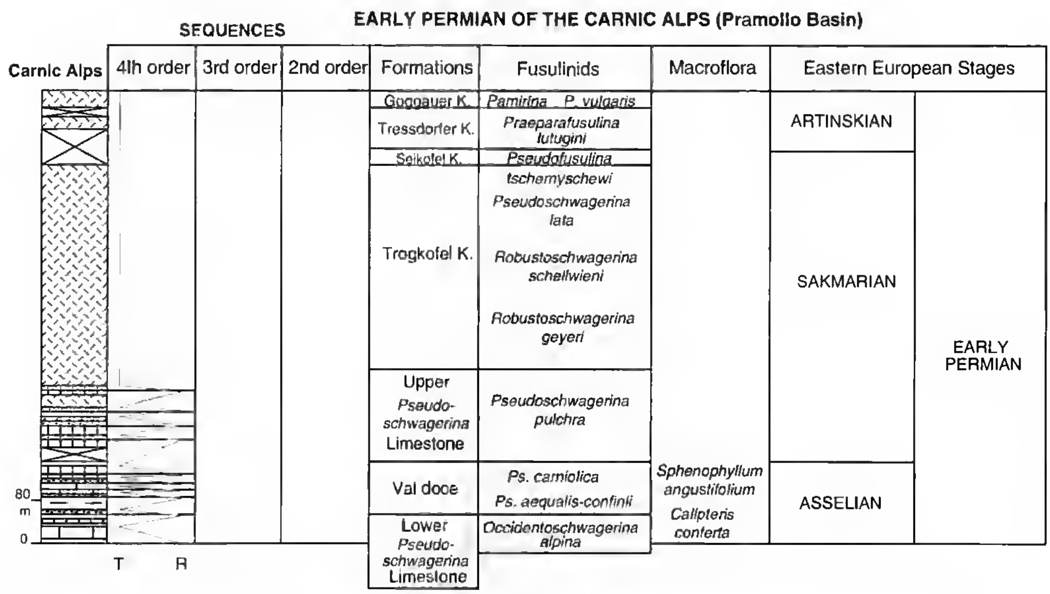
LOG. 43. — Austria boundary, coordinated by Vai, Pasini & Venturi. Moscovian of the Carnic Alps (Pramollo Basin), Pasini (this paper).



LOG. 44. — Austria boundary, coordinated by Vai, Pasini & Venturi. Kasimovian and early Gzhelian of the Carnic Alps (Pramollo Basin), Vai & Venturi (1997).

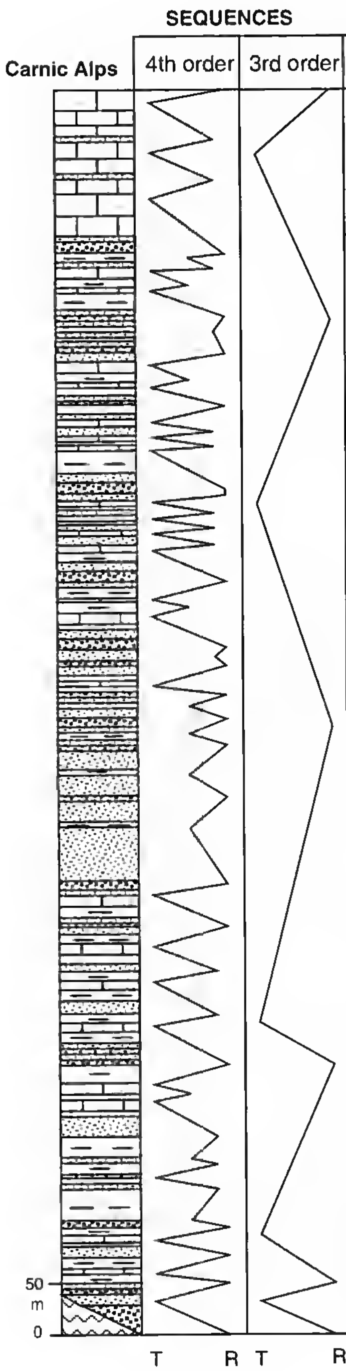


LOG. 45. — Austria boundary, coordinated by Vai, Pasini & Venturi. Late Gzhelian of the Carnic Alps (Pramollo Basin), Vai & Venturi (1997).



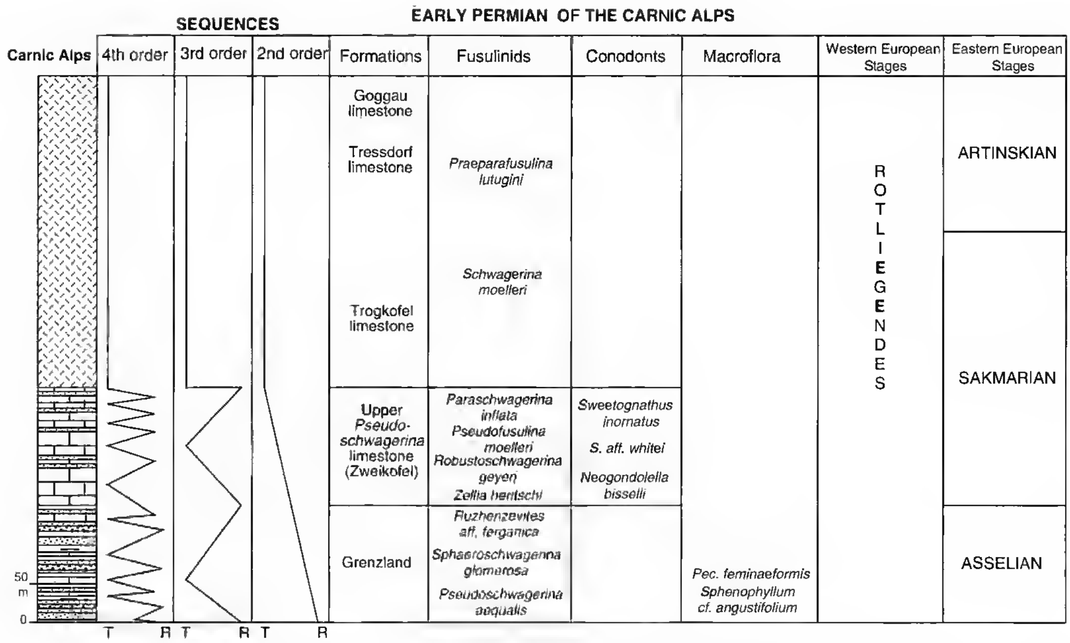
LOG. 46. — Austria boundary, coordinated by Vai, Pasini & Venturi. Early Permian of the Carnic Alps (Pramollo Basin), Vai & Venturi (1997).

LATE CARBONIFEROUS OF THE CARNIC ALPS

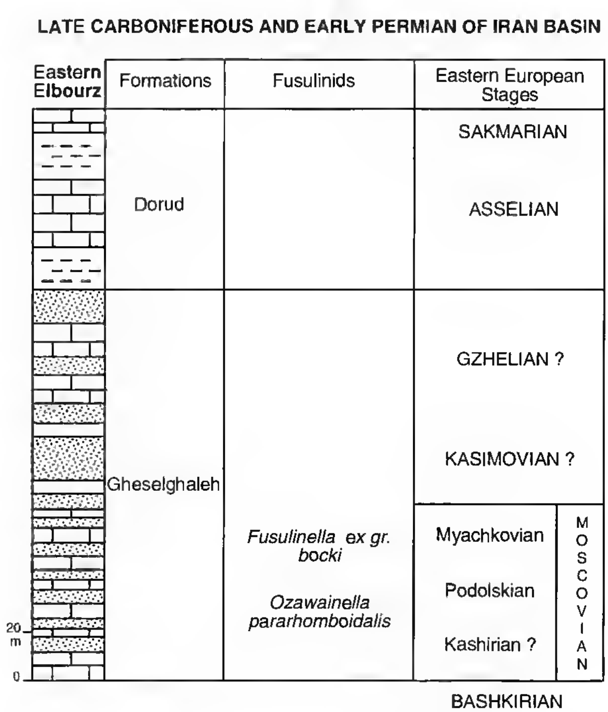


Formations	Fusulinids	Macroflora	West & East European Stages	
Lower Pseudo-schwagerina Limestone (Schulter-kotel)	*Ul.dahtidzhumica*, *Ul. bosbytauensis*, *Occidento-schwagerina alpina*, *Sch.ulukensis*, *Ruzhenzevites ferganensis*		STEPHANIAN C	ORENBURGIAN
Carnizza	*Pseudofusulinoides regularis*, *Triticites immutabilis*, *T. paraduplex*, *T. perlongus*, *T. turkestanensis*	*Sphenophyllum oblongifolium*, *Aphlebia elongata*, *Odont. alpina*, *Odont. brardii*, *Pec. feminaeformis*	STEPHANIAN C	ORENBURGIAN
Auernig	*Schagonella gigantea*, *Pseudofusulina devexa acallosa*, *P. multiseptata*, *P. paraconcinna*, *Dutkevitchia dastarensis*, *D. kargalensis*, *D. ruzhoncevi*	*Aphlebia elongata*, *Alethopt. bohemica*, *Odontopteris brardii*, *Pec. feminaeformis*, *Callipt. pteridium*, *Pec. ex gr. arborescens-schlotheimii*	STEPHANIAN C	ORENBURGIAN
Corona	*Daixina alpina*, *D. ex gr. admirabilis*, *Schagonella spp.*, *Pseudofusulina multiseptata*	*Alethopteris bohemica*, *Odontopteris alpina*, *Odontopteris brardii*, *Pec. feminaeformis*, *Pseudomariopteris busquetii*, *Sigillaria brardii*, *Sphenophyllum oblongifolium*	STEPHANIAN C	GZHELIAN
Pizzul	*Daixina alpina*, *D. sokensis*, *D. naviculaeformis*, *D. sakmarensis*, *Triticites oryziformis*, *Jigulites jigulensis*, *Schagonella spp.*, *Daixina sp.*	*Pseudo-mariopteris busquetii*, *Sphenophyllum oblongifolium*	STEPHANIAN C	GZHELIAN
Meledis	*Rauserites sp.*, *Ferganites aff. ferganensis*, *Montiparus montiparus*, *Protriticites pseudomontiparus*	*Sphenophyllum angustifolium*, *Sphenophyllum oblongifolium*	STEPHANIAN C	GZHELIAN / KASIMOVIAN
Bombaso	*Protriticites ovatus*, *Quasifusulinoides quasifusulinoides*	*Linopteris neuropteroides*, *Neuropteris ovata*, *N. scheuchzeri*, *Sphenophyllum oblongifolium*	CANTABRIAN	KASIMOVIAN / MOSCOVIAN

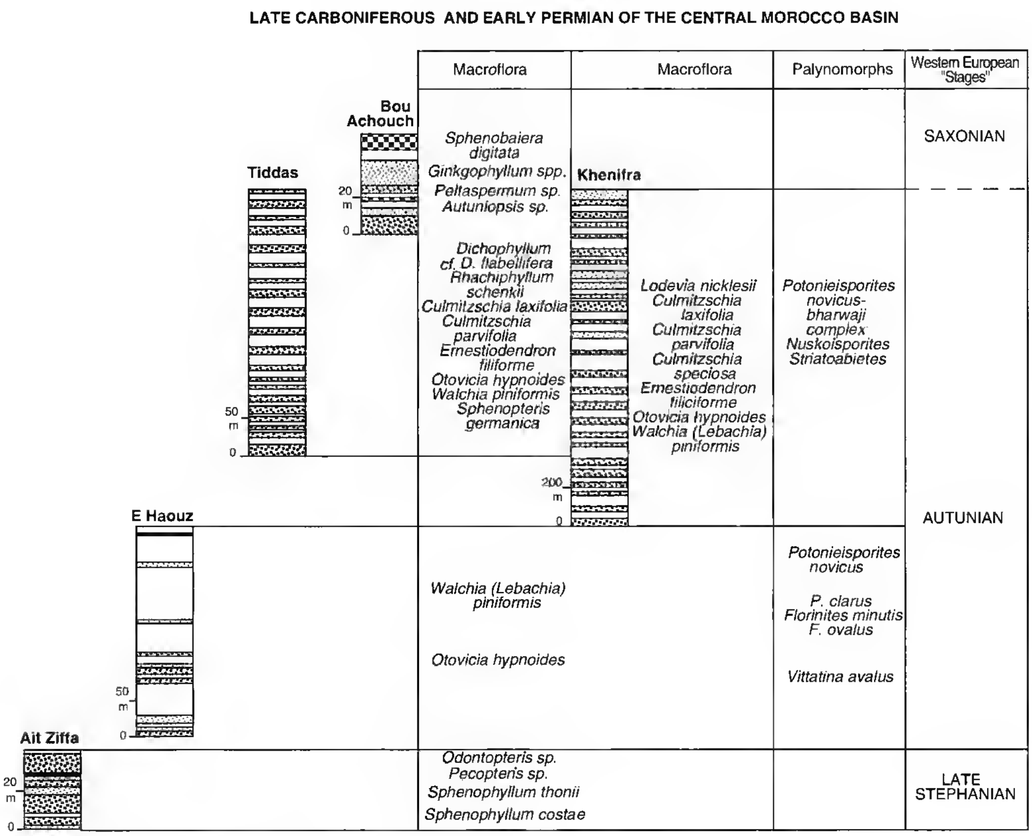
LOG. 47. — Austria boundary, coordinated by Krainer & Davydov. Late Carboniferous of the Carnic Alps, Krainer (this paper).



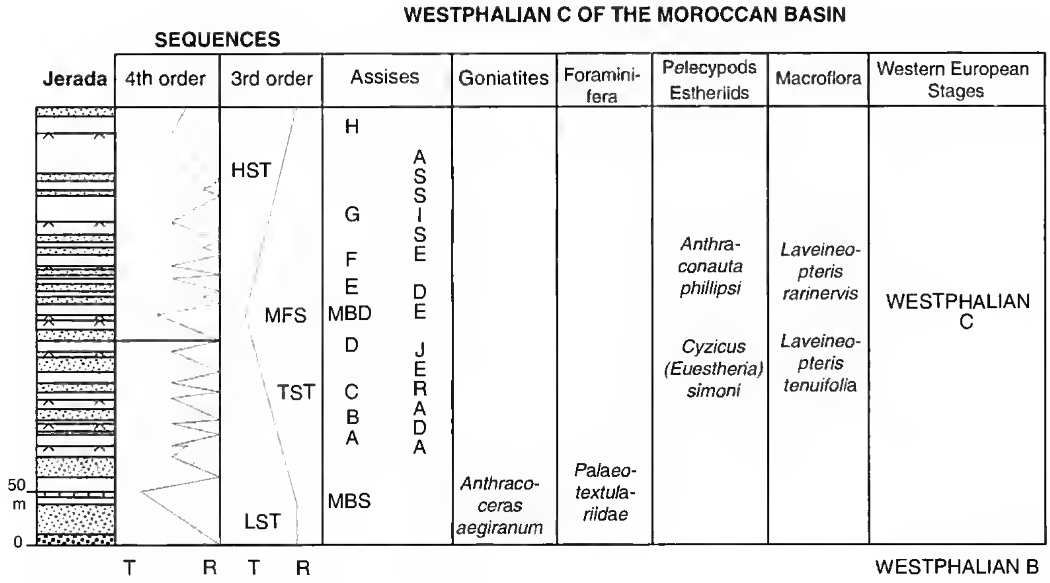
Log. 48. — Austria boundary, coordinated by Vai, Pasini, Venturi, Krainer & Davydov. Early Permian of the Carnic Alps, Krainer (this paper). Auernig, Carnic Alps, 13°17'E - 46°33'N; Trogkofel, Carnic Alps, 13°13'E - 46°35'N.



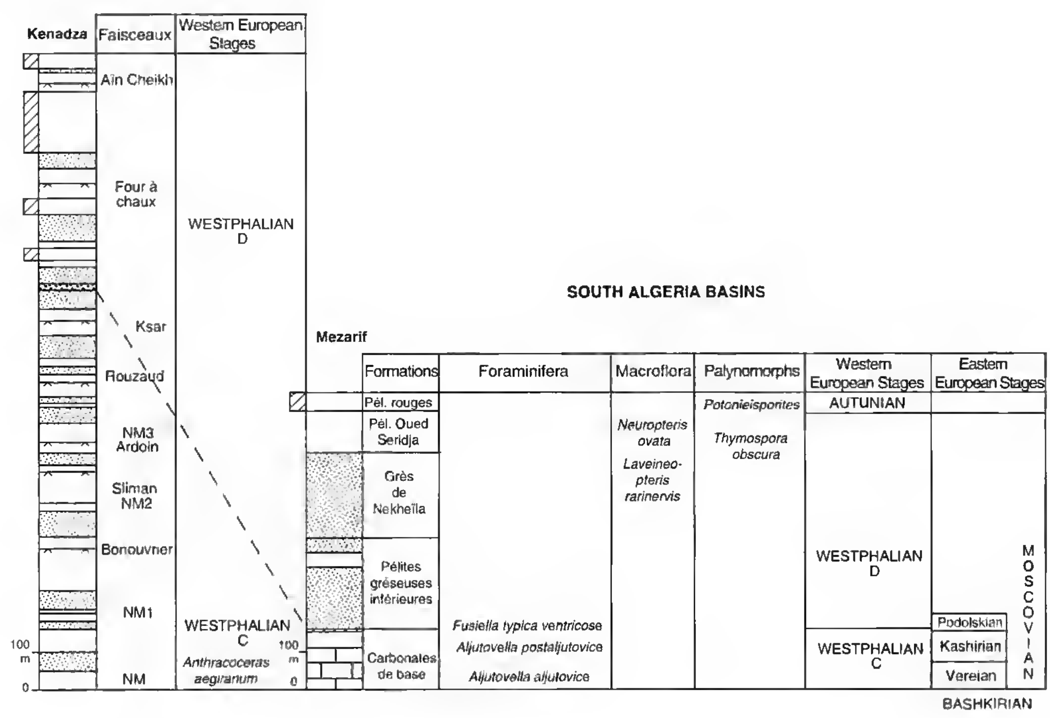
Log. 49. — Late Carboniferous and Early Permian of eastern Elbourz Basin (Iran), coordinated by Jenny & Jenny-Deshusses, after Jenny & Jenny-Deshusses (this paper). Gheselghaleh, Iran, 53°E - 34°N.



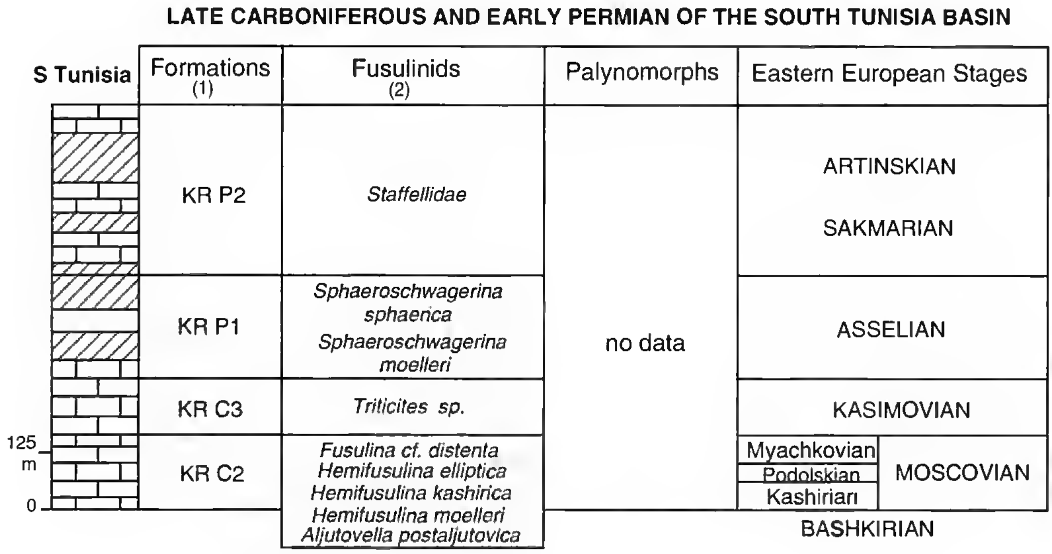
LOG. 50. — Morocco Basins: Late Carboniferous and Early Permian of the Central Morocco Basin, coordinated by El Wartiti and Broutin, after El Wartiti & Broutin (this paper). Ait Ziffa, 7°30'W, 31°27'N; Bou Achouch, 5°44'W, 33°42'N; Khenifra, 5°40'W, 33°N; Tiddas, 6°16'W, 33°34'N; Haouz, 7°10'W, 32°N.



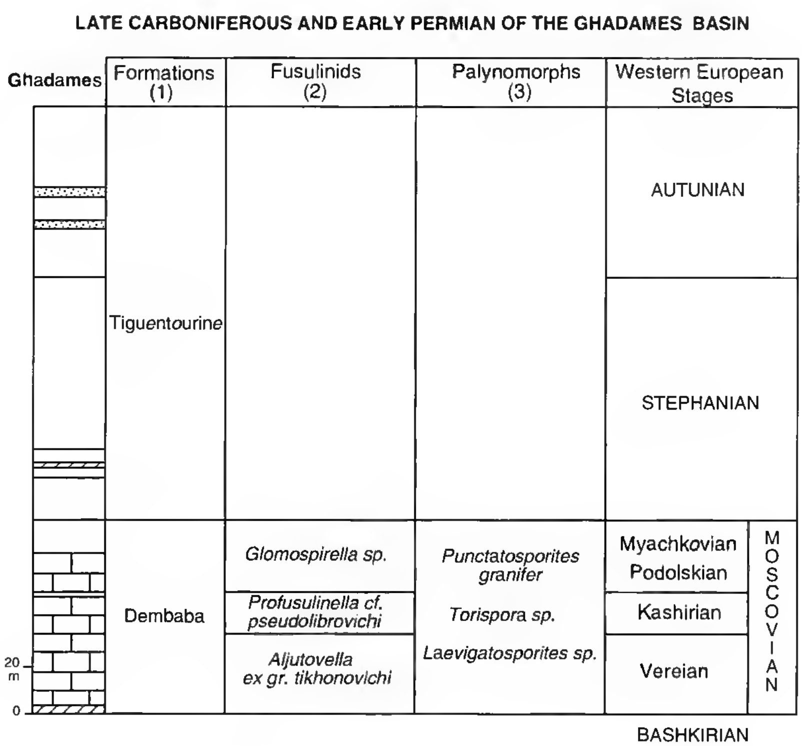
Log. 51. — Morocco Basins: Westphalian of the eastern Morocco Basin, coordinated by Izart, after Izart (this paper). Jerada, 2°W - 34°30'N.



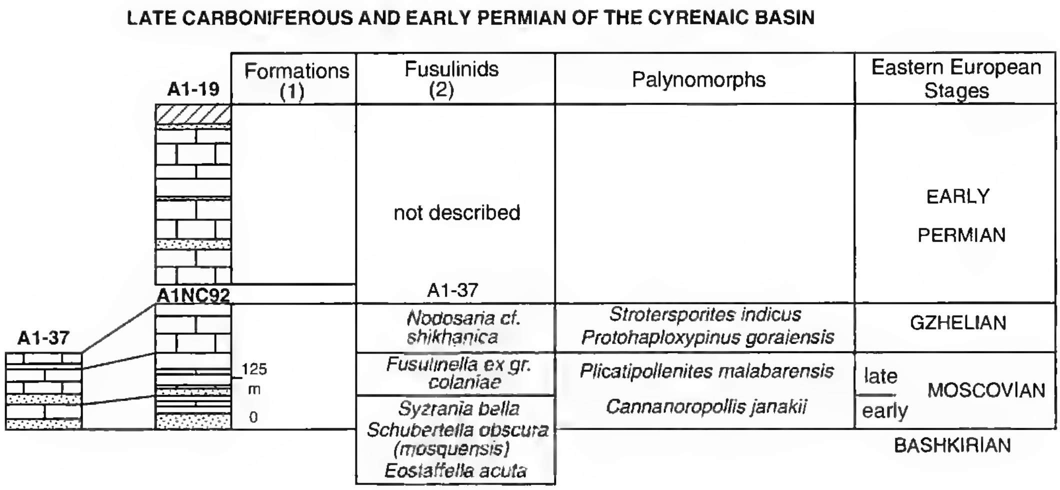
Log. 52. — Westphalian of the southern Algeria Basins, coordinated by Izart, after Nedjari (1982). Kenadza, southern Algeria, 2°W - 31°45'N; Mezarif, Southern Algeria, 1°45'W - 31°45'N.



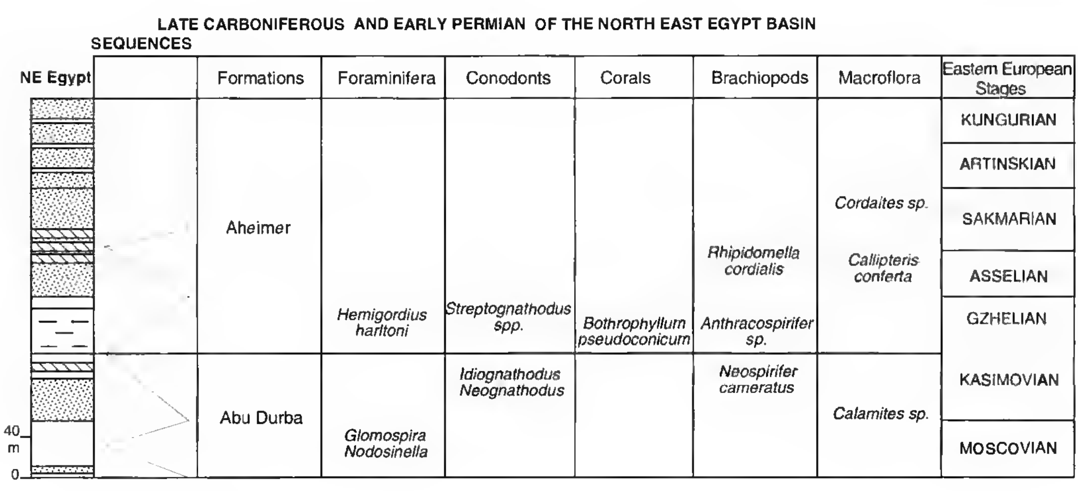
Log. 53. — Late Carboniferous and Early Permian of the southern Tunisia Basin, coordinated by Massa and Lys. **1**, Massa (this paper); **2**, Lys (this paper). Kirchaou, 10°40'E - 33°N.



Log. 54. — Libya Basins, coordinated by Massa, Vachard and Coquel. Late Carboniferous and Early Permian of the Ghadames Basin (Libya). **1**, Massa (this paper); **2**, Vachard (this paper); **3**, Coquel (this paper). Ghadames, Libya, 10°30'E - 29°N.



Log. 55. — Libya Basins, coordinated by Massa, Vachard and Coquel. Late Carboniferous and Early Permian of the Cyrenaic Basin (Lybia). **1**, Massa (this paper); **2**, Vachard *et al.* (1993). A1-37 borehole:), 22°53'E - 30°44'N; A1NC92 borehole, 22°08'E - 31°N; A1-19 borehole, 23°40'E - 31°N.



Log. 56. — Late Carboniferous and Early Permian of the northeastern Egypt Basin, coordinated by Kora, after Kora (1995). Abu Durba, Egypt, 33°18'E - 28°35'N; Wadi Aheimer, Egypt, 32°23'E - 29°30'N.

LATE CARBONIFEROUS AND EARLY PERMIAN OF SOUTHERN TURKEY

Bademli	Formations (1)	Foraminifera (2)	Eastern European Stages
	Cevizli Limestone	*Sphaeroschwagerina sphaerica* *Quasifusulina cayeuxi* *Tubiphytes obscurus*	ASSELIAN
		Daixina sokensis *Triticites sp.*	ORENBURGIAN GZHELIAN
	Quartzites	*Fusulina paradistenta*	KASIMOVIAN
20 m		*Fusulina cf. cylindrica*	MOSCOVIAN
0		*Aljutovella sp.* *Staffellaeformes staffellaeformis*	

LOG. 57. — Late Carboniferous and Early Permian of the southern Turkey, coordinated by Monod. **1**, Monod (1977); **2**, Lys (1988). Bademli, southern Turkey, 32°E - 37°30'N.

LATE CARBONIFEROUS AND EARLY PERMIAN OF SYRIA

Syria	Formations	Fauna - Flora	Eastern European Stages
	Heil		EARLY PERMIAN
	Najeeb	*Potonieisporites sp.* *S. triangulus*	GZHELIAN KASIMOVIAN
125 m 0	Sawanet		MOSCOVIAN BASHKIRIAN

LOG. 58. — Late Carboniferous and Early Permian of Syria, coordinated by Izart, after Al Youssef & Ayed (1992). Sawanet 2, Syria, 38°E - 34°10'N.

PERMIAN OF ISRAEL BASIN

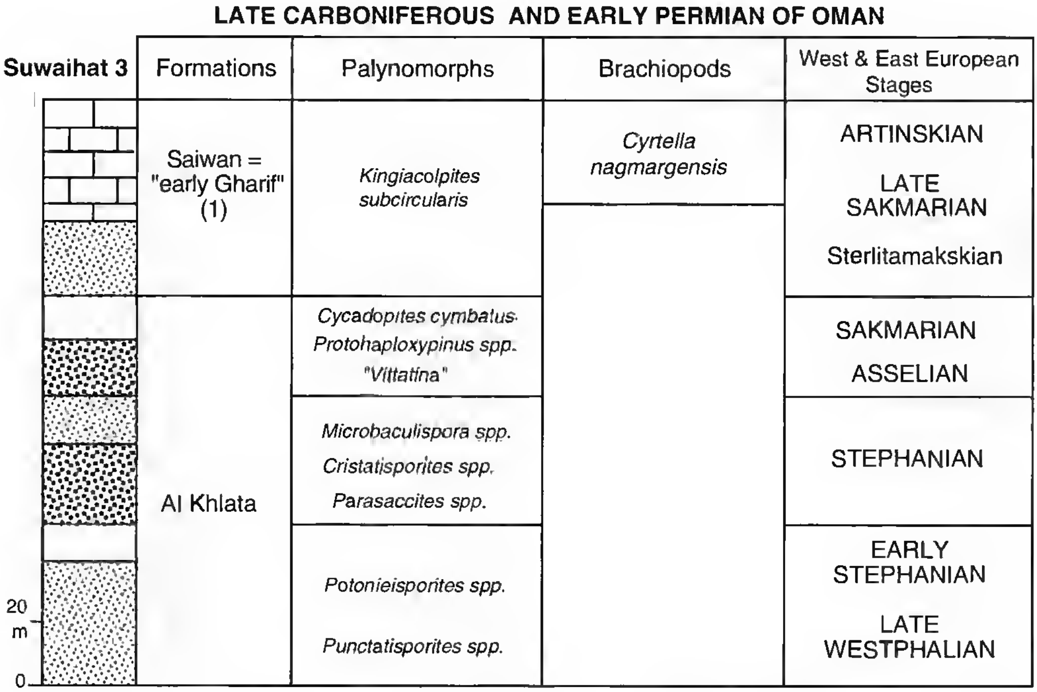
Bakhtesh Qatan 2	Group	Formation	Palynomorphs	Western European Stage
0 – 10 m	Negev	Sa'ad	*Potoniesporites novicus* *Distrialites insolitus* *Vittatina ovalis* *Plicatipollenites indicus* *Punctatoporites minutus* *Lophotriletes novicus* *Vittatina costabilis* *Protohaploxypinus microcorpus* *Laevigatosporites callosus*	AUTUNIAN

LOG. 59. — Permian of Israel Basin, coordinated by Weissbrod, after Weissbrod (this paper). Well Bakhtesh Qatan 2, 35°E - 31°N.

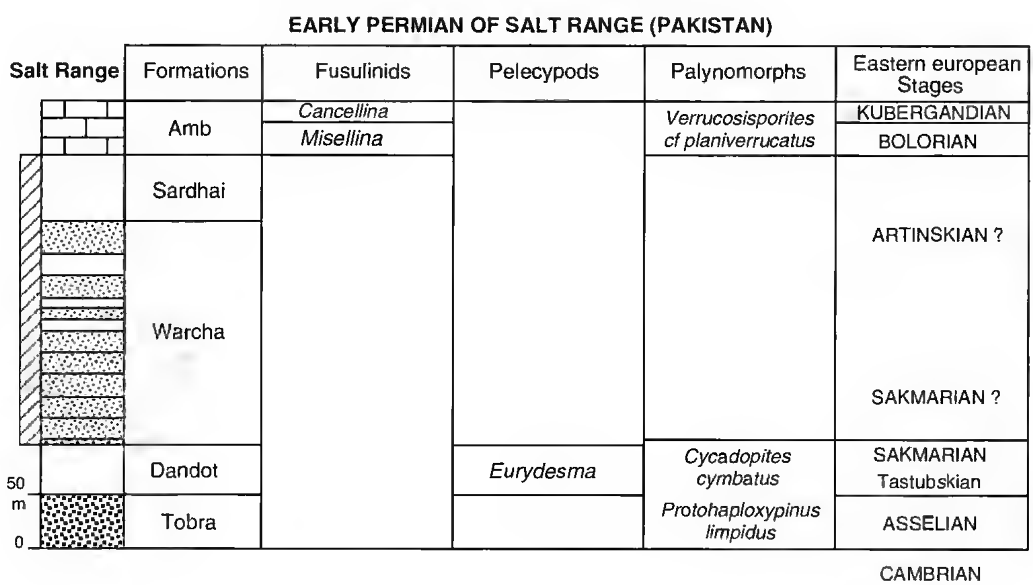
LATE CARBONIFEROUS AND EARLY PERMIAN OF SAUDI ARABIA

Well St 8	Formations	Palynomorphs	West & East European Stages	
	Unayzah		KUNGURIAN	EARLY PERMIAN
			ARTINSKIAN SAKMARIAN	
0 – 50 m	Berwath	*Thymospora obscura* *Torispora granulata* *Punctatosporites spp.* *Potonieisporites spp.*	WESTPHALIAN D	

LOG. 60. — Late Carboniferous and Early Permian of Saudi Arabia, coordinated by Izart and Vaslet, after Owens & Turner (1995) and Al Laboun (1993). Well 8, Saudi Arabia, 42°E - 30°N.



LOG. 61. — Late Carboniferous and Early Permian of Oman, coordinated by Izart and Vaslet, after Broutin *et al.* (1995) and Angiolini *et al.* (1997); **1**, Saiwan = *ex* "early Gharif" *sensu* Love (1994). Well Suwaihat 3, 55°E - 20°N.



LOG. 62. — Early Permian of Salt Range Basin (Pakistan), coordinated by Iqbal *et al.*, after Iqbal (this paper). Salt Range, 72°E - 32°N.

APPENDIX 2

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Stratigraphy, palaeoclimatology and palaeogeography of the Late Palaeozoic continental deposits in the Czech Republic

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KEY WORDS
Peri-Tethys
Bohemian Massif,
Late Carboniferous,
Westphalian,
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Autunian,
continental basins,
palaeogeography.

ABSTRACT

Numerous Late Palaeozoic continental basins were formed within the territory of the Czech Republic. Their sedimentary history began either in the Westphalian (central and western Bohemia, Brandov Basin and basins in Sudetic area) or in the late Stephanian (Blanice and Boskovice Grabens). The incompleteness of the floral record gives an evidence for several hiatuses the most important of which are those between the Bolsovian and Westphalian D and between the Stephanian B and C. During the deposition, an increase in sedimentary area, structural reworking and also considerable changes in source areas took place.

MOTS CLÉS
Péri-Téthys
massif bohémien,
Carbonifère supérieur,
Westphalien,
Stéphanien,
Autunien,
bassins continentaux,
paléogéographie.

RÉSUMÉ

La stratigraphie, la paléoclimatologie et la paléogéographie des dépôts continentaux du Paléozoïque supérieur de Bohème (République Tchèque). De nombreux bassins continentaux d'âge paléozoïque supérieur se sont formés sur le territoire de la République Tchèque. Leur histoire commence soit dans le Westphalien (Bohème centrale et occidentale, bassins de Brandov et des Sudètes) soit dans le Stéphanien supérieur (grabens de Blanice et de Boskovice). On n'y trouve pas toutes les biozones de paléoflore, ce qui montre la présence de plusieurs hiatus, dont les plus importants sont ceux entre le Bolsovien et le Westphalien D et entre le Stéphanien B et C. Pendant le dépôt, on note une augmentation de l'aire de sédimentation et du remaniement structural et aussi des changements considérables dans les sources d'apport.

INTRODUCTION

Czech Republic (CR) occupies a relatively small area of Europe. Geological units are among the best explored areas of the European Variscides. During the Late Palaeozoic time, marine followed by paralic and continental sediments were deposited. Analysis of their spatial and temporal distribution should allow a better definition of the Early Carboniferous-Late Triassic interval which is critical for better understanding of the dynamic evolution of this part of Europe.

Sedimentation in some Late Palaeozoic basins is preceded by the Late Devonian sedimentation. Gradual consolidation of the Variscides during the middle Namurian to Triassic, characterized by general thickening of crustal granite layer of the Bohemian Massif (BM), resulted in an equalization of strongly imbalanced heat and strain conditions. Such consolidation followed by the development of further ocean basins in broader vicinity of the massif led to its collapse which resulted in the development of numerous grabens and horsts and also in splitting the plate along strike-slip faults. These Late Carboniferous and Permian processes initiated the origin, rapid development and relatively short existence of various types of basins (Figs 1-3). In this manner the mostly postcollisional intramontane basins of the Bohemian Massif became a trap for dominantly detrital material. The intramontane sedimentary basins (Fig. 3) grew larger during the late Westphalian time following an intra-Westphalian hiatus, however, the oldest continental deposits are of the late Visean and Namurian age. Formerly isolated depressions were interconnected and formed larger basins (Fig. 7). The sedimentation was interrupted several times. The hiatus approximately between the Stephanian B and C (*e.g.* Late Stephanian, Doubinger *et al.* 1995) was associated with changes in both the existing basins and in the source areas. These changes resulted in structural reconstruction of the central and western Bohemian basins, an increase in the area of sedimentation in central and western Bohemia and interrupted sedimentation in the eastern part of the Krkonoše-piedmont Basin as well as in the Intra-Sudetic Basin and elsewhere. In the source areas, new basins in the form of grabens were established (*e.g.* Blanice and Boskovice Grabens). Other important changes are connected with the Saalic phase of the Variscan orogeny. During the Saxonian to Triassic, these processes resulted in considerable and rapid subsidence in filled basins and in reduction of the sedimentation domain in which detrital material was brought in from gradually eroded and peneplained source areas (today's absence of sediments except the Lugicum, *i.e.* Sudetic basins). The deposition of the Variscan continental molasse within the Bohemian Massif ceased during the Triassic. These sediments cover only a negligible part of the area. The ideas mentioned in this paper are supported by recently compiled palaeogeographical maps (Figs 4, 6, 8) which represent an integral part of the Atlas of the Permo-Carboniferous of the Bohemian Massif (Pešek *et al.* 1998).

VOLCANISM

Considerable mobility of basinal basements as well as movements along the regional and local faults resulted in volcanic activitiy which accompanied sedimentary processes. Several volcanic cycles are represented by acid, intermediate and basic volcanism. The earliest Middle Devonian to early Westphalian cycle (Přichystal 1993) is supposed to reflect the onset of the Brunovistulicum (south-western projection of the Baltica terraine) subduction underneath the central part of the Bohemian Massif. This cycle gradually ceased in the late Namurian and early Westphalian (Kumpera & Martinec 1995). Another cycle is related to the Duckmantian/Bolsovian to early Stephanian interval. It is characterised by abundant acid volcanism the early products of which filled the central and western Bohemian basins. This cycle proves the drift of volcanic centers from Moravia into the western, central and NE Bohemia. The final volcanic cycle coincides with the late Stephanian and Autunian when extensive intermediate to basic effusive bodies originated in central and NE Bohemia. Products of acid volcanism are also abundant but considerably thinner (Pešek & Tásler 1979).

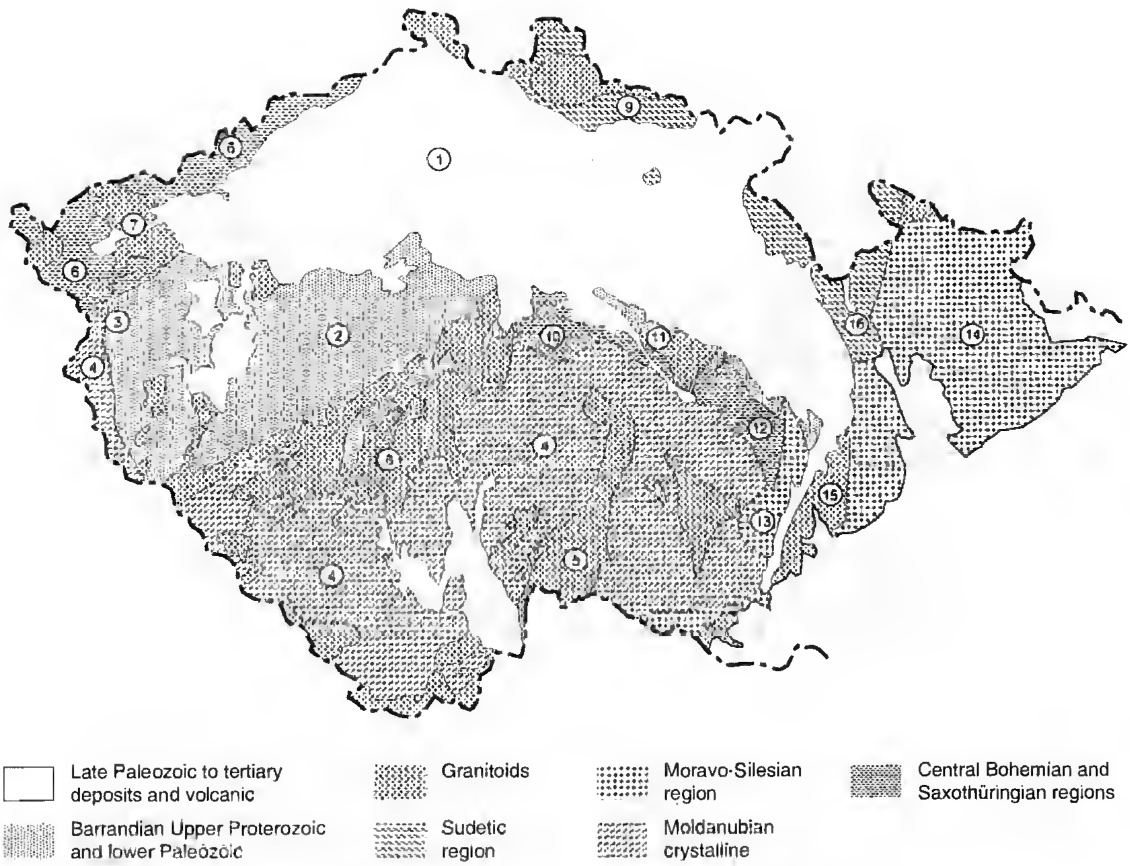


FIG. 1. — Crystalline rock units and the pre-Variscan Palaeozoic formations of the Bohemian Massif. Chlupáč-Vrána eds (1994), simplified. **1**, Late Palaeozoic to Tertiary deposits; **2**, Barrandian Upper Proterozoic and Lower Palaeozoic; **3**, Teplá Crystalline; **4**, Moldanubian Crystalline Complex; **5**, Moldanubian Pluton; **6**, Krušné hory Mts. Crystalline Complex; **7**, Krušné hory Pluton; **8**, Central Bohemian Pluton; **9**, Krkonoše-Jizera Crystalline Complex; **10**, Kutná Hora Crystalline; **11**, Železné hory Mts.; **12**, Svratka Crystalline; **13**, Moravicum; **14**, Silesicum and Moravo-Silesian Palaeozoic; **15**, Brunovistulicum; **16**, East Sudetes region (crystalline units).

CLIMATE

It is generally accepted that the climate during the Late Carboniferous and particularly during the Permian became warmer and consequently drier (Parrish 1995). However, various climatic conditions dominated in the different parts of the newly consolidated supercontinent Pangea, depending on latitude, altitude, topography and the position within the continent (Ruddiman & Kutzbach 1991; Ziegler 1990). Palaeomagnetic measurements (e.g. Krs & Pruner 1995) provide an evidence that the Bohemian Massif was situated between 4° and 6° N during the Late Palaeozoic. Since the middle Namurian it occupied interior position at a distance of several hundred kilometres from the northern coast of the Tethys (Scotese & McKerrow 1990). The Late Palaeozoic continental deposits of the Bohemian Massif exhibit several trends valid at least for the whole Variscan Europe: a decreasing in coal content since the Late Westphalian to the Permian and increasing abundance in the occurrence of red bed deposits. Stephanian sediments are typical by the alternation of thick grey and red units while during the Permian, mostly primary red beds were deposited. Similar alternation reported by Rowley *et al.* (1985) in the United States, is ascribed to variation in intensity of monsoons. Monsoons are proposed in various climatic models for the low latitude regions of the Pangea adjacent to the Tethys (Crowley *et al.* 1989; Kutzbach & Gallimore 1989; Nairn & Smithwick 1976; Parrish & Peterson 1988; etc.). It is expected that the monsoonal circulation with wet summers and dry winters began in the Latest Carboniferous and probably unevenly increased up to its maximum during the Triassic (Parrish *et al.* 1986). Similar conclusion was arrived at by Ziegler (1990) who studied a phytogeographic pattern of the Permian. The oldest evidence of the seasonal climate in the Late Palaeozoic continental deposits of the Bohemian Massif is represented by the laminated lake deposits of the Stephanian B age (lower part of the Forezian, Doubinger *et al.* 1995) covering an extensive area of several thousand square kilometres. Lamination consists of typical dark-light couplets reflecting seasonal variation in organic content (Skoček 1990). Similar lamination occurs in the Autunian deposits of the Rudnik Horizon in the Krkonoše-piedmont Basin as reported by Blecha *et al.* (1997), who also detected cyclic variations in boron content in lake deposits of another Autunian horizon. The origin of cycles may have been related to high frequency climatic changes with a periodicity of thousand or even tens of thousand years. Moreover, the occurrence of evaporites (Prouza *et al.* 1977) and the elevated contents of boron in the Late Palaeozoic sediments of the Bohemian Massif also argue for dry climatic conditions (Bouška & Pešek 1985).

In contrast, Becq-Giraudon & Van den Drissche (1994) proposed periglacial conditions at the altitude of nearly 5000 m for the deposition in Stephano-Permian basins of the Massif central. These authors give sedimentological and floristical evidences enhanced by geotectonic arguments.

Late Palaeozoic continental basins of the Bohemian Massif and the Massif central show the same geotectonic position, latitude, and in many cases comparable tectono-sedimentary history. Despite this, there has not been found any evidence for such a high relief or temperate climate in the Bohemian Massif during this period yet. Floristic records from Bohemia only confirm a rapid decrease in lycopsids plants at the end of the Westphalian and increasing frequency of Walchia during the Stephanian. As a whole, the Bohemian late Westphalian to Autunian floras are rich in species, most of which being known from NW Spain and other, formerly paralic basins of NW Germany, Belgium and N France.

BEGINNING OF THE LATE PALAEOZOIC CONTINENTAL DEPOSITION IN THE BOHEMIAN MASSIF

The oldest Carboniferous continental sediments of the Bohemian Massif are known from the Intra-Sudetic Basin, where purely continental conditions were established after a marine regression in the late Visean. First coarse grained sediments were deposited as alluvial fans in piedmont setting (Blazskow Conglomerates). They grade into marshy-fluvial, partly coal-bearing Walbrzych (Waldenburg) Formation of the early Namurian age. Above, they pass into fluvial deposits (Bialy Kamien Member). These sediments are known mainly from the Polish part of the Basin. In the Czech territory, sedimentation of the Žacléř Formation began around the Namurian/Westphalian boundary after an episodic Visean deposition of the Blazskow Conglomerates. Its lower part, the Lampertice Member consists of coal-bearing fluvial cycles with conglomerates at the base. This unit has yielded rich flora referring to the Langsettian (Westphalian A) age. *Neuralethopteris schlehanii* (Stur) and *Lonchopteris conjugata* (Goeppert) dominate, while *Lonchopteris rugosa* Brongniart, typical for Duckmantian (Westphalian B), is still missing (Kotasowa & Migier 1995; Šetlík 1977). Sediments of the Lampertice Member pass into the Doly Žd'árky Member of the Duckmantian (Westphalian B) age either continuously or after a short hiatus at SW margin. In the Late Silesian Basin, the non-marine deposition took place from the middle Namurian and with several hiatuses lasted until the Stephanian in the Polish part.

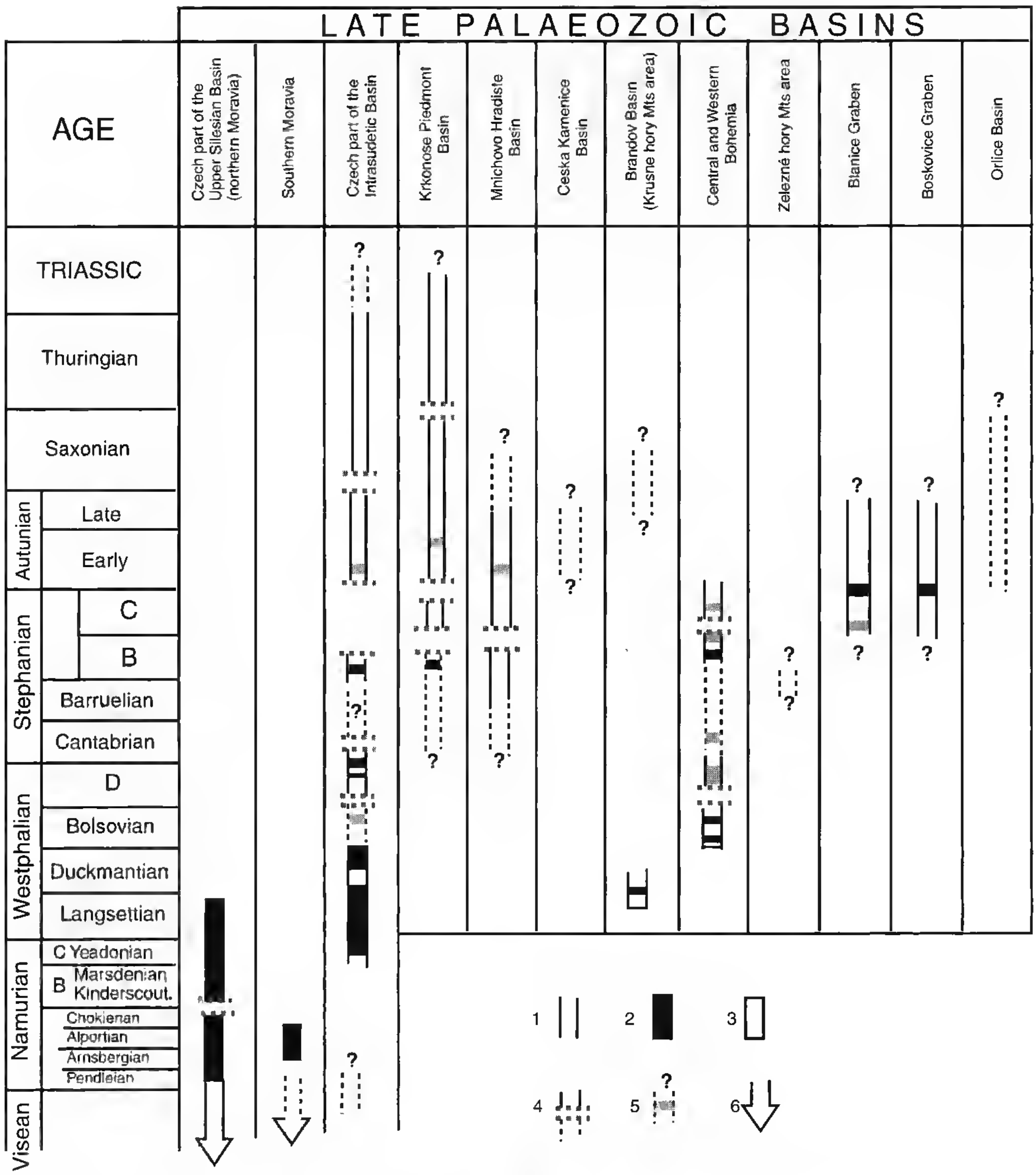


FIG. 2. — The extent of sedimentation and coal formation in Late Palaeozoic basins of the Czech Republic. **1**, coal-barren sedimentation; **2**, period of significant coal formation; **3**, period of less important to negligible coal formation; **4**, problematic age of a unit; **5**, break in sedimentation; **6**, the given interval preceded by an early sedimentation.

DUCKMANTIAN AND BOLSOVIAN (WESTPHALIAN B AND C)

Sediments of the unit studied were deposited in several isolated regions in the Intra-Sudetic Basin, Krušné hory Mountains and in the central and western Bohemia. It is supposed that sedimentation in the Czech part of the Late Silesian Basin continued at least till the Duckmantian. However, these youngest deposits have been later eroded.

Duckmantian and Bolsovian deposits in the

Intra-Sudetic Basin successively filled the basement depressions. The maximum subsidence shifted from the NW to the SE. Detrital material transported to the basin from the SW, W and SE, is represented by talus, alluvial fans and fluvial to fluviolacustrine deposits containing less coal than the overlying unit. The source area which supplied the Intra-Sudetic Basin with detrital material is thought to have had mountaineous relief as suggested by the occurrence of fanglomerates. The present distribution of Duckmantian and Bolsovian sediments seems to be similar to their original extent. Mechanical weathering is thought to have been the dominant process during the Duckmantian and Bolsovian (Tásler *et al.* 1979). Duckmantian and Bolsovian sedimentation was accompanied by gradually increasing volcanic activitity (Mašek 1973). The center of acid volcanism is believed to have been located in the vicinity of the Polish Walbrzych.

Duckmantian and Bolsovian sediments of the Brandov Basin in the Krušné hory Mountains (Fig. 9) were deposited in a narrow, NW-trending depression including Late Palaeozoic basins between the towns of Olbernhau and Flőha in the Flőha river valley, Germany. The SE alignment of these basins possibly trends farther to the Slaný-Třtěno depression marked by acid synchronous volcanism between Peruc and Třtěno in central Bohemia.

The Krušné hory Mountains Carboniferous sediments were deposited on a rugged basement of the Krušné hory crystalline complex (Fig. 1). Sporadic data indicate that the preserved detrital sediments containing abundant local material, were transported for a short distance in streams flanked occasionally by alluvial plains covered with vegetation.

Sediments of the Radnice Member were deposited in the central and western Bohemia (Fig. 5) on an alluvial plain during a period of higher mobility of the basin's basement and associated with extensive volcanic activity. These sediments initially filled two depositional centers which were later connected. The eastern depositional center includes approximately an area of the eastern part of the Kladno-Rakovník Basin including isolated small remnants to the S. The Rakovník, Radnice and Plzeň regions, including remnants in their southern and eastern vicinities, represent the western depositional center. The latter center is thought to have been drained toward the SW into Bavaria whereas the eastern center is believed to have been connected with the sea of the West European foredeep through the Krušné hory and Flőha Basins. The western depositional center might have been drained in this direction during deposition of the upper Radnice Member. Duckmantian and Bolsovian sediments originally did not cover the entire area of the central and western Bohemian basins. Low, NE-trending ridges of mostly Proterozoic basement served as a source of gravity-induced fanglomerates and short debris-flows.

The Late Carboniferous central and western Bohemian basins contain locally very coarse detrital sediments deposited by ephemeral streams. Large peat bogs were formed on broad alluvial plains during warm and humid climate. Coal-forming vegetation is thought to have rapidly expanded into abandoned meanders during stream migration. Numerous volcanic centers were formed in several basins and their broad vicinity.

A major N-S trending stream, parallel to the axis of the Plzeň Basin, transported detritus from the north where an extensive dry land existed during the Duckmantian and Bolsovian. This stream prevented coal formation during the deposition of the lower Radnice Member. At the same time similar stream flowed from Rakovník to Radnice. The fluvial deposition resulted in splitting of coal seams or in their absence in the broad vicinity of the above mentioned towns. Yet another major stream flowed from the SW into an intensively subsiding NW-SE trending depression between Slaný and Třtěno. This stream is assumed to have continued toward Brandov and further into Germany (see above).

Alluvial plain of the Radnice Member subsided along the central Bohemian deep-seated fault (Mísař *et al.* 1983) flanked probably by a zone of piedmont sedimentation. The main sourceland represented by the central Bohemian pluton is supposed to be located S of this fault. Local sourcelands were scattered throughout the alluvial plain. The source areas adjacent to the Carboniferous basins and the remaining area of

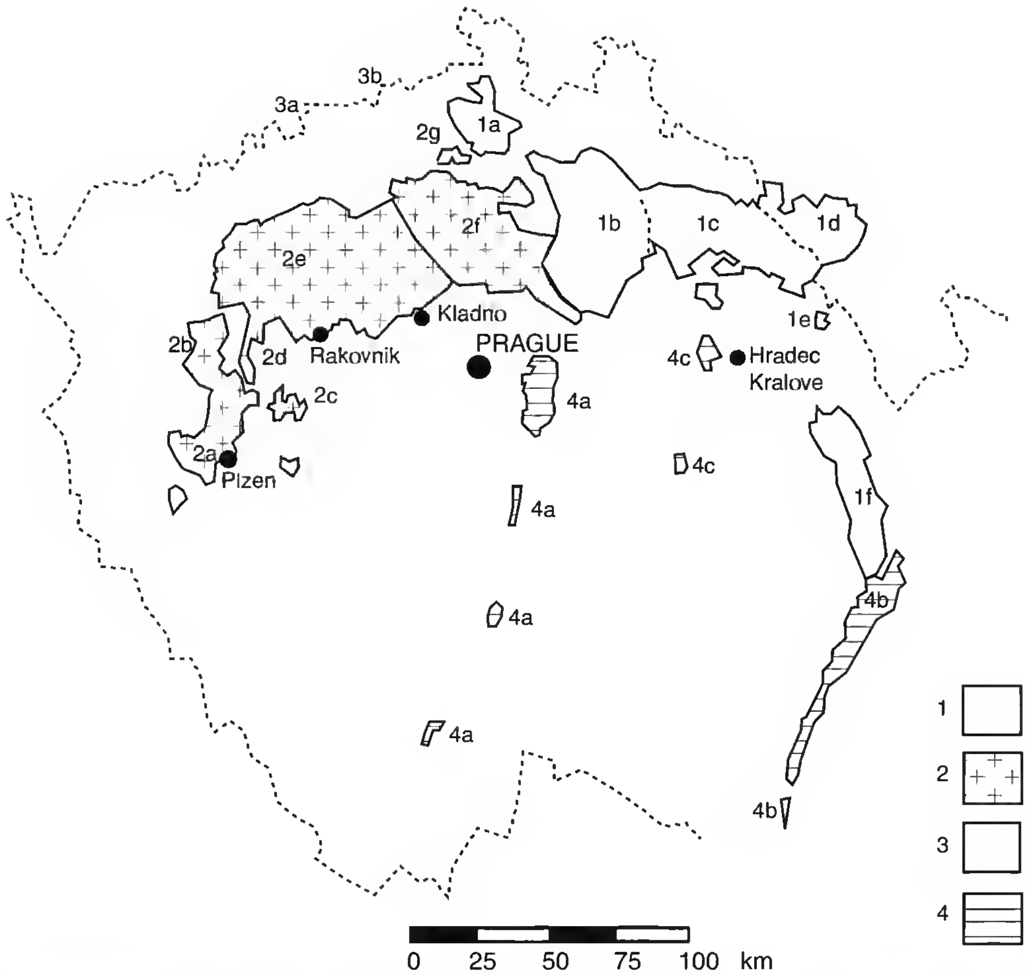


FIG. 3. — Late Carboniferous and Permian continental deposits of the Bohemian Massif Chlupáč-Štorch eds (1992). **1**, Sudetic Late Palaeozoic: **1a**, Česká Kamenice Basin; **1b**, Mnichovo Hradiště Basin; **1c**, Krkonoše-piedmont Basin and occurrences near Zvičina and at the Hořice elevation; **1d**, Intra-Sudetic Basin (Czech part); **1e**, Permian formations in the Orlické hory Mountains; **1f**, Orlice Basin. **2**, central and western Bohemian Late Palaeozoic deposits: **2a**, Plzeň Basin, **2b**, Manětín Basin; **2c**, Radnice Basin; **2d**. Žihle Basin; **2e**, Kladno-Rakovník Basin; **2f**, Mšeno-Roudnice Basin; **2g**, Kravaře occurrence. **3**, Late Palaeozoic of the Krušné hory Mountains: **3a**, Brandov occurrence, **3b**, Mikulov occurrences. **4**, Late Palaeozoic sediments of the graben structures: **4a**, Blanice Graben (from north to south). Český Brod region, Vlašim occurrence, Tábor occurrence, České Budějovice region; **4b**, Boskovice Graben with Miroslav occurrence in south; **4c**, Jihlava Graben (Železné hory Mountains and Hradec Králové occurrences).

the Bohemian Massif are thought to have displayed deeply levelled mountain relief. Sedimentation in all basins took place in depressions between adjacent ridges that exercised considerable control upon sediment distribution. Thicker coal seams originated in their "sedimentary shadow" (Pešek 1968) being protected from considerable supply of detrital material.

The Duckmantian and Bolsovian sedimentation was accompanied by relatively abundant volcanic activity. Warm and humid climate was favourable to the formation and preservation of coal seams. Diversified Duckmantian and Bolsovian flora contains the following stratigraphically important species: *Sphenophyllum myriophyllum* Crépin, *Sphenophyllum cuneifolium* (Sternberg), *Lepidodendron simile* Kidston, *Laveineopteris loshi* (Brongniart) and *Laveineopteris tenuifolia*

(Schlotheim). On the other hand *Pecopteris penaeformis* (Brongniart) is a typical element of the Radnice Member. *Lonchopteris rugosa* Brongniart is common in the Doly Žd'árky Member but it is extremely rare in the lower part of the Radnice Member in central and western Bohemia. The presence of *Annularia sphenophylloides* (Zenker), *A. stellata* (Schlotheim) and *Sphenophyllum emarginatum* (Brongniart) is characteristic of the upper part of the Bolsovian succession in the Intra-Sudetic Basin (Petrovice Member) but these species are very rare in the Radnice Member. The total assemblage of the Radnice Member is indicative of either late Duckmantian or early Bolsovian (Wagner 1977). The age of the Doly Žd'árky Member is mostly Duckmantian, but flora in its upper part is very similar to that of the Radnice Member. However the following unit, the Petrovice Member, is already of the late Bolsovian age.

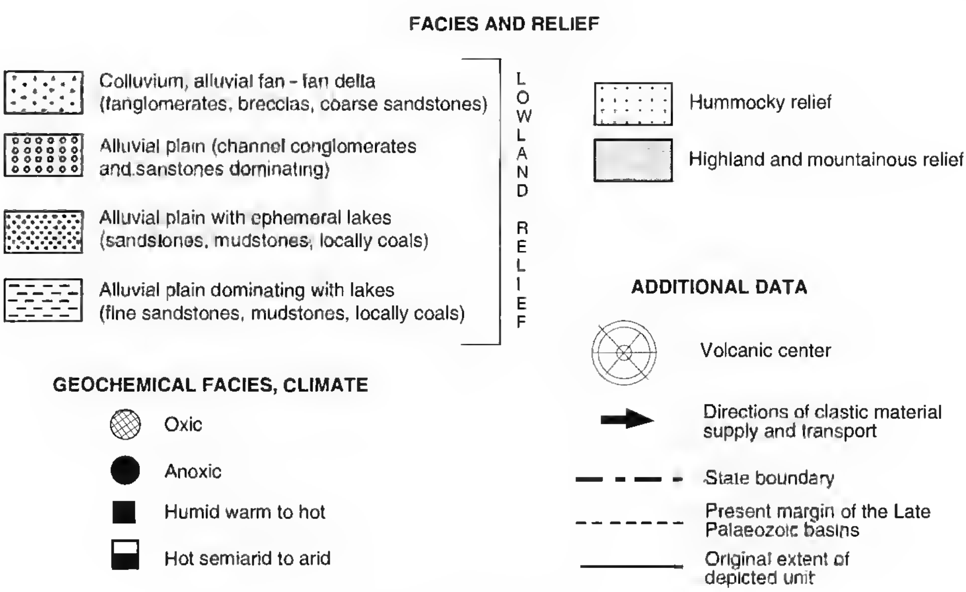
WESTPHALIAN D-CANTABRIAN

The facies pattern of this stratigraphical interval indicates a continuous sedimentary domain extending from the Manětín and Plzeň basins in the west as far as the Intra-Sudetic Basin in the east. This is in contrast to the earlier period when two separate sedimentary basins existed. Havlena & Pešek (1980) believe that the central Bohemian and Sudetic basins formed an arch open to the south at this time.

Westphalian D to Cantabrian sediments in limnic basins of the Bohemian Massif were deposited after a hiatus related to the Leonian phase defined in Northern Spain by Wagner (1965). According to Wagner (1977) differences in floristical assemblages between the Radnice and the lower part of the Nýřany Member provide good evidence of stratigraphical gap comprising the late Bolsovian and substantial part of the Westphalian D. Comparable stratigraphic gap occurs also in the Carboniferous sediments of the Late Silesian Coal Basin (Kotásowa & Migier 1995).

During the Westphalian D period, not only substantial increase in the area of sedimentation occurred but also additional NW-SE trending depressions formed. The extension of sedimentary basin further to the east and the marked increase in thickess of the Nýřany Member, compared to the Radnice Member are also due to Leonian orogenic phase.

Uneven subsidence of the basin's basement governed the pattern of detrital sedimentation at the onset of deposition of the Svatonovice



LEGEND (Figs 4, 6, 8)

Duckmantian and Bolsovian (Westphalian B and C)

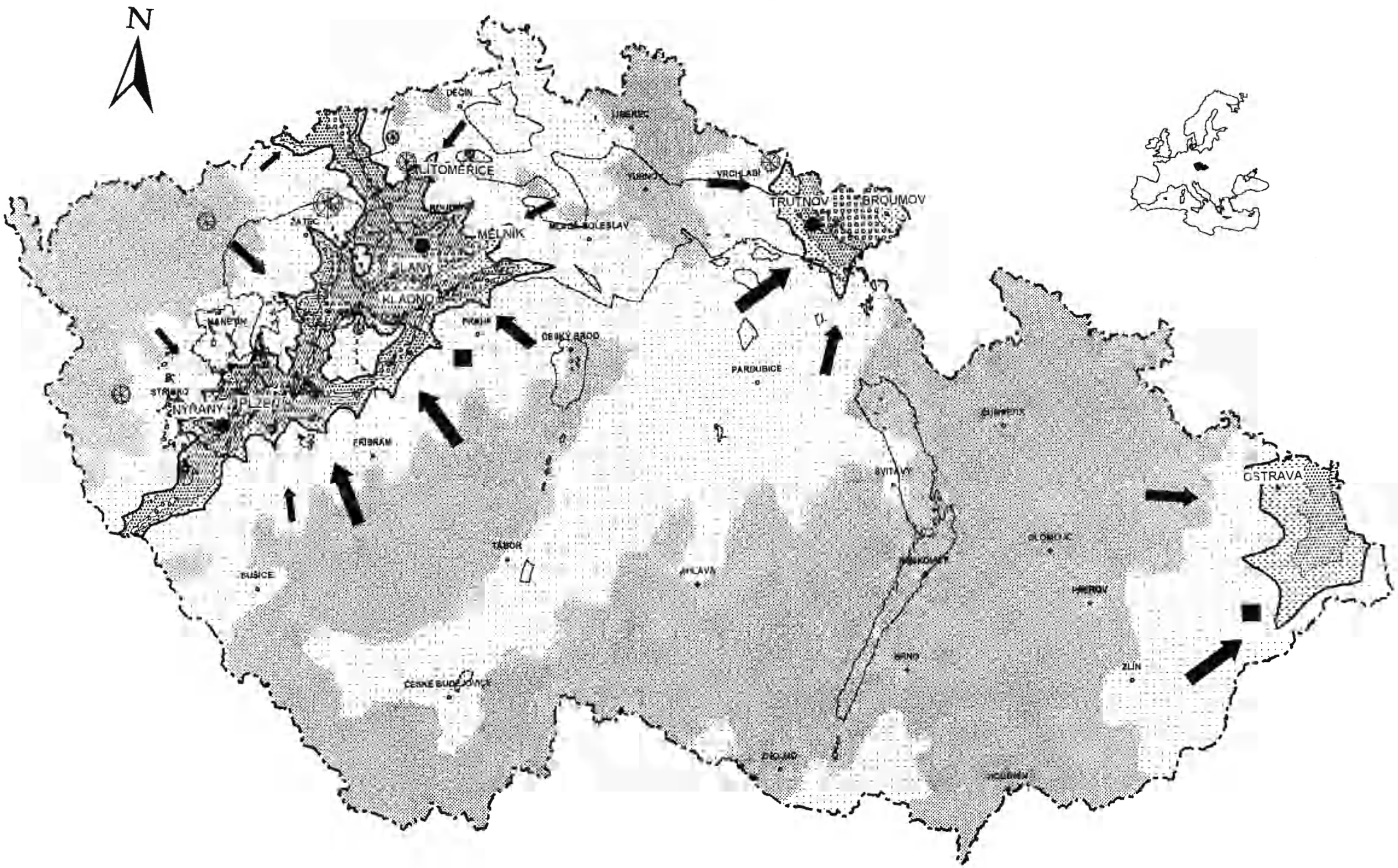


FIG. 4. — Palaeogeography of the Czech Republic during the Duckmantian and Bolsovian.

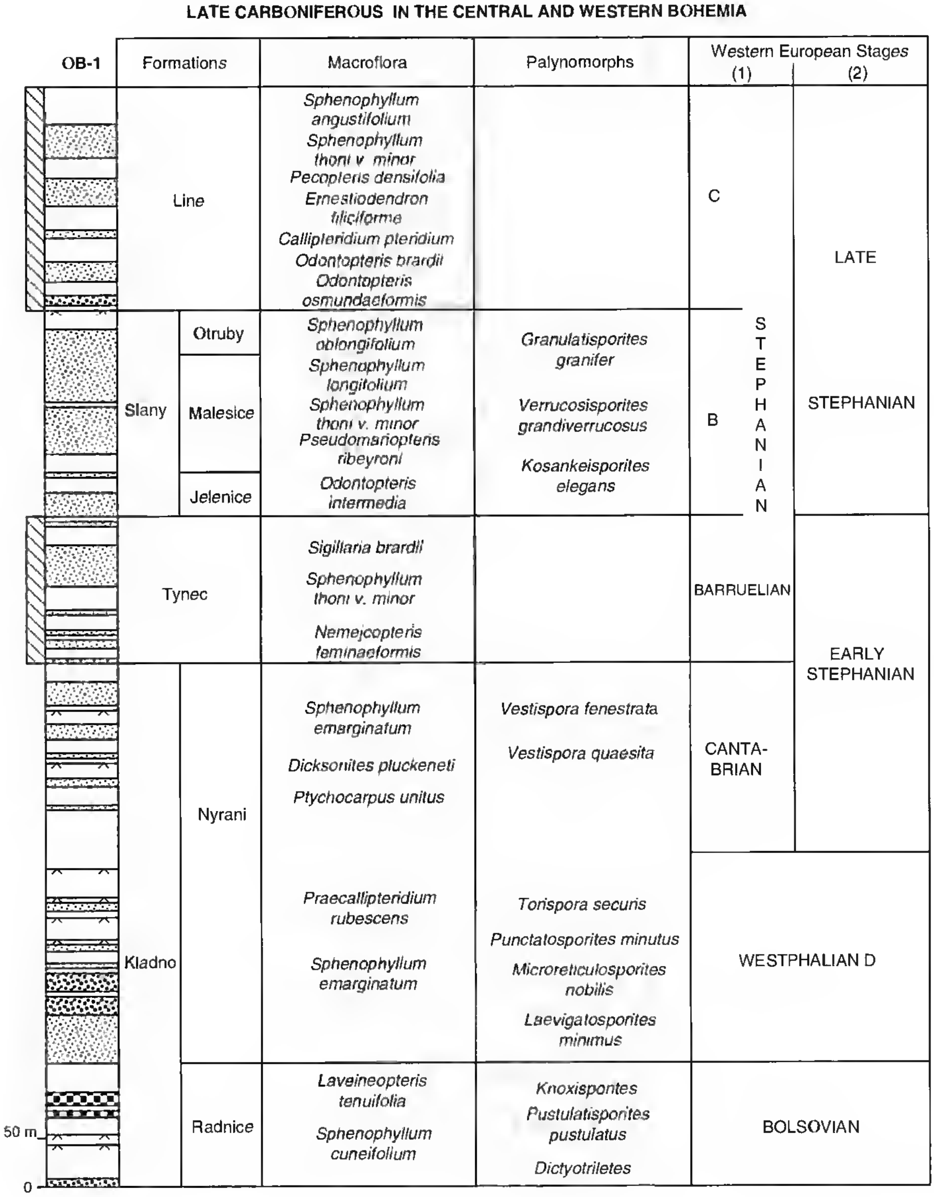


FIG. 5. — Lithology and biostratigraphy of the central and western Bohemian Late Palaeozoic deposits on an example of the borehole Ob1 (Otruby) in the eastern part of the Kladno-Rakovník Basin, Czech Republic, 14°06'E - 50°15'N. **1**, Opluštil & Pešek (this volume); **2**, Doubinger *et al.* 1995.

Member (Figs 7, 12) in the Intra-Sudetic Basin (Tásler *et al.* 1979). Deposition of this unit to the NW and SE of the south-western (*i.e.* Czech) flank of the basin started after a hiatus as evidenced by the kaolinization of rhyolite tuffs, by the redeposition of pebbles of the Petrovice Member to the NW, and by a considerable reduction of the thickness of the Svatoňovice Member to the

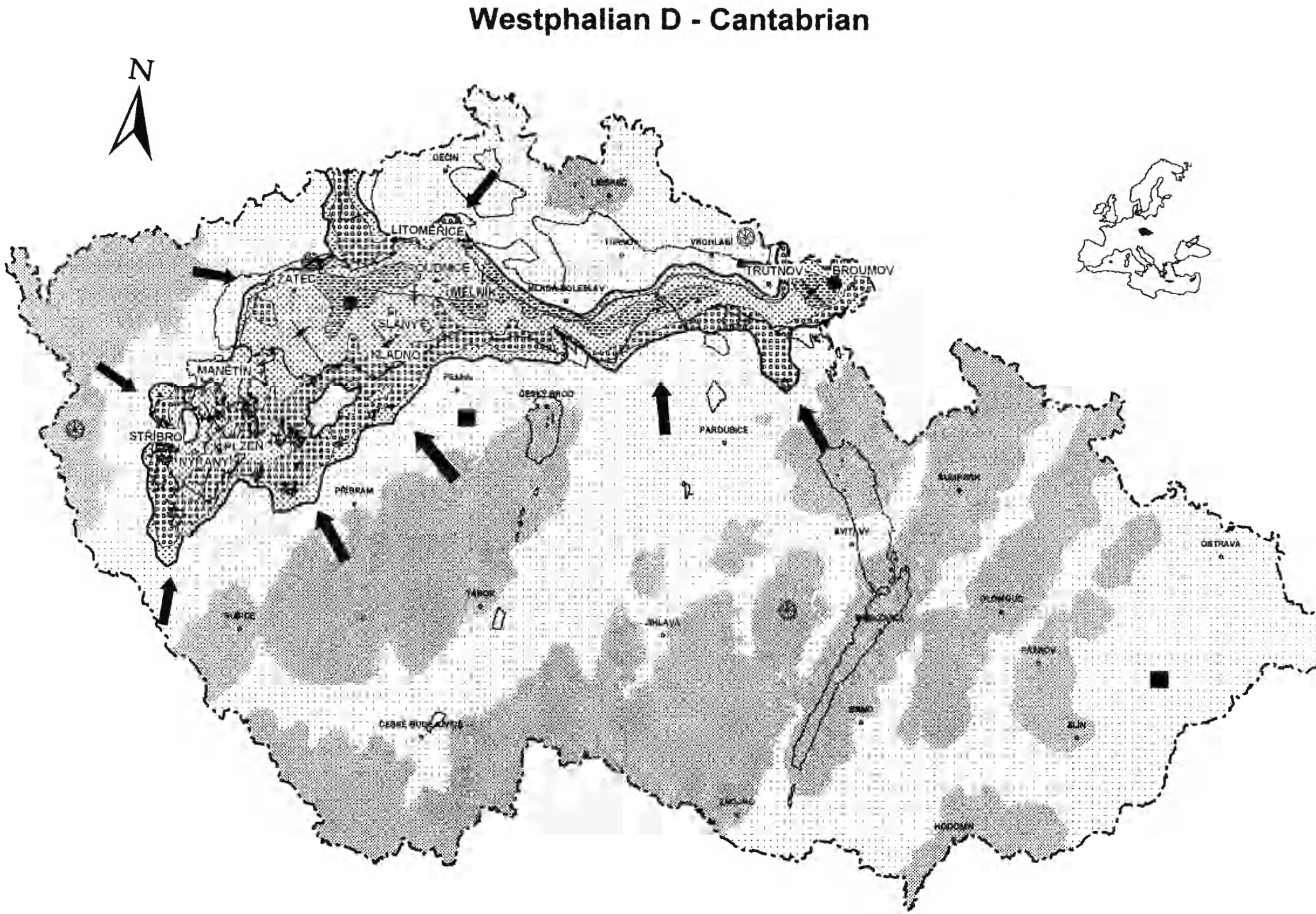


FIG. 6. — Palaeogeography of the Czech Republic during the Westphalian D - Cantabrian (see legend Fig. 4).

SE (Tásler *et al.* 1979). Compared with the Petrovice Member, the alluvial and alluvial-fan deposits are less abundant while the alluvial and intermittent lake fine-grained deposits are thicker. This resulted from higher morphological maturity of the source areas compared to the earlier period of the Petrovice Member deposition and to a decreased energy of streams. A major change took place in the lithological character of conglomerates, arkoses and sandstones. Pebbly and sandy clasts of the lower Svatoňovice Member, transported from the W (*i.e.* adjacent Krkonoše-Jizerské hory Mountains crystalline complex), were deposited in a much reduced basin surrounded by weathered and eroded areas. The sedimentation of the Svatoňovice Member was terminated by extrusion of low viscosity andesitic lavas forming laterally extensive but rather thin body. Deposition of lacustrine and fluvio-lacustrine sediments accompanied by periodic growth of peat followed this andesitic extrusion. Further deposition of the Svatoňovice Member extended over the pre-Carboniferous basement in the vicinity of Bernartice (NW part of the Intra-Sudetic Basin) and around Hronov (SE part). The filling of the Krkonoše-piedmont and Mnichovo Hradiště basins probably began at this time (Fig. 7).

The areal distribution of the Nýřany Member in central and western Bohemia is more extensive than that of the underlying Radnice Member. However, some low structural highs trending NE-SW locally and initially prevented the deposition of the Nýřany Member. Higher structural highs are thought to have existed only in the area of the Křivoklát-Rokycany Volcanic Complex and perhaps even south of the Manětín Basin. Changes in source areas and also in extent of sedimentary basins took place during the break in sedimentation. A system of NW-SE to NNW-SSE trending grabens and horsts was formed prior to, or at the same time as sedimentation of the Nýřany Member began. The earliest deposits of the Nýřany Member occur in the SE part of the Plzeň Basin, in the area of the River Ohře and in the Mirošov Carboniferous relic. Variegated detritus produced by weathering of the Late Proterozoic rocks in the west and the surficial detritus from granitoid massifs was transported into the basin. The size of sedimentary basin was rapidly enlarged and the upper part of the Nýřany Member covered much of the Mšeno-Roudnice Basin. Lithology of the Nýřany Member (Fig. 5) deposited on the alluvial plain varies considerably comparing with the Radnice Member sediments. Whereas in the western Bohemian basins fluvial deposits prevailed, the central Bohemian basins were partly dominated by lacustrine sediments deposited in several intermittent lakes elongated in the E-W direction and located in the central part of the region. Lacustrine sediments are flanked by alluvial fans toward the south and locally even toward the north. Low transporting competence of streams flowing into these lakes was controlled by the velocity and extent of flash floods. Coal seams originated between the channels and abandoned meanders, in intermittent lakes and marshes. Periodical influx of coarse detrital material considerably reduced the early formation of coal seams as peat bogs were not protected from the detrital material by elevations of crystalline basement as in the underlying unit (Pešek 1968). Sedimentation of the Nýřany Member was accompanied by weak, largely acid volcanics.

Detrital material was brought into the central and western Bohemian basins from sources in the S and SE (particularly from the central Bohemian pluton – see Kukal 1983; Pešek 1994). Some other granitic massifs also served as sources of weathered material. Material from weathered metamorphic complexes was washed into the basin, too.

The character and dynamics of the water regime in which these sediments were deposited is poorly understood. We are of the opinion that the central and western Bohemian Carboniferous basins may have been drained into Saxony, Federal Republic of Germany. However, hypothetical drainage in part of the central Bohemian basins through Sudetic basins into N Sudetic Basin in Poland cannot be excluded. The topography of the Bohemian Massif remained almost unchanged as compared with the deposition of the previous unit. Some levelling of the relief probably existed although local occurrences of coarse detritus are indicative of uplifted blocks yielding largely mechanically weathered material.

The deposition of Westphalian D-Cantabrian sequence took place under similar climatic and orogenic conditions as those prevailing during the underlying unit, *i.e.* under warm and humid climate which was favourable for the growth of rich vegetation. The Nýřany Member flora contains two successive assemblages (Šetlík 1977; Wagner 1977). The older one is of the late Westphalian D while the younger one, containing *Sphenophyllum oblongifolium* (Germar & Kaulfus) and *Pecopteris lepidorhachis* Brongniart refers to the Cantabrian. A little younger seems to be the flora of the Svatoňovice Member in the Intra-Sudetic Basin (Wagner 1977) which contains also *Praecallipteridium jongmansi* (Bertrand) and *Odontopteris cantabrica* Wagner.

THE STEPHANIAN IN THE LATE PALAEOZOIC BASINS OF THE CZECH REPUBLIC

It is generally accepted that the Late Palaeozoic continental basins of the Czech Republic contain sedimentary records comprising most of the Stephanian (Havlena 1974; Šetlík 1977; Pešek 1994; etc.). Thus the Westphalian D to Early Cantabrian age is assumed for the Nýřany and Svatoňovice Members in the central and western Bohemia and in the Sudetic area respectively. Similarly, Barruelian (Stephanian A) is supposed for the Týnec Formation (with *Neuropteris ovata* Hoffman), Stephanian B for the Slaný Formation and Stephanian C for the Líně Formation and their lateral equivalents in the Sudetic area (Fig. 7). Lithologically and floristically proved hiatuses of the basinal range are recorded only from the Late Bolsovian to the Late Westphalian D and between Late Stephanian B to the Early Stephanian C (within the Late Stephanian of Doubinger *et al.* 1995). The range of the latter extends up to the Autunian in the Intra-Sudetic Basin. On the other hand, Wagner (1977) proposed another long-lasting hiatus between the Nýřany Member and the Týnec Formation in the central and western Bohemia and adequate units in the Sudetic region. This hiatus comprises most of the Cantabrian, Barruelian and Stephanian B. The Late Stephanian B is therefore proposed for the Týnec and Slaný Formations and their equivalent in the Sudetic area by this author. Continuous floristic succession seems to be present from the the Late Westphalian D to Early Cantabrian and from the Late Stephanian B to Stephanian C. This hiatus is deduced mainly by the presence of *Lilpopia raciborskii* (Lilpop) and *Nemejcopteris feminaeformis* (Schlotheim) from the Týnec Formation and their absence in the top of the Nýřany Member. Only the part occurring above the hiatus between the Stephanian B and C has been selected to present Stephanian palaeogeography in this contribution.

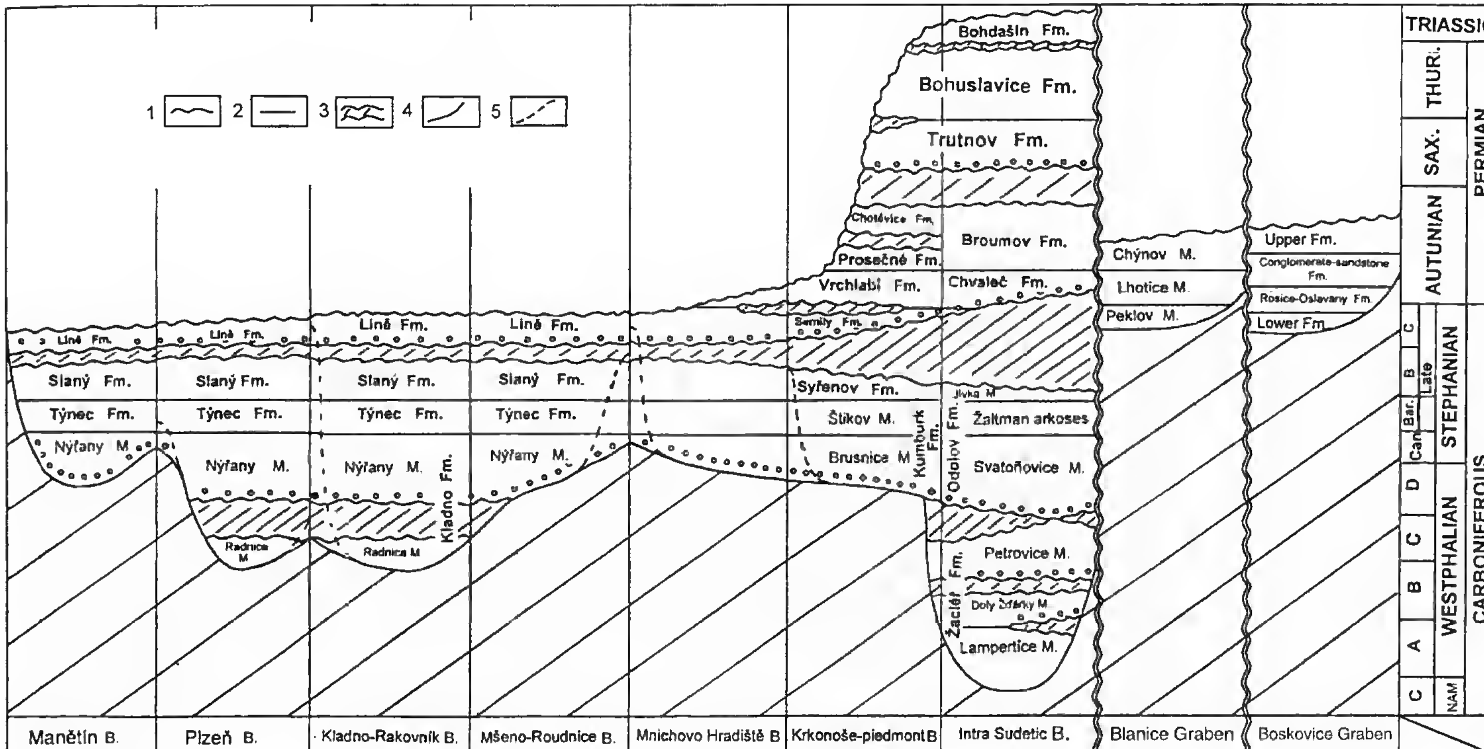
STEPHANIAN C-AUTUNIAN

Stephanian C and Autunian sediments in limnic basins of the Bohemian Massif were deposited after a hiatus related to an intra-Stephanian phase of the Variscan orogeny which is responsible for remarkable changes in the geology of sedimentary basins and source areas. The distribution and abundance of deposits of the studied interval suggest these two stages should be described separately.

Stephanian C and Autunian sediments in the central and western Bohemia as well as in the Sudetic region consist mostly of unfossiliferous red beds in which flora is recorded mainly from several grey horizons accompanied by thin coals or bituminous shales with vertebrates. In the Blanice and Boskovice Grabens the uppermost Stephanian C contains mineable coal seams accompanied by rich flora. Whereas the presence of *Sphenophyllum angustifolium* Germar is typical for the Stephanian C, rich *Callipteris* flora including *Autunia conferta* (Sternberg) dominates in the Autunian deposits.

Recently, the Stephanian was revised in the Saint-Étienne Basin by Doubinger *et al.* (1995). They propose to subdivide the Stephanian into an Early Stephanian (the Barruelian, equivalent to the former Stephanian A), and a Late Stephanian (the Forezian, equivalent to the former Stephanian B and C).

Basic features of the Stephanian C (Havlena & Pešek 1980), can be summarized as follows: an



Formation = Fm.
Member = M.

FIG. 7. — Lithostratigraphic division and correlation of the most important Late Palaeozoic limnic basins in the Czech Republic. **1**, erosional unit boundary; **2**, unit boundary; **3**, hiatus; **4**, a boundary between the Carboniferous/Permian formations and the underlying unit regardless of its age and petrographic composition; **5**, increase in the area of sedimentation over the basement in different basins.

Stephanian C - Autunian

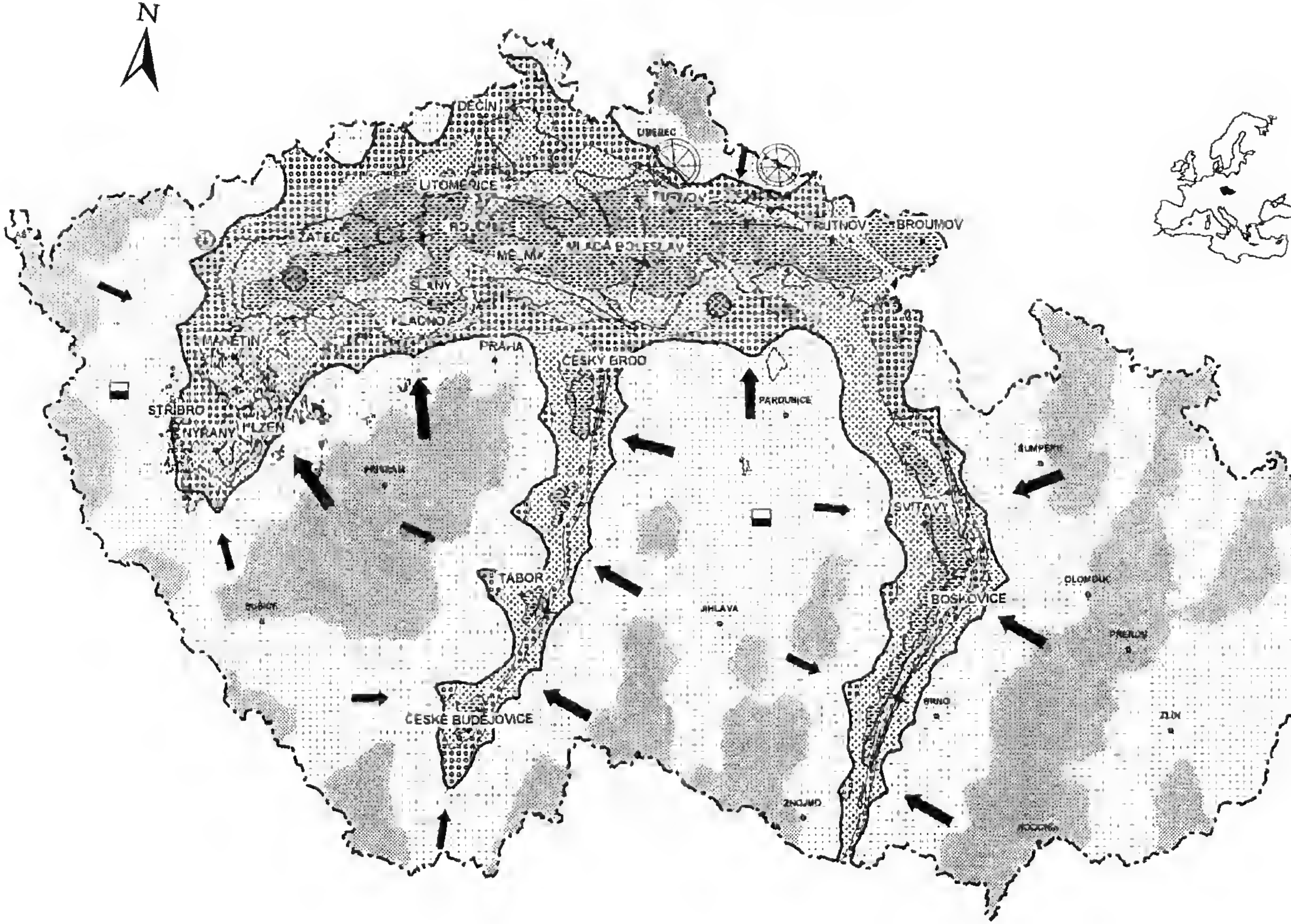


FIG. 8. — Palaeogeography of the Czech Republic during the late Stephanian (Stephanian C) - Autunian (see legend Fig. 4).

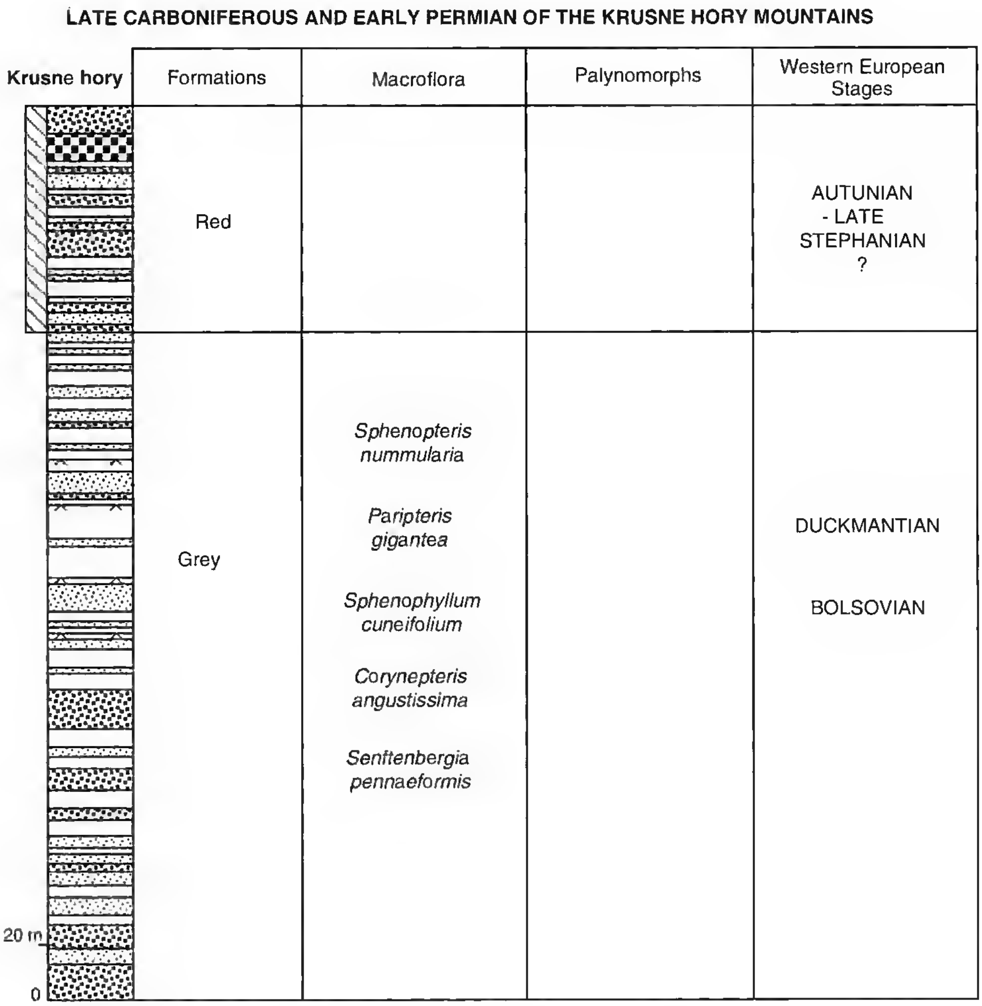


FIG. 9. — Lithological scheme of the Late Palaeozoic sediments of Brandov relic in the Krušné hory Mountains region, Czech Republic, 13°24'E - 50°37'N.

extensive subsidence occurred during which extremely thick sediments were accumulated in the central Bohemian basins as a part of a consistent central Bohemian-Sudetic area. In contrast, much less sediments accumulated in the Sudetic part of this area, or sedimentation may have been interrupted (*i.e.* Intra-Sudetic Basin). During the intra-Stephanian hiatus, a substantial part of Stephanian B sediments was eroded from the Intra-Sudetic Basin but a rather smaller part of these deposits was removed in the Mnichovo Hradiště and Krkonoše-piedmont Basins (Fig. 10). The subsidence and sedimentation in both Grabens (Boskovice and Blanice) as well as in the Česká Kamenice Basin started probably during the Early Stephanian C. The deposition of Stephanian C sediments was also renewed near Brandov in Krušné hory Mountains (Fig. 9) after a long hiatus.

Stephanian C sediments were deposited in a basin extending from western Bohemia as far as to the Krkonoše-piedmont Basin. The sedimentation took place only in the Mnichovo Hradiště and Krkonoše-piedmont Basins due to the

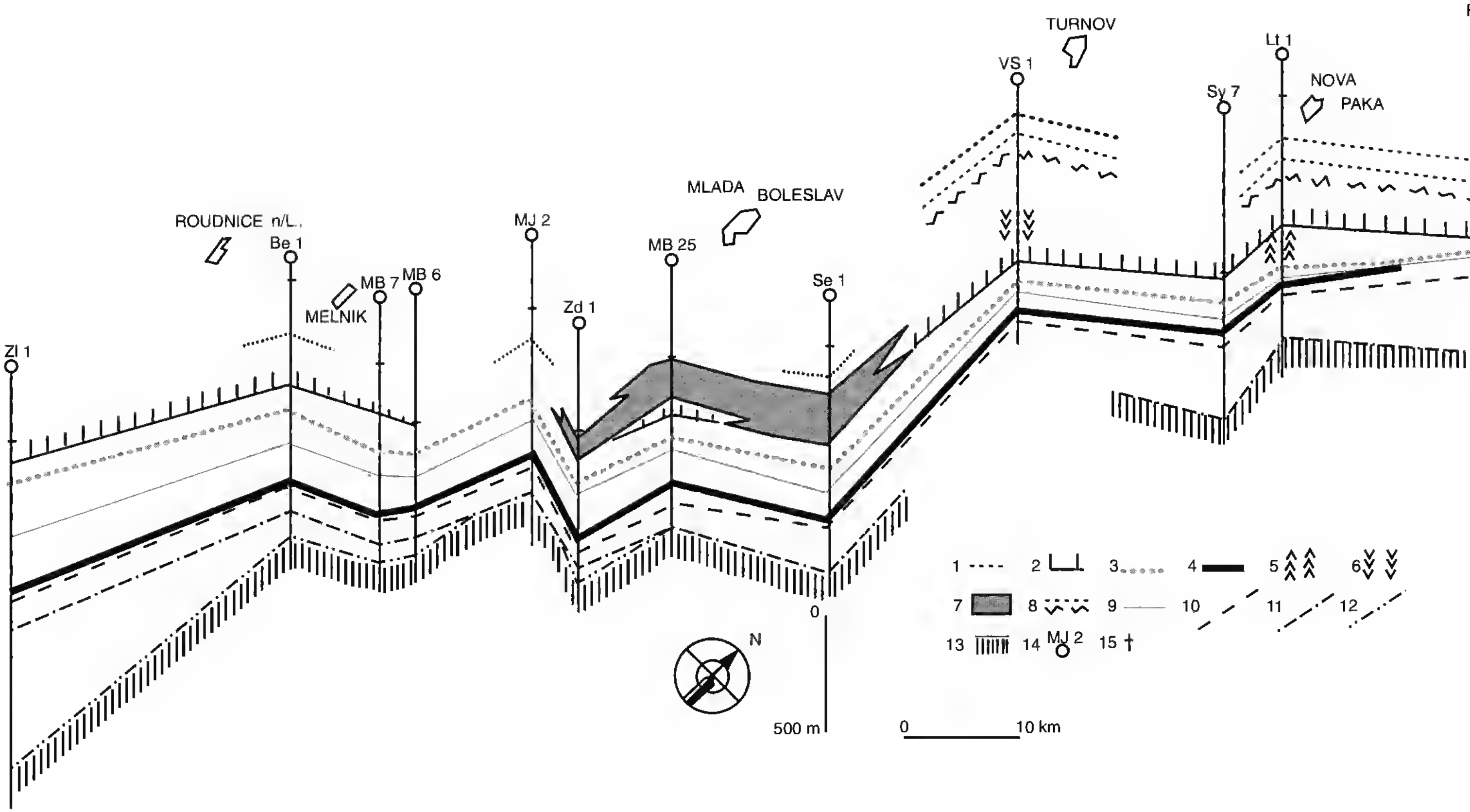


FIG. 10. — Correlation of lithostratigraphical units in parts of the Kladno-Rakovník Basin, Mnichovo Hradiště Basin and Krkonoše-piedmont Basin. Modified after Havlena & Pešek (1980). **1-3**, variegated aleuropelites of the Líně Formation (central Bohemian basins), and/or Semily Formation (Sudetic region): **1**, Stránka Horizon; **2**, thickness of the Klobuky Horizon and/or upper Ploužnice Horizon; **3**, thickness of the Zdětín and/or lower Ploužnice Horizon. **4**, Mšec Member and its black claystones equivalent of the Syřenov Formation. **5**, **6**, volcanites: **5**, intrusive rocks; **6**, extrusive rocks. **7**, sediments with conglomerate interbeds of the Barrandien type (Zikmundová-Holub 1965). **8-12**, formation boundary: **8**, base of the Líbštát Formation; **9**, base of the Líně Formation and its equivalent; **10**, base of the Slaný Formation and its equivalent; **11**, base of the Týnec Formation and its equivalent; **12**, base of the Kladno Formation. **13**, Late Paleeozoic basement. **14**, borehole collar. **15**, borehole data of the Late Palaeozoic strata.

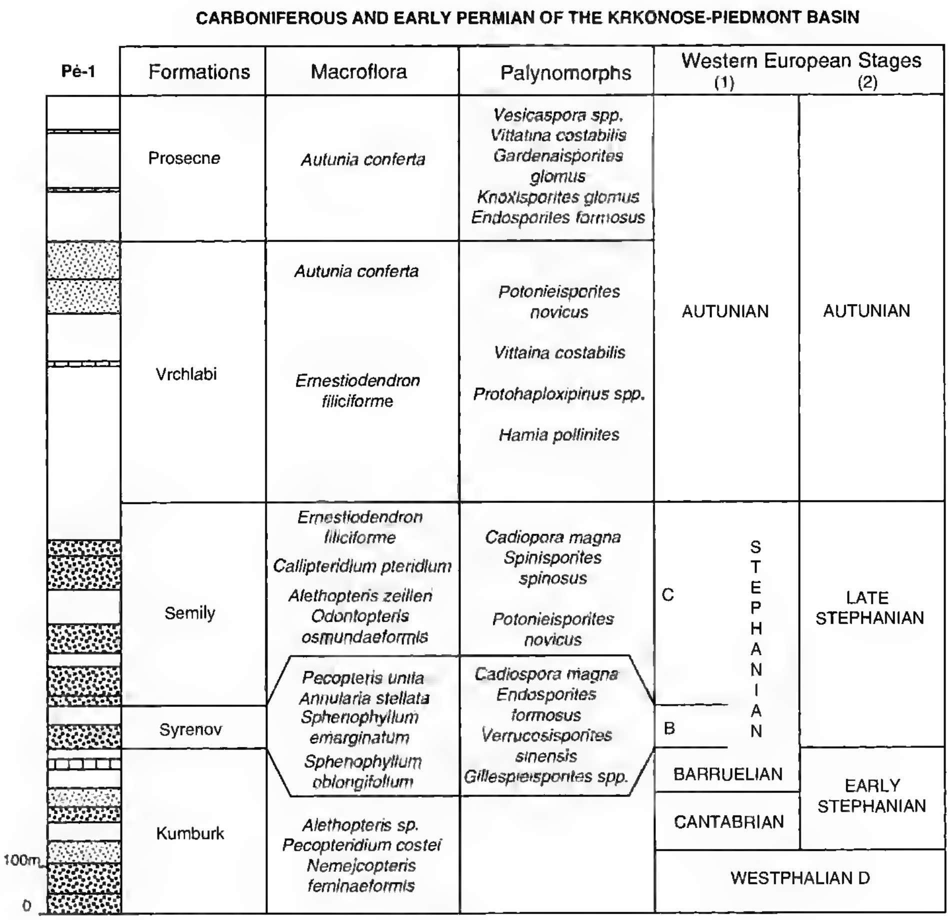


FIG. 11. — Borehole Pé1 (Prosečné) from the central part of the Krkonoše-piedmont Basin, Czech Republic, 15°41'E - 50°34'N. **1**, Martinek (this volume); **2**, Doubinger *et al.* 1995.

arching of the eastern segment of the latter basin and of the entire Intra-Sudetic Basin in particular. The Krkonoše-piedmont Basin was probably interconnected with the Česká Kamenice Basin. The central Bohemian basins were possibly also connected with the Late Palaeozoic relics near Brandov and Český Brod.

An ephemeral lake existed in west and central Bohemian and some Sudetic basins. The extent of this lake was comparable to the lake existing earlier. However, the area of the basin alternately increased or decreased depending on the volume of coarse material supplied. Minor streams also transported mud and rubble from weathered rocks from the N. Kollert *et al.* (1975) and Holub *et al.* (1981) believe that substantial volume of sediments is also of aeolian origin. Shallow water-filled depressions were locally overgrown by vegetation. After the deposition of the Klobuky horizon, a short break in sedimentation perhaps occurred in the eastern part of the Mšeno-Roudnice Basin. Early Palaeozoic rocks in source areas were exposed during this break. Deposits of this age are also known from the Carboniferous basement in the SE part of this basin. The Silurian and Devonian limestones were eroded and their fragments were transported into the basin from the south (Zikmundová & Holub 1965).

The deposition of sediments took place during

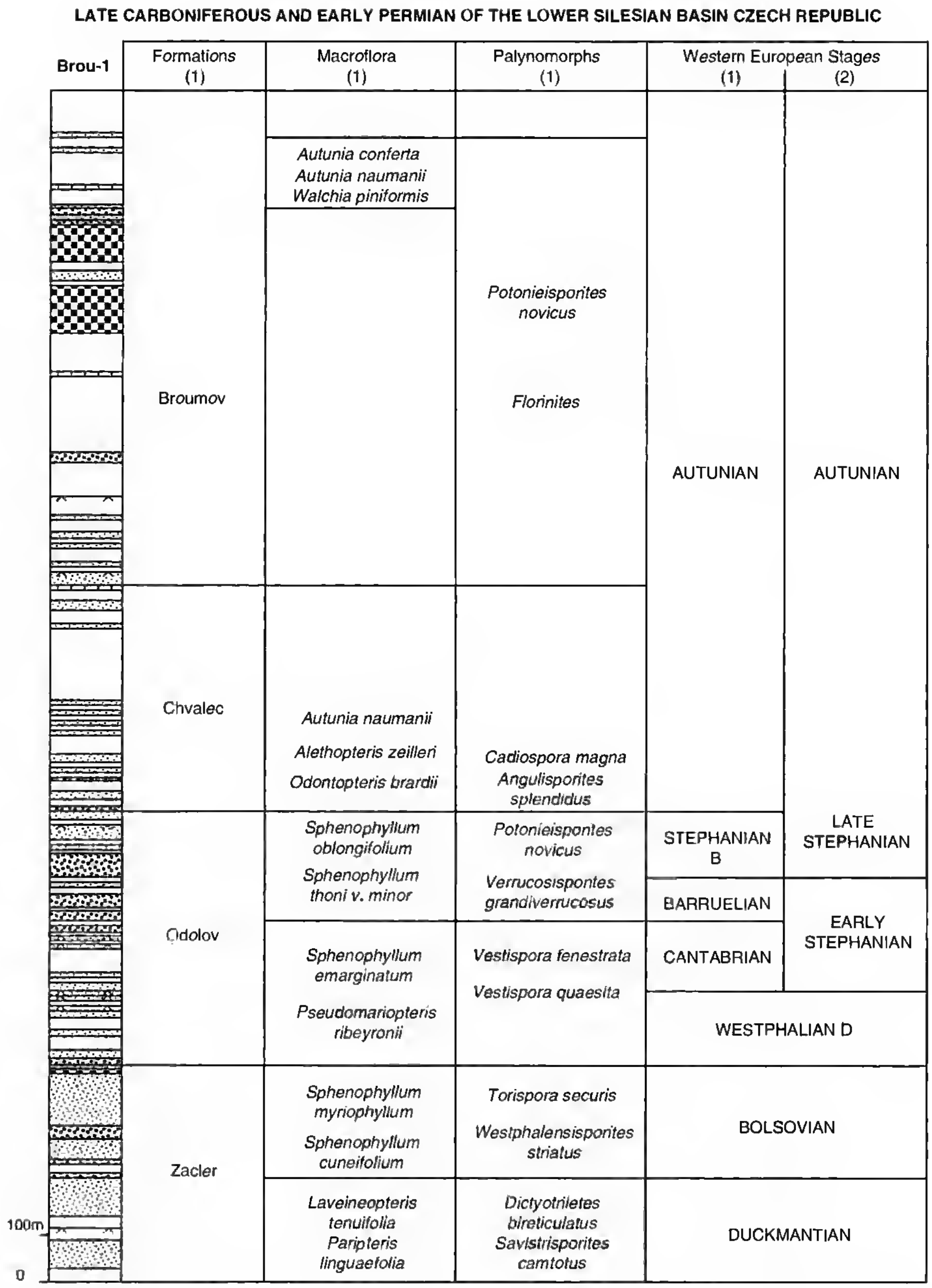


FIG. 12. — Borehole Brou 1 (Broumov) from the central part of the Intra Sudetic Basin, Czech Republic, 16°21'E - 50°35'N, lithology and biostratigraphy. **1**, Opluštil & Pešek (this volume); **2**, Doubinger *et al.* 1995.

intense acid and basic volcanic activity. The volcanic centers existed outside the central and western Bohemian basins and also inside the Kladno-Rakovnik basin in the Žatec area. Detrital material was probably derived from sources which already supplied the underlying units.

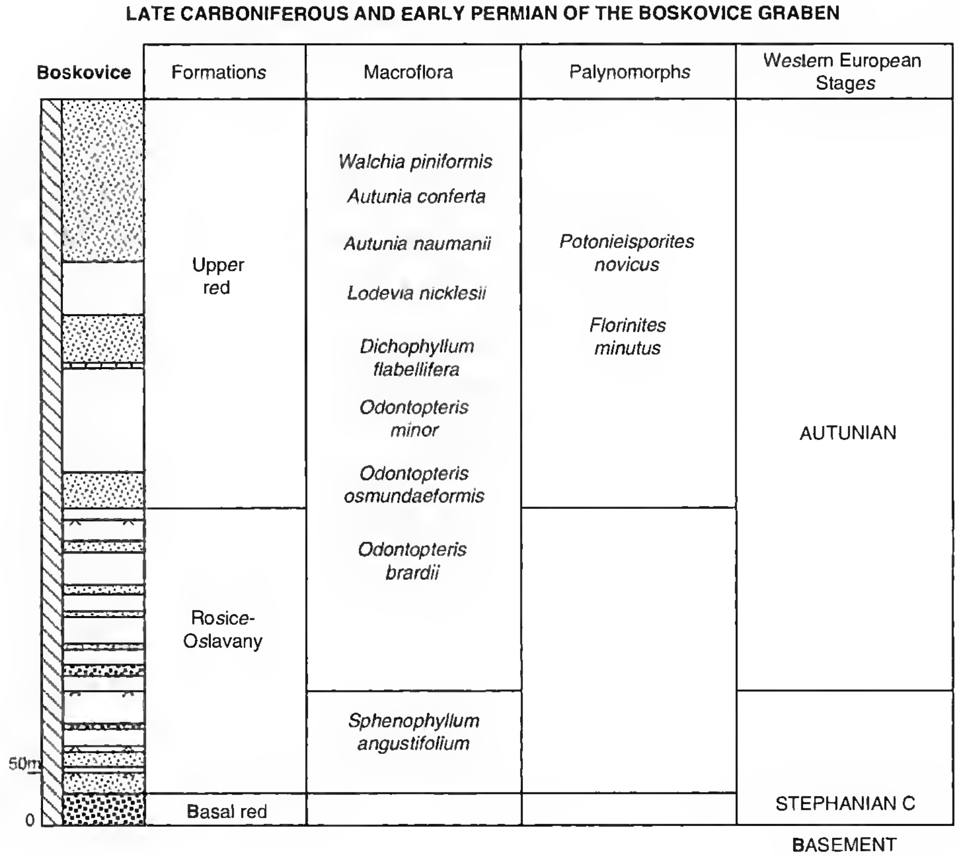


FIG. 13. — Boskovice Graben, Czech Republic, 16°25'E - 49°10'N, lithological and biostratigraphical scheme.

However, the Late Proterozoic metamorphites and Early Palaeozoic rocks of the Barrandian area seem to have played a more important role as a source. In addition, the occurrence of conglomerates containing pebbles of Silurian and Devonian carbonates indicates that some new source areas of detrital material must have existed. Crystalline complexes of the Teplá, Krušné hory Mountains and Lugicum in particular probably also played an important role as source areas.

The Semily Formation (Fig. 11) together with yet unnamed units of the same age constitute Stephanian C sediments in the remaining Sudetic basins. The sedimentary domain of the most important Sudetic basins, the Mnichovo Hradiště and the Krkonoše-piedmont Basins, was surrounded by source areas to the south, east and north. The alluvial plain of the Sudetic basins was connected with the central Bohemian alluvial plain to the West. Both plains share the fluviolacustrine and lacustrine deposits. Lacustrine sediments in these basins pass in fluviolacustrine to fluvial deposits toward the margins of the alluvial plain. Small peat bogs in the Krkonoše-piedmont Basin were formed during the period of reduced sediment supply. The deposition was locally accompanied by contemporaneous intermediate to basic volcanism. It is possible that the Sudetic, central and western Bohemian basins were drained by several streams through the area of present Krušné hory Mountains into Saxony. Individual, small basins elongated NNE-SSW and supplied with clastics from the west and mainly from the E probably existed in the Blanice Graben near České Budějovice and Tábor. The area near Český Brod may have been connected with the central Bohemian alluvial plain in the N (Havlena & Pešek 1980). A marked zone of piedmont sedimentation with alluvial fans and talus was formed along an arched source area E of Český Brod. Minor coal-forming vegetation locally grew in small shallow lakes.

A narrow basin was formed in the Boskovice Graben (Fig. 13) W of the large arched block of the Brno Massif. Morphologically marked boundary of this block was rimmed by a zone of thick talus deposits and alluvial fans. Minor fluviolacustrine and lacustrine sediments were deposited contemporaneously with piedmont sediments west of this area. Organic deposition was restricted only to the Rosice-Oslavany area. Minor contemporaneous volcanic activity was recorded here.

Autunian sedimentation in the Bohemian Massif probably occurred over a large area interconnecting all limnic basins of the Czech Republic. Gradual cessation of deposition was due to arching of the western and central parts of basins in western and central Bohemia. Consequently, higher thicknesses of sediments were deposited in the Mšeno-Roudnice Basin only. This basin and the Sudetic basins constituted a newly formed basin which also included the newly formed Orlice Basin and the Boskovice and Blanice Grabens. In contrast to the Stephanian C, the extensive subsidence during the Autunian time shifted into the Sudetic basins and also in the Boskovice and Blanice Grabens where sedimentation reached its peak.

Autunian sedimentation in the Intra-Sudetic Basin (Fig. 12) includes deposits of alluvial fans and sediments brought probably by ephemeral streams (Vernéřovice Member). The upward decrease in grain size indicates an extensive denudation of source areas which resulted in the prevalence of alluvial plain and lacustrine sediments over fluvial channel deposits. Sedimentation of the Bečkov Member (Chvaleč Formation) in particular was accompanied by strong volcanic activity west of the Intra-Sudetic Basin. However, in the Intra-Sudetic Basin itself, only pyroclastics occur. Similar development of the sedimentary filling is also known from the Krkonoše-piedmont Basin (Fig. 11) but its latest Autunian unit (Chotěvice Formation) includes a large proportion of evaporites (Prouza *et al.* 1977).

The development of the Blanice and Boskovice Grabens reached its peak during the Autunian. Both basins are characterized by extensive subsidence along the eastern boundary of permanently uplifting blocks. Margins of those blocks were source areas for sediments of alluvial fans and talus deposits. Fluviolacustrine sediments occurring in central and eastern parts of both grabens originated in source areas located east of these basins (Fig. 13). These areas were gently arching and formed morphologicaly low relics. Fluviolacustrine sediments which are in heteropic relation to marginal sedimentation in the east, passed gradually toward the north into similar sediments in the Mšeno-Roudnice Basin and/or in the Sudetic sedimentary domain. Sedimentation in the Boskovice Graben was accompanied by a weak volcanic activity. Autunian and Saxonian sediments preserved along the Lužice fault in northern Bohemia provide an evidence for the connection of the Bohemian basins with similar basins in Saxony. These basins may have been also drained into the North Sudetic Basin in Poland.

The deposition of dominantly fine detrital material indicates continuing denudation of the Bohemian Massif. Several formerly buried units were uplifted and exposed to erosion as evidenced for example by pebbles of Early Palaeozoic carbonates in the Mšeno-Roudnice Basin.

The deposition of sediments of both stages studied took place in a warm to hot climate which gradually became arid.

CORRELATION OF THE CZECH LATE PALAEOZOIC CONTINENTAL BASINS WITH SIMILAR BASINS IN EUROPE

Various types of continental basins occur in the Bohemian Massif. Despite their comparable geotectonic position with similar continental basins of Variscan Europe, they usually differ in stratigraphic range of their sedimentary records and in size and architecture. Such differences occur even within the Bohemian Massif. On the opposite, there is a strong resemblance of the Blanice and Boskovice Grabens with similar basins in the French Massif central. In both areas, narrow half-grabens with a high subsidence rate developed during the Stephanian and Permian. Their genesis is related to wrench faulting connected with Variscan orogeny (Ziegler 1986).

Stratigraphic range of the basins in central and western Bohemia and Sudetic area has probably no exact equivalent in any other basin of Europe. Some hiatuses traceable in different basins of the Variscan chain and its foredeep may have been of correlative value. The important hiatus proved in the basins of the central and western Bohemia and poorly developed in the Sudetic area is related to the Leonian phase defined in NW Spain. This hiatus has been also recognized in the Late Silesian Basin in Poland as well as in the Krušné hory Mountains Basin (in German literature the Erzgebirge Becken) and NE part of the Saale Basin in Halle-Delitzsch district (Schneider *et al.* 1994) in Germany. In the W European foredeep this hiatus corresponds with the termination of paralic deposition and onset of non-marine sedimentation.

CONCLUSION

The internal parts of the European Variscides including the Bohemian Massif contain a number of the Late Palaeozoic continental basins whose initiation and development are related to final phases of Variscan orogeny. The dominant role of strike-slip faulting was emphasized by many authors (Arthaud & Matte 1977; Ziegler 1986). In the Bohemian Massif the role of wrench faults was recently demonstrated by Pašek & Urban (1990) on an example of the Pilsen Basin.

Continental basins of the Bohemian Massif were formed in two periods: in the Namurian-Westphalian period and in the late Stephanian period. During the Namurian but mainly in the Westphalian, the basins of central and western Bohemia and Sudetic area were formed. In the late Stephanian only a few kilometres wide but tens of kilometres long half-grabens (Blanice and Boskovice Grabens) of NNE direction were originated.

In the middle Westphalian the deposition took place in two separated areas – in western and central Bohemia and in the Sudetic area. Basal sediments of both depocentres infilled erosively or tectonically established river valleys. SW-NE trending morphological depressions contrast with nearly N-S narrow graben-like tectonical valleys, described from the Plzeň and Kladno-Rakovník Basins (Pašek & Urban 1990; Pešek 1994), the direction of which is comparable with that of the Blanice and Boskovice Grabens.

During the Westphalian D and Cantabrian an extensive increase in sedimentary area resulted in connection of central and western Bohemian depocentre with the one in the Sudetic area around the Westphalian-Stephanian boundary. Another substantial widening took place after a hiatus in the Stephanian C when the sedimentary area reached its maximum due to newly established grabens which were connected with basins of the Sudetic area.

Sedimentary record in most of the Czech Late Palaeozoic continental basins is interrupted by several hiatuses. In the Westphalian and Stephanian two important interruptions have been proved on the basis of floristical and lithological changes. The first one, ranging from the Late Bolsovian to the Early Westphalian D is also detectable in some other basins in Poland and the eastern part of Germany. The second hiatus is dated to the Early Stephanian C. During both hiatuses significant reworking of tectonic and structural plans of basins and their basement resulted in changes of sourcelands and an extensive widening in sedimentary area accompanied by shifting of the axis of maximum subsidence after a hiatus. Another, however, only floristically evidenced gap is supposed by Wagner (1977) from Late Cantabrian to Early Stephanian B. Tectonic activity was connected with intensive volcanism concentrated mostly into middle Westphalian and to the Stephanian C-Autunian. For the Westphalian, humid and probably warm climate is assumed. Since the Late Stephanian (Forezian) a seasonal climate with respect to rainfall fluctuation has been evidenced. Primary red beds predominate in the Late Stephanian and Permian sediments as a consequence of gradual increase in aridity to the end of the Palaeozoic.

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Late Carboniferous to Early Permian time interval in the Western Carpathians: Northern Tethys Margin

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ABSTRACT
Carboniferous to Permian basins reflected compression regime of the Variscan orogeny during the continent-continent collision in final stages. The fragments of these microplates are preserved in the Alpine Western Carpathians basement (CWCZ, NGZ vers. IWCZ). On the basis of sedimentary sequence analysis two zones of continental collision differing in time were established: (1) internal with termination of collision during Bretonian (pre-Sudetian) events, resulting in the syn-collision Tournaisian-Visean flysch; (2) external with termination of collision during pre-Asturian events, comprising the Bashkirian, and in the innermost part of the Western Carpathians (Bükk Mountains in the northern part of Hungary) partly even the Early Moscovian flysch sequences.

KEY WORDS
Peri-Tethys,
Western Carpathians,
Late Variscan orogeny,
Carboniferous-Permian,
syn- and post-orogenic basins,
collision events.

RÉSUMÉ
L'intervalle Carbonifère supérieur à Permien inférieur dans les Carpates occidentales : marge septentrionale de la Téthys. Les bassins d'âge carbonifère à permien reflètent un régime de compression appartenant à l'orogénèse varisque, lors de la collision continent-continent dans les stages finaux. Les fragments de ces microplaques sont préservés dans le socle des Carpates alpines occidentales (CWCZ, NGZ vers. IWCZ). D'après l'analyse des séquences sédimentaires, deux zones de collision continentale peuvent être établies : (1) interne avec la fin de la collision pendant la phase Bretonne (pré-Sudète), entraînant le dépôt du flysch tournaisien-viséen inférieur syn-collision ; (2) externe, avec la fin de la collision pendant la phase pré-Asturienne, comprenant le Bashkirien et, dans la partie la plus interne des Carpates occidentales (Montagne du Bükk dans le nord de la Hongrie), le dépôt de flysch d'âge moscovien inférieur.

MOTS CLÉS
Péri-Téthys,
Carpates occidentales,
orogénèse tardi varisque,
Carbonifère,
Permien,
bassins syn- et post-orogéniques,
collision.

INTRODUCTION

The kinematic evolution of the West Carpathians orogenic system was created during both Variscan and Alpine times. Fragments of newly formed Epi-Variscan crust were incorporated in the Paleo-Alpine West Carpathian units as evidenced by repeating subduction/collision and transform fault processes. The Epi-Variscan crust gradually amalgamated due to crustal thickening during Early to Late Carboniferous collision events, as the colliding microplates of African affinity moved southwards. The Early Carboniferous flysch troughs originated in intrasutural embayment continuing in the Late Carboniferous peripheral basin on the underthrusting plate of the African promontory. The post-collisional Permian evolution of the Western Carpathian realm continued by formation of transtension/transptession and rifting-related sedimentary basins.

Like most of the other collisional fold belts, the Western Carpathians have been traditionally divided into external and internal structural zones. The main difference between distinguished structural zones is in the age of the main Alpine events and in the intensity of their deformational and metamorphic effects. These are: (1) internal zone, the HP/LT Late Jurassic subduction event and Early/Middle Cretaceous collision, followed by nappe stacking; (2) external zone, the Late Cretaceous/Early Paleocene to the Oligocene/Early Miocene subduction/accretion and collision events. The fragments of the Late Paleozoic sedimentary basins filling are preserved only inside of the internal zone, as a part of principal crustal-scale superunits (from N to S: the Tatricum, Veporicum and Gemericum), and several cover nappe systems (Fatric, Hronic and Silic) as well as of the Bôrka and Turňa nappe slivers (Fig. 1).

Relics of the Late Carboniferous sedimentary sequences are proved by lithofacial and biofacial data in a relative wide range of sedimentary environments, from shallow-water marine to paralic and continental. The Early Permian sediments confirm only continental environment as a whole.

GEOLOGICAL FRAMEWORK

Different types of Variscan basement were overstepped by the Late Carboniferous/Early Permian sedimentary sequences. With respect to the metamorphic overprint, independent of the age of metamorphism, the Alpine-Western Carpathian basement may be subdivided into three zones (Fig. 1):

1. The Central Western Carpathian crystalline zone (CWCZ) which comprises mainly metamorphic rocks and huge masses of pre-Mesozoic granitoids. Pieces of pre-Variscan metamorphic crust were most probably included in this zone. Several pre-Alpine terranes were identified within large portion of the CWC-Alpine nappe units (Tatra T., within Tatric, Northern Veporic and Zemplinic Units; Kohút T., within Southern Veporic Unit; Hypoth. Ipoltica T., within Hronic Unit; Vozárová & Vozár 1993, 1996). Nearly all underwent Variscan metamorphism during Early Carboniferous post-dating sometimes such of Silurian/Devonian or also older metamorphic events. Magmatic activity is concentrated into two stages (Rb-Sr; U-Pb: approx. 360-340 Ma and 320-300 Ma; Cambel & Král 1989; Cambel *et al.* 1990).

Rare post-orogenic A-magmatites correspond to Permian age (Rb/Sr: 280-250 Ma; Cambel *et al.* 1989). Geochemical data indicate the operation of subduction system and then collisional-type of orogeny (Hovorka & Petrík 1992; Kohút 1992; Petrík *et al.* 1994, 1995). Granulites and leptinyte-amphibolite complexes with pieces of meta-ultramafic rocks and regressive overprinted eclogites are integral part of the CWCZ basement (Hovorka & Meres 1989, 1990; Vozárová 1993).

2. The Northern Gemeric zone (NGZ) with relics of the Namurian-Visean flysch and thrust wedges of pre-Carboniferous oceanic crust. This zone represents the Variscan collision suture, amalgamating two major Variscan microplates

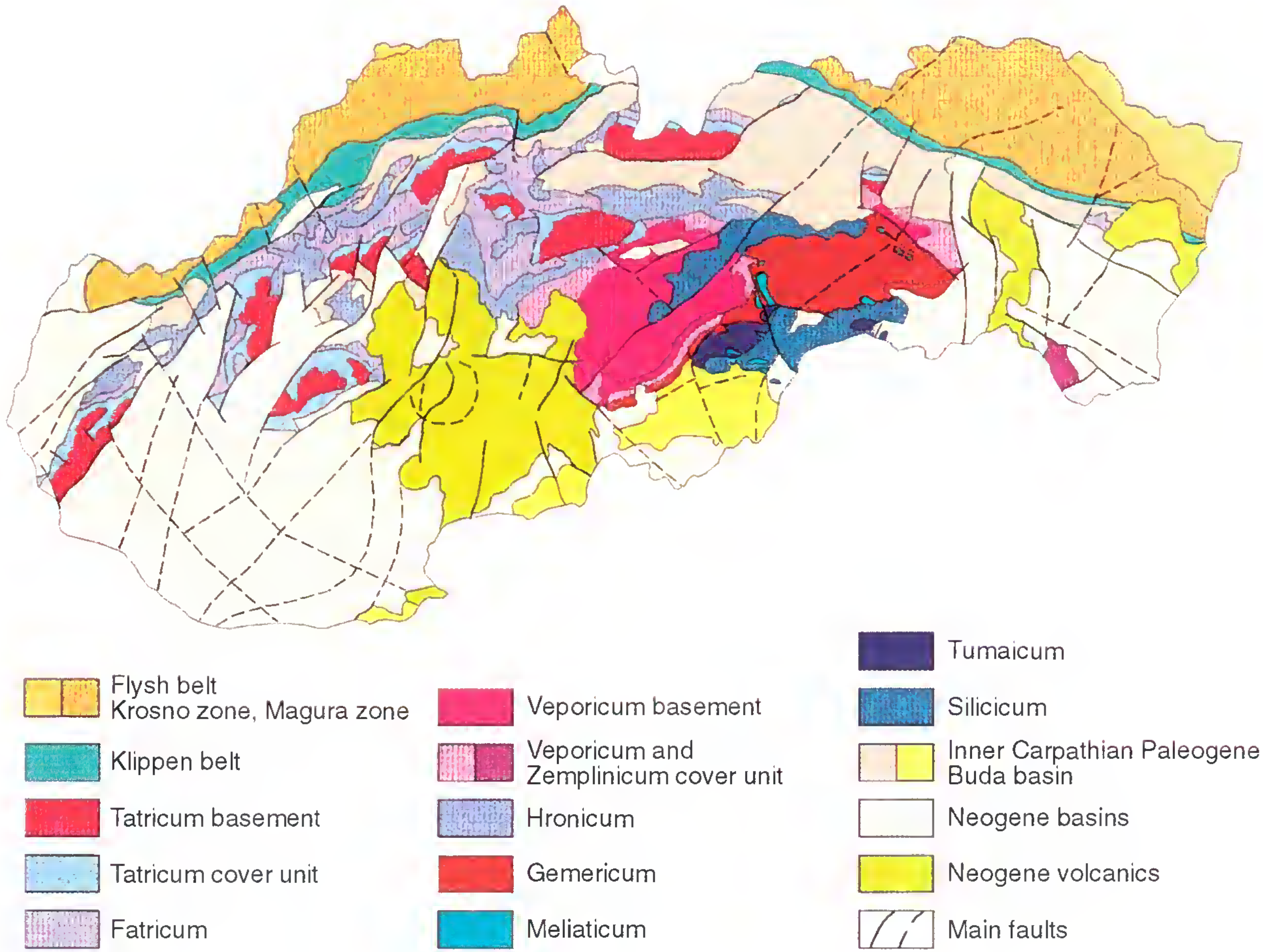


FIG. 1 — Tectonic sketch of the Slovak part of the western Carpathian (see legend Fig. 8).

(Vozárová & Vozár 1987, 1988; Neubauer 1988; Neubauer & Vozárová 1990). To this domain two since undated Variscan terranes (Klátov and Rakovec T.; Vozárová & Vozár 1993, 1996), which differ each of other in tectono-metamorphic development and probably also in the age of protolith. Their gradual amalgamation was taking place in the Early Carboniferous because, as the Uppermost Visean/Serpukhovian is in shallow water carbonate-clastic development (magnesite horizon within the Ochtiná Group) and after stratigraphic hiatus in the Namurian B-C, were unconformably overlapped by the Moscovian marine molasse. This unconformably lying marine molasse partly covered also the Early Carboniferous flysch sequence (eastern part of NGZ), to fix up the Late Variscan thrust sheet structure.

The mutual contact of the pre-Carboniferous crystalline complexes is tectonic, followed by lenses of antigoritic serpentinites.

High-grade crystalline complex (the Klátov T.) consists of mainly amphibolites, less gneisses and meta-ultramafic rocks. Meta-ultramafic rocks and metabasalt were considered as a part of incomplete ophiolite suite (Hovorka *et al.* 1984; Spišiak *et al.* 1985). Findings of regressive overprinted eclogitic rocks make possible to assume a polyphase metamorphic P-T path with previous high-pressure conditions. This is the main reason for recent comparing of this complex with lower-crustal leptinite-amphibolite complexes (Hovorka *et al.* 1992).

Low-grade crystalline complex (the Rakovec T.) is composed predominantly of tholeiitic metabasalts and metabasaltic volcanoclastics, associated with less amounts of sandy-pelitic metasediments and small bodies of gabrodiorites as well as metakeratophyres. The magmatic rocks show geochemical characteristics near to E-MORB/OIT basalts (Ivan 1994) and partly to island arc basalts. Several reasons speak in favour of a back-arc/supra-subduction zone setting of this crust (Vozárová 1993).

3. The Inner Western Carpathian crystalline zone (IWCZ) which is subdivided into two subzones: the Southern Gemeric zone (SGZ), the Turňa-Szendrö-Bükk zone (TSBZ).

Dominant part of the Southern Gemeric zone is composed of the Early Paleozoic volcanogenic flysch formation and its Permian-Triassic cover (the Gelnica T.; Vozárová & Vozár 1993, 1996). A huge mass of volcanogenic flysch comprises a distinct feature of turbidity current and other mass-gravity flow sedimentation (Ivanička *et al.* 1989). Besides of a quantity of redeposited acid to intermediate volcanoclastic material, derived from synsedimentary continental magmatic arc, also detritus from the subduction complex or fragment of oceanic crust are insufficiently present. Regional metamorphism of the SGZ basement did not exceed the low-pressure greenschist facies (Sassi & Vozárová 1987, 1992). The age was proved palynologically within the wide and the most probably not precise range of the Late Cambrian to Early Devonian (Snopková & Snopko 1979). Early Paleozoic ages (497-391 Ma) are also proved by U-Pb dating from zircons in metavolcanics (Cambel *et al.* 1977; Ščerbak *et al.* 1988). The Precambrian age of the continental source area was established from detrital zircons in metasediments (U-Pb: 600-900 Ma; Cambel *et al.* 1977). The SGZ Early Paleozoic flysch sequence (the Gelnica Group) was interpreted as a relic of fore-arc filling related to active continental margin (Vozárová 1993).

Within the Turňa-Szendrö-Bükk zone the pre-Carboniferous complexes are only fragmentary preserved. They are represented mainly by the shallow-water to basinal sequences of passive continental margin of the northern Gondwana promontory (for precise description: Kovács 1989; Fülöp 1994 and others).

The Bashkirian olistostroma flysch complexes are the most typical feature of this subzone. They were described within the Turnaic Unit in the Inner Western Carpathians (Vozárová & Vozár 1992) as well as in the Szendrö and Bükk Mountains (Kovács 1988, 1992). The slight or no Variscan metamorphism is typical for TSBZ Paleozoic complexes. Only exclusion are sequences of the Bashkirian flysch in the Western Carpathian Turnaic Unit, the Variscan regional metamorphism of which reached the low-pressure greenschist facies (Mazzoli & Vozárová 1989).

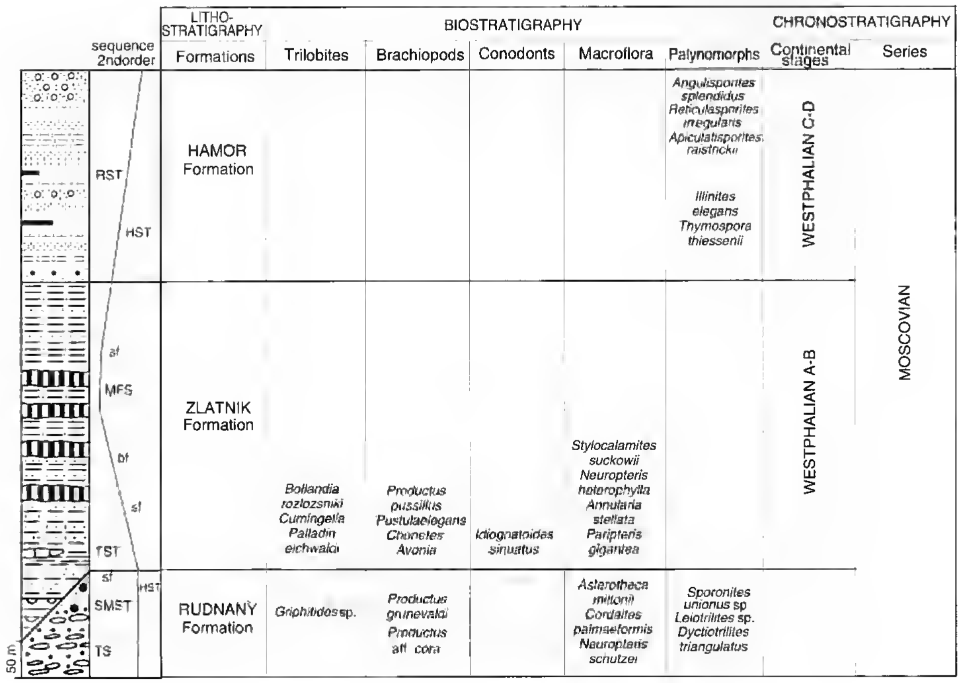


FIG. 2. — The Westphalian of the northern Gemeric Unit (see legend Fig. 8).

UPPER CARBONIFEROUS

MARINE DEVELOPMENT

The Westphalian sequences are preserved within the paleo-Alpine North Gemeric Unit (Fig. 2) as tectonically reduced fragments. Their tectonic setting, related to continental collision, started in the Westphalian A by delta-fan, coarse- grained, very often boulder conglomerates, containing detritus derived from underlying pre-Late Carboniferous rocks complexes. Due to strong Alpine reworking the direct contact of these basement rocks and basal part of the Westphalian deltaic-marine overstep sequences is preserved only in some places. Basal conglomerates of the Rudňany Formation unconformably overlap the gneiss-amphibolite complex of the Klátov Terrane in the vicinity of the Dobšiná town, metasediments and metabasalts of the Rakovec Terrane in the wider area of the Rudňany village, and the Early Carboniferous flysch sequence of Črmel' Formation in the area between Margecany and Košická Belá (more details referring to Variscan and Alpine history of the North Gemeric Terrane *in* Vozárová & Vozár 1993, 1996; Vozárová 1996). Black shales and micaceous grey sandstone intercalations are normal member of the fining upward Rudňany Formation. The floristic finds was determined by Němejc (1947): *Cordaites palmaeformis* Goeppert, *Asterophyllites* cf. *grandis*, *Asterotheca miltonii* Artis, *Neuropteris schutzei* Potonié, *N. gigantea abbreviata* Stockmans.

After initial rapid sedimentation the littoral to shallow-neritic limestones were associated with fine-grained clastic metasediments. This detritic-carbonate lithofacies corresponds to basal part of the Zlatník Formation, from which the Westphalian B-C age is indicated by rich trilobite fauna: *Griffithides dolosinensis* Illés, *Griffithides rozloszniki* Rakusz, 1932; *Cummingella* sp. aff. *balladoolensis* Reed, 1942; *Palladin* sp. aff. *eich-*

waldi Fischer, 1825 (*in* Rakusz 1932; Bouček & Přibyl 1960). Basing on flora findings Němejc (1947, 1953) ranged this sequence to the Westphalian A-B; *Paripteris gigantea*, *Stylocalamites suckovii*, *Neuropteris heterophylla*, *Neuropteris gigantea* Stbg, *Neuropteris flexuosa* Brongiart, *Calamites* cf.*cisti* Brongiart. The conodont *Idiognatoides sinuatus* Harris-Hollingsworth proved Westphalian A age (Kozur & Mock 1977).

Upper part of the Zlatník Formation comprises fine-grained clastic metasediments associated with fine basaltic volcanoclastics and scarce effusions of high-K tholeiitic basalts. It reflects deepening of the Moscovian sedimentary basin. Poor microfloral assemblages proved the Late Carboniferous age, but no accurate division.

Termination of the Moscovian peripheral basin is reflected by the paralic sequence of the Hámor Formation. It is characterized by: (1) distinct cyclical, coarsening-upward shally-sandy-conglomeratic sediments; (2) absence of synsedimentary volcanism; (3) local occurrence of ribbed coal seam. The microfloral assemblages proved the Westphalian D age: *Reticulatisporites irregularis* Kosanke, *Thymospora thiessenii* (Kosanke) Wilson *et* Venkatachala, *Apiculatisporites raistrickii* (Dyb.-Jach.), *Angulisporites splendidus* Bharadw., *Illinites elegans* Kos. (Ilavská 1962 unpublished report; Planderová 1979 unpublished report).

The metamorphic grade in the Moscovian sequences did not exceed P-T condition of the boundary between anchizone and lower limit of the greenschist facies.

Continental development

Westphalian-Stephanian continental sequences are preserved within the several Alpine Central Carpathian nappe units, such as very strong reduced relics within the Zemplinic, Southern Gemeric and Hronic Units. Direct contact between Wesphalian continental overstep sequence and its immediate basement is expressed only in the Zemplinic Unit.

Zemplinic Unit

The crystalline rocks of the Zemplinic Unit (Fig. 3), together with their Late Paleozoic and Mesozoic envelope, make up a tectonic horst striking NW-SE, uplifted from the basement of Tertiary filling of the East Slovakian (Transcarpathian) basin. According to the character of crystalline rocks and mainly Mesozoic development it may be correlated with the other units of the Tatro-Veporic domain (Vozárová 1989; Faryad 1995; Byšta Susp. Terr., *in* Vozárová & Vozár 1996). The Zemplinic Westphalian-Stephanian sequence consists of four partial lithostratigraphic units (Čerhov, Luhyňa, Trňa, Kašov Formations; *in* Bouček & Přibyl 1959; Grecula & Együd 1982; Vozárová 1986). Their stratigraphic range was established according to macro- and microfloral findings (Němejc 1947, 1953; Němejc & Obrhel 1958; Planderová *et al.* 1981).

Polymictic conglomerates, with grain-supported structure and relatively well-rounded pebble material are dominant lithofacies of the Čerhov Formation. They are interpreted mostly as braided-river deposits. The lithostratigraphic profile consists of repeated small fining-upward sedimentary cycles with prevalent conglomeratic or sandy-conglomeratic components. Minor black shale and siltstone intercalations occur in the upper part of the sequence. The dating, Westphalian D-Stephanian A, is based on dominant microflora: *Triquitrites* sp., *Microreticulatisporites sulcatus* (Wils. *et* Kr.), *Tripartites* sp., *Cyrratriradites trizonarius* Dyb. Jach.

The gradually evolving Luhyňa Formation consists of fine grained lacustrine sediments sandstones, mudstones and shales of grey to black colour, interrupted by episodic events of distal- fan streams. The Stephanian A age was proved mainly by macroflora: *Calamites cistii* Brongn., *Pecopteris* cf. *miltonii* Artis, *Alethopteris* sp., *Asterophyllites trichomatosus* Stur. Microfloral assemblages are indicative of the Stephanian A-B range. Dominant spores are: *Torispora securis* Balme; *Lycospora granulata* Kosanke, *Punctatisporites punctatus* (Kosanke, 1920) emend. Alpern, *Densosporites gracilis* Smith *et* Butterworth, and striate pollen of the genus *Vittatina* are less frequent.

Cyclothems with thin coal seams represent the Trňa Formation. The Early Stephanian age was inferred on the basis of plant findings: *Pecopteris*

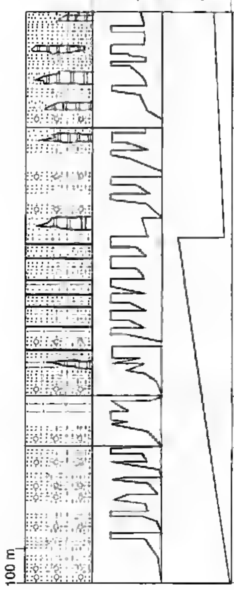
CYCLES (autocycl. allocycl.)	LITHO-STRATIGRAPHY: Formations	BIOSTRATIGRAPHY: Macroflora	BIOSTRATIGRAPHY: Palynomorphs	CHRONOSTRATIGRAPHY: Continental stages
	KASOV Formation	*Dadoxylon* sp.	*Columinisporites ovalis*, *Thymospora perverrucosa*, *Vestispora fenestrata*, *Cyclogranisporites pergranulus*	STEPHANIAN C
	TRNA Formation	*Pecopteris cyathea*, *Cordaites borassiformis*, *Astherotheca arborescens*, *Alethopteris bohemica*, *Sphenophyllum oblongifolium*, *Annularia pseudostellata*	*Columinisporites*, *Lycospora granulata*, *Torispora laevigata*, *Densosporites plicatus*, *Endosporites* div.sp.	STEPHANIAN C
			Torispora securis, *Thymospora thiessenii*, *Thymospora perverucosa*	STEPHANIAN A - B
	LUHTYNA Formation	*Calamites cistii*, *Asterophyllites trichomatosus*	*Lycopsora pusilla*, *Laevigatosporites* div.sp., *Densosporites* div.sp.	STEPHANIAN A - B
	CERHOV Formation		*Triquitrites tricuspis*, *Microreticulatisporites sulcatus*, *Cyrnatriradites trizonarus*	WESTPHALIAN C - D

Fig. 3. — The Westphalian and Stephanian of the Zemplinic Unit (see legend Fig. 8).

cyathea Schlotheim, *Cordaites borassifolius* Sternberg, *Sphenophyllum emarginatum* Brongn., *Asterotheca arborescens* Brongn., *Alethopteris bohemica* Franke, *Calamites cistii* Brongn., *Stigmaria ficoides* (Sternb.) Brongn., *Annularia pseudostellata* Potonie, *Lepidophloios laricinus* Sternb., *Lepidostrobophyllum majus* Brongn, *Pecopteridium* cf. *costeii* Zeiller. The Trňa Formation can be divided into two large cycles (several hundreds of m thick). The lower cycle contains seven limnic- fluvial cyclothems with coal seams of variable thickness (from several cm up to 160 cm). Generally, the sediments are rich in clastic mica, plant debris, fragments of tree trunks and barks. Distinct cyclicity of fining-upward type, with sets of layers of black shales with thin coal seams and occasionally dark clayey lenses and nodules of limestones, indicate limnic-fluvial and swamp environments. The second large cycle is characterized by alluvial stream-channel lithofacies, with dominant sandstone members and absence of the coal-bearing association. Several levels of rhyolite-dacite, calc-alkaline volcanoclastics are typical for this part of sequence.

Thick layers of rhyolite-dacite volcanoclastics (including ignimbrites) and alluvial, stream-channel and flood plain sediments with dominant sandstones are predominating lithologies of the Kašov Formation. Based on the microfloral assemblages, the Kašov Formation was assigned to the Stephanian B-C. The following microflora assemblages were identified: *Thymospora perverrucosa* (Alp.) Wils. *et* Ven., *Columinisporites ovalis* Peppers, *Latensina triletus* Alpern, *Vittatina ovalis* Klaus, *Spinosporites* sp., *Disaccites striatiti* div. sp., *Cordaitina* sp., *Vestispora fenestrata* (Kos.) Wils. *et* Ven., *Cyclogranisporites pergranulus* Alp.

Hronic Unit

The Hronic Unit (Fig. 4) has been defined as a rootless megastructural Alpine unit consisting of two partial nappes: Šturec and Choč nappes (accord. to Andrusov *et al.* 1973). Due to their internal structure and mutual relations as well as

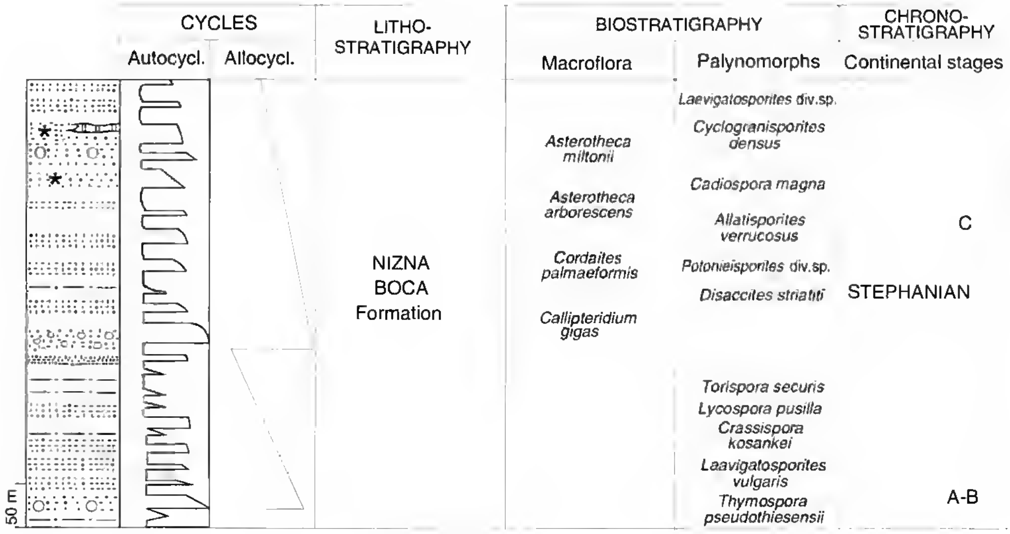


FIG. 4. — The Stephanian of the Hronic Unit (see legend Fig. 8).

facial characteristics the partial nappes have been distinguished as mainly Triassic complexes. Both Hronic nappe units contain Late Paleozoic volcano-sedimentary formations, preserved variably as a consequence of tectonic reduction during the nappe thrusting. Remains of these sequences are known in many mountain ranges in the Western Carpathians, whereby their tectonic position is always equal, between the Veporic/Fatric Unit and Northern Gemeric Unit resp. higher Mesozoic nappe units.

There is no evidence neither for the underlying pre-Stephanian sediments nor for the immediate crystalline basement. Tectonic slices of granitoid blastomylonites found in the basal part of the Šturec nappe might be partly indicative of its composition (Andrusov 1936; Vozárová & Vozár 1979). Data obtained through petrofacial analysis of clastic sediments proved an affinity to a magmatic arc source area (the hypothetical Ipoltica Terr., Vozárová & Vozár 1993).

The Stephanian, Nižná Boca Formation, is generally a regressive clastic sequence with a distinct tendency of coarsening upward. Numerous small repeating fining-upward sedimentary cycles are the most typical feature. Abundant graded-bedded sandstones with minor mudstone intercalations, as well as layers rich in plant detritus indicate a fluvial-lacustrine delta association. Sequences of fine-grained sandstones, mudstones and shales of grey to black colour correspond to lacustrine lithofacies. Syngenetic, mostly subaerial dacite volcanism is represented by abundant redeposited volcanogenic material mixed with non-volcanic detritus, less by thin layers of dacitic tuffs and exceptionally with small lava flows of dacite.

Macroflora from the uppermost part of the Nižná Boca Formation indicates its Westphalian-Stephanian age. Sitár (*in* Sitár & Vozár 1973) described well-preserved relics of *Asterotheca miltonii* Artis, *Asterotheca arborescens* Brongn., *Cordaites palmaeformis* Goepp. and *Callipteridium gigas* Gutb. The similar flora was determined by Němejc (*in* Mahel' 1954) from strongly tectonically reduced remains of the easternmost Nižná Boca Formation occurrences: *Calamites* sp., *Lepidostrobophyllum majus*, *Stigmaria ficoides* (Sternb.) Brongn., *Astherotheca miltonii* Artis, *Palmatopteris furcata* Potonié. Basing on palynological analysis Planderová (1979) distinguished two microflora assemblages: (1) the Stephanian A-B, *Torispora securis* Balm., *Lycospora pusilla* (Ibr.) Som., *Verrucosisporites pergranulus* (Alp.)

Smith., *Crassispora kosankei* (Pot. Kremp.) Bharadw., *Laevigatosporites vulgaris* (Ibr.) Alp. Doub., *Thymospora pseudothiessenii* (Kos.) Alp. Doub., (2) the Stephanian C, *Laevigatosporites* div. sp., *Cyclogranisporites densus* Bharadw., *Lycospora pusilla* (Ibr.) Som., *Foveolatisporites junior* Kos., *Planisporites kosankei* (Knox) Pot. Kr., *Cadiospora magna* Kos., *Allatisporites verrucosus* Alp., *A. hexalatus* Alp., *Potonieisporites* div. sp. and *Disaccites striatiti.*

Southern Veporic Unit

The Southern Veporic basement is a composite and very strong Alpine reworked segment of the Variscan crust. Dominant part of this basement consists of several types of low- to medium-grade metamorphic complexes. The occurrences of Al-Fe rich metasediments (Korikovskij *et al.* 1989; Kováčik 1991; Meres & Hovorka 1991) and orthogneisses of magmatic arc provenance (Hovorka *et al.* 1987) are special type. Besides of these rock complexes relics of migmatitized and strongly diaphtorized high-grade crystalline complexes were distinguished (?Proterozoic in age: Bezák 1991). The Carboniferous cover is represented by upward-coarsening sequence of the Stephanian sediments (the Slatviná Formation). Their direct contact with the basement is hard to prove, due to either Alpine thrusting or contact-thermic effects of younger granitoids (Vozárová & Vozár 1982; Vozárová 1990).

Well-preserved cyclical structure as a multiply vertical alternation of gray metasandstones and dark-gray/black metapelites and their regional unification in two large coarsening upward regressive cycles indicate mutual prograding from deltaic to fluvial environment. This prograding trend is, on the contrary to the rapid change of sediment colour from black or dark-gray to light-gray/light-green, due to changes in sedimentary environment as well as climatic conditions. In reaches of stillwater there tended to develop anoxic conditions, resulting in formation of black shales. Abundant carbonized plant detritus, relics of tissue fragments, spores of terrestrial plants are indicative of the proximity of plant covered continent.

Conspicuous stratification and cyclicity, tabular and relatively uniform sandstone strata are the main sedimentary features. Most others were destroyed by the Alpine regional tectonometamorphism and by consequent thermal relaxation (Vozárová 1990).

On the basis of abundant pollen of the genera *Potonieisporites* Bhardw., 1957, *Illinites* Kos, 1950, *Striatosaccites jizba*, and *Florinites* S.W. *et* B., 1944 and the species *Thymospora thiessenii* (Kos.) Wils. *et* Venk. The sediments are classed with the Stephanian C (Planderová & Vozárová 1978).

EARLY PERMIAN

Generally, the Early Permian sequences are represented by continental, mainly coarse-grained sedimentary formations, the origin of which was first of all related to transpressional and then extensional tectonic regime. Integral part of these formations are volcanites and their volcanoclastics, among them the calc-alkaline rhyolite-dacite less andesite and continental tholeiitic andesite-basalts are the most extensive.

The Early Permian sediments prove mostly very low structural and mineral maturity. They show provenances from the uplifted and tectonic rejuvenated crystalline basement or uneven cut magmatic arc. The prevalent sediments deposited in alluvial or fluvio-lacustrine and ephemeral lake environment, as well as semiarid to arid climatic conditions caused the absence of horizons containing fauna and flora. Biostratigraphical data are supported by microfloristic investigations, based on relative poor pollen and sporomorph spectrum.

Central Western Carpathians crystalline zone

Within the Central Carpathians crystalline zone the superposition of the Early Permian deposits is the following:

– unconformably lying on the crystalline basement;

– gradual prograding from the underlying Stephanian sediments with the sharp change of sediment colour due to rapid climatic alternations.

A representative of the first type formations is

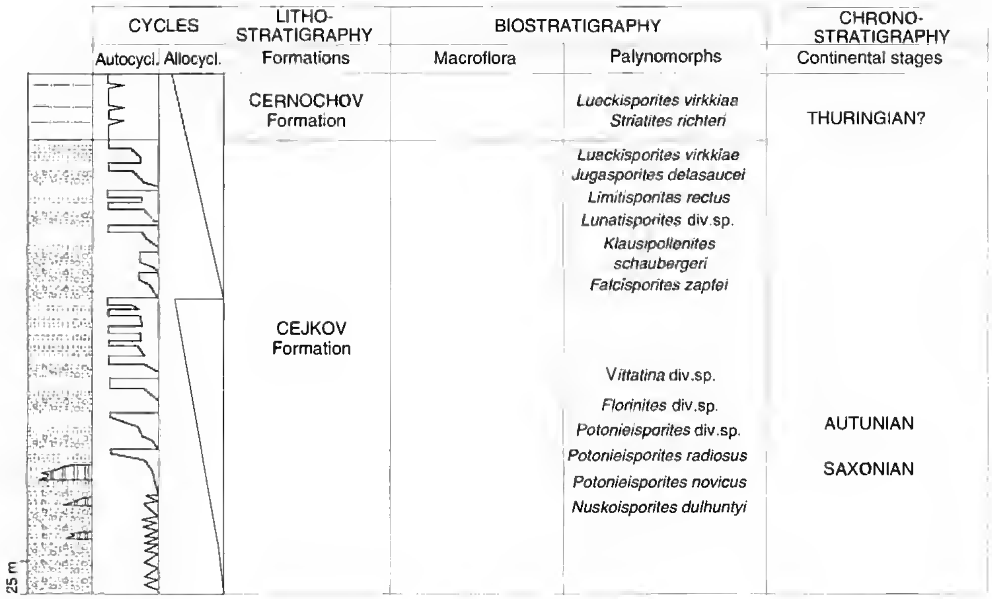


FIG. 5. — The Autunian and Saxonian of the Zemplinic Unit (see legend Fig. 8).

the sequence of the Ľubietová Group comprising the Brusno and Predajná Formations (Vozárová 1979).

Principal features of the Brusno Formation are the following: dominant arkosic sediments of psamitic/psephitic grade and evidence of synsedimentary volcanism (the Harnobis volcanogenic horizon). Monotonous, mostly light-grey and greenish-grey coarse-grained sediments indicate an environment of low-sinuosity rivers. Frequent washouts, erosive channels and in fact poorly preserved overbank and crevasse sediments are evidences of quick and chaotic changes of braided alluvia with prevalent autocyclic erosive processes. The provenance of detrirus was proved to be underlying crystalline basement, mainly the granitoid and migmatite rock complexes (Vozárová 1979). The Harnobis volcanogenic horizon consists mostly of dacite effusions associated with dominant pyroclastic tuffs, in part of them ignimbrites and epiclastic deposits. Less frequent are andesites and their volcanoclastics. According to their chemical composition the volcanics correspond to calc-alkaline variety with affinity to subalkaline magmatic trend. The age of the Brusno Formation is not reliably biostratigraphically dated.

The Predajná Formation overlaps disconformably the Brusno Formation. Hiatus is documented by a conspicuous change of the drainage system as well as of the source area, the latter being reflected in distinct differences in composition of the detritus (mostly micaschist, paragneisses, microgranites and the Harnobis volcanics). Variegated polymict clastic sediments indicate an alluvial fan and piedmont flood plain sedimentary environment with isolated distal ephemeral lakes. Two regionally developed megacycles, with thick horizon of conglomerates at the base of each of them, are reflection of the synsedimentary tectonic. The second is partially reduced due to pre-Triassic erosion.

The Permian age of the Predajná Formation was assigned according to poor microflora: *Monosulcites minimus* Cookson, *Gnetaceaepollenites* sp., *Gymatiosphaera* sp., *Karpatisporites minimus* Pland., *Punctatisporites* sp., *Reticulatisporites* sp., *Florinites* sp. (Planderová *et* Vozárová 1982).

The grade of metamorphism of the North

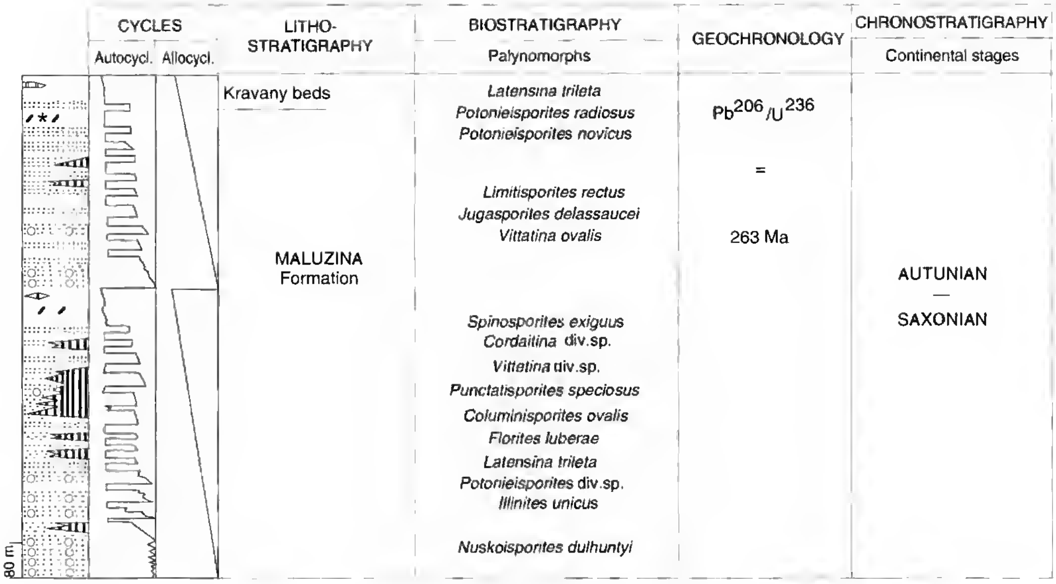


FIG. 6. — The Autunian and Saxonian of the Hronic Unit (see legend Fig. 8).

Veporic Permian deposits did not exceed the boundary between anchizone and the lower-temperature part of greenschist facies.

Representatives of the second type of formations are the Early Permian deposits in the Zemplinic, Southern Veporic and Hronic Units.

A sharp transition from a humid to arid climate is characteristic for Permian sediments of the Zemplinic Unit (Fig. 5). During the Permian sedimentary development the synsedimentary tectonics was less intense compared to the Westphalian-Stephanian and, as a consequence, the rates of sedimentation and volcanic activity were reduced. Generally, the deposition proceeded in an alluvial environment with the typical features of semi-arid and arid regions. Many coloured sedimentary complexes of the Cejkov Formation comprise proximal and distal alluvial facies (polymict conglomerates and sandstones) alternating with deposits of flood plain or of ephemeral arid lakes (mudstones alternating with shales and fine-grained sandstones and calcrete horizons). Characteristic, poorly sorted sediments resemble fossil mudstone and debris-flow. A part of this sequence includes several layers of rhyolite tuffs. The Early Permian age of the Cejkov Formation is assigned for abundance of the species from the genera *Potonieisporites* and *Vittatina*. The assemblages of sporomorphs are: *Potonieisporites radiosus* Schwarz, *P. novicus* Bhardw., *Nuskoisporites dulhuntyi* Pot. Klaus, *Vittatina* div. sp., *Florinites* div. sp. (Planderová *et al.* 1981). The microflora from the upper part of the Cejkov Formation proved the Late Permian: *Lueckisporites virkkiae* (Pot. Klaus), *Jugasporites delasaucei* Klaus, *Limitisporites rectus* Lesch., *Lunatisporites* div. sp., *Klausipollenites schaubergeri* (Pot. Klaus) Lesch, *Falcisporites zapfei* (Pot. Klaus) Lesch. (Planderová *et al.* 1981).

A complex of monotonous violet-red, vaguely schistose mudstones represents the youngest lithostratigraphic unit, the Černochov Formation. Relatively thin (max. 50 m) sequence of monotonous playa association is unconformably overlain by light-grey quartzose conglomeratic sandstones of Early Triassic age. Almost massive claystones and mudstones are rich in Al_2O_3 (20-21 %) and ferric iron (7 %). Poor microflora remains, *Lueckisporites wirkkiae* (Pot. Klaus), *Striatites richteri* (Klaus) Jizba, *Jugasporites lueckuides* Klaus, *Limitisporites rectus* Leschik, *Klausipollenites schaubergeri* (Pot. Klaus) Iansonius correspond most likely to the Thuringian. Sedimentological and paleoecological data indicate that a short intra-Permian hiatus is possible.

The Early Permian sequences of the Hronic Unit (Fig. 6, the Malužiná Formation) are developed gradually from the underlying Stephanian. They comprise a thick succession of red beds which consist of alternating conglomerates, sandstones and shales. Lenses of dolomites, gypsum and calcrete/caliche horizons occur locally. Fining-upward cycles of the order of several meters, as well as three regional megacycles arranged above each other, are most typical. An important phenomenon is the polyphase synsedimentary andesite-basalt volcanism with continental tholeiitic magmatic trend (Vozár 1977, 1983).

Generally the sediments of the Malužiná Formation originated, in fluvial and fluvial-lacustrine environment, at permanently semiarid/arid climate. Basal parts of the three megacycles consist of chanel-lag and point-bar deposits, associating laterally with flood plain and natural levee sequences. Upper part of megacycles is characterized by a playa, scarce inland sabcha and ephemeral lake associations.

The microflora proved the Early and Late Permian age of the Malužiná Formation. The following assemblages were described by Planderová (1973; *in* Planderová & Vozárová 1982): (1) Autunian: *Spinosporites exiguus* Upthaw-Hedl., *Thymospora* div. sp., *Columinisporites ovalis* Peppers, *Punctatisporites speciosus* Kalib., *Cordaitina* div. sp., *Illinites unicus* Kos., *Vittatina* div. sp.; (2) Autunian-Saxonian: *Latensina trileta* Alp., *Potonieisporites novicus* Bharadw., *P. radiosus* Shwarz., *Jugasporites delasaucei* Klaus, *Vittatina ovalis* Klaus; (3) Thuringian: *Calamospora nathorstii* Klaus, *Klausipollenites* div. sp., *Carpathisporites sittleri* Pland., *Lueckisporites parvus* Klaus, *Vittatina angulistriata* Klaus, *Monosulcites minimus* Cookson.

The Autunian-Saxonian microflora assemblages correspond approximately to the first and second megacycles. This assumption is supported by $^{206}Pb/^{238}U$ and $^{207}Pb/^{235}U$ dating of 263 and 274 Ma from uranium-bearing layers of the uppermost part of the second megacycle (Lepka *in* Rojkovič *et al.* 1992).

Sediments of both formations contain detritus derived from: (1) granitoids and high-grade metamorphics; (2) ?synsedimentary or a little older dacite volcanics; (3) andesite/basalt synsedimentary volcanics; (4) low-grade metamorphics. Generally the grade of regional metamorphism did not exceed P-T conditions of diagenesis/ anchizone boundary.

The strongly Alpine reworked metasediments of the Southern Vepotic Unit consists of coarse-grained metaarkoses, meta-arkosic wackes and meta-conglomerates with abundant granitoid detritus. Fine-grained metasediments are only minor component. They provide very poorly preserved spore species of the genus *Lueckisporites*, ranging these sequence with the Early Permian (Planderová & Vozárová 1982).

Northern Gemeric Zone (Fig. 7)

Continental Permian sequences overlapped slightly deformed relics of the Westphalian peripheral basin filling as well as all pre-Westphalian complexes of the North Gemeric Zone. Prevalent coarse-clastic sediments derived from the collision belt are associated with bimodal andesite/basalt-rhyolite volcanism. The development of the Permian depositional realm was connected with post-Asturian transpression/ transtension stage, as a result in extensional regime during the Late Permian-Mesozoic time.

Following are the characteristic features: (1) multi-coloured clastic sediments with dominant violet and violet-red; (2) gradual fining-upward; (3) cyclicity manifested within the framework of small cycles as well as megacycles; (4) bimodal calc-alkaline volcanism.

The basal part (the Knola Formation) contains mostly poorly sorted polymict conglomerates and breccias of extremely variable thickness, with pebble material reflecting the composition of the direct underliet. The coarse-grained sediments overlapped different parts of both pre-Carboniferous crystalline complexes as well as irregurally eroded surface of the Westphalian formations. They represent fossil mudflows, partly reworked in some places, relieved by alluvial, mainly stream channel deposits. Age of these sediments is not determined, due to lack of fossils' remains.

Volcanics and volcanoclastics of bimodal magmatic association are the main features of the

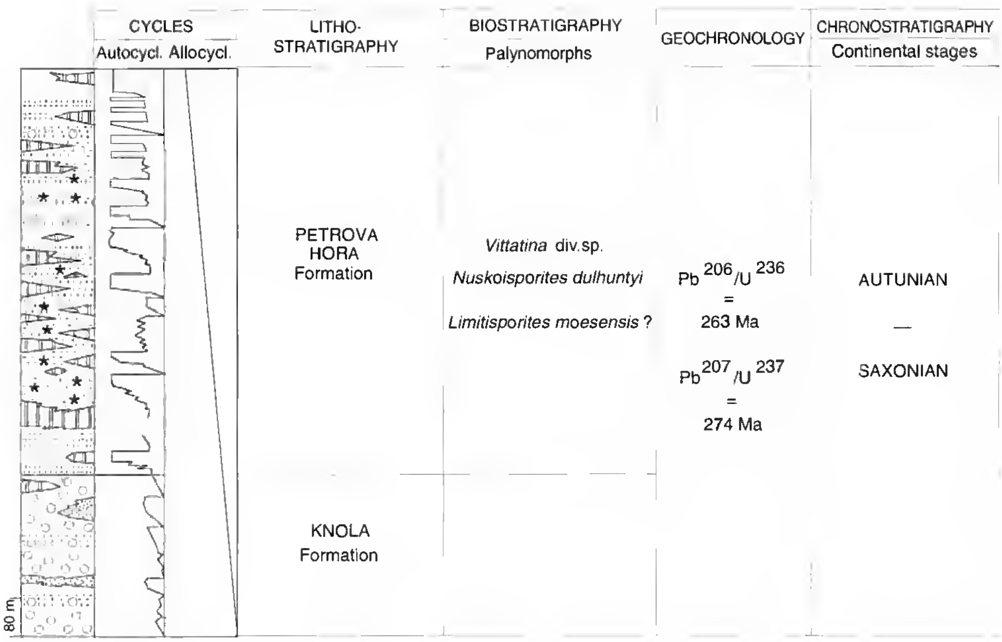


FIG. 7. — The Autunian and Saxonian of the North Gemeric Unit (see legend Fig. 8).

Petrova Hora Formation. The polyphase volcanic activity manifested regional and time relations to large sedimentary cycles. Sediments are characteristic by low degree of maturity and mixture of syngenetic volcanic and non-volcanic detritus. Among the most striking features are the fining-upward alluvial cycles, with channel lag, pointbar and flood plain lakes facies alternating with playa lake subenvironment at the topmost part of large cycles.

The microflora found in the upper part of the Petrova Hora Formation proved Saxonian age: *Limitisporites moesensis* (Grebel) Klaus, *Vittatina* div. sp., *Nuskoisporites dulhuntyi* Klaus (Planderová 1979 unpublished report). This age is supported by isotopic analysis of sulphides from volcanogenic horizons: $^{206}Pb/^{236}U$ = 263 Ma; $^{207}Pb/^{235}U$ = 274 Ma (Novotný & Rojkovič 1981).

The Autunian-Saxonian terrigenous and terrigenous-volcanogenic sequences are overlapped by a relatively mature sandy-conglomerates horizon, with contents of pebble material derived from direct stratigraphic underlier. This could have been a consequence of the break in sedimentation after Saxonian, but biostratigtaphic evidence to support this assumption is missing. Alluvial, stream channel deposits prograde gradually upward to the inland sebkha and near-shore sebkha/lagoonal facies, with anhydrite-gypsum and salt breccia horizons (the Novoveská Huta Formation). Isotopic analysis of sulphur shows the results close to data on the Late Permian-lower part of the Early Triassic (Kantor *et al.* 1982). There are gradual transitions up to the *Claraia clarai* horizon.

The grade of metamorphism of the Permian rock complexes did not exceed the P-T condition of anchizone.

INNER WESTERN CARPATHIANS CRYSTALLINE ZONE

The Early Permian sediments were developed only within the Southern Gemeric Unit (Fig. 8). Late Variscan, post-orogenic overstep sequences of the Southern Gemeric Unit are represented only by the Permian to Early Triassic continental and near-shore, lagoonal-sabcha formations.

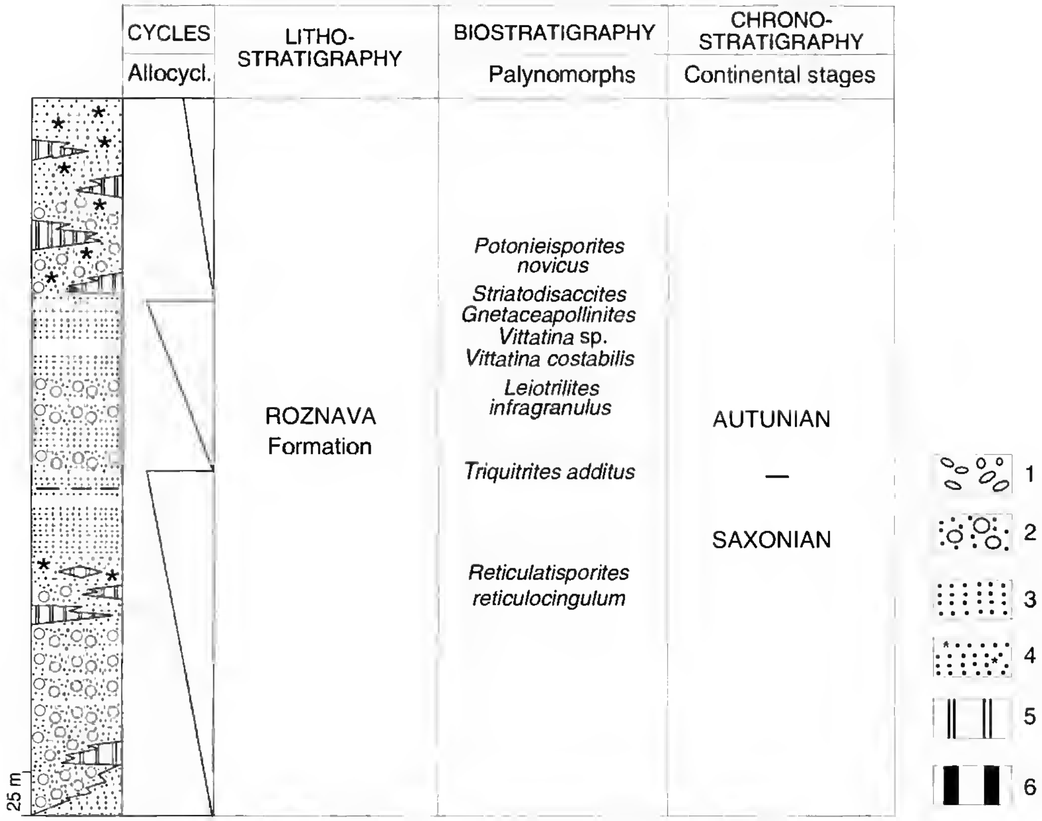


FIG. 8. — The Autunian and Saxonian of the South Gemeric Unit. **1**, delta-fan, shallow marine boulder conglomerates; **2**, marine conglomerates; **3**, marine sandstones; **4**, sandstones with admixture of volcanoclastic detritus; **5**, acid to intermediate volcanics; **6**, andensite-basalt volcanics.

They unconformably overlapped their Early Paleozoic basement, the volcano-sedimentary flysch of the Gelnica Group (defined together as the Gelnica Terr., Vozárová & Vozár 1993, 1996). Generally, the Early Permian volcano-sedimentary complexes are characterized by a high content of mature detritus, mainly in their basal part. Conspicuous upward fining is accompanied by relative decrease of compositional maturity and grain-size of sediments. Sediments represent the relics of sedimentary basin filling which originated in transpression/transtension regime, prograded to the initial stage of post-Variscan rifting. The whole sequence is subdivided into two lithostratigraphic units: the Rožňava and Štítnik Formations.

Characteristic lithotype of the Rožňava Formation are the oligomict, quartzose conglomerates, with indistinct stratification. The whole sequence is subdivided vertically into two large cycles, with conglomerate horizons at the base of each and sandstone-shale member between their two. Dominant are stream channel and sheet-flood deposits, with unimodal transport system. Both conglomeratic horizons are connected with rhyolite-dacite subaerial volcanism. Their chemical composition correspond to calc-alkaline magmatic type. The Early Permian age of the Rožňava Formation is assumed on the basis of microflora, with the predominant species of the genera *Potonieisporites*, *Striatodisaccites*, *Vittatina* sp. and mainly the form *Triquitrites additus* Wils. *et* Hofm., *Potonieisporites novicus* Bharadw., *Vittatina costabilis* Wils (Planderová 1980).

The gradually prograded Šritnik Formation is a monotonous complex of cyclically alternating sandstones, siltstones and shales. Lenses of carbonatic sandstones and dolomitic limestones with intercalations of shales occur only in its upper part. Thin lenses of phosphatic sandstones and sediments with extremely high content of albite (albitolites) are exceptional. Sediments contain relatively high amount of rhyolite/dacite detritus (?synsedimentary or redeposited from the Rožňava Formation). Sedimentary environment is interpreted as alluvial-lacustrine and lacustrine, with high-alkaline lakes in some places, prograding into near-shore, lagoonal-sabcha facies. Age determinations are known only from the uppermost part. The Late Permian was proved on the basis of cone slice and twig of *Pseudovoltzia liebeana* (Geinitz) Florin, and leaves of the genus *Sphenozamites*, as well as remains of bivalve tests of the genus *Carbonicola* McCoy, 1855 (Šuf 1963). Microfloral assemblages confirm the Late Permian-Early Triassic age of this horizon (Planderová 1980).

Generally, sequences of the Southern Gemeric Permian are distinctly dynamometamorphically deformed, with grade of metamorphism reaching P-T conditions of anchizone to low-temperature part of greenschist facies.

Within the Inner Western Carpathians (the Turnaic Unit; TSBZ) the continental red-beds unconformably overlying the Bashkirian flysch are most probably the Late Permian in age (since biostratigraphical undated).

DISCUSSION

The Carboniferous-Permian sedimentary basins of the Western Carpathians originated in time and space as a consequence of collision/subduction events of Variscan orogeny. The topical distribution of these basins, as well as the lithofacial character of their filling, document southern polarity of the Variscan orogeny of the Western Carpathians, responsible for the opposite vergency in comparison with that in the Alpine branch. Basins originated gradually as a consequence of microplate interaction.

The beginning of collisional events was connected with the Bretonian movements and development of the Early Carboniferous flysch remnant basin sequences preserved within the Northern Gemeric Unit. The prolongation of collision carried on closing the Early Carboniferous flysch basin and caused hiatus during Namurian B-C. The Sudetian movements gave rise to the Bashkirian-Moscovian marine peripheral basin, whose basal sequences fixed the Early Carboniferous flysch and both two pre-Carboniferous complexes (fragments of crust with oceanic/supraoceanic affinity). Closing of this basin was connected with Asturian events and is reflected in hiatus during Stephanian. The North-Gemeric Early and Late Permian continental red-beds sequences originated under transpression/transtension and extension post-orogenic regime.

Due to these compression events, the different evolution basins were established on formerly overthrusted continental plate, whose fragments are dismembered within the several CWCZ Alpine megaunits. Continental sedimentation under humid climatic conditions was characteristic for this part of the plate during the Late Carboniferous. These relics are preserved within the Alpine Zemplinic, Hronic and Southern Veporic Units. Sequences from the last of them are very strong Alpine reworked. Generally, a characteristic feature for these developments is gradual prograding into the Permian arid/semi-arid red-beds formations. The sedimentary basins were established in pull-apart and extensional tectonic setting (most probably in back-arc position). The latest stage of this process affected the formations which were incorporated into the Northern Veporic and Tarric Units (Saxonian even Thuringian).

Particular features have been observed in the Permian formations of the Southern Gemeric unit. Their mineral extremely mature detritus, as compared with other contemporal sediments of the Western Carpathians unit allows to correlate them with other early-Alpine riftogenic tectofacies of the Alpine-Mediterranean domain. They were most probably already connected with the previous Baskhirian flysch zone sedimentation (TSBZ), characteristic for the South-Alpine/Dinaric development. Discovering the

Baskhirian flysch sediments (the Turiec Formation, Vozárová 1992) within one of the topmost tectonic units of the Inner Western Carpathians (Turňa Nappe) confirms this assumption (Vozárová & Vozár 1992; Vozárová 1996).

From the point of view of comparison of Carboniferous-Permian sequences in the Alpine-Carpathian arc, the position of synorogenic flysch sediments in space and time is an important criterion (Ebner 1991). The Tournaisian-Visean (pre-Sudetic) flysch, which is preserved in the Northern Gemeric Zone (NGZ), reflects the stage of convergence. This flysch trough contained shreds of oceanic crust (serpentinites) as well as detritus from a collisional fold-thrust belt and from the rejuvenated basement (source of low-grade metasediments and metavolcanites as well as granitoides and gneisses). Its most probable paleotectonic position was that of residual basin, arising with oblique collision. This is testified by gradual transition from flysch environment to terrestrial-carbonate, shallow-water sediments of Serpukhovian age.

Synorogenic, pre-Sudetic flysch sediments are represented in the Eastern Alps, in the Stolzalpe Nappe (Gurktal thrust system) in central Carinthia (Neubauer & Herzog 1985). They are also covered by Late Carboniferous molasse sediments (Murau area), which is, however, on the contrary to the NGZ, in continental development. Early Permian sediments in both units indicate continental environments (Ebner *et al.* 1990a). An equivalent of the Late Visean-Serpukhovian shallow-marine horizon with magnesites (upper part of the Ochtina group in the NGZ) is development in the Veitsch Nappe of the Grauwackenzone (Neubauer & Vozárová 1990). Equally also lithological characteristics and the paleoenvironment of the Carboniferous from Noetsch are comparable with marine molasse sediments in the NGZ.

In the Southern and Eastern Carpathians siliciclastic and/or siliciclastic-carbonate sequences of Early Carboniferous were described (Nastaseanu 1987; Nastaseanu & Krautner 1990; Krautner 1990), which, however, are poorly proved biostratigraphically (Infrabucovinian N., Bucovinian N., Supraghetic N., Danubian Unit) and from sedimentological point of view are of untypical flysch development. A feature common in both compared areas is Variscan metamorphism of Early Carboniferous complexes. Well correlable sequences are, however, continental Late Carboniferous and Permian from the Central Western Carpathians (CWCZ) and in the Ghetic Unit in Romania described by Nastaseanu *et al.* (1973) and Nastaseanu (1978). In the Apuseni Mountains (Biharia and Codru Nappe system) continental Late Carboniferous and Permian sediments with andesite-basaltic riftogenic volcanism are known, similarly as in the Hronic Unit in the CWCZ.

Relics of Late Devonian-Early Carboniferous flysch formations were also described in the region of the Balkanides and in the Kraishrides (Yanev & Spasov 1985; Tenchov 1990). They are covered by Westphalian and/or even Permian continental deposits.

The pre-Asturian flysch, which is preserved in the Inner Western Carpathians (IWCZ) in the Turnaic Unit, has its continuation in the Szendrö and Uppony Mountains in northeastern Hungary, where, it was described in details by Kovács & Péro (1983) and Kovács (1987). This flysch has its equivalents in the Southern Alps and Karawanken (Ebner *et al.* 1991). The flysch complexes are Variscan low-grade metamorphosed (Mazzoli & Vozárová 1989; Ebner *et al.* 1990b). The pre-Asturian flysch complexes are usually covered by shallow-water or even deltaic sediments of Westphalian to Stephanian age. An exception is the Turnaic Unit (IWCZ) where the marine molasse is missing and the flysch is covered by Permian, continental sediments (riftogenic stage of the Alpine cyclus).

In the Bükk Mountains the pre-Asturian flysch reaching even the Westphalian is continuously replaced by shallow-marine sediments of Late Westphalian-Stephanian age (Kovács & Péro 1983). The sediments are not Variscan-metamorphosed and only in places affected by weak Alpine metamorphism (Arkai 1983). Permian sediments are lagoonal-nearshore marine, interrupted by a short-dated Middle Permian event of continental sedimentation only. An analogous development of the Permian is also the Carnic Alps and Karawanken (Ebner *et al.* 1990; Ramovš *et al.* 1990).

In the Transdanubian Mid-montains Unit the Carboniferous is represented by Visean limestones (Földvari 1952) and Westphalian-Stephanian conglomerates (Mihaly 1980). These sequences as well as all pre-Carboniferous complexes show South Alpine-Dinaric affinity. The Late Carboniferous-Permian continental sediments unconformably overlapped medium- and high-grade Variscan and pre-Variscan metamorphic rocks of Tisia Unit in the southeastern part of Hungary (Mecsék and Villany Mountains, Kassai 1976). Complexes of the Tisia Unit as well as its Carboniferous-Permian enveloppe have no equivalent in the Western Carpathians.

In the context of stratigraphic age of the sedimentologically well established flysch sequences and clastic/volcanoclastic piles which take in synorogenic position, the following comparison can be done:

1. Internal zone of Alpine Variscides belt with pre-Sudetic flysch environment: CWCZ joined with NGZ in the Western Carpathians, eastern Grauwackenzone and Gurktal thrust system and Carboniferous of Noetsch area in the Eastern Alps, nappe thrust system of Bucovinian and Ghetic Units in the Eastern and Southern Carpathians in Romania, part of Balkanides and Kraishtides in Bulgaria. This zone comprises mainly medium- and high-grade metamorphic basement with huge masses of pre-Mesozoic granitoids, as a result of predominantly Variscan metamorphism and magmatism. With respect to these characteristics, this zone corresponds to the Mediterranean crystalline zone (MCZ) defined by Neubauer & Raumer (1993). The pre-Sudetic flysch zone covered by Visean-Serpukhovian marine molasse, which is designated as the NGZ in the Western Carpathians, has continuation in the high Eastern Alps Units (Noetsch-Veitsch-Ochtina zone according to Flügel 1990, North Gemeric-Veitsh zone after Neubauer & Vozárová 1990). It is interpreted as an intrasutural basin amalgamating two major Variscan microplates (Vozárová & Vozár 1988; Neubauer & Vozárová 1990) or as southern extension of the MCZ (Neubauer & Raumer 1993).

2. External zone of alpine Variscides belt with pre-Asturian flysch environment: IWCZ with Turnaic Unit, Szendrö Mountains and Uppony Mountains and Bükk Mountains in Hungary, southern Alps and Karawanken. The basement of this zone is either unknown or consits of dominantly shallow-water carbonates including pelagic limestones. An exception is the Southern Gemeric Unit (IWCZ) with the long-timing Early Paleozoic Flysch sequence. This external zone could be correlated with the Noric-Bosnian and Betic-Serbian zones distinguished by Neubauer & Raumer (1993).

CONCLUSION

The distribution of Carboniferous-Permian basins in time and space as well as the lithofacial character of their filling indicate a reverse polarity (southern) in comparison with the Alpine orogeny. The results of Variscan orogenic events was the unevenly consolidated continental crust which, after a short period of stability (from the south to the north in the Late Permian/Early Triassic to Middle/Late Triassic), was incorporated again in the new orogenic Alpine cycle.

On the basis of filling relics of Carboniferous-Permian basins in the Western Carpathians two zones of continental collision differing in time were identified:

– the *internal zone*, with termination of collision during Bretonian-Sudetian events, resulting in syn-collision Early Carboniferous flysch and marine Late Carboniferous perisutural basin as well as continental, back-arc transpression basins;

– the *external zone*, with termination of collision during Asturian events (IWCZ). This zone is represented by the Baskhirian flysch and the Late Westphalian/Stephanian marine perisutural basin (relics preserved only on the territory of northern Hungary) and the post-orogenic continental Permian deposits (Southern Gemeric and Turnaic units on the territory of Slovakia).

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Facies and biostratigraphy of the Late Carboniferous/Early Permian sedimentary sequence in the Carnic Alps (Austria/Italy)

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In memoriam Franz Kahler (1900-1996)

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ABSTRACT
The Late Carboniferous/Early Permian sequence in the Carnic Alps (Austria/Italy) is a more than 2000 m thick succession of shallow marine clastic and carbonate sedimentary rocks. The succession unconformably overlies the folded Variscan basement and is divided into Bombaso Formation, Auernig Group, Rattendorf Group and Trogkofel Group. Auernig Group and Rattendorf Group are characterized by clastic-carbonate cycles related to Gondwana glacioeustatic sea level changes. Carbonates contain abundant fossils throughout the sequence, biostratigraphy is mainly based on fusulinids. Fine-grained clastic intervals contain abundant plant fossils, allowing a close correlation with fluvial succession of the Eastern Alps (Stangnock Formation of the Gurktal Nappe). Fusulinids of the Carnic Alps show high similarity with those of the Russian Platform, Donets Basin and Predonets Trough, Southern Urals and particularly with Central Asia. Uppermost Moscovian, Kasimovian, Gzhelian, lowermost Asselian, late Asselian, Sakmarian and Artinskian equivalents are established and precise correlation with stratotype regions have been completed. Fusulinid, conodont and plant fossil data well correspond with each other.

KEY WORDS
Peri-Tethys,
Late Carboniferous,
Early Permian,
Carnic Alps,
facies,
biostratigraphy,
fusulinids,
conodonts,
plant fossils.

RÉSUMÉ

Faciès et biostratigraphie de la séquence sédimentaire Carbonifère supérieur/Permien inférieur dans les Alpes carniques (Autriche/Italie). La séquence Carbonifère supérieur/Permien inférieur dans les Alpes carniques (Autriche/Italie) est constituée de plus de 2000 m de roches clastiques et carbonatées marines peu profondes. La succession recouvre en discordance le socle varisque plissé et est subdivisée en la Formation Bombaso, les Groupes Auernig, Rattendorf et Trogkofel. Les Groupes Auernig et Ratendorf sont caractérisés par des cycles clastiques et carbonatés produits par des variations glacio-eustatiques (Gondwana). Les carbonates contiennent des fossiles abondants tout au long de la séquence, la biostratigraphie étant principalement fondée sur les fusulines. Les intervalles clastiques fins contiennent des fossiles de plantes abondants, permettant une corrélation étroite avec la succession fluviatile des Alpes orientales (Formation Stangnock de la nappe de Gurktal). Les fusulines des Alpes carniques montrent de grande similarité avec celles de la plate-forme russe, bassins du Donetz et Predonetz, Oural du Sud et particulièrement Asie centrale. Des équivalents de la partie supérieure du Moscovien, Kasimovien, Gzhélien, de la partie inférieure de l'Assélien, de l'Assélien supérieur, du Sakmarien et de l'Artinskien ont pu être établis et une corrélation précise avec les régions stratotypes a été accomplie. Les données sur les fusulines, conodontes et plantes fossiles correspondent bien les unes aux autres.

MOTS CLÉS
Péri-Téthys, Carbonifère supérieur, Permien inférieur, Alpes carniques, faciès, biostratigraphie, fusulines, conodontes, plantes fossiles.

INTRODUCTION

In the Carnic Alps (southern Austria/northern Italy) the folded Variscan basement is unconformably overlain by a thick succession of shallow marine clastic and carbonate rocks of the Late Carboniferous Bombaso Formation and Auernig Group and the Early Permian Rattendorf and Trogkofel Group (Fig. 1). These rocks were deposited in discrete basins formed by block and wrench faulting subsequent to the Variscan orogenic phase with its climax during the Westphalian. Classic outcrops occur in the central Carnic Alps along the Austrian/Italian border (Fig. 2). Sedimentary rocks of all formations, particularly the carbonates, contain abundant fossils providing the basis for biostratigraphic subdivision and correlation. Biostratigraphy of the Late Paleozoic sequence in the Carnic Alps is mainly based on fusulinids, although plant fossils and conodonts are of importance too. During the last decades major progress has been achieved concerning sedimentology, paleontology and biostratigraphy of this sequence (see Flügel 1980 a-b, 1981; Kahler 1983, 1985, 1986, 1989; Fritz *et al.* 1990; Venturini 1990; Krainer 1992, 1993 and Forke 1995 for further informations and references). The present paper gives a summary of the Late Carboniferous/Early Permian sequence with special emphasis on the biostratigraphy and correlation with other regions.

FACIES

Bombaso Formation

The Bombaso Formation consists of poorly sorted immature breccias and conglomerates which are either predominantly composed of radiolarian chert and volcanic clasts (Pramollo Member) or of Silurian to Devonian carbonate clasts (Malinfier Horizon). Thickness ranges from a few meters up to about 200 meters. The clasts are derived from the Variscan basement of the uplifted Paleocarnic Chain. The succession of the Bombaso Formation generally shows a fining upward trend. Bioclasts of brachiopods, crinoids and fusulinids are rarely present indicating

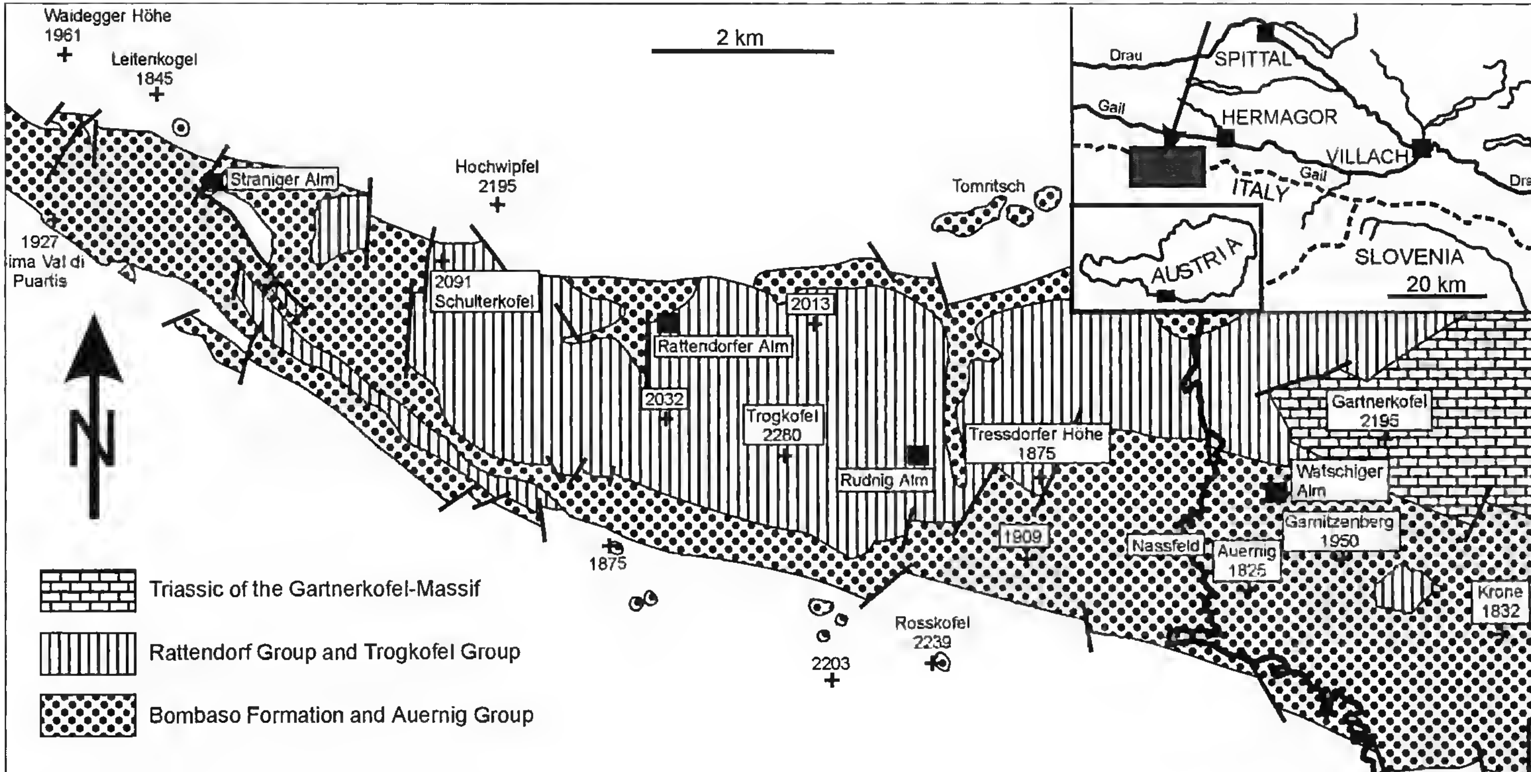


FIG. 1. — Map showing the distribution of Late Carboniferous and Early Permian sedimentary rocks in the Carnic Alps (Austria/Italy).

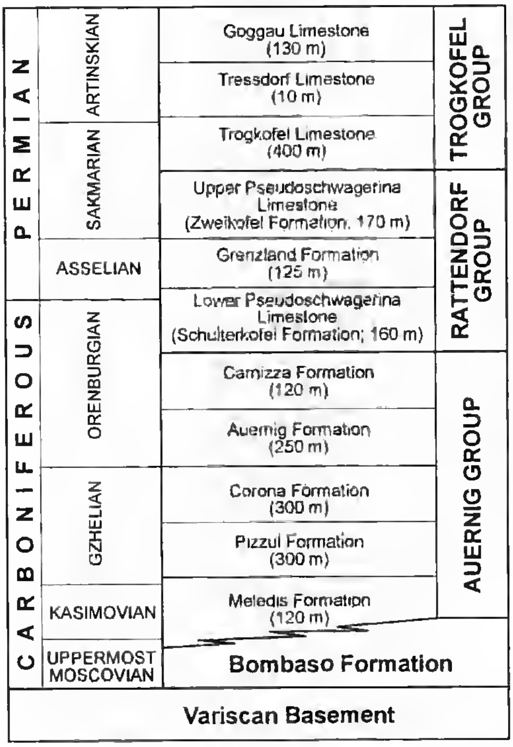


FIG. 2. — Stratigraphy of the Late Carboniferous and Early Permian strata in the Carnic Alps.

deposition in a marine environment. These breccias and conglomerates are interpreted as mass gravity flow deposits primarily deposited on fan deltas, partly subaerially, partly submarine.

AUERNIG GROUP

The Bombaso Formation is overlain by the Auernig Group, which is up to 1.200 m thick and composed of Meledis-, Pizzul-, Corona-, Auernig- and Carnizza Formations according to Selli (1963) (Fig. 2). The succession consists of cyclic clastic and carbonate rocks of a shallow marine environment. Meledis-, Corona- and Carnizza Formations predominantly consist of clastic sediments, Pizzul- and Auernig Formations contain substantial quantities of fossiliferous carbonate rocks. The main lithofacies types are a quartz-rich conglomerate of a nearshore environment, frequently overlain by shale containing abundant and well-preserved megaplant fossils, trough-crossbedded and hummocky crossbedded sandstone (shoreface), bioturbated and locally fossiliferous siltstones and shales (offshore) and fossiliferous limestones containing calcareous algae (*Anthracoporella spectabilis, Archaeolithophyllum missouriense, Epimastopora, Eugonophyllum*), fusulinids, small foraminifers, echinoderms, bryozoans, *Tubiphytes*, sphinctozoans, solitary corals and others. Massive limestones represent algal mounds (*Anthracoporella* mounds; Krainer 1995), in the Meledis Formation small mounds formed of auloporid corals are present (Flügel & Krainer 1992). In the upper part of the Auernig Group (Corona-, Auernig- and Carnizza Formations) these lithofacies types form prominent clastic-carbonate regressive-transgressive cycles ("Auernig cyclothemes") with thicknesses of 10-40 m (Fig. 3). Within these cycles conglomerates formed during relative sea-level lowstands and fossiliferous limestone was deposited during periods of relative sea-level highstands. The formation of these cycles is related to eustatic sea-level changes caused by Gondwanan glaciation (Massari & Venturini 1990; Krainer 1992, 1995).

RATTENDORF GROUP

The Rattendorf Group comprises a succession of shallow marine sediments of nearshore, inner shelf and outer shelf environments. The succession is divided into Lower Pseudoschwagerina Limestone (LPL), Grenzland Formation and Upper Pseudoschwagerina Limestone (UPL) (Fig. 2).

The LPL is composed of three depositional cycles consisting of shallow marine limestones and thin intervals of clastic sediments (Fig. 4). Clastic intervals form the base of the depositional succession and were deposited during relative sea-level lowstands. During transgression well bedded fossiliferous limestones and massive algal mounds accumulated. Bedded cherty limestones with marl intercalations are interpreted to have been deposited during relative sea-level highstands with water depths of some tens of meters. Fusulinid-rich limestone beds are present in different stratigraphic levels, particularly at the base and on top of the clastic intervals. Fusulinids of these beds are considered as parautochthonous assemblages, accumulated during periods of low

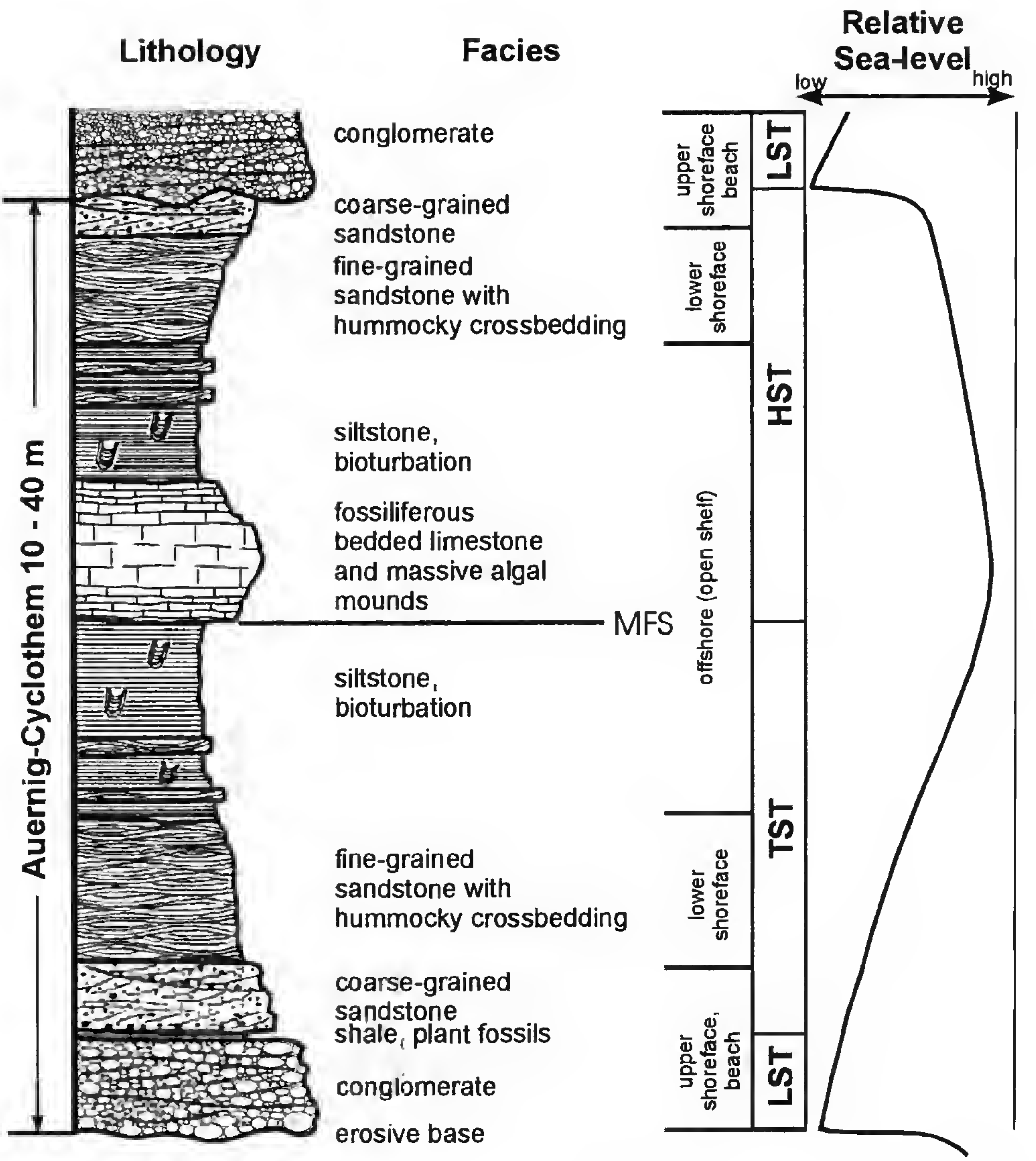


FIG. 3. — Idealised "Auernig-Cyclothem" from the upper part of the Auernig Group in the Garnitzenberg-Kronalpe area, Carnic Alps.

sediment input (see Homann 1969; Flügel 1974, 1977; Buggisch *et al.* 1976; Forke *et al.* in press). The Grenzland Formation is a cyclic succession, predominantly composed of shallow marine clastic sediments (quartz-rich conglomerate, sandstone and siltstone) and intercalated thin fossiliferous carbonate intervals (Buttersack & Boeckelmann 1984; Boeckelmann 1985). A caliche unit and a red shale unit with scattered angular quartz grains in the upper part of the succession indicate subaerial exposure. Fusulinids were described from the thin carbonate intercalations (Kahler & Kahler 1937; Kahler 1985; Forke 1995). Plant fossils have been described

from a thin shale intercalation by Fritz & Boersma (1984).
The Upper Pseudoschwagerina Limestone is represented by a cyclic succession composed predominantly of dark-grey, thin bedded fossiliferous limestones and intercalated thin intervals of silt- and sandstones and fine-grained, well-rounded and well-sorted quartz rich conglomerates. Limestones contain abundant fossils, particularly calcareous algae (Homann 1972), small foraminifers (Flügel 1971), fusulinids, corals, bryozoans, brachiopods, gastropods, pelecypods and echinoderm fragments. Microfacies has been described by Flügel (1968) and Buttersack & Boeckelmann (1984). Cycles indicate repeated shifting from nearshore to offshore environments in an open marine shelf-lagoon with normal water circulation (Flügel 1981). Compared to the LPL and Grenzland Formation the limestones are characterized by more diverse biota and microfacies types (Flügel 1971, 1981; Flügel *et al.* 1971).

Trogkofel Group

The Trogkofel Group is composed of approximately 400 m thick, predominantly massive, subordinately bedded limestones (Trogkofel limestone, Tressdorf limestone and Goggau limestone). The limestones were deposited in shallow, restricted and open marine shelf-lagoons with only minor bathymetrical differences. *Tubiphytes/Archaeolithoporella* build-ups composed of sediment-binding organisms like encrusting foraminifers, phylloid algae, *Tubiphytes*, *Archaeolithoporella* and bryozoans formed at the shelf edge (Flügel 1980a, b, 1981). Flügel & Flügel-Kahler (1980) described 46 species of calcareous algae, the fusulinid fauna is represented by 70 species (Kahler & Kahler 1980).

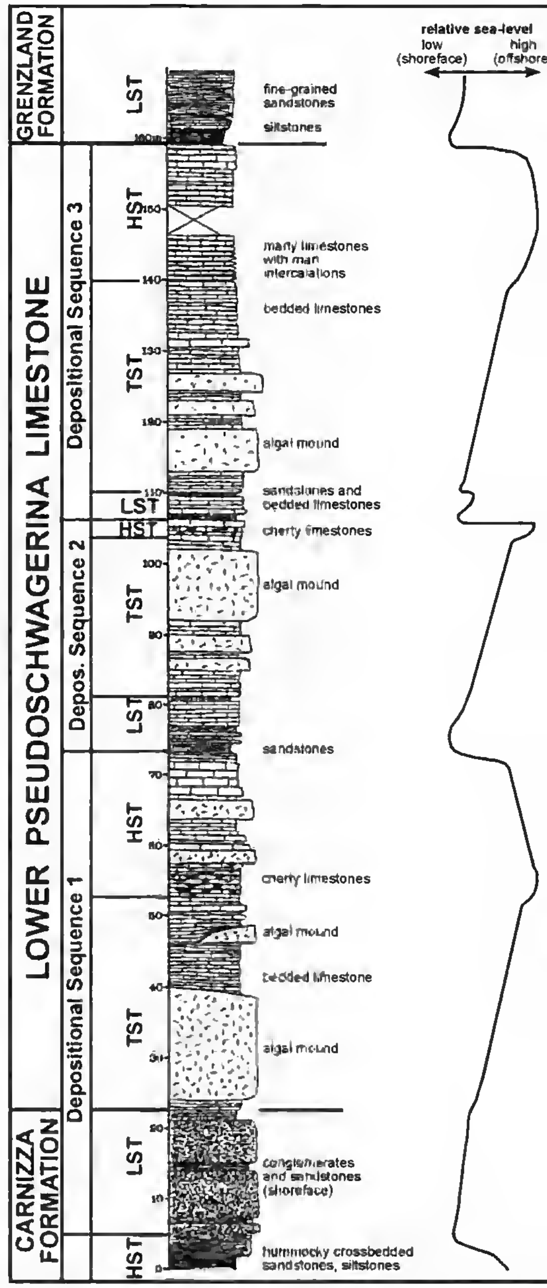


Fig. 4. — Stratigraphic column of the Lower Pseudoschwagerina Limestone (Rattendorf Group) from the north-western side of the Schulterkofel (type section).

BIOSTRATIGRAPHY

Fusulinids

The first comprehensive paper on fusulinids from Late Paleozoic limestones of the Carnic Alps was presented by Schellwien (1898). From 1932-1996 F. Kahler (till 1982 with his wife G. Kahler) intensively studied the fusulinid faunas of the Bombaso Formation, Auernig, Rattendorf and Trogkofel Groups. The biostratigraphic classification and subdivision of the Late

Paleozoic sequence of the Carnic Alps is mainly based on the detailed investigation of fusulinids by F. Kahler & G. Kahler. Their data are published in numerous papers, summaries are given in Kahler (1983, 1985, 1986, 1989). Additional data concerning fusulinid stratigraphy have been contributed by Pasini (1965, 1990) and recently by Forke (1995), Forke *et al.* (in press) and Davydov (Davydov & Krainer, in press). We use the sign * in cases of difference from original authors taxonomy.

Bombaso Formation and Meledis Formation

The oldest fusulinid fauna of the Carnic Alps is described from carbonate rocks on top of the Bombaso Formation west of Zollnersee, consisting of *Ozawainella angulata, O. kumpani* and *O.* cf. *mosquensis, Fusulinella colaniae rasdorica, F. fluxa, Beedeina* nytvica callosa, Fusulina* (s.str.) *fortissima, Quasifusulinoides* mjachkovensis, Quasifusulinoides* quasifusulinoides* and *Quasifusulinoides juvenatus* (Kahler 1983). According to Kahler (1983), this fusulinid fauna corresponds to the *Fusulinella bocki* zone of the Late Myachkovian of the Russian classification.

Carbonate from the lowermost Meledis Formation of the Auernig Group yielded a *Fusulinella, Fusulina* and *Quasifusulinoides* fauna near Waidegger Alm indicating lowermost Kasimovian C_3A_1 (Kahler 1986) and a *Protriticites*-fauna containing *P. pseudomontiparus* SW of Zollnersee pointing to lowermost Kasimovian A_1 (Kahler 1983).

Recent investigation yielded a small fusulinid assemblage from conglomerates of the Bombaso Formation near Straniger Alpe, composed of *Quasifusulinoides quasifusulinoides, Q. fallax, Q. intermedia, Protriticites ovatus, P.* cf. *ovoides.* The composition of this assemblage is most similar to that from the *Protriticites ovatus - Praeobsoletes burkemensis* zone in the stratotype section in the Moscow Basin and occurs only in the Peskovskaya Formation of the Myachkovian Horizon of the Moscovian (Davydov 1997; Davydov & Krainer, in press). A similar assemblage was found near the top of the Bombaso Formation west of Zollnersee and includes *Fusiella lancetiformis, Beedyina consobrina, B. peskensis, B. pseudocylindrica, Fusulinella rara, Quasifusulinoides pakhrensis, Q. pulchella, Protriticites ovatus.*

Carbonates from the basal Meledis Formation near Zollnersee and at Cima Val di Puartis contain fusulinids of the *Protriticites pseudomontiparus* zone in its lowermost part, and of the *Montiparus paramontiparus* zone in the middle portion of this formation. The *Protriticites pseudomontiparus* zone is characterized by *Protriticites globulus, Pr. pseudomontiparus, Pr. sphaericus, Pr. rotundatus, Pr. ovoides, Pr. lamellosus* and *Praeobsoletes burkemensis.* These species are characteristic only in the *Protriticites pseudomontiparus - Obsoletes obsoletus* zone of the Russian Platform (Kreviakian Horizon) and Timan-Pechora region, in the Urals, Donets Basin, Central Asia, Spitsbergen and in the Cantabrian Mountains (see Davydov & Krainer, in press).

The *Montiparus paramontiparus* subzone is characterized by the occurrence of *Praeobsoletes pauper, P. burkemensis, Obsoletes timanicus, O. obsoletus, Montiparus paramontiparus, M. umbonoplicatus, M. montiparus, M. likharevi, M. rhombiformis* and *M. priscus. Montiparus* species found in the Carnic Alps are well-known from middle Kasimovian strata of the Russian Platform (Khamovnicheskian), Timan-Pechora Basin, the Urals (upper part of the Orlovskyi Horizon), Central Asia, Spitsbergen and the Cantabrian Mountains. In Central Asia and the Southern Urals the *Montiparus montiparus* zone is divided into two subzones: the *M. paramontiparus* subzone in the lower part and the *M. subcrassulus* subzone in the upper part. The assemblage recognized in the Carnic Alps corresponds to the *M. paramontiparus* subzone (see discussion by Davydov & Krainer).

It should be indicated that the representatives of the *Praeobsoletes-Obsoletes* lineage in the Carnic Alps appear later. In the Russian Platform, the Urals, Donets Basin and Central Asia *Praeobsoletes* first appears in the uppermost Myachkovian and ranges into the lowermost Kasimovian. *Obsoletes* first appears at the base of the Kasimovian and is most characteristic for the Early Kasimovian (Kreviakian). Only rarely *Obsoletes* ranges into the middle Kasimovian (Kahmovnicheskian). In the Carnic Alps, similarly with the Cantabrian Mountains and

Spitsbergen (Villa *et al.* 1992; Nilsson & Davydov 1993), the representatives of the *Praeobsoletes-Obsoletes* lineage are rare. *Praeobsoletes* first appears only in the lowermost Kasimovian (Kreviakian) and *Obsoletes* first appears in the uppermost Kreviakian or only in the Khamovnicheskian.

In the very top of the Meledis Formation in the RC section (RC-12b and RC-13) the following fusulinids were identified: *Ferganites ferganensis* Miklukha-Maclay, *Rauserites* sp., and *Rauserites rossicus* (Schellwien) (Fig. 5A-E). The last species in the Russian Platform and the Urals characterise lowermost Gzhelian or Rechitskyi Horizon of the Russian Platform (Rosovskaya 1958; Makhlina *et al.* 1984; Davydov & Popov 1986). *Ferganites ferganensis* in Central Asia as well as in S. Urals characterises also early Gzhelian, an equivalent of Amerevskyi Horizon of the Russian Platform (Fig. 6) (Davydov & Popov 1986; Popov *et al.* 1989). We suggest that the very upper portion of the Meledis Formation is early Gzhelian in age (Fig. 6).

Pizzul Formation, Corona Formation, Auernig Formation and Carnizza Formation

According to Kahler (1985) the Pizzul Formation (Untere kalkreiche Schichtgruppe) is characterized by the occurrence of the following fusulinid species: *Triticites oryziformis*, *Rauserites* noinskyi plicatus*; *Daixina alpina vetusta*, *D. sokensis* (s.str.*), *D. naviculaeformis*, *D. sakmarensis* and *Quasifusulina eleganta*. Recent studies of non-oriented thin-sections from the Pizzul Formation show dominance of a *Schagonella* and *Daixina* fauna. Because in Central Asia and southern Urals representatives of the *Daixina sokensis* group appear earlier than in the Russian Platform, and because of the stratigraphic position of the Pizzul Formation above the early Gzhelian and below the Orenburgian, we believe that the Pizzul Formation has to be an equivalent of the late Gzhelian (*s.str.*).

From a thin carbonate bed of the Corona Formation at Garnitzenberg (Mittlere kalkarme Schichtgruppe) Kahler (1983) reported "*Pseudofusulina multiseptata*". *Daixina alpina*, *D.* ex gr. *admirabilis* and *Schagonella* spp. also were recently identified by Davydov. The species *Pseudofusulina multisepta* originated from the Carnic Alps (Schellwien 1898), but for more then sixty years was used in the literature as a Late Permian *Parafusulina* species, reported from many Tethyan regions. Until revision and solving of this taxonomical problems we use inverted commas for this species.

In Darvas and in S. Urals *Schagonella* in general dominated in the middle Gzhelian. *Daixina admirabilis* originally was described from the Orenburgian of the Urals (Zolotova *et al.* 1978), but also was reported from the late Gzhelian (*s.str.*) of Darvas (Davydov 1986). Fusulinid data from Pizzul and Corona Formations do not constrain a specific age. Based on the stratigraphic position of Pizzul and Corona Formations above an equivalent of the early Gzhelian (Upper Meledis) and below the Orenburgian Auernig Formation, the age of both formations can be estimated as late Gzhelian (*s.str.*) (Amerevskyi and Pavlovoposadskyi Horizons of Russian Platform).

The Auernig Formation (Obere kalkreiche Schichtgruppe) of Garnitzenberg and Kronalpe contains *Boultonia europaea*; *Triticites schwageriniformis*, *T. perstabilis*; *Daixina* alpina*, *D.* communis*, *D.* alpina fragilis*, *D.* devexa acallosa*; "*Pseudofusulina multiseptata*", "*P. paraconcinna*"; *Dutkevitchia dastarensis*, *D.* "*kargalensis*", *D.* "*ruzhencevi*"; *Quasifusulina tenuissima*, *Q. compacta*, *Q. karawankensis*, *Q. kaspiensis*, *Q. phaselus*, *Q. pseudoelongata*, *Q. pseudolonga* (Kahler 1983, 1985).

The Carnizza Formation (Obere kalkarme Schichtgruppe) of Garnitzenberg contains *Daixina alpina antiqua* = *alpina* and the subspecies *fragilis*, and *Dutkevitchia dastarensis*.

According to Kahler (1986, 1989) Pizzul Formation, Corona Formation, Auernig Formation and Carnizza Formation are of Gzhelian age (Gzhelian E).

Recent studies in the southern Urals, Donets Basin and in Central Asia (Darvas and southern Fergana) showed that *Boultonia europaea* and *Dutkevitchia dastarensis* first appear at the basal Orenburgian *Daixina sokensis* zone (Davydov 1984, 1992; Popov *et al.* 1989; Davydov *et al.* 1993). *Dutkevitchia ruzhenzevi* and *Dutkevitchia kargalensis* everywhere first appear only in the

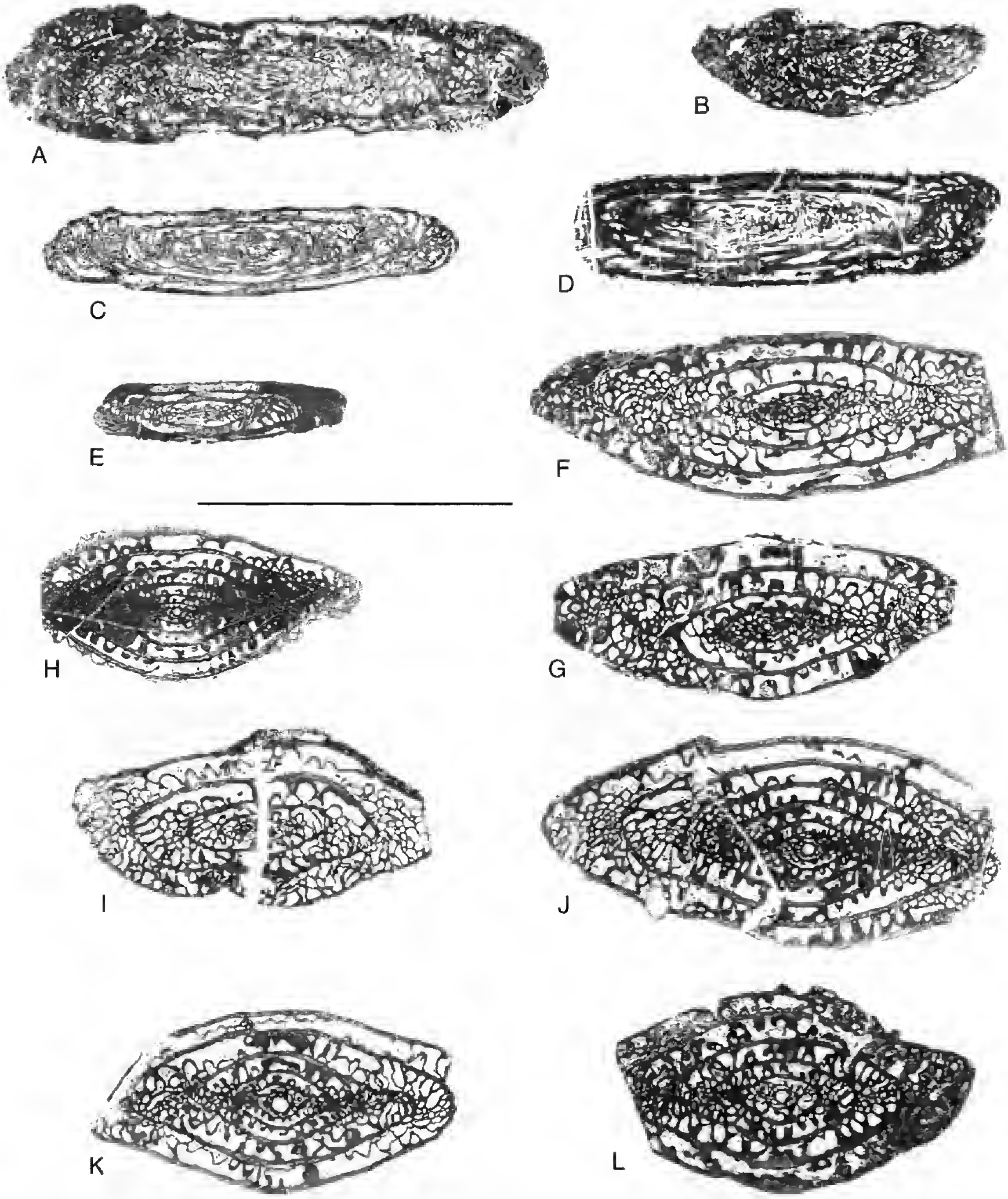


FIG. 5. — Stratigraphically significant fusulinids from the Meledis Formation (basal Auernig Group) and Lower Pseudoschwagerina Limestone (Rattendorf Group). **A**, *Rauserites rossicus* (Schellwien, 1908), tangential section, RC-13-4. **B**, *Rauserites* sp., oblique section, RC-13-4. **C-E**, *Ferganites* aff. *ferganensis* (Miklukho-Maclay, 1948): **C**, axial section, RC-12b-9; **D**, tangential section, RC-12b-12; **E**, paraxial section, RC-12b-2. **F**, **G**, *Schellwienia bornemani* (Leven *et* Scherbovich, 1978): **F**, axial section of typical specimen, SK-157-4; **G**, axial section of short specimen, SK-157-2. **H**, *Zigarella panjiensis* (Leven *et* Scherbovich, 1978), axial section of typical specimen, SK-157-5. **I**, *Likharevites inglorius* (Bensh, 1962), axial section, SK-157-1. **J-L**, *Schellwienia bornemani* (Leven *et* Scherbovich, 1978): **J**, axial section of specimen with small axial fillings, SK-157-12; **K**, axial section of typical specimen, SK-157-13; **L**, axial section of short specimen, SK-157-9. Scale bar: 0,5 cm.

early Asselian, and we believe that their occurrence in the Orenburgian Auernig Formation is misidentified. Therefore we place inverted commas with both of these species. The age of Auernig and Carnizza Formations for now can be estimated as Orenburgian (equivalent of Nogonskian of Russian Platform) (Fig. 6).

Lower Pseudoschwagerina Limestone (Schulterkofel Formation)

From the uppermost part of the Lower Pseudoschwagerina Limestone near Rudnigalm Kahler (1985) described the following fusulinid species: *Boultonia europaea*; *Rugosofusulina arianica*, *R. directa*, *R. latioralis*, *R.* cf. *pandae*, *R. praevia egregia*, *R. stabilis*, *R. stabilis longa*; *Paraschwagerina* cf. *tinvenkiangi elongata*, *Occidentoschwagerina alpina* and *"Eozellia mibaranoensis"* (= *Ultradaixina* ex gr. *postgallowayi)*. From Schulterkofel Kahler (1983) listed *Boultonia europaea*; *Ruzhenzevites* parasolidus*; *Rugosofusulina* cf. *pandae*, *R. serrata*, *R. likana*, *R. praevia* and *Rugosochusenella* pseudogregaria*.

In a recent paper Kahler & Krainer (1993) described a fusulinid fauna composed of about 30 species from the upper part of the LPL of the Schulterkofel section. Species of *Triticites* and *Rugosofusulina* dominate, whereas those of rare *"Daixina"* (=*Schellwienia*), *Rugosochusenella* and *Ruzhenzevites* occur. The Carboniferous/Permian boundary was drawn at the first appearance of *"Pseudoschwagerina"* and *"Occidentoschwagerina alpina"* (= *Ultradaixina*) in the upper part of the section. From our point of view, specimens named as *Pseudoschwagerina* could not be identified even with genus name, because in the tangential sections reported, the juvenarium structure, which is most important for taxonomy, is not present.

According to Forke *et al.* (in press) the lower part (depositional Sequence 1) of the LPL in the Schulterkofel section, characterized by the occurrence of *Ruzhenzevites ferganensis* and *Ruzhenzevites parasolidus* without species of the genus *Ultradaixina*, is correlated with the *Sokensis* zone. The overlying part (uppermost part of depositional Sequence 1 up to the top of depositional Sequence 3) corresponds to the *Bosbytauensis-Robusta* zone. The C/P-boundary of Forke *et al.* lies near the base of the overlying Grenzland Formation.

The following species were identified in recent studies of LPL in the Schulterkofel section: in the very lower portion of LPL (TST of Sequence 1) we found *Daixina sokensis*, *Schellwienia oblonga* and *Dutkevitchia bimorpha*. In the HST of Sequence 1 *Ultradaixina postsokensis* and *Schellwienia ulukensis* and within Sequence 2, *Schellwienia ulukensis* and *Zigarella elegans* were identified. Most interesting data were retrieved from the top of Sequence 3, where *Schwagerina versabile*, *Schellwienia bornemani*, *Zigarella panjiensis* and *Likharevites inglorius* were identified (Fig. 5 F-L).

To estimate the age of the LPL Formation we can indicate the following: in Southern Fergana and Darvas *Ruzhenzevites ferganensis* first appears in the middle portion of an equivalent of the *Daixina sokensis* zone (Davydov 1984; Popov *et al.* 1989). *Ruzhenzevites parasolidus* is a more advanced species and in Darvas it first appears in the very top of the *Daixina sokensis* zone and ranges higher. In Southern and Northern Fergana this species occurs in the *Schwagerina robusta-Ultradaixina bosbytauensis* zone and ranges higher into the Asselian. *Schellwienia ulukensis* in Central Asia as well as in the Southern Urals section occurs only in the *Schwagerina robusta-Ultradaixina bosbytauensis* zone. *Schwagerina versabile* in Darvas and in the Southern Urals appears in the very top of the *Schwagerina robusta-Ultradaixina bosbytauensis* zone, but is characteristic of the early Asselian. *Schellwienia bornemani*, *Zigarella panjiensis* and *Likharevites inglorius* in Central Asia and the Southern Urals are known only from the Asselian (Bensh 1962 ; Leven & Scherbovich 1978; Davydov 1984; Popov *et al.* 1989) (see correlation chart, Fig. 6).

Based on all this data we can suggest the following. The TST (transgressive systems tract; Fig. 4) of Sequence 1 of LPL can be correlated with the uppermost part of the *Daixina sokensis* zone. The HST (highstand systems tract) of Sequence 1 can be correlated with the lower portion of the *Schwagerina robusta-Ultradaixina bosbytauensis* zone or with the *Ultradaixina postsokensis* zone of the Southern Urals and

Darvas. Most part of Sequence 2 (except the HST) conventionally can be correlated with the middle portion of the *Schwagerina robusta-Ultradaixina bosbytauensis* zone or with the *Ultradaixina bosbytauensis* zone of the Southern Urals and Darvas. The HST of Sequence 2 and LST (lowstand systems tract) and TST of Sequence 3 should be correlated with the upper portion of the *Schwagerina robusta-Ultradaixina bosbytauensis* zone or with the *Ultradaixina postgallowayi* zone of the Southern Urals and Darvas. The HST of Sequence 3 very probably is Early Asselian in age. The last conclusion is based on the following: in Darvas, the Southern Urals and in the Donets Basin the acme-zone (maximum of occurrences) for *Ultradaixina* is in the upper portion (but not uppermost) of the *Schwagerina robusta-Ultradaixina bosbytauensis* zone. In the very upper portion of this zone *Ultradaixina* is rare and perhaps extinct, and absolutely absent in the Asselian. Similarly in the Schulterkofel section the acme-zone for the *Ultradaixina* is the HST of Sequence 2 and the LST of Sequence 3. In the TST of Sequence 3 *Ultradaixina* is extremely rare and absolutely no *Ultradaixina* is present in the HST of Sequence 3. *Schellwienia bornemani* and *Zigarella panjensis* originally were described from the middle Asselian of Darvas. In the Southern Urals they occur in the early-middle Asselian. *Likharevites inglorius* in Darvas, Northern Fergana, the Southern Urals and Predonets Trough was found in the early-middle Asselian (Bensh 1962; Leven & Scherbovich 1978; Davydov 1990; Davydov *et al.* 1993). So, occurrences of *Schellwienia bornemani*, *Zigarella panjiensis* and *Likharevites inglorius* suggest Asselian age for the HST of Sequence 3 of the Lower Pseudoschwagerina Limestone.

Grenzland Formation

From limestones of the Grenzland Formation at Rudnigsattel Kahler (1985) reported the occurrence of *Quasifusulina* cf. *compacta*, *Q. eleganta*, *Q. kaspiensis*, *"Darvasites contractus"*, *Zigarella pseudopointeli*, *Sphaeroschwagerina carniolica*, *Pseudoschwagerina extensa* and *Sphaeroschwagerina sphaerica*.

From the type section near Rattendorfer Alm, Kahler & Kahler (1937) described *Pseudoschwagerina aequalis*, *Ps. extensa* and *Sphaeroschwagerina* confinii*, from the eastern side of Schulterkofel, *Pseudoschwagerina turbida* and *Sphaeroschwagerina* carniolica*.

Based on the occurrence of *Pseudoschwagerina aequalis*, *Sphaeroschwagerina* confinii* and *Sphaeroschwagerina* carniolica* Kahler (1986) dated the Grenzland Formation as middle Asselian.

Forke (1995) described *Sphaeroschwagerina glomerosa* from the Grenzland Formation near Rudnigsattel.

Most of the species of Grenzland Formation, except *Quasifusulina* species, are known from the middle as well as from the late Asselian. *Sphaeroschwagerina glomerosa* indicates only late Asselian age. Base on this we can suggest middle-late Asselian age for the Grenzland Formation (see Fig. 6).

Upper Pseudoschwagerina Limestone

From the type section of the Upper Pseudoschwagerina Limestone at Zottachkopf Kahler described the following fusulinid species: *Boultonia willsi*, *Pseudofusulina regularis*, *McCloudia* haydeni*, *Darvasites contractus*, *Schwagerina "krtowi"*, *Pseudoschwagerina pulchra*, *Biwaella inopinata* and *Rugosochusenella paragregaria*.

Red limestones at Troghöhe and at point 2016 (according to Kahler belonging to the Trogkofel Limestone, after Forke to the Upper Pseudoschwagerina Limestone) contain a rich fusulinid fauna. Kahler (1983, 1985) reported the following species: *Boultonia willsi*, *Quasifusulina uimia*, *Q. pseudoelongata*, *Q. tenuissima*, *Q.* cf. *kaspiensis*, *"Chusenella cheni"*, *"Ch. chihsiaensis"*, *"Ch. rabatei"*, *Schwagerina* moelleri*, *Schw.* paraconfusa*, *Eoparafusulina* "tschernyschewi"*, *Robustoschwagerina geyeri*, *R. schellwieni*, *Paraschwagerina inflata longa*, *Sphaeroschwagerina* carniolica*, *S.* lata*, *S.* pulchra*, *Zellia heritschi*, *Z. galatea*.

According to Forke (1995) the red limestones contain the following stratigraphically important species: *Zellia heritschi*, *Robustoschwagerina schellwieni*, *R. geyeri*, *Paraschwagerina inflata*, *Schwagerina moelleri*, *Schwagerina* cf. *verneuili*

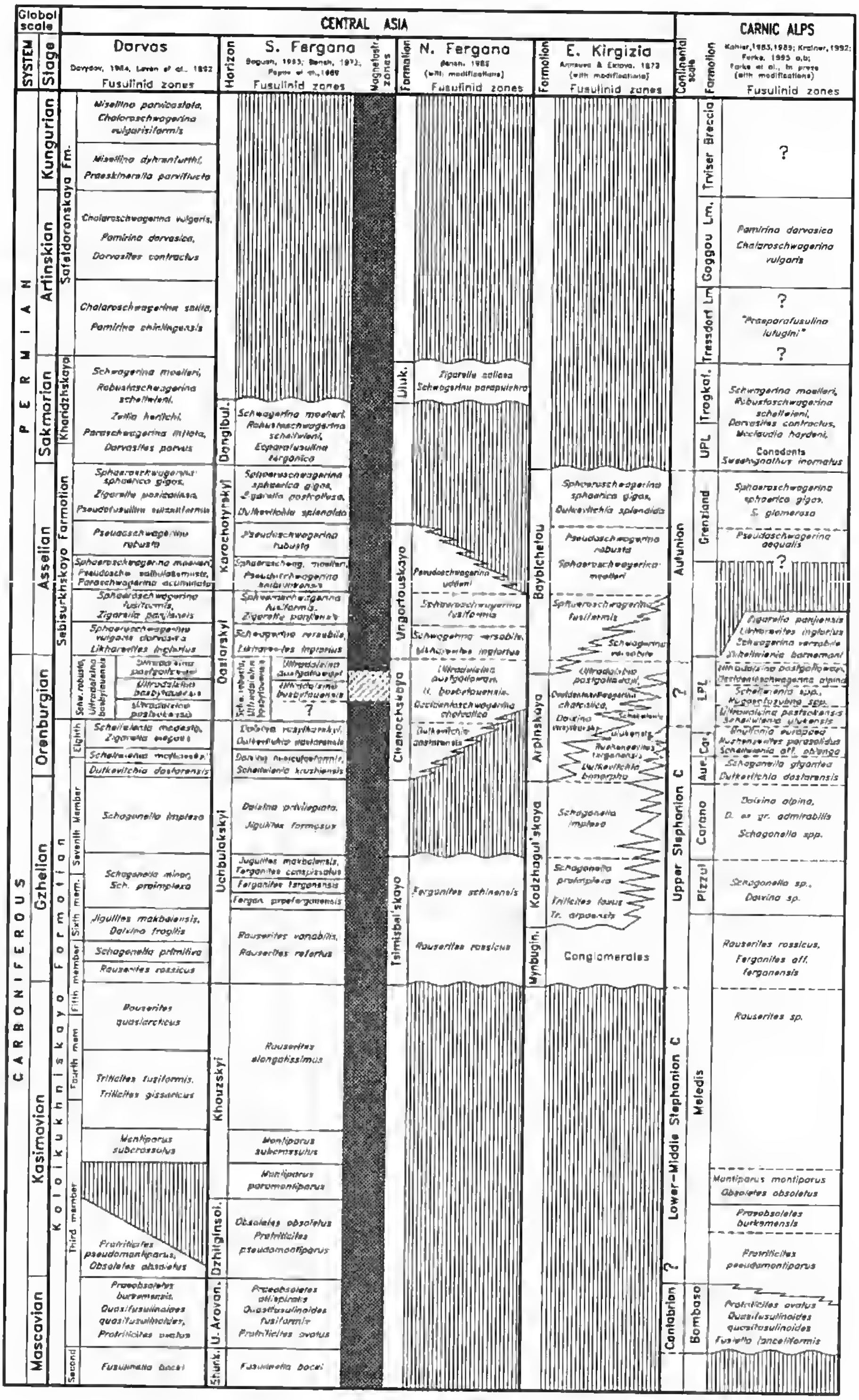
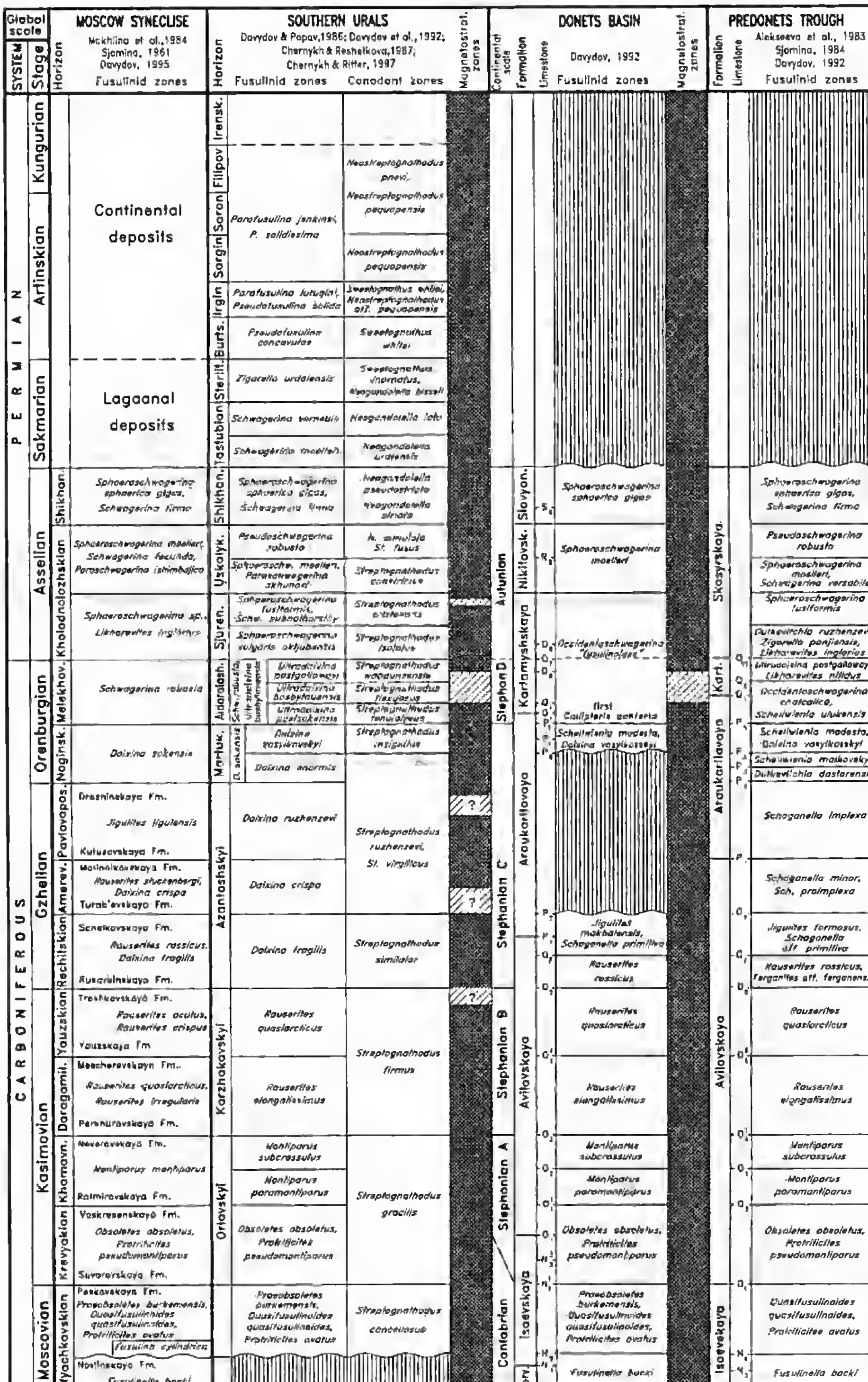


FIG. 6. — Correlation chart for the Late Carboniferous and Early Permian.


Global scale
SYSTEM
Stage
Horizon
MOSCOW SYNECLISE
Makhlina et al., 1984
Sjomina, 1961
Davydov, 1995
Fusulinid zones
SOUTHERN URALS
Davydov & Popov, 1986; Davydov et al., 1992;
Chernykh & Reshetkova, 1987;
Chernykh & Ritter, 1997
Fusulinid zones
Conodont zones
Magnetostrat. zones
Continental scale
Formation
Limestone
DONETS BASIN
Davydov, 1992
Fusulinid zones
PREDONETS TROUGH
Alekseeva et al., 1983
Sjomina, 1984
Davydov, 1992
PERMIAN
CARBONIFEROUS
Kungurian
Artinskian
Sakmarian
Asselian
Orenburgian
Gzhelian
Kasimovian
Moscovian
Continental deposits
Lagoonal deposits
Autunian
Stephanian D
Stephanian C
Stephanian B
Stephanian A
Cantabrian
Streptognathodus gracilis
Streptognathodus firmus
Rauserites quasiarcticus
Rauserites elongatissimus
Montiparus subcrassulus
Montiparus paramontiparus
Obsoletes obsoletus, Protriticites pseudomontiparus
Fusulinella bocki
Daixina fragilis
Daixina crispa
Daixina ruzhenzevi
Schwagerina robusta
Schagonella implexa

and *Pseudofusulinoides pusillus*. Forke (1995) dates the Upper Pseudoschwagerina Limestone as Sakmarian (*Robustoschwagerina geyeri* zone and *Zellia heritschi* zone).

Trogkofel Group

After Kahler & Kahler (1980) the fusulinid fauna of the Trogkofel Group consists mainly of species of the genera *Triticites*, *Darvasites*, *Pseudofusulinoides*, *Pseudofusulina*, "*Praeparafusulina*", *Pamirina* and *Minojapanella*. They described about seventy species. Stratigraphically important index fossils are *Schwagerina* moelleri*, characteristic for the lower part (Trogkofel limestone), "*Parafusulina lutugini*" typical for the Tressdorf limestone, and the *Chalaroschwagerina* vulgaris*-group together with *Pamirina darvasica* in the Goggau limestone. True parafusulinids and *Misellina* species are lacking.

Kahler (1986) dated the Trogkofel limestone as Sakmarian (Tastubian-Sterlitamakian) due to the occurrence of *Robustoschwagerina schellwieni* and *Pseudoschwagerina lata*. The Tressdorf limestone, containing "*Praeparafusulina lutugini*" is classified as Early Artinskian (Burchev), and the Goggau limestone, which contains *Chalaroschwagerina* vulgaris* and *Pamirina*, is dated as Late Artinskian (Irgin). According to Forke (1995) the Trogkofel limestone is Late Sakmarian to Early Artinskian in age.

It should be noted, that Sakmarian and Artinskian fusulinids of the Urals can not occur in the Tethyan section, as the Carnic Alps, because beginning in the early Sakmarian the Boreal province was completely isolated from the Tethyan provinces. None Artinskian fusulinid species of the Urals are known from Tethys sediments, but those listed, we believe, are identified erroneously. For this reason "*Praeparafusulina lutugini*" takes inverted commas and indicates taxonomical misidentification.

We cannot estimate the age of the Trogkofel limestone based only on fusulinids for now. It could be Sakmarian as well as early Artinskian. Because the Goggau Limestone contains *Chalaroschwagerina vulgaris* and *Pamirina darvasica*, which in Darvas characterises the late Yakhtashian (Early Artinskian) (Leven *et al.* 1992), we can conventionally estimate the age of the Tressdorf limestone as early Artinskian (Fig. 6).

The following problems for fusulinid biostratigraphy should be addressed immediately:

– precise fusulinid biostratigraphy of Pizzul, Corona, Auernig and Carnizza Formations;
– complete characteristic of C/P boundary beds and better criteria for the C/P boundary position;
– age of Grenzland Formation;
– fusulinid biostratigraphy and succession of the Trogkofel Limestone;
– restudy of the Tressdorf and Goggau Limestones.

Conodonts

The occurrence of conodonts in Late Paleozoic carbonates of the Carnic Alps was first noted by Flügel *et al.* (1971) from the Rattendorf Group and Boeckelmann (1983) from the Auernig Group (discoveries of individual conodont fragments, which have no stratigraphic importance). Forke (1995) described a conodont fauna from red limestones of the Upper Pseudoschwagerina Limestone. The conodont fauna is composed of the following species: *Aethotaxis advena*, *Hindeodus minutus*, *Mesogondolella* cf. *bisselli*, *Diplognathodus expansus*?, *Sweetognathus inornatus* and *Sweetognathus* aff. *whitei*.

In central and western USA *S. inornatus* and *S.* aff. *whitei* appear in the Late Wolfcampian. *S. inornatus* belongs to the *Sweetognathus whitei*-*Mesogondolella bisselli* zone. In the Urals, *Sweetognathus inornatus* appears in the Sterlitamakian (Late Sakmarian) and ranges into the Artinskian. *Sweetognathus whitei* is known only in Aktastian (Early Artinskian) (Chernykh & Reshetkova 1987; Chernykh & Chuvashov 1993). *Sweetognathus whitei* in the Trogkofel Group is represented by incomplete atypical specimens (identified with "affinity" sign). The appearance of *Sweetognathus inornatus* and *S.* aff. *whitei* together with *Robustuschwagerina* and *Zellia*, but without typical Artinskian fusulinid faunas (*Pamirina*, *Chalaroschwagerina*) in the Carnic Alps, indicates at this time Sakmarian age. According to Forke (1995) the Upper Pseudoschwagerina Limestone is of Sakmarian age (based on the occurrence of *Robustoschwagerina geyeri* and *Zellia heritschi*). Forke (1995) in his paper presenrs correlation charts of the Rattendorf and Trogkofel Group with sections from the Urals, Darvas, N-China, S-China, Japan and USA.

Fossil flora

Plant fossils were reported from the Bombaso Formation and Auernig Group more than 100 years ago. Höfer seems to be the first who collected plant fossils in 1869 in the Monte Corona/Kronalpe and Casera For/Ofenalm area. The specimens were determined and described by Unger (1869), the taphoflora list contains 19 taxa.

The determinations of Unger (1869) were later revised by Reichardt (1937) and Fritz & Boersma (1982).

Taphoflora lists from the Monte Corona section (Corona Formation) have been published by Stache (1874), Schellwien (1892), Frech (1894) and Geyer (1897).

From the localities Cason di Lanza (?Meledis Formation) and Monte Pizzul (type locality for the Pizzul Formation) plant fossils were described by Tommasi (1889), Bozzi (1890) and Vinassa De Regny & Gortani (1905).

Later, numerous new localities of plant fossils within the Auernig Group were discovered by Kahler, Metz and others in the Auernig, Nassfeld and Schulterkofel areas. The plant fossils were described by Reichardt (1933) and Kielhauser (1937), a first summary on the fossil flora of the Auernig Group including 25 taxa was given by Reichardt (1937) and Jongmans (1938).

Jongmans (1938) classified the flora of the Auernig Group as Westphalian D (= Early Stephanian) and Westphalian E (= Late Stephanian). He also pointed out that within the Auernig Group the Schulterkofel flora represents the youngest flora.

Berger (1960) reported 30 taxa from new localities, most of them within the Bombaso Formation and lowermost part of the Auernig Group. He classified the fossil flora as Westphalian D. Plant fossils have also been described from several new intervals within the uppermost Corona-, Auernig- and Carnizza Formations. (Kahler *et al.* 1933; Kahler & Prey 1963; Fenninger & Schönlaub 1972; Francavilla 1974).

Fritz & Boersma (since 1980) and Fritz & Krainer (since 1993) systematically investigated the fossil flora of the Bombaso Formation and Auernig Group from more than 30 localities. Plant fossils are found in all formations of the Auernig Group, from most localities the stratigraphic position within the section is exactly known.

From all localities 105 taxa are described (Equisetophyta 26 taxa, Lycophyta 12 taxa, Filicophyta, Pteridospermae and Pteridophylla 57 taxa, Cordaitospermae 9 taxa; Coniferae 1 taxon, see Fritz *et al.* 1990; Fritz & Krainer 1993, 1994, 1995).

From the Grenzland Formation the occurrence of plant fossils (no determinations) has been noted by several authors (Felser *et al.* 1956; Felser & Kahler 1963; Kahler & Prey 1963; Flügel 1974). Herzog (1984) discovered a plant fossil bearing interval and collected a flora which was determined and described by Fritz & Boersma (1984) and Fritz *et al.* (1990). So far known this locality is the only one within the Rattendorf Group and thus the youngest fossil flora of the Late Paleozoic sequence in the Carnic Alps.

Flora of the Bombaso Formation

From the Bombaso Formation 3 localities containing plant fossils are known (Tomritsch 1, 2 and 6). The lowermost locality (Tomritsch 6) is characterized by the occurrence of *Sphenophyllum oblongifolium*, *Linopteris neuropteroides*, *Neuropteris ovata*, *Neuropteris scheuchzeri* and others (Fritz & Krainer 1995). According to Wagner (1984) *N. scheuchzeri* is a guideform of the Cantabrian (*Odontopteris cantabrica* zone). This correlation quite precisely corresponds with fusulinid data, which suggests for Cantabrian Uppermost Moscovian and Early Kasimovian age (Ginkel 1971; Rauser-Chernousova & Scherbovich 1974).

Flora of the Auernig Group

From the Auernig Group plant fossils are known from many horizons within all formations. The lowermost horizon containing plant fossils is from perhaps the basal part of the Meledis Formation (localities Tomritsch 3, Zollnersee and Straniger Alm). The fossil assemblages of these localities are characterized by the abundance of *Linopteris neuropteroides*. The presence of *Sphenophyllum angustifolium*, *S. oblongifolium*, *Callipteridium pteridium*, *Odontopteris brardii* and *Pecopteris* species of the group *P. arborescence -P. schlotheimii* indicates Stephanian age (early to middle Stephanian C according to the megaflora zonation of Wagner 1984). However, there is a contradiction between fusulinid and floral dating of the lower Meledis Formation. Based on fusulinids the lower Meledis Formation is Early to Middle Kasimovian in age and should correspond at least with the upper portion of the Cantabrian, Stephanian A and perhaps Stephanian B (Wagner & Winkler-Prins 1985; Davydov 1990). Only the uppermost Meledis Formation, which contains early Gzhelian fusulinids, could correspond with Stephanian C. The age of the Meledis Formation in the Tomritsch 3, Zollnersee and Straniger Alm localities should also be dated by fusulinids.

The uppermost portion of the Auernig Group containing plant fossils lies within the upper part of the Carnizza Formation (locality Schulterkofel). From this locality Fritz & Boersma (1981, 1983) Fritz *et al.* (1990) described a flora composed of 30 taxa, characterized by the occurrence of *Callipteridium gigas*, *C. pteridium*, *Odontopteris alpina*, *O. brardii*, *Pecopteris feminaeformis* and index fossils for Late Stephanian age: *Aphlebia elongata*, *Pseudomariopteris busquetii* and *Sphenophyllum alatifolium* (*Sphenophyllum angustifolium* zone, Stephanian C according to Wagner 1984).

Flora of the Grenzland Formation

The flora of the Grenzland Formation contains 16 species including *Annularia sphenophylloides*, *A. stellata*, *Sphenophyllum* cf. *angustifolium*, *Callipteris conferta*, *Odontopteris brardii*, *Pecopteris feminaeformis* and *P. schlotheimii*. The occurrence of *Callipteris conferta* and *Sphenophyllum* cf. *angustifolium* indicates Early Permian age (*Callipteris conferta* zone according to Wagner 1984).

Typical guideforms of the *Lobatopteris lamuriana* zone (Barruelian) and *Alethopteris zeilleri* zone (Stephanian B) have not been discovered till now.

According to the plant fossils the Bombaso Formation is of Cantabrian age, the Auernig Group contains typical guideforms of Stephanian C, and the Grenzland Formation is characterized by a flora of Early Permian age (see Table Carnic Alps, this volume). Based on Donets Basin data (Davydov 1990) Stephanian A corresponds to the middle and perhaps part of late Kasimovian, Stephanian B corresponds to the late Kasimovian and Stephanian C to the most part of Gzhelian. Autunian begins from the *Schwagerina robusta-Ultradaixina bosbytauensis* zone of the Orenburgian and also corresponds to the whole Asselian (Fig. 6).

The flora of the Bombaso Formation, Auernig Group, and Grenzland Formation is well dated by fusulinids. Fluvial sequences of the Eastern Alps (Stangnock Formation, Gurktal Nappe), which contain a similar assemblage of plant fossils ranging from the *Odontopteris cantabrica* zone to the *Callipteris conferta* zone, can be well correlated with the marine sequence of the Carnic Alps (Bombaso Formation-Grenzland Formation).

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Evolution trends in Middle Carboniferous Petalaxidae (Rugosa)

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ABSTRACT

Various aspects of the study of the Petalaxidae Fomichev, 1953 are considered. Detailed observations from previous investigations together with new, more precise data on the stratigraphic distribution of the Petalaxidae in the northern and central part of the Russian Platform are used as a framework for phylogenetic reconstruction. Five main morphological groups are recognized within *Petalaxis* Milne Edwards *et* Haime, 1852, based on the combination of stable and variable features predominant in each group. The main trend in Petalaxidae evolution during the Bashkirian and Moscovian stages is an increase in the colony integration and the stabilization of multitrabecular septal structure. The diagnosis and species content are given for taxa included in Petalaxidae after author's revision. Four new taxa are described: *Donastraea* n.g., *Ivanovia (Procystophora)* n.sg., *Petalaxis (Petelaxis) primitivum* n.sp. and *P. (P.) gigas* n.sp.

KEY WORDS
Peri-Tethys,
Petalaxidae,
Middle Carboniferous,
phylogeny,
biostratigraphy,
microstructure,
new taxa.

RÉSUMÉ

Tendances évolutives des Petalaxidae (Rugosa) du Carbonifère moyen. Des aspects variés de l'étude des Petalaxidae Fomichev, 1953, sont considérés dans cette publication. Des observations détaillées provenant d'investigations anciennes et récentes, des données plus précises sur la distribution stratigraphique des Petalaxidae dans la partie septentrionale et centrale de la plateforme russe sont utilisées comme un guide pour la reconstruction phylogénétique. Cinq groupes morphologiques principaux sont reconnus dans *Petalaxis* Milne Edwards *et* Haime, 1852, fondés sur la combinaison de caractères stables et variables prédominant dans chaque groupe. La principale tendance évolutive des Petalaxidae pendant le Bashkirien et le Moscovien est une croissance dans l'intégration coloniale et la stabilisation de la structure septale multitrabéculée. La diagnose et le nombre d'espèces sont donnés par taxons inclus dans les Petalaxidae, d'après la révision de l'auteur. Quatre nouveaux taxons sont décrits : *Donastraea* n.g., *Ivanovia (Procystophora)* n.sg., *Petalaxis (Petalaxis) primitivum* n.sp. and *P. (P.) gigas* n.sp.

MOTS CLÉS
Péri-Téthys,
Petalaxidae (Rugosa),
Carbonifère moyen,
phylogénie,
biostratigraphie,
microstructure,
nouveaux taxa.

INTRODUCTION

Based on previous data (Hill 1981; Sando 1983) the Petalaxidae range from Early Carboniferous (Visean) to Early Permian. This investigation shows that the Middle Carboniferous Petalaxidae are a remarkably widespread, abundant and short-lived taxonomic group. They range through uppermost early Bashkirian, late Bashkirian and Moscovian stages (Fig. 3), and are found in the Urals, Arctic Canada, U.S.A., Northern Timan, Novaya Zemlya, Moscow and Donetz Basins, China, Japan, Thailand, Cantabrian Mountains, Alaska and North Africa. Thus, they occur in the shelf facies in the Tethyan and the North American-Uralian basins. They are also known in Spitsbergen and Arctic Canada (Bamber & Fedorowski 1995; Somerville 1997).

MATERIAL

The data for this study were obtained from bed to bed collections of coral faunas from the uppermost Early Bashkirian-Moscovian of the Novaya Zemlya Archipelago (Cape Makarov, Northern Island), Sula River and Malaya Pokayama sections of Northern Timan (Figs 1, 2) and some sections of the Moscow region. Also, new material collected from the Moscow Basin was included and the works of Dobrolyubova (1935) and Fomichev (1953) were revised.

STRATIGRAPHIC POSITION

Two partial-range zones, the *Petalaxis* zone and the *Ivanovia* zone, have been defined (Kossovaya 1995), based on the evolutionary patterns shown by the Petalaxidae from the uppermost Early Bashkirian to the top of the Moscovian stage. The determination of the partial-range generic zone boundaries was based on taxonomic diversity dynamics, the structure of the assemblages and phylogeny of the Petalaxidae. Analysis and estimation of zonal boundaries show that the more precise levels for correlation are those characterized by the biotic events in the development of the coral assemblages (extinction, initial phase of recovery and radiation). Three main phases of variation in rugosan diversity were distinguished after the abrupt elimination of many genera as a result of the Mid-Carboniferous event (base of *Homoceras* zone, Kossovaya 1996, fig. 3). These data have been used for international correlation (Kossovaya 1996, fig. 8), but now should be modified a little.

THE *Petalaxis* ZONE

The appearance of Bashkirian representatives of *Petalaxis* coincides with the stabilization of favourable marine conditions and marks the beginning of the recovery interval that correspond to the base of the *Petalaxis* zone. It begins approximately at the base of the *praegorskyi-staffelliformis* fusulinacean zone (= *Streptognathodus expansus-Idiognathodus sinuosus* conodont zone (Koren 1989)) with the sudden appearance and rapid expansion of massive colonial *Petalaxis* along the eastern margin of the Euro-american paleocontinent (Fig. 5). This boundary was observed in Novaya Zemlya and Northern Timan sections and has been documented in the Bashkirian Mountains stratotype region (Ogar 1985). This level is also emphasized by diversification of solitary and fasciculate corals (Kossovaya 1996). In the Cape Makarov section (Novaya Zemlya, Loc. 801, Fig. 1) the first representatives of *Petalaxis primitivum* n.sp. (*P. stylaxis* group) were found with *Pseudostaffella antiqua*, *P. grandis* and *P.* cf. *praegorskyi* (determined by Dr. V. Davydov, Fig. 1). In the Sula River section (northern Timan), at Loc. 31 (bed 9) *Petalaxis*, represented by *P. persubtilis* Kozyreva, 1974 which occurs together with *Donophyllum reticulatum* (Fomichev, 1953) (bed 9) and *Yakovleviella tschernysnhewi* (Gorsky, 1978). The first occurrence of *P.* sp. aff. *P. mcoyanus* Milne-Edwards *et* Haime, 1851 was fixed in the Askynbashskian substage in the Southern Urals (Ogar 1985). Numerous species of *Petalaxis* are known from the Bashkirian deposits of the Voronezh uplift. The Early Bashkirian interval is characterized by *P. persubtilis* Kozyreva, 1974, *P. korkhovae* Kozyreva, 1974, *P. immanis* Kozyreva, 1974, *P. exilis* Kozyreva, 1974 and *P. confertus* Kozyreva, 1974 (Fig. 5). Some of these species extend into the Late Bashkirian, where *P. mirus* Kozyreva, 1974, *P. evidens* Kozyreva, 1974 also appear (Kozyreva 1974, 1984). In the Cantabrian Mountains *Petalaxis* occurs in the equivalent Westphalian A (Rodriguez 1984; Rodriguez *et al.* 1986). In Arctic Alaska (Northern Flank, Eastern Brooks Range) *Petalaxis wahooensis* is found at the base of the Atokan stage (foraminiferal zone 21, Armstrong 1972). *Petalaxis* was shown in the list of Bashkirian genera in the midcontinent and the western interior of USA by Sando (Rodriguez *et al.* 1986; Sando 1989). The precise stratigraphic position of *Petalaxis* is known from four southern Midcontinent Morrowan localities, all associated with the *Idiognathodus sinuosus* conodont zone (Sutherland & Grayson 1992).

The appearance of *Petalaxis* [*P. kitakamiensis* (Minato, 1955)] was fixed in grainstone or packstone beds of Bashkirian age near Ban Tat So (Km 13), Thailand (Fontaine *et al.* 1991). The level of the *Petalaxis* appearance seems to be useful for international correlation and allows to correlate the base of *Petalaxis* zone with the middle part of Morrowan and the base of the Westphalian A (see Kossovaya 1996, fig. 8).

After the decrease of diversity until Vereian substage (Fig. 3) in which no new species appeared, *Petalaxis* reached its greatest geographic distribution in the Kashirian substage. Some species with internal structure differing from those in the Bashkirian appear in the Kashirian of the eastern part of Russian Platform (Oka-Zna uplift, Studentz quarry). The predominance of massive colonial *Petalaxis* defines the *P. mcoyanus* zone in the Donets Basin (Zonal Stratigraphy 1989). *P. stylaxis uralica* (Gorsky, 1978) occurs in coeval deposits of Gornaya Bashkiria, in the Urals (Ogar 1990). The number of species is not very high, only the main branch still exists (Fig. 5). In different regions, coral diversity begins to increase: in interval 12 of the western interior of USA, at the beginning of the Westphalian C, in the base of the Kashirian substage in the Moscow region (post-Vereian increase of diversity in recovery interval, Kossovaya 1996)

The *Ivanovia* zone

The appearance of asteroid colonies within one of the *Petalaxis* branch seems to be the most remarkable event in the family evolution. The first representatives of *Ivanovia* Dobrolyubova, 1935 appear in the Podolsk quarry (stratotype of the Podolskian substage, Moscow region, Kossovaya's collection) and then become abundant in the Myachkovian substage, where the *Petalaxis vesiculosus* (Dobrolyubova, 1935) group is dominant (Fig. 6). *Ivanovia podolskiensis* Dobrolyubova, 1935 is known from the Uppermost Kashirian and Podolskian substages in the Cantabrian Mountains, Asturias, Spain (Escalada Formation) (Rodriguez 1984). The first appearance of *Ivanovia* coincides approximately with the base of

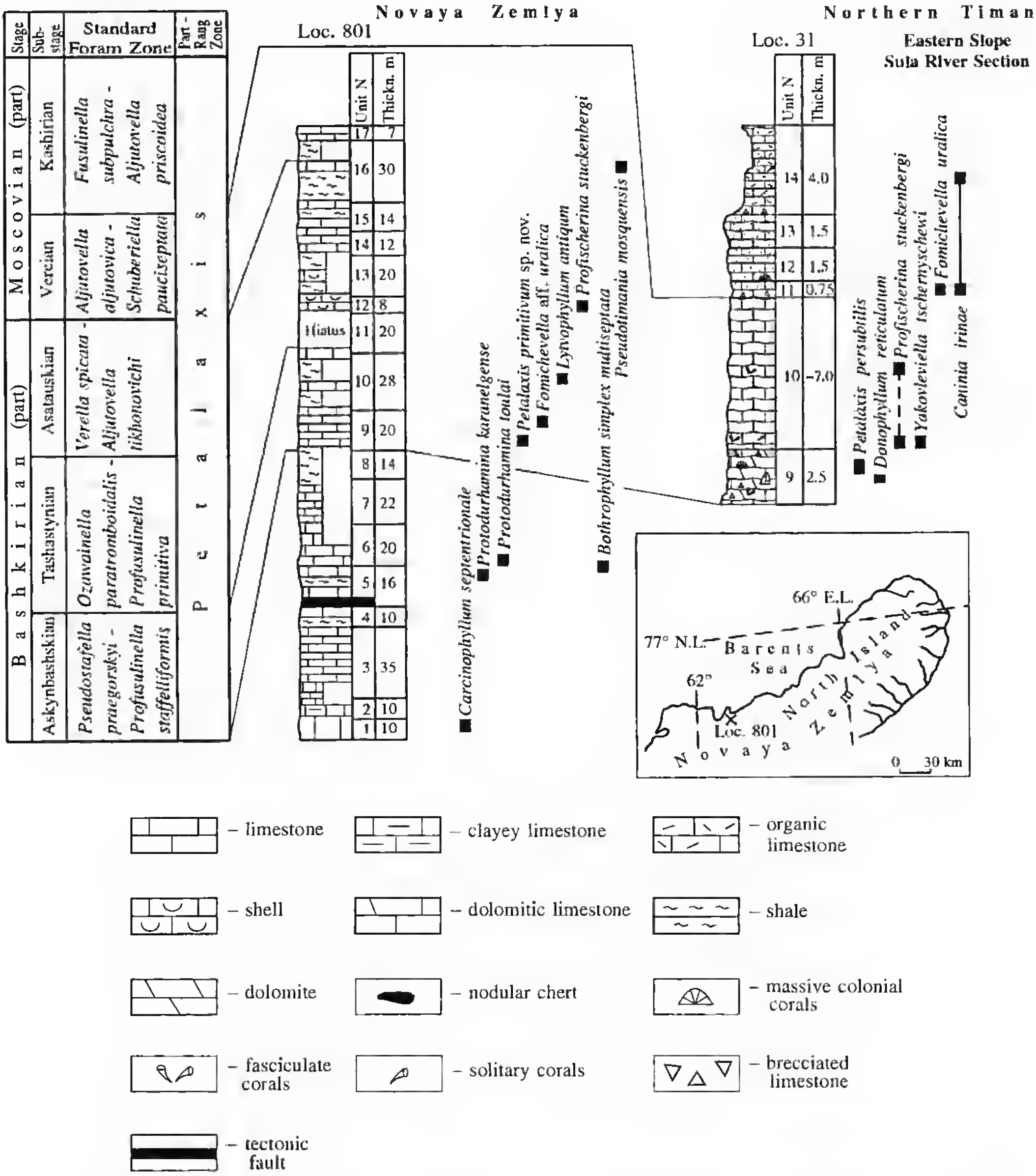

FIG. 1. — The occurrence of *Petalaxis* and associated species in the Bashkirian and Early Moscovian deposits of the northern part of Russia (loc. 801, northern island of Novaya Zemlya; loc. 31, Northern Timan, Sula River section).

the Podolskian substage (Figs 3, 5, 6), which is considered to be the beginning of the radiation of the Petalaxidae and is defined as the lower boundary of the *Ivanovia* zone (the base of *colaniae-vozhgalensis-kamensis* foraminifera zone, Fig. 5). In the Donets Basin, *Ivanovia* occurs from limestones K8-L6 (Fomichev 1953), slightly below the first appearance of *Ivanovia* in the type area. The maximum diversity of *Petalaxis* and astreoid forms is record-ed in the Myachkovian substage, especially in the Donets and Moscow Basins, where numerous species of *Ivanovia* (*Ivanovia*) (Dobrolyubova, 1935), *I.* (*Procystophora*) n.sg., *Donastraea* n.g. and *Cystophorastraea* Dobrolyubova, 1935 (Fig. 15) occur. In the radiation interval (Figs 5, 6) all groups of *Petalaxis* exist almost simultaneously,

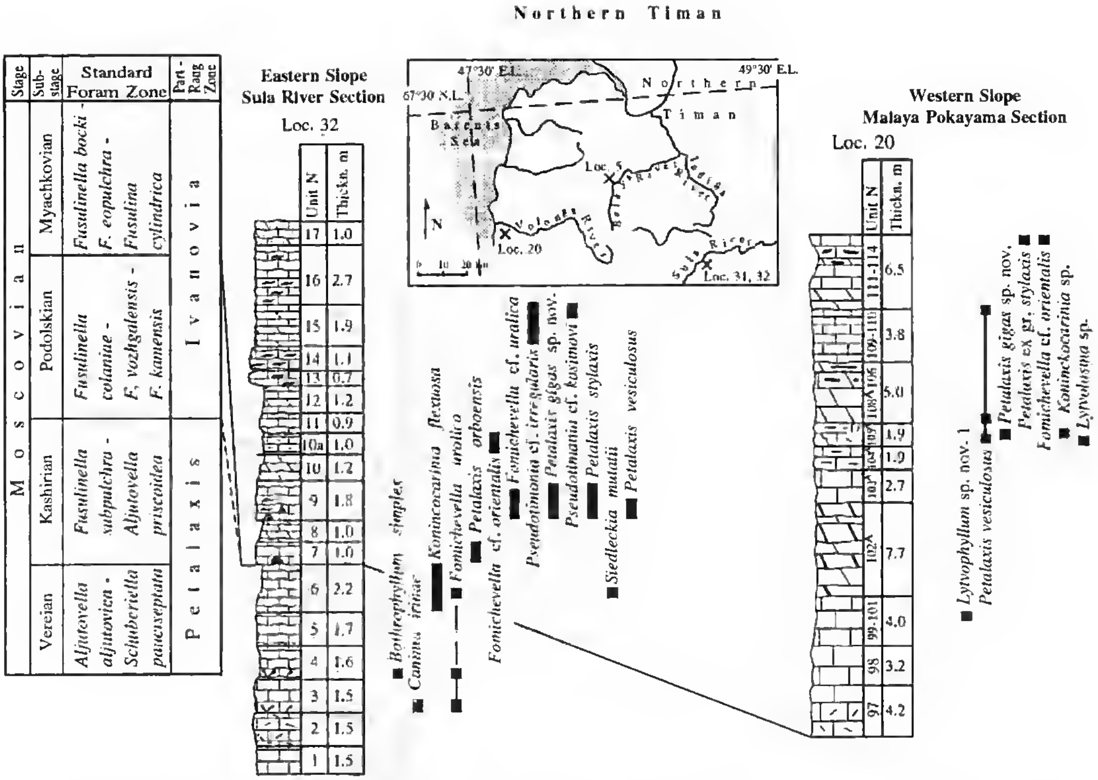

FIG. 2. — The occurence of *Petalaxis* and associated species in the Moscovian deposits of the northern Timan sections (see legend Fig. 1).

but the *P. vesiculosus* group is most widespread. This interval is defined as the *Petalaxis vesiculosus* species-range zone in the northern Timan sections (Kossovaya 1995) and is also characterized by *P. flexuosus* (Trautschold, 1879) (Moscow Basin, northern Timan, Belaya River section), *P. gigas* Kossovaya n.sp. (Northern Timan, Sula River section and Malaya Pokayama section), *P. orboensis* (de Groot, 1963) and *P. stylaxis* (Trautschold, 1879) (Moscow Basin). In the Malaya Pokayama section *P. gigas* n.sp. (*vesiculosus* group) was found together with index-species of the *Neognathodus roundyi-Streptognathodus cancellosus* conodont zone (zonation by Goreva *in* Goreva & Kossovaya 1997). In Belaya River section, *P. flexuosus* (loc. 5, bed 5-7) was found in the limestone, overlying that containing the *Parastaffella bradyi* Moeller, 1877 and *Parastaffella moelleri* Ozawa, 1925 (determined by Alekseeva, pers. com.). These foram species are widespread in Moscovian deposits of the Russian Platform. In the type section of the Myachkovian substage at Domodedovo quarry, *Petalaxis* species (*stylaxis, flexuosus*) occur in the lower part of substage (Novlinskaya Formation) and the last representatives of *P. stylaxis* group occur in the upper part of Sula Formation in the Malaya Pokayama section (bed 113) slightly below the Moscovian/Kasimovian boundary (Fig. 2). In most areas of western Russia, the Petalaxidae became extinct before the end of the Myachkovian.

Ivanovia zone coincides with radiation phase, which is easily recognisable in Novaya Zemlya, in the Moscow Basin and surrounding area and in the Northern Timan section at the base of the *colaniae-vozhgalensis-kamensis* zone (Fig. 5) at the base of Podolskian substage on the Russian Platform. In addition, the peak of diversity is fixed in the base of Westphalian D, and the base of the Desmoinesian (Interval 13, Western interior, USA, Sando 1989). *P. yosti* Stevens, 1995 (belonging to *P. Grootia* group) occured in Bird Spring Formation of the Desmoinesian (Stevens 1995) and could be correlated with the upper part of Moscovian.

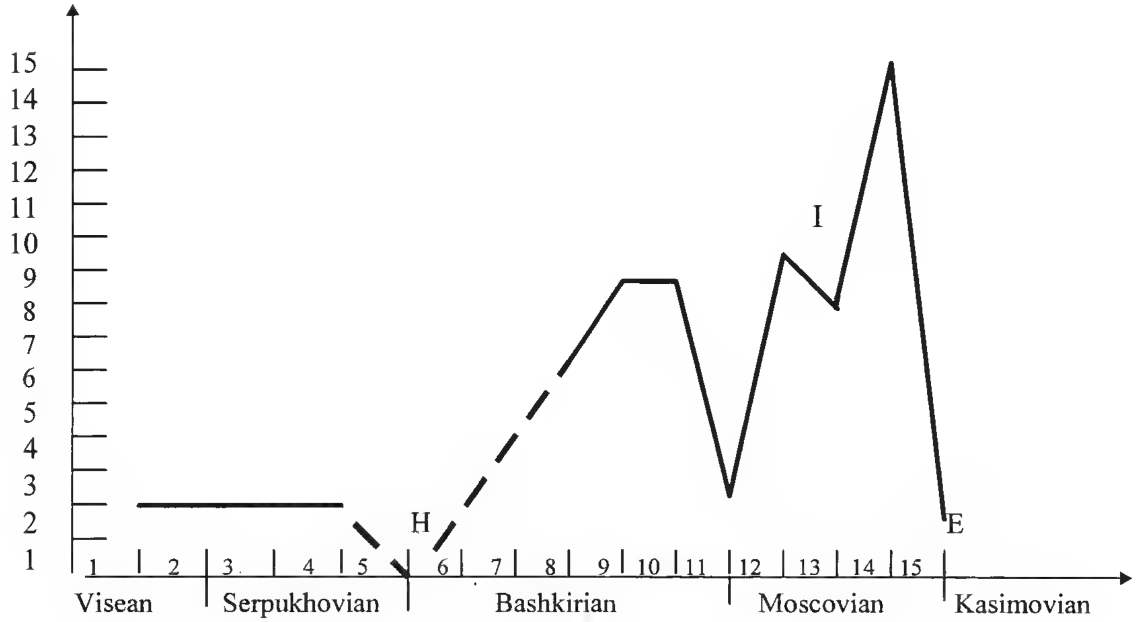

FIG.3. Taxonomic diversity of Petalaxidae Fomichev, 1953. **I**, innovation level at the base of Podolskian substage; **H**, hiatus in the Petalaxidae distribution at the end of Serpukhovian and the beginning of the Bashkirian; **E**, extinction at the end of the Moscovian. **1-15**, foram zones of the Russian Platform (Zonal Stratigraphy 1989). **Visean**: 1, *Eostaffella ikensis*; **2**, *Eostaffella tenebrosa*, *Endothyranopsis parvus*. **Serpukhovian**: **3**, Tarusian-Steshevian substages, *Pseudoendothyra globosa*, *Neoarchediscus parvus* zone; **4**, Protvian substage, *Eostaffella protvae* zone; **5**, Zapaltubian substage, *Eosigmolina explicata*, *Monotaxinoides subplana* zone. **Bashkirian**: **6**, Voznesenskian substage, *Plectostaffella bogdanovskensis* zone; **7**, Syranian substage, *Eostaffella pseudotruvei*, *E. postmosquensis*, *E. varvariensis* zone; **8**, Akavasskian substage, *Pseudostaffella antiqua*; **9**, Askynbashian substage, *Pseudostaffella praegorsky*, *Profusulinella staffelliformis*; **10**, Tashastynian substage, *Ozawainella pararhomboidalis*, *Profusulinella primitiva*; **11**, Asatauskian substage, *Verella spicata*, *Aljutovella tikhonovichi*. **Moscovian**: **12**, Vereian substage, *Aljutovella aljutovica*, *Schubertella pauciseptata*; **13**, Kashirian substage, *Fusulina pseudoelegans*, *Aljutovella znensis*; **14**, Podolskian substage, *Fusulinella colaniaea*, *F. vozhgalensis*, *Fusulina kamensis*; **15**, Myachkovian substage, *Fusulinella bocki*, *F. eopulchra*, *F. cylindrica*. **Kasimovian**: Krevyakinian substage, *Protriticites pseudomontiparus*, *Obsoletes obsoletus*.

TAXONOMIC REVIEW

The Family Petalaxidae was established by Fomichev (1953) (Fig. 4). According to his initial diagnosis, only genera of massive colonial corals with a continuous intercorallite wall, a lamellar, complex axial structures containing axial dissepiments and/or axial plates were included in this family. The dissepimentarium consists of large dissepiments interrupting the septa. Within this family, Fomichev (1953) recognized only one genus *Petalaxis* Milne Edwards *et* Haime, 1852 (type species *P. mcoyanus* Milne Edwards *et* Haime, 1852) including the subgenus *Cystolonsdaleia* Fomichev, 1953. According to Fomichev (1953), a possible ancestor could be *Thysanophyllum* Nicholson *et* Thomson, 1876 or *Endophyllum* Milne-Edwards *et* Haime, 1851 (Early Carboniferous). Similar corals, distinguished by an interrupted intercorallite wall, were grouped into the Family Cystophoridae Fomichev, 1953. It embraced *Ivanovia* Dobrolyubova, 1935, *Cystophora* Yabe *et* Hayasaka, 1916, *Polythecalis* Yabe *et* Hayasaka, 1916, and *Lonsdaleiastraea* Gerth, 1921 with the possible ancestor *Thysanophyllum*. Later Hill (1981) revised Fomichev's systematics and included all of these genera, partly as junior synonyms, into one family (the Petalaxidae), and changed the family diagnosis accordingly. Sando

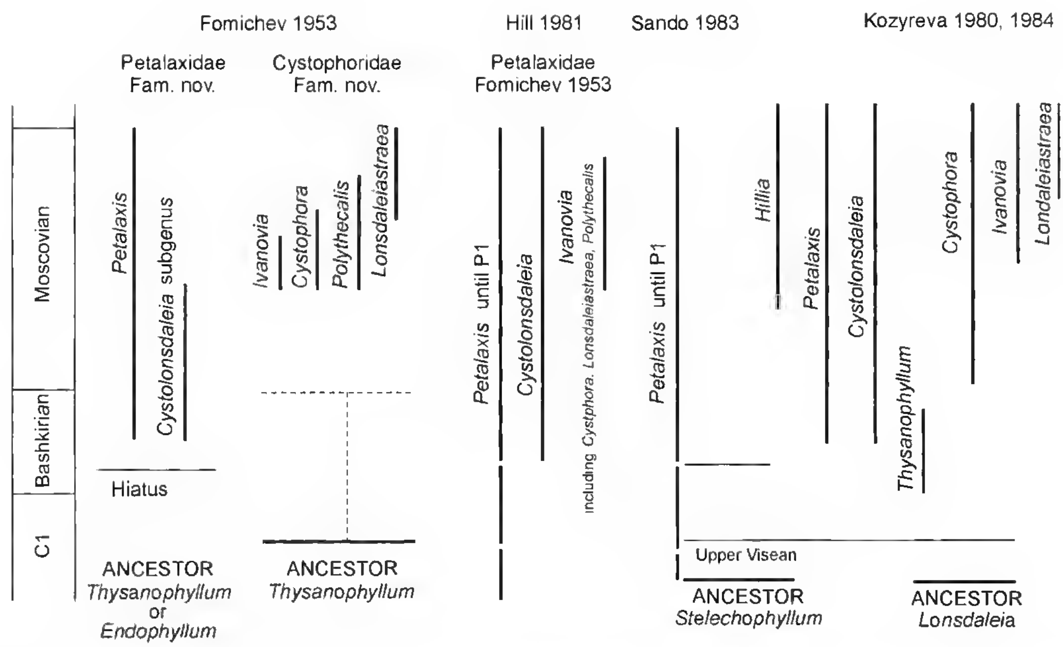

FIG. 4. — Historical review of previous investigations showing stratigraphic range of genera within Petalaxidae. Hiatus in the Petalaxidae distribution embraces Voznesenskian, Syranian and Akavasskian substages (Bashkirian stage). **C1**, Early Carboniferous.

(1983) published a very important revision of *Petalaxis*, where five species groups were distinguished: the *simplex* group, the *flexuosus* group, the *wagneri* group, the *mcoyanus* group, and the *vesiculosus* group. *Stelechophyllum* Tolmachev, 1933 (Lithostrotionidae) was suggested as a possible ancestor. Kozyreva (1984) dealt with the evolutionary aspects of the Petalaxidae, where *Lonsdaleia* Mc Coy, 1849 was suggested as a possible ancestor. The present investigation and supporting phylogenetic reconstruction makes some changes to Hill's (1981) system, but follows a few of the main principles established (Hill 1938; Sando 1983) in general aspect, but in a somewhat modified form:

– comparison of the adult stages of different species;
– investigation of variability within one species;
– use of budding and early stages of development for recognition of the connection between species (genera) based on the recapitulation law;
– comparative analysis of septal microstructure;
– use of different type of stratigraphic data, including event stratigraphy as a framework for a phylogenetic model.

TAXONOMIC DIVERSITY ANALYSIS

The first appearance of species included in *Petalaxis* is suggested from the Late Visean deposits of North America [*P. simplex* (Hayasaka, 1936), Little Flat Formation, Utah] (Bamber 1961; Sando 1983). *P. simplex* is characterized by very short major septa, which are poorly expressed in the early stages of corallite development (Sando 1983, plate 18, fig. 1). The taxonomic diversity analysis of the Petalaxidae shows an interruption of *Petalaxis* lineage and associated genera in the uppermost Serpukhovian-lowermost Bashkirian (Fig. 3). Disappearance at that level affects not only *Petalaxis* species, but numerous taxa of rugose corals and has been described as a minor mass extinction event (Kossovaya

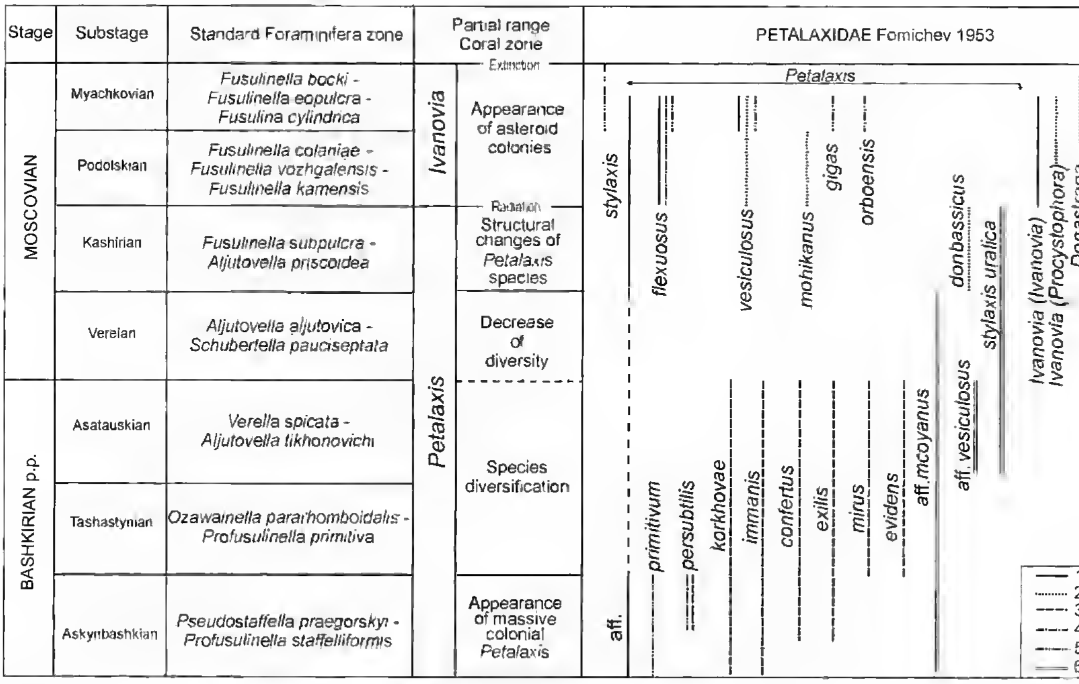

FIG. 5. — Distribution and stratigraphic range of *Petalaxis* and *Ivanovia* species in the Bashkirian and Moscovian deposits of the western part of Russia. **1**, Moscow Basin; **2**, Donets Basin; **3**, Voronezh anticline; **4**, Nova Zemlya; **5**, Northern Timan; **6**, Gornaya Bashkiria. N.B. Early Bashkirian substages omitted (see Fig. 6).

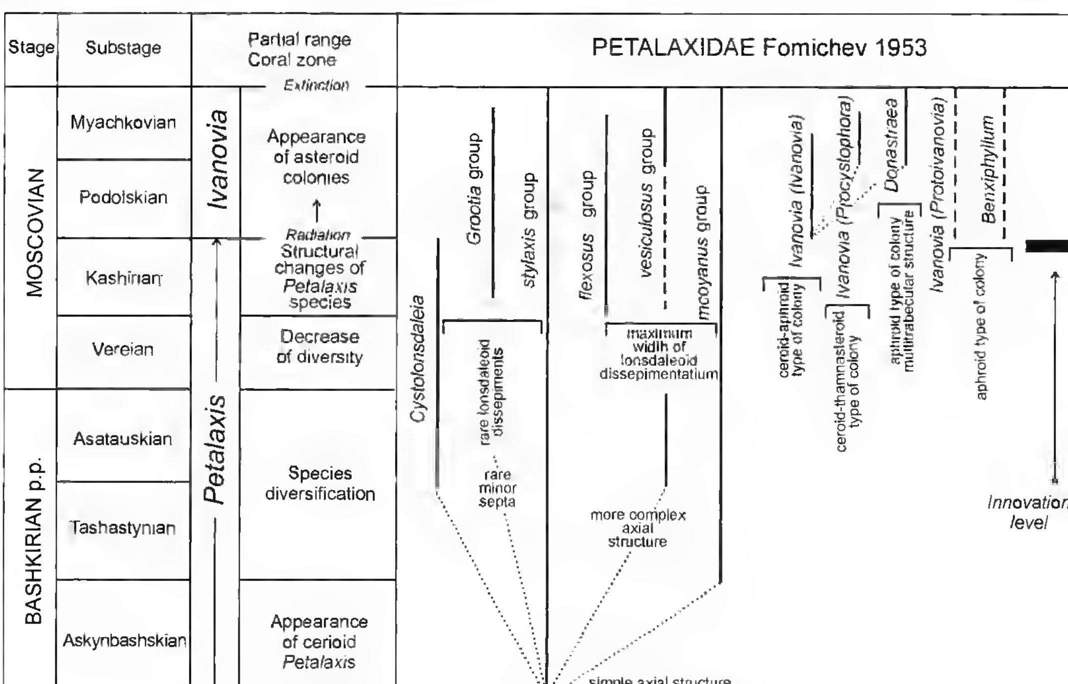

FIG. 6. — Phylogenetic relations between morphogenetic groups within Petalaxidae.

1996). The distribution of the Petalaxidae is restricted by extinction of the most species before the begining of the Kasimovian. Permian representatives of *Petalaxis*, numerous in the Wolfcampian deposits of California (Wilson 1982) are absent from the Kossovaya's collection and everywhere in Russia, and are not considered here. The punctuated character of diversification of the Petalaxidae is expressed by two remarkable hiatuses: one near the mid-Carboniferous boundary and another near the lower Kasimovian boundary (Figs 3, 5). During the uninterrupted sequence within the Bashkirian and Moscovian, a significant decrease in the diversity occurs at the base of the Vereian substage (Fig. 5) coinciding with stabilization of conditions unfavourable for massive corals. The beginning of a short transgression followed by the abrupt change to regression took place during the Vereian in the Moscow Basin (Briand *et al.* 1998). The same diversity pattern is characteristic for coeval deposits of the Urals (Gorsky 1978; Ogar 1984, 1990). A gradual increase in diversity is characteristic for the Kashirian substage. The appearance of *Petalaxis* at the middle of this substage in the Moscow Basin coincides with a transgressive system tract (Studenetz Quarry) (Briand *et al.* 1998). Adaptive radiation and widespread expansion of the Petalaxidae occur in the Podolskian substage and coincides with the appearance of morphological innovation, characterized by a type of colony with a higher degree of integration (aphroid and thamnasterioid colonies of *Ivanovia* and *Donastraea*). In the Moscow Basin, the levels of Petalaxidae radiation and the appearance of astreoid colonies also coincides with a maximum flooding surface (Briand *et al.* 1998). The disappearance of Petalaxidae in the Moscow Basin can be illustrated in Domodedovo quarry where it is correlated with a regression at the base of Peski Formation at the end of the Myachkovian time. Only one species (*stylaxis* group) with maximum morphological simplification has been found near the Moscovian-Kasimovian boundary and may be considered as the last species of long-living lineage of the *Petalaxis* genus.

There are some data on longer duration (Late Carboniferous) of very restricted assemblage of astreoid colonies in the Donets Basin (Fomichev 1953) and China (*I. jiaozuoensis* Peng, Lin *et* Li, 1992).

SYSTEMATICS

Family PETALAXIDAE Fomichev, 1953

Petalaxidae Fomichev, 1953: 449-452. – Hill 1981: F 401. – Sando 1983: 23-40. – Bamber & Fedorowski 1995: 4.

Cystophoridae Fomichev, 1953: 469 (type genus *Cystophora* Yabe *et* Hayasaka, 1916)

TYPE GENUS. — *Petalaxis* Milne-Edwards *et* Haime, 1852.

GENERA INCLUDED. — *Petalaxis* Milne-Edwards *et* Haime, 1852; *Petalaxis* (*Petalaxis*) Milne-Edwards *et* Haime, 1852; *P.* (*Grootia*) X. Yu, 1984; *Cystolonsdaleia* Fomichev, 1953; *Ivanovia* (*Ivanovia*) (Dobrolyubova, 1935); *I.* (*Procystophora*) n.sg.; *I.* (*Protoivanovia*) X. Yu, 1977; *Benxiphyllum* Wu *et* Lin, 1992.

AGE. — Early Carboniferous?, Middle Carboniferous, Early Permian?.

DIAGNOSIS. — Cerioid, cerioid-astreoid, aphroid and thamnasterioid; axial structure represented by lathlike columella conjoined with long cardinal septum, becoming narrow axial column by addition of few, short septal lamellae and axial tabellae. The latter forms the discontinious column wall. Periaxial tabulae subhorizontal or concave or decline abaxially. Some taxa have a very complete axial structure similar in texture to cone in cone. Tabular subhorizontal or slightly con-cave or convex. Dissepimentarium commonly lonsdaleoid. Microstructure from mono- to multitrabecular.

REMARK

The proposed phylogeny model (Fig. 6) is based on the comparative analysis of the following morphological features and estimation of their variability and stability.

Such morphological features are considered to be important: the number of rows of dissepiments, the complexity of the axial structure, the ratio of the width of dissepimentarium to diameter of tabularium, the degree of development of minor septa. This is the basis for distinguishing several main groups within the *Petalaxis* genus showing independent evolution trends of the each lineage.

Some of this group have to be considered as a subgenus after redescription of most of the species.

Discussion

By the Kossovaya's opinion, based on the observation of *Petalaxis* species in the American Museum of Natural History (Washington), the Early Carboniferous species, which had been included in the *Petalaxis* genus by Sando (1983) have to be revised from the point of microstructure. By their morphological macrofeatures, they are more similar to *Stelechophyllum* Tolmachev, 1933 (Sando 1983).

Genus *Petalaxis* Milne-Edwards *et* Haime, 1852

Petalaxis Milne-Edwards *et* Haime, 1852: 205. – Fomichev 1953: 449-452;. – Hill 1981: 401. – Sando 1983: 23-25;

Stylaxis Milne Edwards *et* Haime, 1851: 452 (part.).

Lithostrotionella Yabe *et* Hayasaka, 1916 – Dobrolyuhova 1935: 14.

Lonsdaleia Mc Coy, 1849 – Dobrolyubova 1935: 29.

Type species. — *Petalaxis mcoyana* Milne-Edwards *et* Haime, 1852. Lectotype: sample 1/251, St Petersburg State University, Museum of Historical Geology department (Fedorowski & Gorianov 1973: 58-59, pl. XII, fig. 4, text-fig. 20).

Age and locality. — Middle Carhoniferous, Moscovian stage, Myachkovian horizon, Moscow region, Myachkovo village (Fedorowski & Gorianov 1973).

Diagnosis. — Cerioid colonies; corallites with simple, narrow axial structure of lathlike columella continuous with one or two long protosepta, commonly cardinal one, reinforced by one or two very short septal lamellae and sparse, steep axial tabella next below; other major septa withdraw from axis; dissepimentarium of different width; tabulae subhorizontal; supplemented peripherally by abaxially declined tabellae. *Petalaxis* genus includes four morphogenetic groups of *Petalaxis* (*Petalaxis*): *stylaxis, flexuosus, vesiculosus, mcoyanus* and *Petalaxis* (*Grootia*).

Subgenus *Petalaxis* (*Petalaxis*) Milne-Edwards *et* Haime 1852

Diagnosis. — As for genus, excluding representatives with weak development of lonsdaleioid dissepiment.

Petalaxis (*P.*) *stylaxis* group
(Figs 7, 13C, D, 15A, B, 16A, B; Table 1)

Species included. — *P.* (*P.*) *stylaxis* (Trautschold, 1879), *P.* (*P.*) *primitivum* n.sp., *P. kitakamiensis* (Minato, 1955), *P. penduelensis* (de Groot, 1963).

Age. — Late Bashkirian-Moscovian, Early Kasimovian?.

Diagnosis. — Cerioid colonies with complete intercorallite wall, simple axial structure, composing the thickened end of cardinal septum or conjoined cardinal and counter septa. Dissepimentarium from 1-3 rows of dissepiments, but constant. Minor septa are very short or inconstant. The earliest species, belonging to the *P. stylaxis* group, are characterized either by a very simple axial structure or by conjoined cardinal and counter septa. They became longer in Moscovian species. In their earliest growth stage, the corallites have no dissepiments. Only a few rows of dissepiments are characteristic for the adult stages of the Bashkirian *Petalaxis* (*P.*) *primitivum* n.sp. (Fig. 7G, H). The Myachkovian *Petalaxis* (*P.*) *stylaxis* is characterized by thicker axial structure and by variation in the length of minor septa at maturity (Fig. 7A-F). The trend from reduced minor septa, typical for Bashkirian representatives, to variable minor septa in those of the Moscovian seems to be the evolutionary trend within this group. The most stable features are: (1) the number of dissepiments rows (1-3); (2) a simple axial structure; (3) the ratio of dissepimentarium width to tabularium diameter Wdis/Drab is about 0.2-0.3 (Table 1).

Petalaxis* (*P.*) *primitivum n.sp.
(Figs 7G-I, 16A, B; Table 1)

Holotype. — Collection CNIGR museum, St Petersburg, 801/11, Novaya Zemlya, Northern Island, Cape Makarov, loc. 801, bed 11, Bashkirian stage, Askynhashskian substage.

Material and occurence. — Bashkirian stage, Askynbashskian substage, Novaya Zemlya, Northern Island, Cape Makarov, loc. 801, bed 11, one colony (collecting of Dr. V. P. Matveev).

Etymology. — From primitive (lat.), very simple.

Description

Small cerioid colony with five to six angles corallites. Intercorallite wall is thin. Major septa thin, long and reach two-third of corallite diameter. Diameter of corallite 4-5 mm, rare 7 mm. Number of major septa 15-18. Minor septa

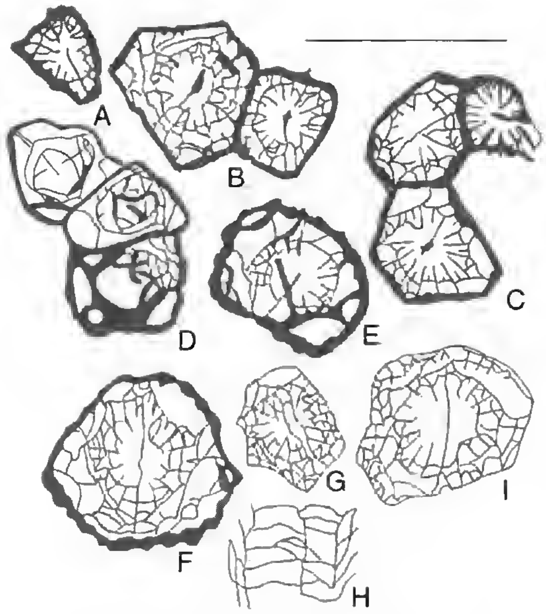

FIG. 7. — *Petalaxis* (*P.*) *stylaxis* group: **A**, **B**, *Petalaxis* (*P.*) *stylaxis* (Trautschold) = *P. stylaxis* var.1, Dobrolyubova, N 17/140 museum PINRAN, Moscow Basin, Moscovian stage, Myachkovian substage; **C**, *Petalaxis* (*P.*) *stylaxis* (Trauschold) = *P. stylaxis* var.2, Dobrolyubova, N 22/140 museum PINRAN, Moscow Basin, Ruza-Ojigova, right bank of Moscow River, down stream from Novaya Ruza, Moscovian stage, Myachkovian substage; **D-F**, *Petalaxis* (*P.*) *stylaxis* (Trautschold), N 32-9-4a/1 CNIGR museum, St Petersburg, Russia, Northern Timan, Sula River section, loc. 32, bed 9, Moscovian stage, Myachkovian substage; **G-I**, *Petalaxis* (*P.*) *primitivum* Kossovaya n.sp., Novlaya Zemlya, Northern Island, Cape Markarov, N 801/1, bed 9, collecting by Dr V. Matveev, Bashkirian stage, Askynbashskian substage. Scale bar: 1 cm.

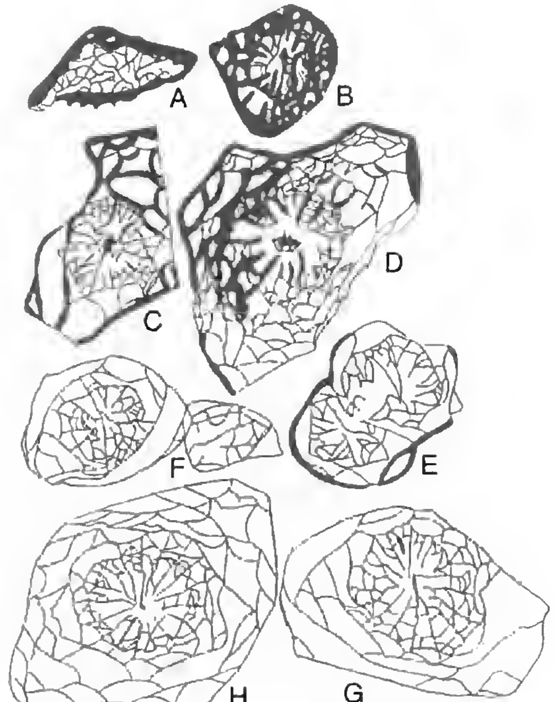

FIG. 8. — *Petalaxis* (*P.*) *vesiculosus* group: **A-D**, *Petalaxis* (*P.*) *vesiculosus* (Dobrolyubova), N 27/140 museum PINRAN, Moscow Basin, Ruza-Ojigova, right bank of Moscow River, down stream from Novaya Ruza, loc. XXVI, bed 3, Moscovian Stage, Myachkovian substage; **E-H**, *Petalaxis* (*P.*) *gigas* Kossovaya n.sp., N 32-9-3a/3 CNIGR museum, St Petersburg, Russia, Northern Timan, Sula River section, loc. 32, bed 9, Moscovian stage, Myachkovian substage. Scale bar: 1 cm.

poorly developed, short and in some corallites they are absent. Thin interrupted column consists of conjoined axial parts of cardinal and counter septa or separated medial plate. Dissepimentarium consists of two or three ranks of interseptal dissepiments and few lonsdaleoid dissepiments. The latter do not form a constant ring. Dissepimentarium is separated from tabularium by thin inner wall. The width of dissepimentarium is 1.0 mm. Tabulae are flat, or slightly concave or convex. Microstructure is of monotrabecular type. Diameter of tabularium 4-4.5 mm. Wdis/Dtab 0.2-0.25.

DISCUSSION

This species differs from *P. stylaxis* by less development of lonsdaleoid dissepiments and more numerous major septa; from *P. kitakamiensis* by rare occurence of lonsdaleoid dissepiments (Fontaine 1991); from *P. penduelensis* by constant and thicker column.

Petalaxis (*P.*) *vesiculosus* group (Figs 8, 9, 10B, C, 13A, B, F, G, 14C-E; Table 2)

SPECIES INCLUDED. — *P.* (*P.*) *vesiculosus* (Dobrolyubova, 1935), *P.* (*P.*) *belinskiensis* Fomichev, 1953, *P.* (*P.*) *lisitschanskensis* Fomichev, 1953, *P.* (*P.*) *gigas* n.sp., *P.* (*P.*) *mohikanus* Fomichev, 1953, *P.* (*P.*) *exilis* Kozyreva, 1974, *P.* (*P.*) *korkhovae* Kozyreva, 1974, *P.* (*P.*) *persubtilis* Kozyreva, 1974, *P.* (*P.*) *confertus* (Kozyreva, 1974), *P.* (*P.*) *mirus* (Kozyreva, 1974), *P.* (*P.*) *evidens* (Kozyreva, 1974).

TABLE 1. — *Petalaxis* (*P.*) *stylaxis* group. **D**, diameter of corallite (mm); **Wdis**, dissepimentarium width (mm); **Dtab**, diameter of tabularium (mm); **S1**, major septa; **S2**, development of minor septa; **DR**, the number of rows of lonsdaleoid dissepiments; **Wdis/Dtab**, the ratio of dissepimentarium width to tabularium diameter; **r**, reduced; **pd**, poorly developed; **d**, developed. The measurements of *P* (*P.*) *stylaxis* are based on Dobrolyubova (1935) and Kossovaya's collection and of *P.* (*P.*) *primitivum* is based on the holotype.

	D (mm)	Wdis (mm)	Dtab (mm)	S1	S2	DR	Wdis/Dtab
stylaxis	6-8	1	3-4	13-16	pd	1-2	0.25
primitivum	5	1	4-4.5	17-18	r	2-3	0.2-0.25
kitakamiensis	5-6	1.1	4	16-20	r	1-2	0.27

TABLE 2. — *Petalaxis* (*P.*) *vesiculosus* group (see legend Table 1).

	D (mm)	Wdis (mm)	Dtab (mm)	S1	S2	DR	Wdis/Dtab
vesiculosus	6-12	4.0	3-3.5	10-14	d	2-3	1.3
belinskiensis	7-9	4.0	4.0	17-19	d	2-3	1.0
lisitschanskensis	12-15	7.0	6.0	18-21	d	3	1.2
gigas	11-16	5	5	19-21	d	2-4	1
mohikanus	6-8	2	1	13-18	d	2-4	1.7
exilis	8-9	3	2.5	10-14	r	3-5	1.2
korkhovae	9-15	3.5	2.5	16-18	r	2-4	1.4
persubtilis	9-15	6.0	2.5	15-17	pd	2-4	1
confertus	8-12	2	2	15-17	pd	2-4	1
mirus	7-15	2-3	2	16-18	r	1-2	1-1.5
evidens	13-15	2-2.5	2	19-20	pd	1-2	1-1.7

TABLE 3. — *Petalaxis* (*Grootia*) group (see legend Table 1).

	D (mm)	Wdis (mm)	Dtab (mm)	S1	S2	DR	Wdis/Dtab
ivanovi	6-6.5	0.5	2	13-14	d	0-1	0-0.25
yosti	5-8	2	4.6	18-22	d	0-4	0.4
perapertuensis	5-7	0-1	2.3	17	d	0-1	0-0.4
radians	7-8	–	5	17	d	0	0
santaemariae	5	–	2	19	d	0	0
cantabrica	6-7	0-1	3	23	d	1-2	0.3
wahooensis	5	1.3	3	24	d	1-2	0.4

TABLE 4. — *Petalaxis* (*P.*) *gigas* n.sp. (see legend Table 1).

Sample number	D (mm)	Wdis (mm)	Dtab (mm)	S1	S2	DR	Wdis/Dtab
32-9-4/2	14	3.5	3	20	d	2-3	1
32-9-4/2	14	3	4	21	d	2-3	0.7
32-9-4/2	12.5	3.5	3	20	d	3-4	1.7
20-109a-3/1	11	5	5	19	d	3-4	1
20-109a-3/1	16	5	6	19	d	2-3	0.8

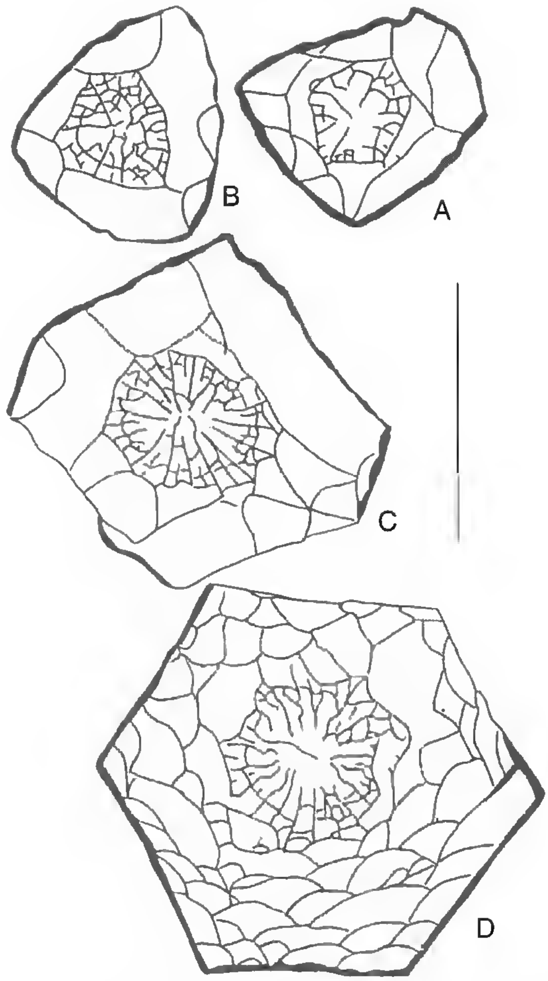

FIG. 9. — *Petalaxis* (*P.*) *vesiculosus* group: **A-D**, *Petalaxis* (*P.*) *gigas* Kossovaya n.sp., N 32-9-4a/2 CNIGR museum, St Petersburg, Russia, Northern Timan, Sula River section, loc. 32, bed 9, Moscovian stage, Myachkovian substage. Scale bar: 1 cm.

DIAGNOSIS. — This group evolved towards the stabilization of minor septa and the widening of the dissepimentarium, which reached a maximum width in Myachkovian time. The most stable features are: (1) a well-developed lonsdaleoid dissepimentarium; (2) the ratio of the dissepimentarium width to the tabularium diameter is equal to one or more. The structure of the axial part is the most changeable feature of representatives of this group. The septal lamellae occur frequently. For species included in *Petalaxis* (*P.*) *vesiculosus* Group, Wdis/Dtab is about 1-1.7. The representatives of this group which are characterized by maximum width of dissepimentarium are most widespread in the middle and upper parts of the Myachkovian substage, where they are stratigraphically important.

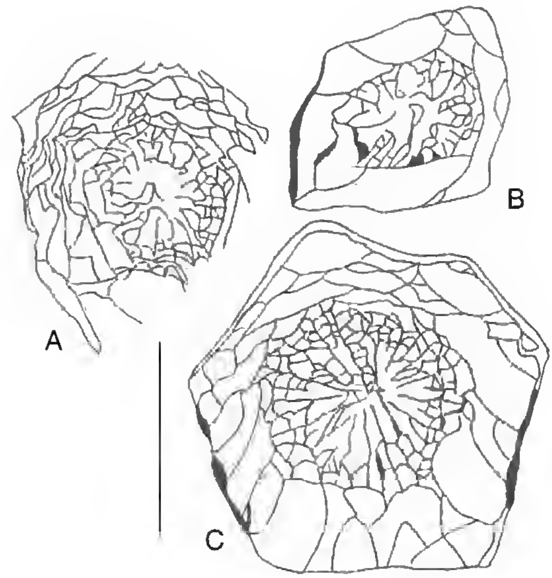

FIG. 10. — **A**, *Petalaxis* (*P.*) *flexuosus* group: *Petalaxis* (*P.*) *orboensis* de Groot, N 32-9-3a/1 CNIGR museum, St Petersburg, Russia, Northern Timan, Sula River section, loc. 32, bed 9, Moscovian stage, Myachkovian substage; **B**, **C**, *Petalaxis* (*P.*) *vesiculosus* group: *Petalaxis* (*P.*) *gigas* Kossovaya n.sp., N 20-109a-3/1 CNIGR museum, St Petersburg, Russia, Northern Timan, Malaya Pokayama section, Volonga River, loc. 20, bed 109a, Moscovian stage, Myachkovian substage, holotype. Scale bar: 1 cm.

Petalaxis (*P.*) *gigas* n.sp.
(Figs 8E-H, 9A-D, 10B, C, 13F, G, 14C, D; Table 3)

HOLOTYPE. — Collection CNIGR museum, St Petersburg, N 20-109a-3/1, Volonga River, Malaya Pokayama section, Sula Formation, Moscovian stage, Myachkovian substage, *Ivanovia* partial range zone, *Petalaxis vesiculosus* species zone.

MATERIAL AND OCCURENCE. — Moscovian stage, Myachkovian substage, Northern Timan, Sula Formation, Myachkovian substage, Volonga River (Malaya Pokayama section), CNIGR museum, St Petersburg, loc. 20, bed 109, two colonies, two transverse and two longitudinal sections Sula River, Sula River section, loc. 32, bed 9.

ETYMOLOGY. — From "gigas" (lat.), enormous.

DESCRIPTION

Cerioid colonies with maximum size 1.0-1.7 m. Corallite 5-6 angle shape. Intercorallite wall thick, sometime waved. Major septa long, nearly

TABLE 5. — *Petalaxis* (*P.*) *flexuosus* group (see legend Table 1).

	D (mm)	Wdis (mm)	Dtab (mm)	S1	S2	DR	Wdis/Dtab
flexuosus	5-7	2	3-4	14-17	d	1	0.6
major	7-9	1.5-2	1.7-2.0	17-22	d	2-3	0.8-1.0
orboensis	6-8	1.7-3.5	3.5-4	17-19	d	1-3	0.5-0.8

TABLE 6. — *Petalaxis* (*P.*) *mcoyanus* group (see legend Table 1).

	D (mm)	Wdis (mm)	Dtab (mm)	S1	S2	DR	Wdis/Dtab
wagneri	4	0-1	2-3.5	14-16	pd	1-2	0.3
mcoyanus	5.4-7.8	0.5-1.0	1.5-1.7	16	pd	1	0.3
donbassicus	5-7	1.0	1.5	14-17	d	1-2	0.6
grootae	4-6	0.7	1.6	14-16	d	1-3	0.4
sexangulus	3-4	1.0	2.5-3	13-15	r	0-1	0.4
intermedius	5-6	1-1.2	2	16-19	r	4	0.6

reach the axis of corallite. Number of major septa-19-21. Minor septum egual à half of major septum. Column thin, constructed from the inner part of the cardinal septum. Cardinal septum short in the poorly distinguished fossula in some corallites. In longitudinal section (Fig. 13C) there are two septal lamellae parallel to the axial lamella of column. Internal wall separates tabularium and dissepimentarium. Tabulae subhorizontal. Dissepimentarium consists of three to four rows of large, convex dissepiments. Microstructure is of monotrabecular type. There are some differences in dimentions of corallites from different localities.

DISCUSSION

New species differs from *P. vesiculosus* by larger diameter of corallites and wider ring of dissepiments.

Petalaxis (*P.*) *flexuosus* group
(Figs 10A, 11, 13E, 14A, B; Table 4)

SPECIES INCLUDED. — *P. flexuosus* (Trautschold, 1879), *P. major* (de Groot, 1963), *P. orboensis* (de Groot, 1963).

DIAGNOSIS. — The nominal species of this group shows a more complex axial structure and a narrow ring of dissepiments. Axial structure consists of the axial lamellae, few irregular radial lamellaes. Peripheral parts of septa can continue into dissepimentarium. The most constant morphological characteristics in corals of this group are a complex axial structure and a narrow dissepimentarium consisting of small dissepiments developed in mature stages. For species included in *Petalaxis* (*P.*) *flexuosus* group Wdis/Dtab is about 0.7-1.

Petalaxis (*P.*) *mcoyanus* group
(Table 5)

SPECIES INCLUDED. — *P.* (*P.*) *wagneri* (de Groot, 1963), *P.* (*P.*) *mcoyanus* (Milne-Edwards *et* Haime, 1852), *P.* (*P.*) *donbassicus* Fomichev, 1953, *P.* (*P.*) *grootae* Sando, 1983, *P.* (*P.*) *sexangulus* (de Groot, 1963), *P.* (*P.*) *intermedius* (de Groot, 1963).

DIAGNOSIS. — This group occupies a position intermediate between the *P. stylaxis* group and *P. flexuosus* group and is characterized by a more complex axial structure, than the former and by a narrower dissepimentarium, than that found in representatives of the *P.* (*P.*) *flexuosus* group. For species included in *Petalaxis* (*P.*) *mcoyanus* group Wdis/Dtab is about 0.3-0.7.

Petalaxis (*Grootia*) group
(Figs 12A, 14F; Table 6)

SPECIES INCLUDED. — *Petalaxis* (*Grootia*) *ivanovi* (Dobrolybova, 1935), *P.* (*G.*) *parapertuensis* (de Groot, 1963), *P.* (*G.*) *radians* (de Groot, 1963), *P.* (*G.*) *santaemariae* (de Groot, 1963), *P.* (*G.*) *cantabricus* (de Groot, 1963), *P.* (*G.*) *wahooensis* Armstrong, 1972, *P.* (*G.*) *yosti* Stevens, 1995.

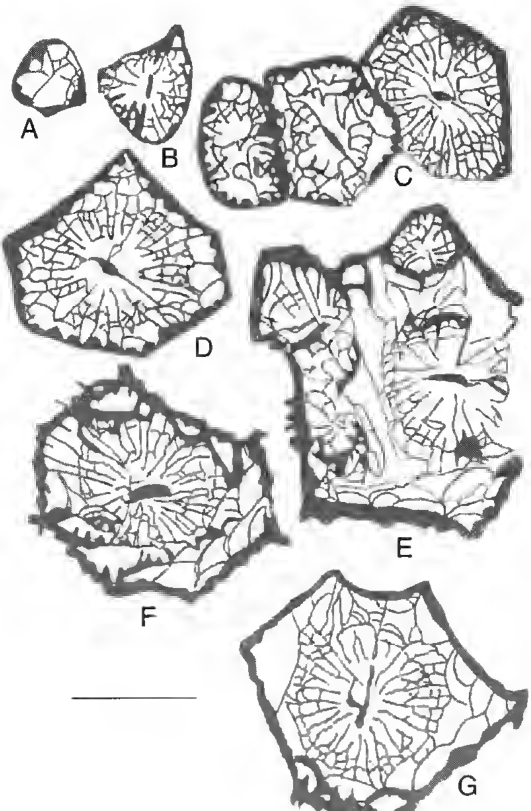

FIG. 11. — *Petalaxis* (*P.*) *flexuosus* group: **A-D**, *Petalaxis* (*P.*) *flexuosus* (Trautschold) N 24/140 museum PINRAN, Moscow Basin, Moscovian stage, Myachkovian substage; **E**, **F**, *Petalaxis* (*P.*) *flexuosus* (Trautschold), N 5-6-1 CNIGR museum, St Petersburg, Russia, Northern Timan, Belaya River section, loc. 5, bed 6, Moscovian stage, Myachkovian substage; **G**, *Petalaxis* (*P.*) *flexuosus* (Trautschold), N 5-5-2 CNIGR museum, St Petersburg, Russia, Northern Timan, Belaya River section, loc. 5, bed 5, Moscovian stage, Myachkovian substage. Scale bar: 0.5 cm.

DIAGNOSIS. — This group embraces species characterized by the absence or weak development of lonsdaleoid dissepiments and had been primerally determined as *Hillia* n.g. by de Groot (1963). This name was preoccupied (see Sando 1983). Sando considered this group as a special group within the *Petalaxis* genus. The genus was renamed as *Grootia* by Yu (1977). Most of the species of this group are known from the Bashkirian and Moscovian deposits of the Cantabrian Mountains (de Groot 1964). Only one species [*P.* (*Grootia*) *ivanovi*] from the Moscow Basin can be included and it is characterized by an absent or very weak development of a lonsdaleoid dissepimentarium. Species included in *Petalaxis* (*Grootia*) group are characterized by Wdis/Dtab 0-0.4

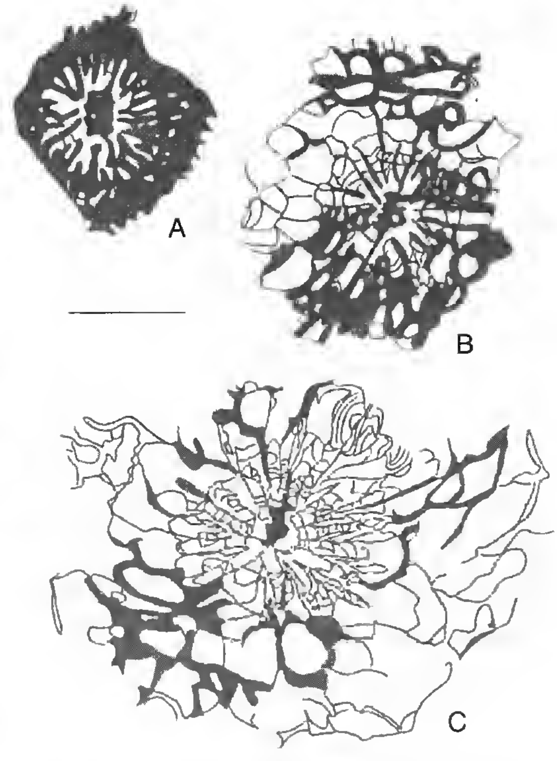

FIG. 12. — *Petalaxis* (*Grootia*) group: **A**. *Petalaxis* (*Grootia*) *ivanovi* (Dobrolyubova). N 88/140 (holotype) museum PINRAN, Moscow Basin. Prolopopovo quarries in the vicinity of Kolomna, Moscovian stage, Myachkovian substage; **B**. *Ivanovia* (*Ivanovia*) *podolskiensis* (Dobrolyubova). N 106/140 (holotype), museum PINRAN Moscow Basin, Schurovo, Moscovian stage, Myachkovian substage; **C**. *Donastraea bulla* (Dobrolyubova) N 68/140 (holotype) museum PINRAN, Moscow Basin, Podolsk, Moscovian stage, Myachkovian substage. Scale bar: 0,5 cm.

Genus *Cystolonsdaleia* Fomichev, 1953

DIAGNOSIS. — As *in* Fomichev (1953) and Hill (1981). Astreoid colonies of Petalaxidae family. The main morphological features that have been used as a basis for taxonomical revision of the astreoid colonies of Petalaxidae are: the type of colony, the differences in the axial structure of corallites and the development of minor septa.

Genus *Ivanovia* Dobrolyubova, 1935

Ivanovia Dobrolyubova, 1935: 35. – Hill 1981: F403 (partly). – Fomichev 1953: 477. – Wu & Lin 1992: 105, 106.

Cystophora – Dobrolyubova 1935: 20. – Fomichev 1953: 407.

Subgenus *Ivanovia* (*Ivanovia*) (Dobrolyubova, 1935) (Figs 12B, 15C, D, 16C, D)

Type species. — *Ivanovia podolskiensis* Dobrolyubova, 1935 (Figs 12B, 16C, D). Holotype: sample 106/140 Museum of Palaeontological Institute of Russian Academy of Science, Moscow (Dobrolyubova 1935: 35-36, plate XII, figs 1-2).

Age and localities. — Moscovian stage, Podolskian and Myachkovian substages of Moscow Basin, Donets Basin, Kashirian? Podolskian substages of Spain. Moscovian stage of China.

Specied included. — *I.* (*I.*) *podolskiensis* Dobrolyubova, 1935, *I.* (*I.*) *freieslebeni* (Fischer, 1830), *I.* (*I.*) *expansa* Dobrolyubova, 1935, *I.* (*I.*) *sparsa* (Fomichev, 1953), *I.* (*I.*) *cystiseptata* (Fomichev, 1953), *I.* (*I.*) *nadeini* (Fomichev, 1953), *I.* (*I.*) *aster* Fomichev, 1953, *I.* (*I.*) *? pogrebitskyi* Fomichev, 1953, *I.* (*I.*) *occidentalis* Fomichev, 1953) (= *Polythecalis occidentalis* Fomichev, 1953), *I.* (*I.*) *intermedia* Wu *et* Lin, 1992, *I.* (*I.*) *mirabilis* Wu *et* Lin, 1992.

Diagnosis. — Aphroid colony with some traces of walls; major septa long, but few reaching columella, dilated in tabularium; minor septa present or not; septa discontinious in dissepimentarium; axial structure compact, consists of thickned part of the counter septum or thickened median plate; sometime axial structure is very simple: periaxial tabellae slightly inclined. Septal microsrructure of monotrabecular type (Fig. 15E, F).

Subgenus *Ivanovia* (*Protoivanovia*) X. Yu, 1977

Type species. — *Protoivanovia regularis* X. Yu, 1977.

Species included. — *Ivanovia* (*Protoivanovia*) *regularis* X. Yu 1977, *I.* (*P.*) *ditulathecata* Wu *et* Lin, 1992, *I.* (*P.*) *mayicunensis* Wu *et* Lin, 1992, *I.* (*P.*) *shanchengziensis* Wu *et* Lin, 1992, *I.* (*P.*) *shanchengziensis pluriseptata* Wu *et* Lin, 1992.

Ivanovia (*Procystophora*) Kossovaya n.sg. (Fig. 16E, F)

Type species. — *Cystophora densivesiculosa* Dobrolyubova 1935, plate VII, figs 3-4. Holotype: collection of the Museum of Palaeontological Institute of Russian Academy of Science, Moscow, N140, thin sections 188-190.

Species included. — *Ivanovia* (*Procystophora*) *densivesiculosa* (Dobrolyubova, 1935) [= *Cystophora densivesiculosa* Dobrolyubova, 1935] (Fig. 16E, F), *I.* (*P.*) sp. 1 [= *I. freieslebeni* (Stuckenberg, 1888) *in* Dobrolyubova 1935, plate IV, figs 1, 2)

Age and localities. — Middle Carboniferous, Moscovian stage, Myachkovian substage, right bank of Moscow River, near Sonino village.

Diagnosis. — Cerioid-thamnasterioid colonies with or without traces of walls: major septa rather long, minor septa of inconstant lenght present; axial structure compact, comprising thickened median plate and sometimes few short lamellae with few axial tabellae arranged in cones; periaxial tabulae sagging, some peripheral clinotabellae. Microstructure of septa-multitrabecular.

Donastraea n.g. (Figs 15F, 16G, H, 12C)

Lonsdaleiastraea Fomichev, 1953: 498 (partly).

Cystophora – Dobrolyubova 1935: 27 (partly).

Type species. — *Lonsdaleiastraea cystiseptata* Fomichev, 1953. Holotype: CNIGR museum, coll. 122/5030, (Fomichev 1953, plate XLI, fig. 2) (Fig. 16G, H).

Species included. — *Donastraea cystiseptata* (Fomichev, 1953) [=*Lonsdaleiastraea cystiseptata* Fomichev, 1953] (Fig. 16G, H), *D. yakovlevi* (Fomichev, 1953) [=*Polythecalis yakovlevi* Fomichev, 1953], *D. bella* (Dobrolyubova ,1935) [=*Cystophora bella* Dobrolyubova, 1935] (Fig. 15F).

Age and locality. — Moscovian stage, Myachkovian substage-the base of the Kasimovian? stage, Donets Basin, limestone O1, to the east from Rjazantsev village.

Etymology. — Derivation of name from Don River.

Diagnosis. — Aphroid colonies with axial structure from simple median plate to compound structure of regular shape with numerous radial lamella, sometime forming the structure cone-in-cone, inner series of tabellae sagging. Dissepimentarium wide, consisting of the horizontal rows of dissepiments. Naotic dissepiments and septal carinae may be presenr. Microstructure of multitrabecular type.

Genus *Benxiphyllum* Wu *et* Lin, 1992.

Cystophora Yabe *et* Hayasaka, 1916: 76. – Yabe & Sugiyama 1944: 74, pl. 3, figs 1-4.

Type species. — *Cystophora manchurica* Yabe *et* Hayasaka, 1916: 70; Yabe & Sugiyama 1944: 74, pl. 3, figs 1-3.

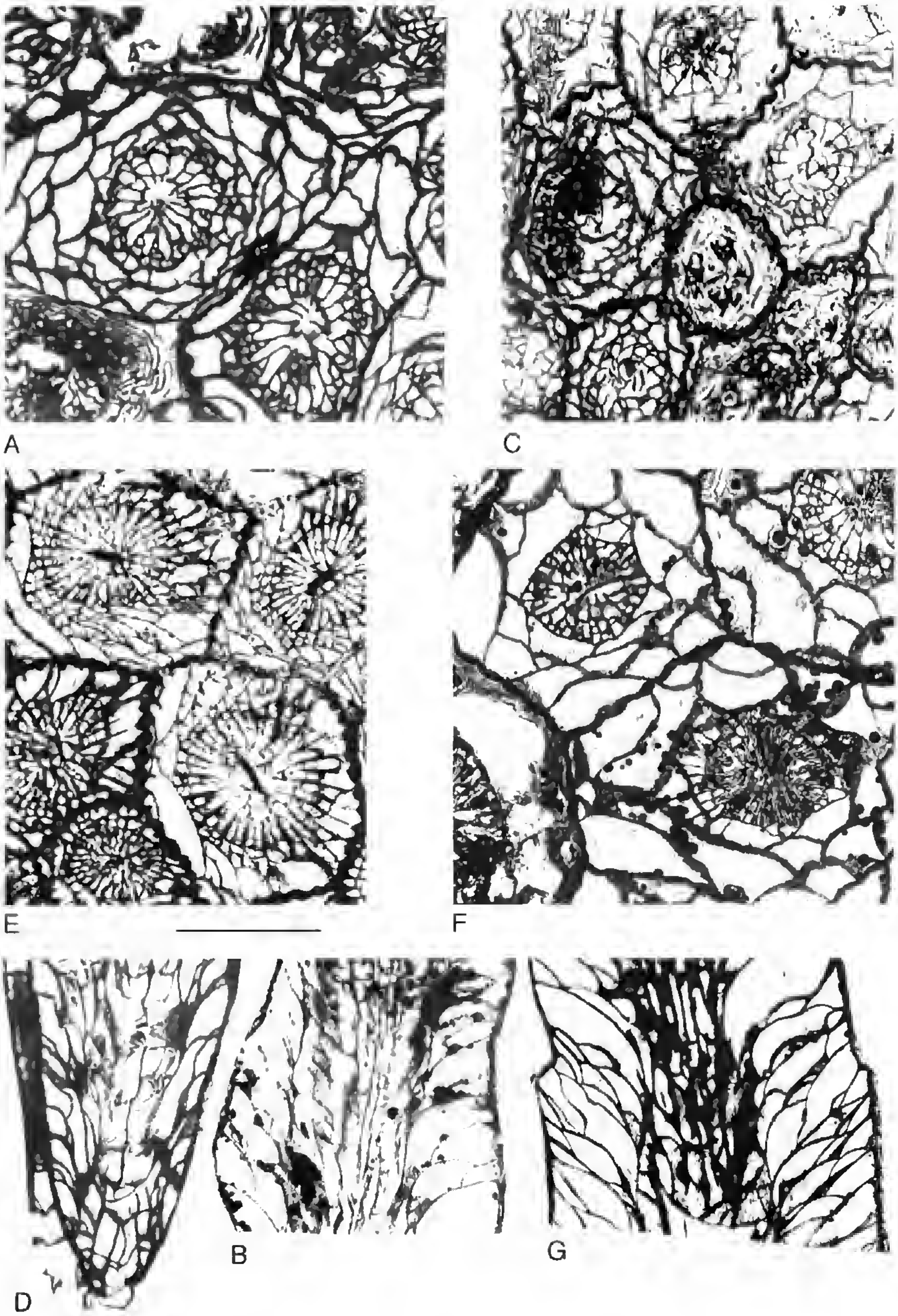

FIG. 13. — **A**, **B**, *Petalaxis* (*P.*) *vesiculosus* (Dobrolyubova), N 32-9-3a/3 CNIGR museum, Northern Timan, Sula River section. loc. 32, bed 9, Sula Formation, Myachkovian substage, (A) transverse section, (B) longitudinal section; **C**, **D**, *Petalaxis* (*P.*) *stylaxis* (Trautschold), N 32 -9-4a/1 CNIGR museum, Northern Timan, Sula River section. loc. 32 , bed 9, Sula Formation, Myachkovian substage, (C) transverse section, (D) longitudinal section; **E**, *Petalaxis* (*P.*) *flexuosus* (Trautschold), N 5-6-1 CNIGR museum, Northern Timan, Belaya River section, loc. 5 , bed 9, Sula Formation, Myachkovian substage; **F**, **G**, *Petalaxis* (*P.*) *gigas* Kossovaya n.sp., N 32-9-4a/2, Northern Timan, Sula River section. loc. 32 , bed 9, Sula Formation, Myachkovian substage, (F) transverse section, (G) longitudinal section. Scale bar: 0.5 cm.

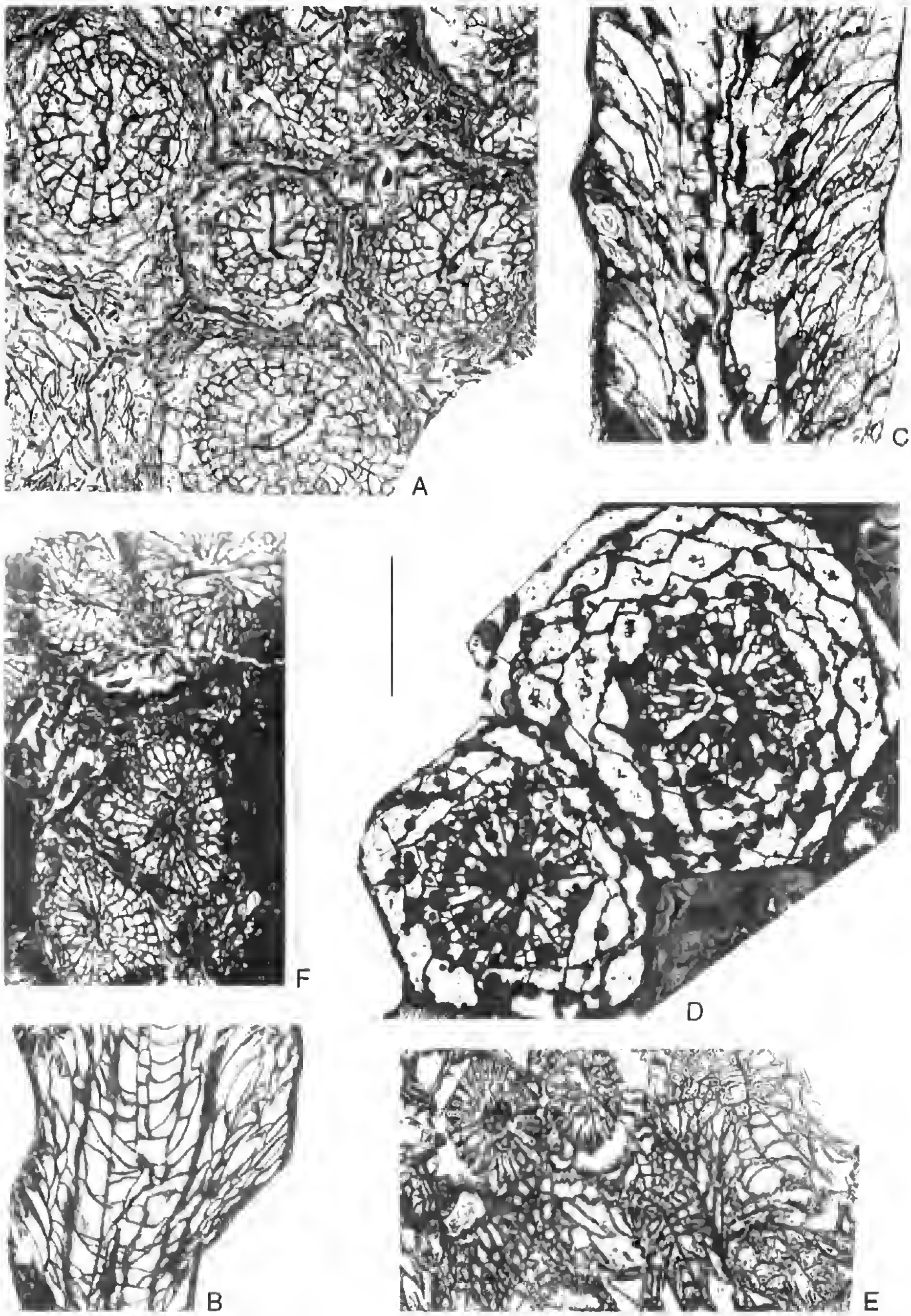

FIG. 14. — **A**, **B**, *Petalaxis* (*P.*) *orboensis* (de Groot), N 32-7-3/1 CNIGR museum, Northern Timan, Sula River section, loc. 32, bed 7, Sula Formation, Myachkovian substage, (A) transverse section, (B) longitudinal section; **C**, **D**, *Petalaxis* (*P.*) *gigas* Kossovaya n.sp., N 20-109a-3/1 CNIGR museum, Northern Timan, Malaya Pokayama section, loc. 20, bed 109, Sula Formation, Myachkovian substage, (C) transverse section, (D) longitudinal section; **E**, *Petalaxis* (*P.*) *persubtilis* Kozyreva, N 31-9-1/4 CNIGR museum, Northern Timan, Sula River section, loc. 31, bed 9, Askynbashskian substage; **F**, *Petalaxis* (*P.*) *intermedius* (de Groot), N 32-7-3/3, Northern Timan, Sula River section, loc. 32, bed 9, Sula Formation, Myachkovian substage. Scale bar: 0.5 cm.

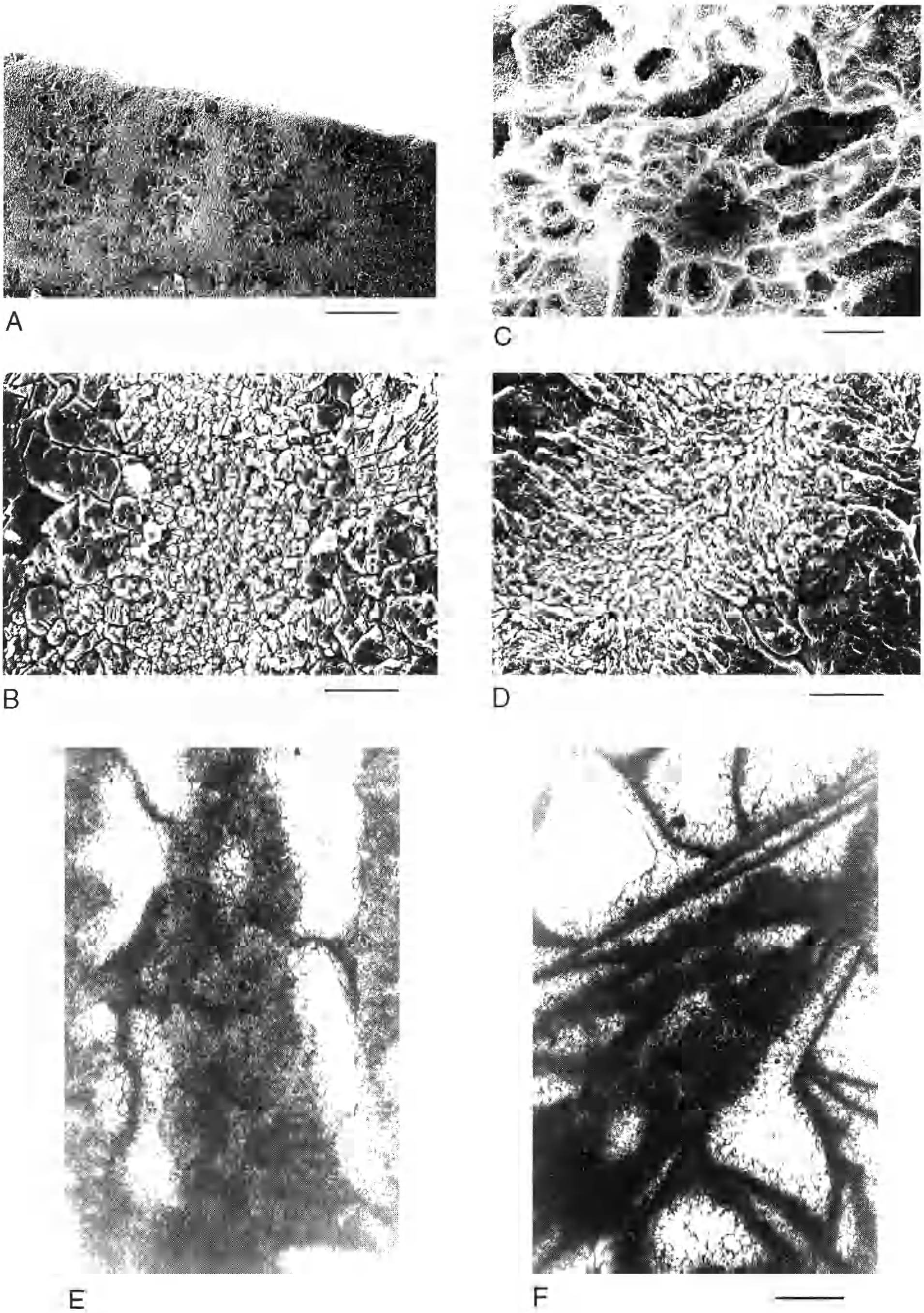

FIG. 15. — **A**, **B**, *Petalaxis* (*P.*) *stylaxis* (Trautschold), N 32-9-4a/1, Northern Timan, Sula River section, loc. 32, bed 9, Sula Formation, Myachkovian substage, (A) transverse section of corallite, (B) transverse section of septum (SEM); **C**, **D**, *Ivanovia podolskiensis* Dobrolyubova, P-15-1a CNIGR museum, Moscow region, Podolsk quarry, bed 15, Podolskian substage, (C) transverse section of corallite, (D) transverse section of septum; **E**, *Cystophorastraea moelli* (Stuckenberg), N 10/140 museum PINRAN, Moscow, Moscow Basin, Myachkovian substage; **F**, *Procystophora bella* (Dobrolybova), N 140 museum PINRAN, Moscow Basin, Myachkovian substage. Scale bars: A, 200 µm; B, D, 20 µm; C, 600 µm; E, F, 140 µm.

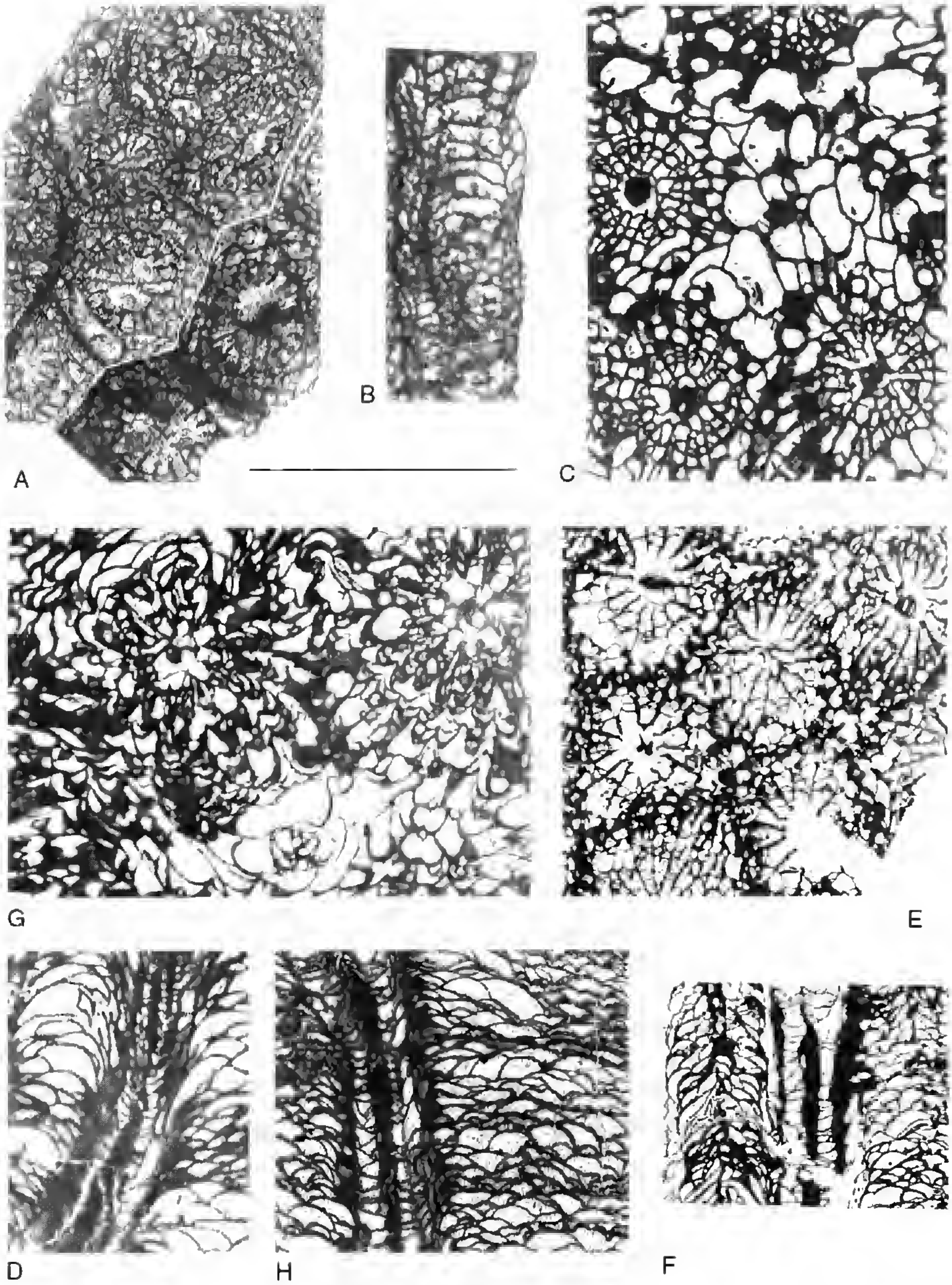

FIG. 16. — **A**, **B**, *Petalaxis* (*P.*) *primitivum* Kossovaya n.sp. CNIGR museum, St Petersburg, N 801-11, Novaya Zemlya, Northern Island, Makarov Cape, loc. 801, bed 11, Bashkirian stage, Askynbashskian substage (collecting of Dr V. P. Matveev), (A) transverse section, (B) longitudinal section; **C**, **D**, *Ivanovia* (*Ivanovia*) *podolskiensis* Dobrolyubova PINRAN, coll. 140, N 106/140, Moscow Basin, Myachkovian substage, Schurovo village, (C) transverse section, (D) longitudinal section; **E**, **F**, *Ivanovia* (*Procystophora*) *densivesiculosa* (Dobrolyubova), PINRAN (Dobrolyubova, 1935), coll. 140, N 65/140, holotype, Moscow Basin, Myachkovian substage, near Sonino village, (E) transverse section, (F) longitudinal section; **G**, **H**, *Donastraea cystiseptata* (Fomichev), CNIGR museum (Fomichev 1953), coll. 5030, holotype N 436/503. Donets Basin, limestone O1, to east from Rjazantsev village, (G) transverse section, (H) longitudinal section. Scale bar: 1 cm.

SPECIES INCLUDED. — *Benxiphyllum manchurica* (Yabe *et* Hayasaka, 1916); *B. bacilliforme* Wu *et* Lin, 1992; *B. temcolumnarum* Wu *et* Lin. 1992; *B. brachyseptatum* Wu *et* Lin, 1992; *B. ellipticum* Wu *et* Lin, 1992.

AGE. — The upper part of the Late Carboniferous (Moscovian stage).

DIAGNOSIS. — Corallum compound, cystose-aphroid, wall occasionally appeared. Septa of two order, distinctly thickened, with large almond-shape columella (Amygdalophylloid) in transverse section, in which there is a texture of middle and radial lines. Tabulae inclined towards the inner, lateral tabellae developed.

PHYLOGENY

Evolution of Petalaxidae could be subdivided into main phases within the uppermost lower Bashkirian to the end of the Moscovian. The appearance of the first representatives of *Petalaxis* seems to be the result of colonization of numerous niches in stabilized environments. The stepwise increase in diversity was interrupted by the unfavorable conditions at the end of Bashkirian in which only a few species survived in the basins.

The beginning of the radiation phase of Petalaxidae family coinsides with the maximum diversity level of the other groups of rugose corals (Kossovaya 1996). The structural changes of massive Petalaxidae have resulted in the increase in the degree of integration (Fig. 6). Microstructural changes are displaied by gradual change in the type of microstructure, from monotrabecular (typical for most species of *Petalaxis*) to inconstant multitrabecular [characteristic for *Donastraea* (Figs 11C, 15F)] and gradual stabilization of the multitrabecular structure in *Donastraea*.

Phyletic evolution has resulted in the following skeletal expression in *Petalaxis-Ivanovia* (*Ivanovia*) lineage: (1) simplification of the inner structure of the earliest species with locally interrupted wall; (2) increase in the width of the dissepimentarium as a connecting structure between corallites.

The gradual change is characteristical for change in the type of colony from cerioid-aphroid to thamnasterioid in the *Ivanovia* (*Ivanovia*)-*Ivanovia* (*Procystophora*) lineage. The completness of inner structure and stabilization of multitrabecular structure seems to be the main evolution tendency in the *Ivanovia* (*Ivanovia*)-*Donastraea* lineage.

CONCLUSIONS

The evolution history of Petalaxidae from the origination of cerioid *Petalaxis stylaxis* with simple inner structures (Fig. 6), followed by rather rapid expansion and morphological diversification both in *Petalaxis* and related groups resulting in morphological innovation, could be subdivided into two phases.

The first phase, recovery of long duration, is characterized by stabilization of several *Petalaxis* lineages, shown here as morphogenetic groups. Stabilization of minor septa occured within different groups of *Petalaxis* after a short period of ecological depression at the beginning of the Moscovian. Then, the flourish of Petalaxidae was established within the Podolskian-Myachkovian interval (Fig. 6). The second phase of adaptive radiation with increase both in the generic and specific diversity is characterized by morphological innovation expressed in the increase in degree of the integration in colonies. After the origination of aphroid *Ivanovia* (*Ivanovia*) with simple axial structure a few trends are displaied with the appearance of thamnasterioid type of colony *Ivanovia* (*Procystophora*) n.sg. and aphroid colonies with gradually complicated axial structures (*Donastraea* n.g.).

The paleogeographical realm of the *Petalaxis* species are very wide; it embraces all the margin shelf of Tethyan paleoocean, including both the Peri-tethyan basins surrounding the Euroamerican paleocontinent and numerous epicontinental basin of eastern part of Tethyan. Species of *Ivanovia* lineage have a more narrow realm. They were widespread both in eastern and southern margin shelf basins of Euroamerican palaeocontinent and east-northern margin basins of Tethyan ocean. At the same time representatives with most complete axial structure of *Donastraea* and *Benxiphyllum* lineages occur in the southern margin basins of Angarian and Euroamerican paleocontinents.

It seems possible to consider *Lytvophyllum* Dobrolyubova, 1941 as an ancestor of the Petalaxidae because of the similarity of the budding of the earliest *Petalaxis* (*P. stylaxis* group). Mature stages of fasciculate *Lytvophyllum* species characterized by very high variability are widespread in the recovery assemblage after the Mid-Carboniferous event (Kossovaya 1996).

ADDENDUM. — After the drawing up of this article, an important work on Petalaxidae family was published by Bamber & Fedorowski (1998). Unfortunatly, the material from that publication are not taken in account in the present paper.

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La bordure est du Bassin précaspien et le bassin d'avant-pays de l'Oural (Kazakhstan) au Carbonifère et Permien inférieur

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RÉSUMÉ

Des corrélations stratigraphiques sont proposées à partir de données micropaléontologiques (fusulines), de données géophysiques (sismique réflexion et diagraphies) et de données sédimentologiques. La bordure est du Bassin précaspien est constituée au Carbonifère d'une plate-forme carbonatée et d'un bassin à turbidites entrecoupé d'un horst à l'ouest et au Permien inférieur d'un bassin à turbidites entrecoupé d'un horst. Le Bassin préouralien situé plus à l'est est le lieu d'une sédimentation turbiditique pendant le Carbonifère et le Permien inférieur. Un déplacement des dépôts-centres du Bassin préouralien vers le Bassin précaspien est observé du Carbonifère au Permien en même temps que les nappes se déplacent vers l'ouest.

MOTS CLÉS
Péri-Téthys,
stratigraphie,
sédimentologie,
Carbonifère,
Permien,
Bassin précaspien,
Bassin préouralien,
Kazakhstan.

ABSTRACT

The eastern border of the Precaspian Basin and the foreland Ural Basin (Kazakhstan) during the Carboniferous and lower Permian. Stratigraphic correlations are proposed after micropaleontology (fusulinids), sismic reflexions, well-logging and sedimentology. The eastern border of the Precaspian Basin exhibits during the Carboniferous, an eastern carbonated platform and a western turbiditic basin interrupted by a horst and, during the lower Permian a turbiditic basin interrupted by a horst. The Preuralian Basin located eastwards shows a turbiditic basin during the Carboniferous and the lower Permian. A shifting of the depocenters is observed from the Preuralian Basin to the Precaspian Basin between the Carboniferous and the lower Permian during the western progress of the nappe structures.

KEY WORDS
Peri-Tethys,
stratigraphy,
sedimentology,
Carboniferous,
Permian,
Precaspian Basin,
Preuralian Basin,
Kazakhstan.

INTRODUCTION

La région étudiée est située au sud d'Aktubinsk (Figs 1, 2) sur la bordure orientale du bassin précaspien dans la région pétrolifère de Janajol. Ce bassin montre au Carbonifère une dépression centrale entourée de plate-formes carbonatées riches en pétrole et en gaz à Karachaganak au nord, Astrakhan et Tengiz au sud et Janajol à l'est. Elle présente de l'est vers l'ouest (Fig. 3) : la nappe de l'Oural, le bassin d'avant-pays ouralien formé des nappes de Sakmare et de Zilair, et de l'autochtone ou sillon préouralien et la bordure est du Bassin précaspien (Yanchin 1962 ; Garetskyi *et al.* 1963 ; Abdulin 1973 ; Milnitshuk *et al.* 1988 ; Joltaev 1990). La nappe de l'Oural présente des ophiolites du Paléozoïque inférieur et moyen. La nappe de Sakmare montre des roches volcaniques et sédimentaires détritiques ou calcaires du Cambrien à l'Assélien ; la nappe de Zilair des roches détritiques du Dévonien supérieur et Carbonifère inférieur ; l'autochtone préouralien des roches sédimentaires détritiques turbiditiques ou calcaires du Moscovien *pp* au Sakmarien. La bordure est du Bassin précaspien (Fig. 1) est composée de deux parties du Dévonien moyen au Carbonifère supérieur : une plate-forme marine à l'est et un bassin entrecoupé d'un horst à l'ouest. La plate-forme marine montre sur un socle précambrien des roches sédimentaires calcaires ou détritiques. Le bassin présente des turbidites sur la pente et des argilites dans le bassin. À partir de l'Assélien et jusqu'à la fin de l'Artinskien, toute la bordure du Bassin précaspien est occupée par les turbidites sur la pente et les argilites dans le bassin, puis au Kungurien, par les évaporites. Cette publication concerne essentiellement la bordure orientale du Bassin précaspien et apporte des arguments sédimentologiques, stratigraphiques et tectoniques quant à l'existence de faciès de bassin dès le Carbonifère dans la région centrale de ce bassin.

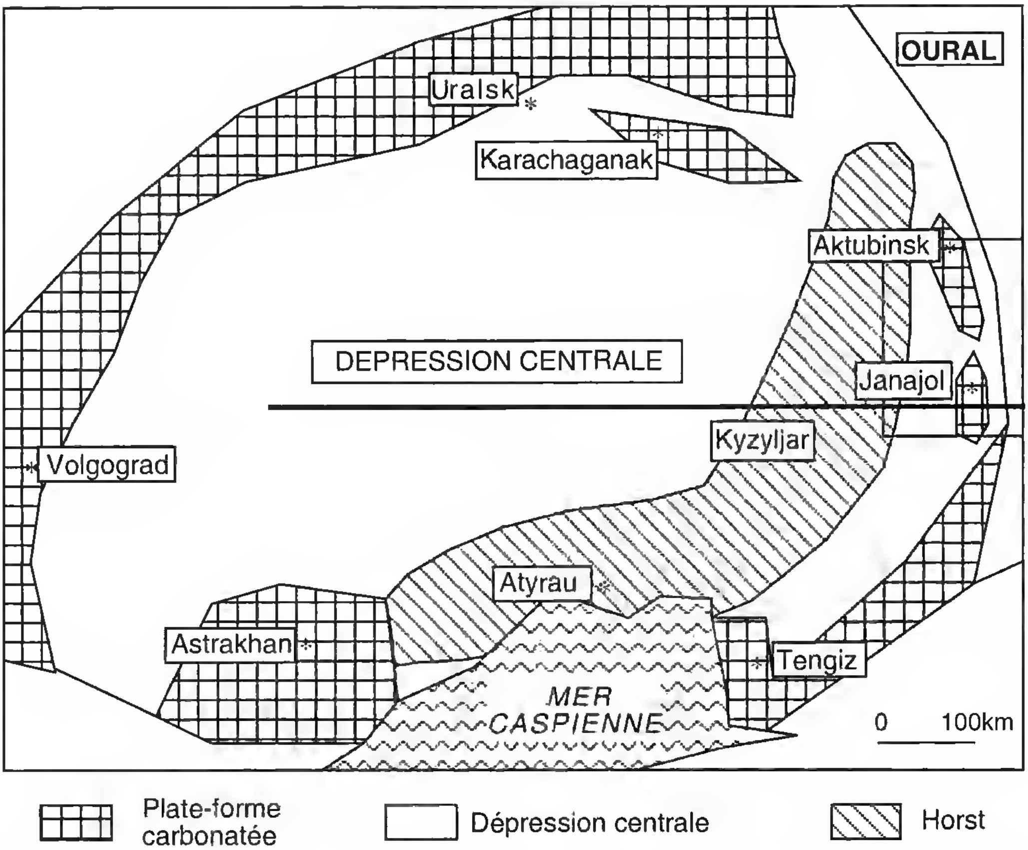


Fig. 1 — Carte du Bassin précaspien montrant la paléogéographie au Carbonifère. La région étudiée (Fig. 2) est représentée par un rectangle et la coupe de la figure 8 par un trait épais.

STRATIGRAPHIE

La bordure est du Bassin précaspien

Cette bordure a été étudiée récemment par Joltaev (1989, 1992) et Ensepbaev (1990, 1993). La région de Janajol a été choisie pour représenter la plate-forme carbonatée du Dévonien et du Carbonifère se transformant en bassin turbiditique au Permien inférieur (Figs 4-6). Des études lithologiques, micropaléontologiques et stratigraphiques y ont été faites par Khvorova (1961), Boulekbaev *et al.* (1967), Scherbovitsh (1969), Kukhtinov *et al.* (1981), Akhmetchina *et al.* (1982, 1984), Kukhtinov (1983), Ghibchman (1988). Des groupes lithologiques composés de formations locales y ont été définis en utilisant la nomenclature stratigraphique internationale (Salvador 1994). Ces groupes ont pu être suivis sur les profils géophysiques (Fig. 6). Les biozones de fusulines et de conodontes définies dans l'Oural russe (Kagarmanov & Donakova 1990) ne sont pas toutes reconnues au Kazakhstan. Seules quelques espèces ont pu être observées (Fig. 5). Les étages ont été définis par comparaison avec l'Oural russe (Sinytsin *et al.* 1975).

La bordure est du Bassin précaspien peut être subdivisée en une plate-forme sur laquelle ont été définis six groupes lithostratigraphiques du Dévonien à la base du Kungurien et en un bassin où quatre groupes lithostratigraphiques existent (Fig. 4).

La plate-forme montre partout les mêmes unités lithologiques à épaisseur grande à Alibek à l'est, moyenne à Janajol au centre et faible à Kojassai P1 à l'ouest (Figs 4, 6). Ce secteur montre le groupe carbonaté (D2-D3) du Dévonien moyen

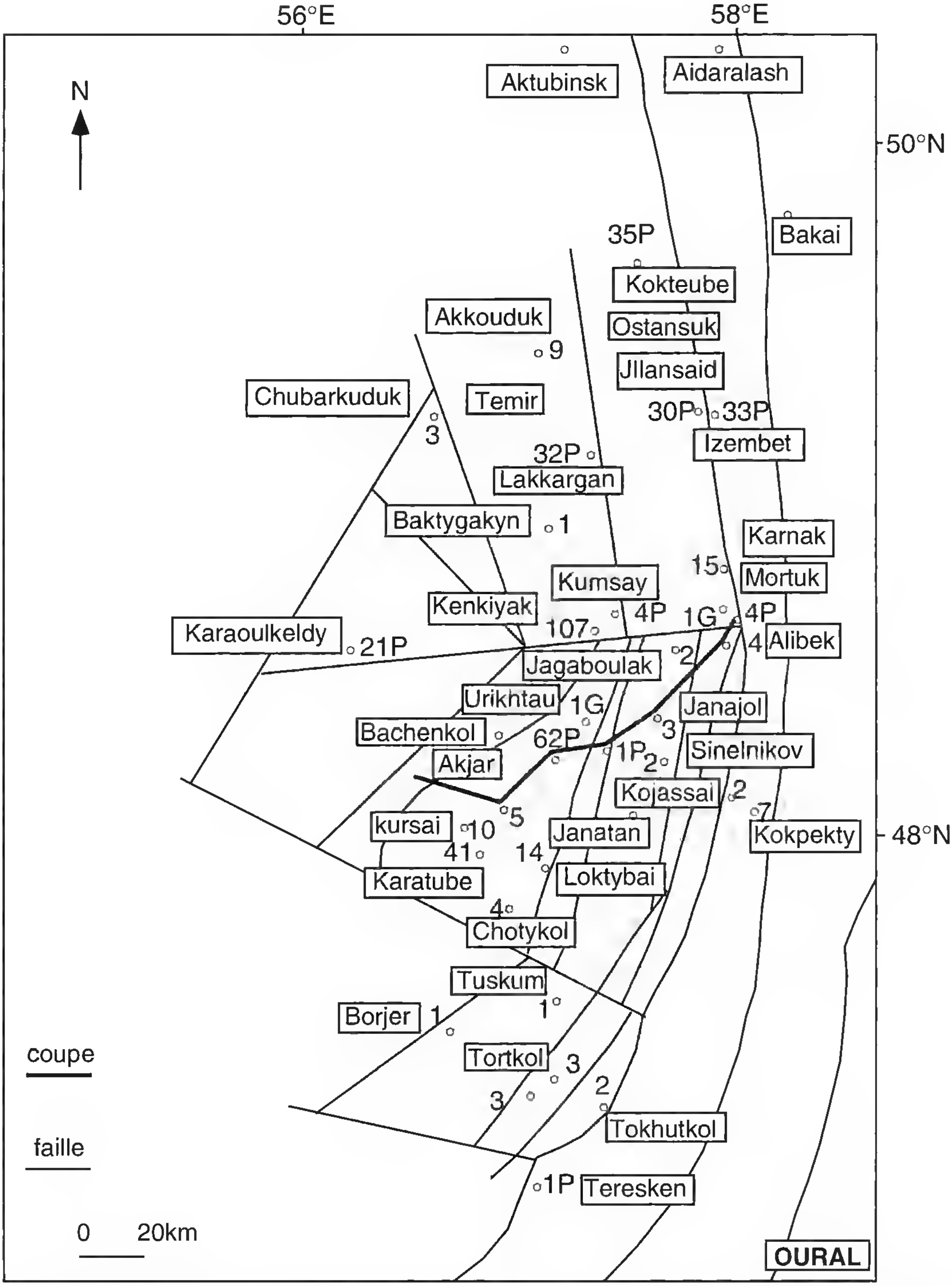


FIG. 2. — Carte de l'est du Bassin précaspien et du Bassin préouralien (Kazakhstan) avec situation des forages et des failles. Le trait épais représente le trait de la coupe (Figs 3, 5).

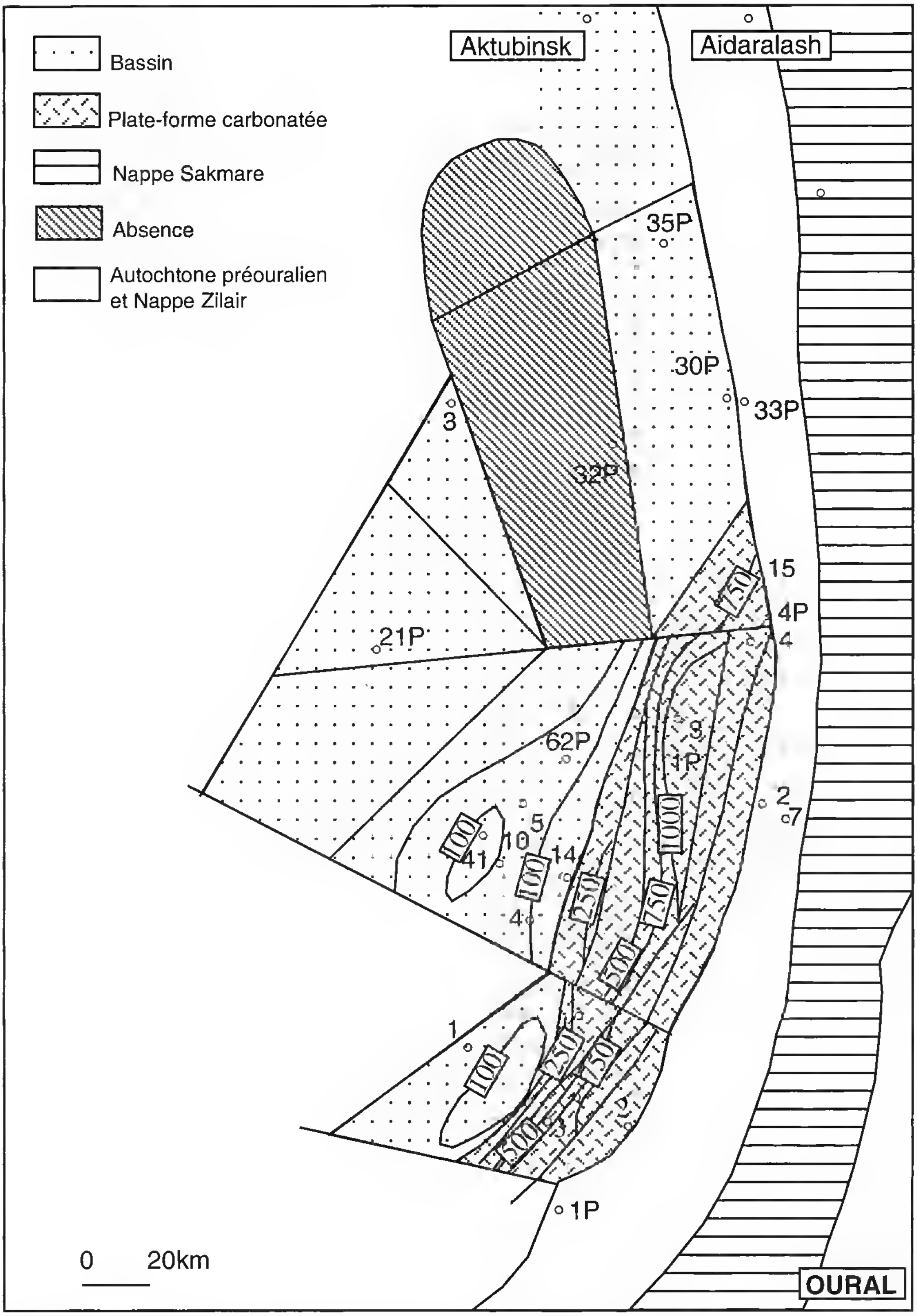


FIG. 3. — Carte paléogéographique de la partie est du Bassin précaspien et du Bassin préouralien au Carbonifère supérieur. Les courbes isopaques représentent l'épaisseur du Carbonifère supérieur (Moscovien, Kasimovien et Gzhélien).

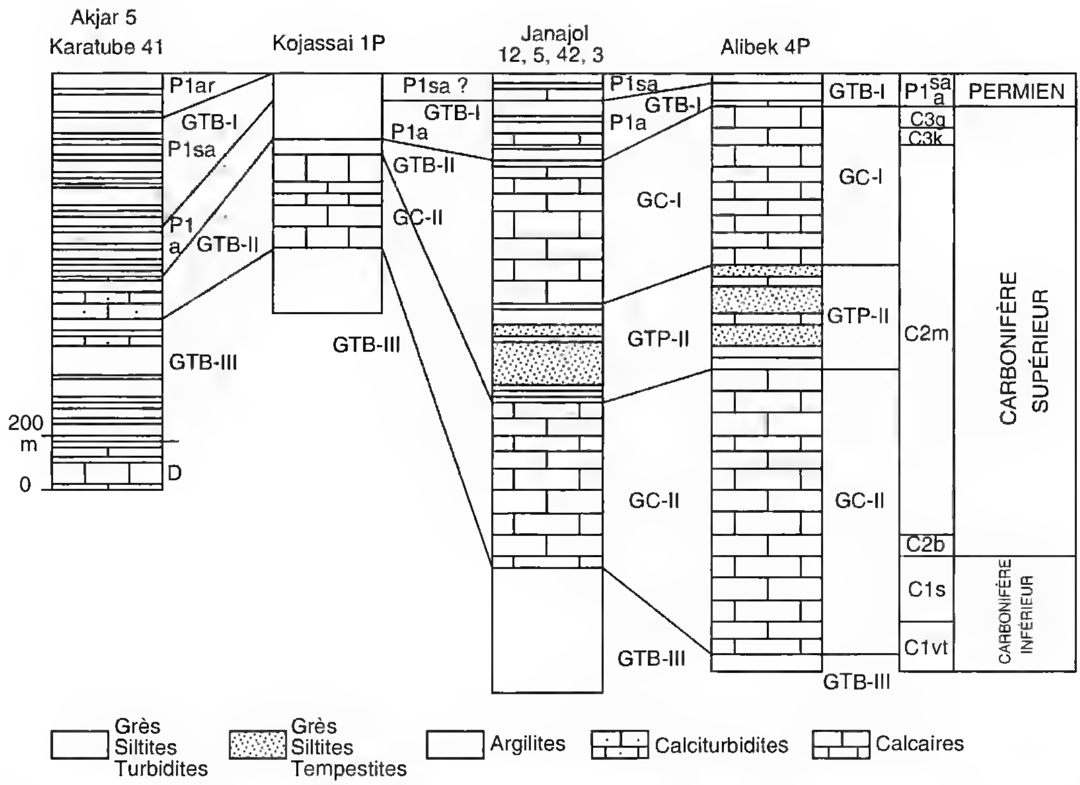


FIG. 4. — Corrélations des forages de l'est du Bassin précaspien. **GTP**, groupe terrigène de plate-forme ; **GTB**, groupe terrigène de bassin ; **GC**, groupe carbonaté de plate-forme ; **D**, Dévonien moyen et supérieur ; **C1vt**, Tournaisien-Viséen ; **C1s**, Serpukhovien ; **C2b**, Bashkirien ; **C2m**, Moscovien, **C3k**, Kasimovien ; **C3g**, Gzhélien ; **P1a**, Assélien ; **P1sa**, Sakmarien ; **P1ar**, Artinskien

(Givétien) et supérieur (Frasnien), le groupe terrigène du Tournaisien, Viséen inférieur et moyen (GTB-III), le groupe carbonaté (GC-II) du Viséen supérieur, Serpukhovien, Bashkirien et Moscovien (Véreien, Kashirien), le groupe détritique intermédiaire (GTP-II) d'âge podolskien inférieur, le groupe carbonaté (GC-I) d'âges podolskien supérieur, myachkovien, kasimovien et gzhélien, le groupe détritique (GTB-I) à turbidites gréseuses et silteuses, et argilites d'âges assélien, sakmarien et artinskien, le groupe évaporitique du Kungurien. Les étages proposés ci-dessus ont été définis par l'analyse biostratigraphique. Les descriptions qui suivent ont été réalisées par Vachard. À Janajol 45G (NE Janajol, 3716-3744 m), un calcaire grainstone a été daté du Bashkirien inférieur par *Pseudostaffella* ex gr. *antiqua*, *Semistaffella* ex gr. *variabilis*. À Uriktau 1G (2855-2862 m), un calcaire grainstone a été daté du Moscovien supérieur par *Fusulinella pseudobocki*, *Fusiella typica*, *Ozawainella mosquensis*, *Syzrania bella*, *Schubertella* ex gr. *obscura*. À Uriktau 2G (S Uriktau 1G, 3367-3390 m), un calcaire grainstone a été daté du Moscovien supérieur par *Fusulinella bocki*, *Schubertella* sp., *Profusulinella* sp. Les études antérieures ont mis en évidence les biozones à *Montiparus montiparus* et *Triticites arcticus* du Kasimovien, les biozones à *Triticites stukenbergi*, *Jigulites jigulensis*, *Daixina sokensis* du Gzhélien, les biozones à *Sphaeroshwagerina fusiformis*, *Sphaeroschwagerina moelleri* de l'Assélien, à *Schwagerina moelleri* du Sakmarien.

Il n'existe pas de datation sur des fossiles autochtones dans le bassin, seuls les bioclastes remaniés par les coulées de débris et les turbidites ont pu être datés. Ces datations réalisées par Vachard seront signalées dans la partie sédimentologique. La corrélation a été réalisée en suivant les réflecteurs géophysiques et les données de forage à

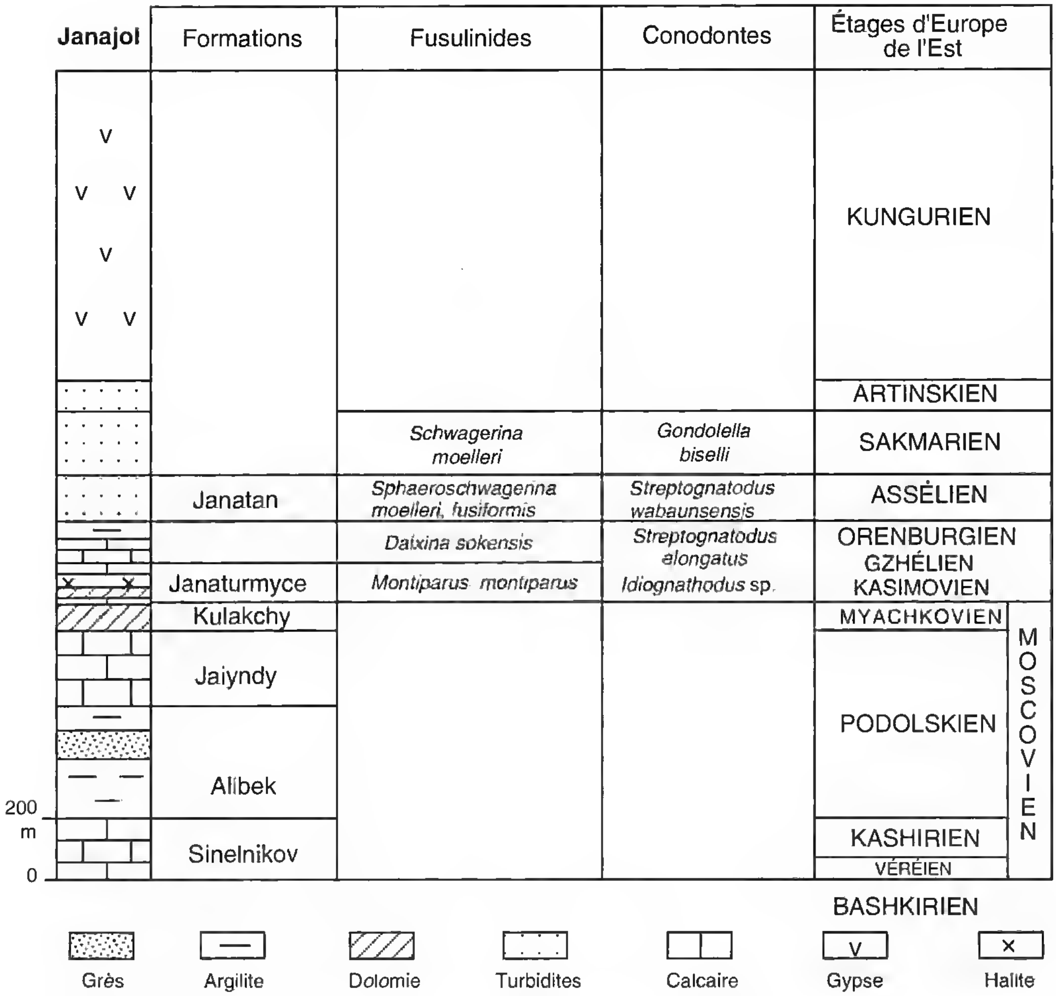


FIG. 5. — Stratigraphie du Carbonifère supérieur et du Permien inférieur de l'est du Bassin précaspien.

Loktybai 34 (près de Loktybai 14), Akjar 5, Akjar-Kenkyiak 62P et Karatube 41. La sismographie permet de définir un groupe d'âge dévonien (D), un groupe turbiditique (GTB-III) d'âge carbonifère inférieur, un groupe turbiditique calcaire (GTB-II) allant du Viséen supérieur au Gzhélien, un groupe turbiditique (GTB-I) d'âges assélien, sakmarien et artinskien, un groupe évaporitique d'âge kungurien.

Le bassin d'avant-pays de l'Oural.
Ce bassin comprend un domaine autochtone appelé sillon préouralien et un domaine allochtone constitué de deux nappes, les nappes de Zilair et de Sakmare. Les limites de ces deux nappes (Figs 3, 7) étant les limites tectoniques actuelles, le domaine de sédimentation au Carbonifère et Permien correspondant à ces deux nappes était plus large que celui indiqué sur ces cartes et s'étendait plus vers l'est. Le sillon préouralien présente au nord à Aidailarash (Khvorova 1961 ; Davydov *et al.* 1993, 1997) et au sud à Kokpekty (Garetskyi 1962 ; Garetskyi *et al.* 1963) des turbidites du Moscovien *pp* à l'Assélien. La nappe de Zilair montre des roches détritiques du Dévonien supérieur et du Carbonifère inférieur. La nappe de Sakmare présente des roches détritiques et volcaniques du Cambrien au

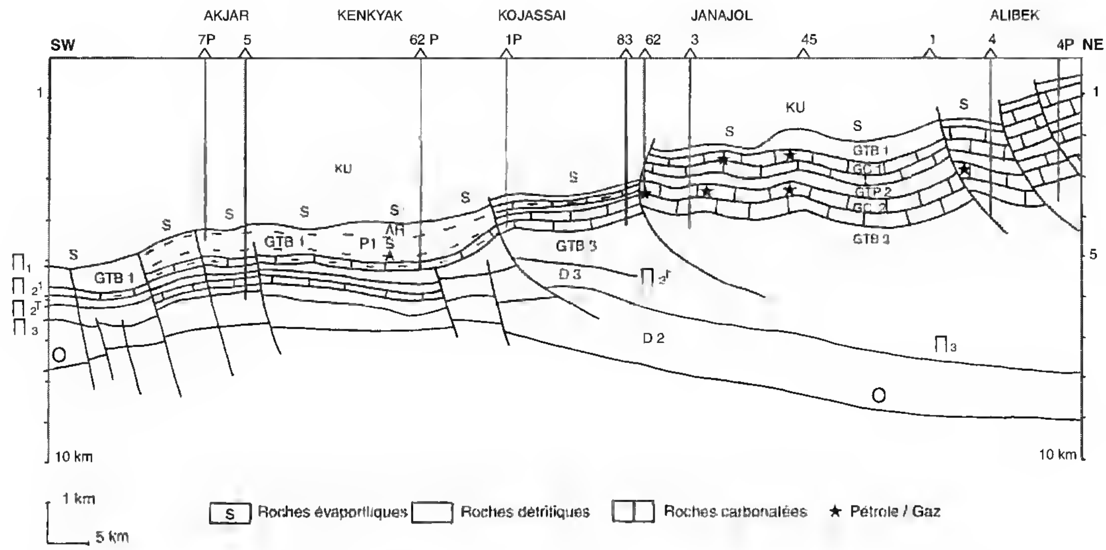


FIG. 6. — Coupe de la partie est du Bassin précaspien d'après les forages et profils sismiques. **GTP**, groupe terrigène de plate-forme ; **GTB**, groupe terrigène de bassin ; **GC**, groupe carbonaté de plate-forme ; **D2**, Dévonien moyen ; **D3**, Dévonien supérieur ; **P1A**, Assélien ; **P1SA**, Sakmarien ; **P1AR**, Artinskien ; **KU**, Kungurien à Quaternaire. Réflecteurs sismiques : Φ, base de la couverture paléozoïque ; П3, base du Dévonien supérieur D3 ; П2-T, base du Carbonifère inférieur ; П2-1, base du Viséen supérieur ; П1, base du Kungurien.

Tournaisien et dans le synclinal Bakai des roches détritiques et calcaires du Viséen, Serpukhovien, Moscovien discordantes sur le Serpukhovien, des roches détritiques et calcaires du Kasimovien et Gzhélien, des roches détritiques de l'Assélien.

SÉDIMENTOLOGIE ET PALÉOGÉOGRAPHIE

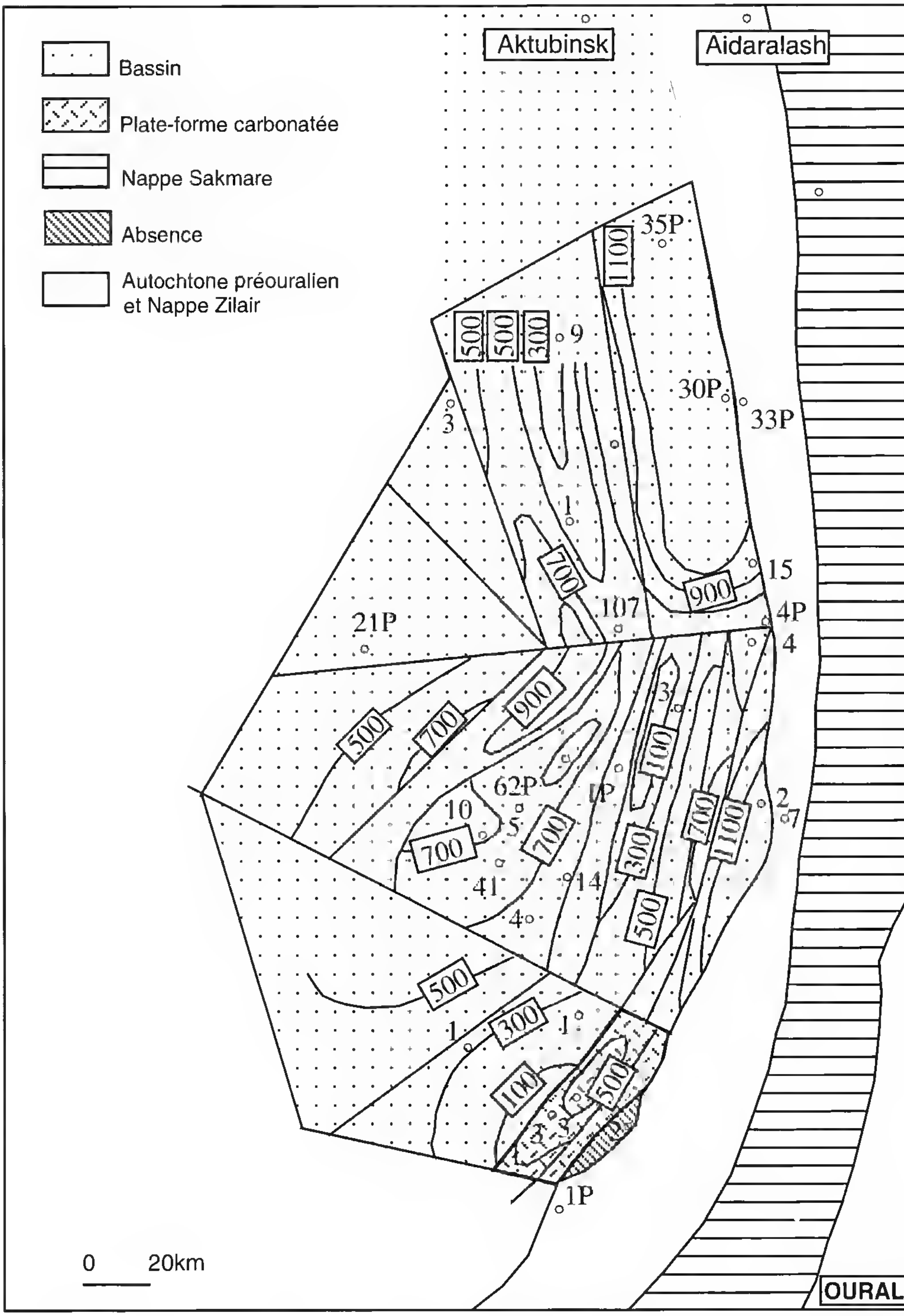
MÉTHODOLOGIE

Les carottes de dix forages ont été échantillonnées, deux cent cinquante lames minces ont été étudiées. Lors de la mission de 1996, les faciès ont été levés en continu sur les carottes des forages de Loktybai 34 (près de Loktybai 14), Janajol 72 (secteur Janajol), Sinelnikovsk 2, Kojassai 51 et Alibek 4 ainsi que sur la coupe d'Aidalarash. Les faciès et environnements utilisés pour les carbonates sont ceux de Wilson (1975). Les faciès turbiditiques ont été classés selon les séquences de Bouma (1962).

LA PLATE-FORME EST DU BASSIN PRÉCASPIEN AU DÉVONIEN ET CARBONIFÈRE

La carte (Fig. 3) représente la paléogéographie au Carbonifère et les isopaques du Moscovien au Gzhélien. L'épaisseur des dépôts est grande (1000 m) dans le secteur de Janajol à l'est et diminue vers l'ouest vers la bordure faillée de la plate-forme. Au nord-ouest de la plate-forme de Janajol, une autre plate-forme existait au niveau de Temir (Fig. 3), mais a été érodée avant l'Assélien comme les plate-formes de Tenguist et Astrakhan au sud du bassin précaspien (Fig. 1).

Le Dévonien (D2-D3) présente des calcaires à Stromatoporoides (wackestone et rudstone) au forage Kumsay 4P, formés en bordure de récif. Le Carbonifère inférieur (GTB-III) n'a pas pu être échantillonné sur la plate-forme. Le Viséen supérieur (GC-II) montre des calcaires (packstone à foraminifères et algues) à Kojassai 1P déposés sur la plate-forme interne et des faciès récifaux à Kojassai 3P (NE Kojassai 1P). Le Serpukhovien (GCII) présente à Janajol et Lakkargan 32P des calcaires de type packstone à foraminifères, algues, crinoïdes, pellets et de type grainstone à pellets, intraclastes, foraminifères déposés en plate-forme interne et à Sinelnikovskaia, Kojassai 3P, Janatan II des faciès récifaux (boundstone à Spongiostromides). Le Bashkirien inférieur (GC-II) est constitué à Alibek, Janajol, Sinelnikovskaia,



Fɪɢ. 7. — Carte paléogéographique de la partie est du Bassin précaspien et du Bassin préouralien au Permien inférieur. Les courbes isopaques représentent l'épaisseur du Permien inférieur (Assélien, Sakmarien, Artinskien).

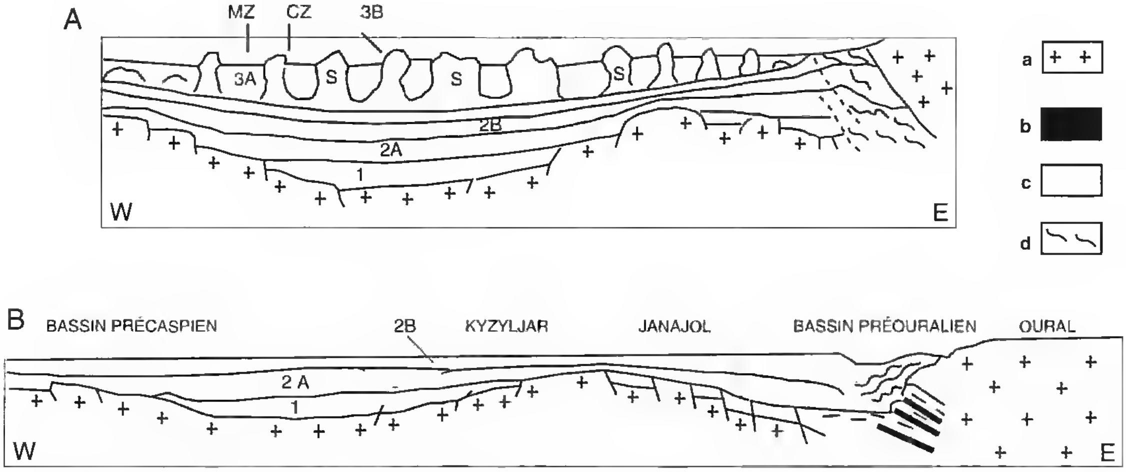


FIG. 8. — Coupe (A) et modèle géodynamique (B) des Bassins précaspien et préouralien, à partir des profils sismiques, modifiés d'après Joltaev (1989). **a**, croûte continentale ; **b**, croûte océanique ; **c**, sédiments du Bassin précaspien ; **d**, sédiments du Bassin préouralien . **S**, dôme de sel ; **MZ**, Mésozoïque ; **CZ**, Cénozoïque. Complexes stratigraphiques : **1**, (inférieur, Paléozoïque inférieur) ; **2**, moyen (dont **2A**, Dévonien à Tournaisien et **2B**, Viséen à Artinskien) ; **3**, supérieur (dont **3A**, Kungurien à Trias et **3B**, Jurassique à Quaternaire).

Kumsay des calcaires de type packstone à algues et foraminifères déposés sur la plate-forme interne, grainstone à oolithes déposés sur la barrière. Janajol 45G (NE Janajol 3) montre des faciès récifaux. Le Bashkirien supérieur est absent, alors qu'il est présent plus au nord en Russie (Sinytsin *et al.* 1975). Le Moscovien inférieur (GC-II) présente à Janajol, Alibek et Sinelnikov des calcaires de type packstone à algues, foraminifères et pellets, grainstone à oolithes et fusulines déposés en plate-forme interne et barrière. Kojassai montre des faciès récifaux de type boundstone à stromatopores. Du Serpukhovien au Moscovien, on observe une migration de la barrière et du récif vers l'est. Le groupe détritique (GTP-II) présente des grès, siltites, des alternances de siltite à mamelons et argilite, observés à Alibek 4 et Janajol 72 (secteur Janajol), interprétés comme des dépôts de tempête sur une plate-forme externe. Des calcaires de type mudstone, wackestone à foraminifères, algues y sont intercalés à Janajol, Kojassai et de type boundstone à algues à Jagaboulak 2G. Le Moscovien supérieur (GC-I) montre à Janajol des calcaires de type wackestone à pellets, à Kojassai de type micrite à matière organique et quartz, à Alibek de type grainstone à oolithes, fusulines et pellets, déposés en plate-forme interne et barrière. Le Kasimovien (GC-I) est formé à Alibek de calcaires de type wackestone à foraminifères, à Sinelnikovskaia de type grainstone oolithique, à Janajol de type wackestone à radiolaires et spicules, déposés respectivement en plate-forme interne, barrière et plate-forme externe. Le Gzhélien (GC-I) présente à Alibek et Janajol des calcaires de type wackestone à fusulines et pellets, de type packstone à pellets, algues, fusulines, déposés en plate-forme interne.

Les faciès carbonatés permettent de reconstituer la plate-forme carbonatée de Janajol : wackestone et packstone à algues, petits foraminifères et fusulines sur la plate-forme interne, grainstone à oolithes sur la barrière, boundstone à algues, stromatopores sur le récif, wackestone à radiolaires et spicules sur la plate-forme externe. La répartition bathymétrique des animaux et végétaux est conforme à la plate-forme russe (Chuvashov 1983). La position de la barrière ou du récif a varié pendant toute la durée de vie de cette plate-forme. Étant donné la présence d'un bassin à l'ouest et à l'est de cette plate-forme, on pourrait s'attendre à trouver une barrière ou un récif en bordure de celle-ci comme plus au nord en Russie en bordure de la plate-forme russe (Chuvashov 1983).

La pente est du bassin Précaspien au Carbonifère

Dans ce secteur, des problèmes de datation subsistent et d'après Joltaev (1989), étant donné la faible épaisseur par rapport à la plate-forme de Janajol, une plate-forme carbonatée d'âge dévonien à carbonifère aurait pu y être érodée entre le Carbonifère supérieur et le Permien. Mais, l'analyse sédimentologique apporte des arguments nouveaux quant à l'existence de faciès bassin dans ce secteur. La pente de ce bassin commencerait à la faille située à l'est de Loktybai 14 (Fig. 3) et le bassin s'étendrait vers l'ouest en direction de Akjar, Kursai, Tuskum avec une épaisseur faible (100m). D'après la géophysique, ce bassin est entrecoupé d'un horst (Fig.1). Le Dévonien (D) est présent et mal daté. À Loktybai 14 et Janatan, le Viséen inférieur et moyen (GTB-III) montre des alternances de turbidites gréseuses (grauwacke, sublitharénite, subarkose) et d'argilites ; le Viséen supérieur (GTB-II) des calcaires de type wackestone à spicules et radiolaires ; le Serpukhovien (GTB-II) des argilites, des calcaires de type wackestone à spicules ; le Bashkirien (GTB-II) des calcaires de type wackestone à foraminifères, crinoïdes et radiolaires ; le Moscovien (GTB-II) des brèches de pente à galets de calcaire d'âge bashkirien et kashirien, des argilites à galets, des calcaires de type mudstone à matières organiques à Loktybai, des calcaires de type grainstone et packstone passant à des mudstones granoclassés correspondant à des calciturbidites, de type mudstone à radiolaires à Janatan. Le Moscovien (Myachkovien) présente à Kojassai 1P (Fig. 4) des conglomérats, brèches à éléments calcaires, argilites et calcaires bitumineux (GTB-II) reposant sur les calcaires de plate-forme du Moscovien (GC-II). Ce secteur montre donc soit des faciès de pente (débrites et turbidites), soit des faciès de bassin (argilite ou calcaire à radiolaires ou spicules) de faible épaisseur. Les faciès les plus grossiers sont situés à proximité de la faille bordière. Les turbidites s'installent sur la plate-forme carbonatée à Kojassai dès le Moscovien supérieur. Au nord de la faille de Alibek, la plate-forme de Janajol s'arrête pour passer au bassin à turbidites d'Ostansuk (forage Kokteube 35P), qui passe vers le nord au bassin d'Aktubinsk et vers l'est au sillon préouralien.

La pente est du Bassin Précaspien au Permien

La carte paléogéographique du Permien inférieur (Fig. 7) nous montre les isopaches pour l'Assélien, le Sakmarien et l'Artinskien. Les faciès de pente et de bassin s'observent aussi bien sur la plate-forme carbonatée que sur la pente et le bassin d'âge carbonifère. Seules les zones de Tortkol et Alibek montrent des faciès de plate-forme. L'épaisseur est grande vers l'est à Janajol (660 m) et Kokteube (1100 m) et vers l'ouest (900 m). Elle est faible entre la faille de Loktybai 14 et la faille de Janajol 3, à l'est vers Alibek. L'épaisseur diminue vers le centre du bassin.

L'Assélien montre des turbidites gréso-argileuses avec des grès de type grauwacke et litharénite et des argilites à Loktybai 14, Mortuk, Bachenkol, Kokteube, des argilites et des micrites à radiolaires à Akjar-Kenkiyak, Koumsai, Akkouduk, Lakkargan. Des séquences turbiditiques de type tabc, tbc, tde (Bouma 1962) ont été observées sur les carottes de Loktybai 34 (près de Loktybai 14).

Le Sakmarien présente des brèches à éléments calcaires provenant de la plate-forme carbonatée d'âge carbonifère (Viséen à Moscovien), des turbidites gréso-argileuses et silto-argileuses à séquences tcde, tde à Loktybai 34, des brèches à éléments calcaires d'âge carbonifère (Viséen à Moscovien) à Koumsai, Karnak, des turbidites gréseuses (litharénite, grauwacke) à Mortuk, Koumsai, Kokteube, Lakkargan.

L'Artinskien montre des grès (litharénite), des brèches à éléments calcaires d'âge carbonifère (Viséen à Moscovien) à Akjar-Kenkiyak, des micrites à matières organiques et quartz (Bachenkol), des argilites à radiolaires et des turbidites silto-argileuses à séquences tcde, tde à Loktybai, Akkouduk, Kokteube, Karatube. Une zone de non-dépôt est connue entre la faille à l'est de Loktybai 14 et Janajol 3.

Des faciès de pente sont donc connus à l'est avec les faciès les plus grossiers à proximité des failles et les faciès de bassin à l'ouest vers Akjar-Kenkiyak et au nord vers Kokteube, Akkouduk et Kumsay. Mais, nous ne connaissons l'extension de ces faciès de bassin vers l'ouest que par les profils sismiques (Joltaev 1989 ; Fig. 8), étant donné leur faible épaisseur, l'épaisseur considérable des évaporites du Kungurien, la présence du Mésozoïque et du Cénozoïque au centre du Bassin précaspien. Ce bassin, compartimenté en grabens et en horsts (Joltaev 1989, fig. 1), présente une croûte continentale et trois complexes stratigraphiques (Fig. 8) : I attribué au Paléozoïque inférieur présent uniquement au centre du bassin, II d'âge paléozoïque moyen et supérieur présent partout, III du Kungurien au Quaternaire présent partout.

LE BASSIN D'AVANT-PAYS DE L'OURAL (Figs 3, 7)
D'après Garetskyi *et al.* (1963), les forages de la région de Kokpekty situés au sud du sillon préouralien montrent des turbidites calcaires et gréso-argileuses pendant le Kasimovien et le Gzhélien, des turbidites et des conglomérats à galets de calcaire d'âge viséen à moscovien pendant l'Assélien inférieur et moyen, des conglomérats, grès, calcaires, dolomies et évaporites de l'Assélien supérieur au sommet du Sakmarien. Les conglomérats sont plus fréquents et épais vers l'est. Dans ce secteur, la bathymétrie du sillon préouralien diminue à partir du sommet de l'Assélien. Nous avons pu observer la coupe d'Aidalarash appartenant au nord du sillon préouralien. Le Carbonifère supérieur (Moscovien et Kasimovien) montre des turbidites gréso-argileuses à séquences tab présentant des flute-casts et des microbrèches. Le Gzhélien, l'Assélien et le Sakmarien montrent des alternances de microconglomérats à galets de quartzite, calcaire, lamellibranches, fusulines, de grès quartzeux ou de calcaire gréseux à nombreux bioclastes de fusulines, lamellibranches, de siltite et d'argilite. Les microconglomérats sont ravinants, les grès présentent des granoclassements, des litages parallèles, des litages obliques plans et des rides de courant. Des séquences métriques à décamétriques strato- et grano-décroissantes sont observées avec à la base des microconglomérats, puis des grès granoclassés, des grès à litage parallèle, des grès à litage oblique et à rides, des siltites et des argilites. C'est un mélange de dépôts de coulées de débris, de courant de turbidité grossier et de courant de traction, de suspension silto-argileuse, qui se dépose sur la pente d'un fan delta sur la plate-forme ou la pente d'un bassin (Ethridge & Westcott 1984 ; Surlyk 1984 ; Kleinspehn *et al.* 1984). Ces séquences strato- et grano-décroissantes s'expliquent par une augmentation de la bathymétrie par subsidence ou eustatisme du bas vers le haut de la séquence. Ce mélange d'éléments minéraux provenant de l'Oural en surrection et des fossiles vivant sur la plate-forme produit des roches intermédiaires entre les roches détritiques et calcaires. Ces roches gréso-carbonatées sont très riches en fusulines, conodontes et les argilites contiennent des goniatites. Ce bassin présente donc au Carbonifère supérieur et au Permien inférieur des dépôts turbiditiques comme dans le sillon préouralien que l'on trouve plus au nord en Russie (Chuvashov & Nairn 1993). Les faciès du Permien sont plus grossiers, et plus proximaux par rapport à l'Oural. Snyder & Gallegos (1997) ont décrit à Aidalarash neuf séquences de l'Assélien à la base du Kungurien. Au Carbonifère, il n'y a pas de relation entre les turbidites du bassin préouralien et du bassin précaspien, puisque la plate-forme carbonatée de Janajol les sépare. Néanmoins, les éléments détritiques du groupe GTP-II sont à mettre en relation avec une activité tectonique ouralienne. Au Permien, l'avancée des nappes de l'Oural vers l'ouest alimente en éléments détritiques les turbidites proximales du bassin préouralien qui alimentent à leur tour les turbidites du bassin précaspien. La présence d'Assélien dans la nappe Sakmare et de Sakmarien dans le sillon préouralien montrent que la mise en place des nappes est post-Sakmarien.

TECTONIQUE

Du Cambrien au Viséen existait à l'est du secteur étudié l'océan Ouralien. Le bord est du Bassin précaspien était la marge passive continentale de cet océan (Joltaev 1990, 1992). La collision entre la plaque de l'est de l'Europe et la plaque du Kazakhstan au Permien inférieur a plissé l'Oural et son avant-pays. Le domaine océanique ouralien et la plaque de l'est de l'Europe se sont ensuite enfouis sous la plaque du Kazakhstan par subduction, ce qui provoqua la mise en place de nappes de charriage, le chevauchement du sillon préouralien sur le bassin précaspien et les failles inverses de la bordure est du Bassin précaspien (Figs 6, 8). Mais certaines de ces failles existaient déja pendant la sédimentation et étaient alors des failles normales qui limitaient des zones paléogéographiques différentes à faciès différents et épaisseurs différentes, comme le montrent les cartes du Carbonifère et du Permien inférieur (Figs 3, 7). La faille à l'est de Loktybai 14 sépare le bassin de la plate-forme au Carbonifère. La zone entre cette faille et la faille de Kojassai 1P est une zone de plate-forme à épaisseur faible, qui alimente par glissement le bassin. D'autres failles figurées sur ces cartes sont certainement tardives. Plus à l'ouest, d'autres failles découpaient le Bassin précaspien en horsts et grabens (Joltaev 1989 ; Fig. 8).

CONCLUSION

Des données nouvelles sont apportées sur la stratigraphie et la sédimentologie de la bordure est du Bassin précaspien. Il y est prouvé que des faciès de pente existaient bien au Carbonifère et que des faciès de pente progradaient sur la plate-forme carbonatée d'âge carbonifère pendant le Permien inférieur. Les premiers sont alimentés par la plate-forme carbonatée sous forme de calciturbidites ou de brèches. Les seconds sont alimentés par la surrection de l'Oural au Permien inférieur. On observe un déplacement des dépôts-centres du Bassin préouralien vers le Bassin précaspien du Carbonifère au Permien en même temps que les nappes se déplacent vers l'ouest. Cette évolution est à rapporter à la collision entre la plaque de l'est de l'Europe et la plaque du Kazakhstan au Permien inférieur ayant plissé l'Oural et son avant-pays. Le domaine océanique ouralien et la plaque de l'est de l'Europe se sont ensuite enfouis sous la plaque du Kazakhstan par subduction, ce qui provoqua la mise en place de nappes de charriage, le chevauchement du Sillon préouralien sur le Bassin précaspien et les failles inverses de la bordure est du Bassin précaspien.

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The Permo-Carboniferous outcrops of the Gulf of Suez region, Egypt: stratigraphic classification and correlation

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ABSTRACT
The Permo-Carboniferous succession in the Gulf of Suez region is subdivided into: the Abu Thora Formation (Late Visean-Early Westphalian), the Abu Durba Formation (Middle Westphalian), and the Aheimer Formation (Late Westphalian/Stephanian-Early Permian). The Abu Thora and Abu Durba formations of Sinai are coeval with the Abu Darag Formation in the Northern Galala. The Aheimer Formation corresponds to the Ataqa Formation in the subsurface of the Gulf of Suez. These clastic-dominated deposits reflect shallow subtidal, prograding shoreline and fluviatile conditions. They overlie conformably open marine Early Carboniferous carbonates of the Um Bogma Formation and are overlain unconformably by continental red bed succession of Late Permian-Triassic age known as the Qiseib Formation. The whole Carboniferous-Permian succession in the region is bounded by two unconformities; a lower one resulted from the removal of the underlying Early Palaeozoic and the basal beds of the Early Carboniferous, and an upper one manifested by the partial erosion of the Permo-Carboniferous deposits from the area. Stratigraphic correlations with equivalent units recorded from the southern Peri-Tethyan basins indicate that great areas of North Africa and the Near East were situated near the southern margin of the Tethyan seaway during most of the Late Carboniferous-Early Permian time.

KEY WORDS
Peri-Tethys,
correlations,
Late Palaeozoic,
Gulf of Suez,
Near East.

RÉSUMÉ

Les affleurements d'âge carbonifère et permien de la région du golfe de Suez, Égypte : codification et corrélation stratigraphique. La succession permo-carbonifère dans la région du golfe de Suez est subdivisée en : la Formation Abu Thora (Viséen supérieur-Westphalien inférieur), la Formarion Abu Durba (Westphalien moyen) et la Formation Aheimer (Westphalien supérieur/Stéphanien-Permien inférieur). Les formarions Abu Thora et Abu Durba du Sinaï sont contemporaines de la Formation Abu Darag dans le Galala septentrional. La Formation Aheimer correspond à la Formation Ataqa en subsurface dans le golfe de Suez. Ces dépôts à dominance clastique reflètent des conditions subtidales peu profondes, ligne de rivage et fluviatile. Ils reposent en conformité sur les carbonates marins ouverts d'âge carbonifère inférieur de la Formation Um Bogma et sont recouverts en discordance par une succession continentale à bancs rouges du Permien supérieur-Trias, la Formation Qiseib. La succession permo-carbonifère de la région est limitée par deux discordances : l'inférieure qui résulte de l'érosion du Paléozoïque inférieur et des bancs inférieurs du Carbonifère inférieur et la supérieure qui se manifeste par l'érosion partielle du Permo-Carbonifère dans la région. Des corrélations stratigraphiques avec les bassins du domaine Sud péritéthysien indiquent que le Nord de l'Afrique et le Proche-Orient étaient situés près de la marge sud de la Téthys pendant le Carbonifère supérieur et le Permien inférieur.

MOTS CLÉS
Péri-Téthys,
corrélations,
Paléozoïque supérieur,
Golfe de Suez,
Proche-Orient.

INTRODUCTION

Of the Palaeozoic of Egypt, the Carboniferous-Permian rocks are sporadically exposed on both sides of the Gulf of Suez. Good outcrops are studied from west-central Sinai at Um Bogma, Wadi Feiran and Abu Durba, and west of the gulf in the Northern Galala, Abu Darag, Wadi Araba and in Wadi El-Dakhel (Fig. 1). Despite numerous investigations over the last century, stratigraphic correlations of the Late Palaeozoic successions in the region remained controversial and different lithostratigraphic schemes have been proposed by various authors (Fig. 2). The summary of stratigraphic subdivisions of the Palaeozoic rocks in Egypt outlined by Abdallah (1992) emphasises the great dispute between different authors concerning some of the rock units.

The objective of this paper is twofold: (1) to bring together in a single document a comprehensive summary of what is now known of the stratigraphy of the Permo-Carboniferous rocks exposed in the Gulf of Suez region and to establish a unified stratigraphic scheme, and (2) to correlate this succession with synchronous units known from other countries in the Middle East. Much of the text is devoted to a systematic account of the stratigraphic classification of the Permo-Carboniferous in the area. Within individual stratigraphic units, local rock sequences are described and illustrated. These local sections are related to each other and to equivalent rock sequences outside the Gulf of Suez region to depict the distribution, lateral changes, age and gaps in the stratigraphic record necessary to untaveling the geologic history of the region.

The literature dealing with the subject has been recently reviewed and the history of the palaeontological research has been outlined by Kora (1995a, b). Therefore, only some significant publications are cited herein. Macrofloral elements are quoted from Lejal-Nicol (1990) whereas the microfloral assemblages are concluded from Kora (1993). Also, the micro- and macrofauna are summed up from the works of Kora (1989), Kora & Mansour (1991, 1992) and Kora (1992) which are utilizing some data from earlier literature. The present study has also gained much from the tectono-sedimentary synthesis and facies interpretations given by Issawi & Jux

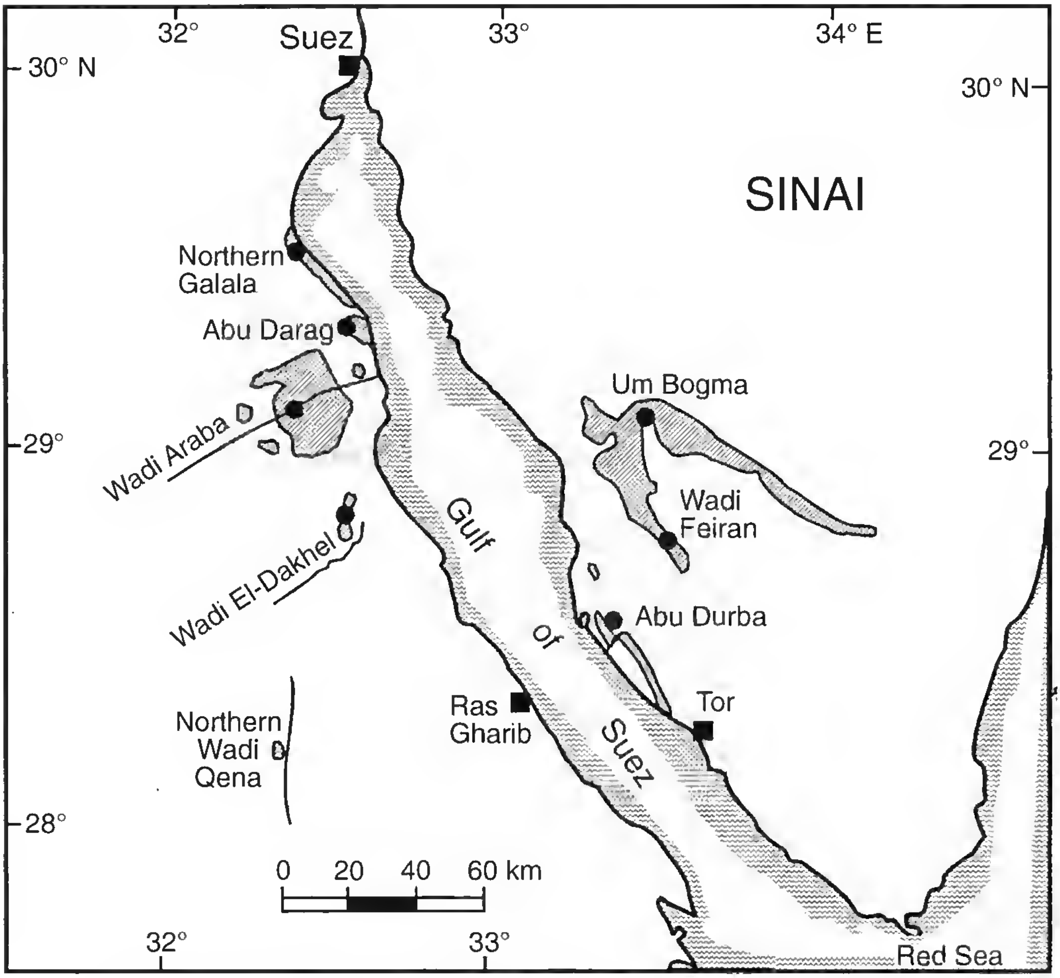

FIG. 1. — Location map of Permo-Carboniferous outcrops (hatched areas) in the Gulf of Suez region.

(1982), Jux & Issawi (1983), Keeley (1989), Abdallah *et al.* (1992), Darwish (1992), Weissbrod (1994) and Issawi (1996).

However, many gaps still exist and the present biostratigraphic zonation is only tentative. Obviously, these successions need to be closely investigated to look for more reliable fossils in these rarely fossiliferous clastic-dominated successions. Scattered land mines drifted in the area partly make it dangerous. Nevertheless, the dominant depositional environments could be concluded from macro- and microfacies interpretations. The biostratigraphy of the Early Carboniferous richly fossiliferous carbonates of Um Bogma Formation is not included in this study.

LITHOSTRATIGRAPHY

The Permo-Carboniferous succession exposed in the Gulf of Suez region consists mainly of sandstones and shales intercalating minor siltstones and sandy dolostones. In Sinai, this succession overlies conformably Early Carboniferous carbonate sequence known as the Um Bogma Formation. The Permo-Carboniferous deposits are overlain unconformably either by Permo-Triassic red beds of the Qiseib Formation or by Early Cretaceous pebbly sandstones of the Malha Formation.

The first priority of this study was to establish a reliable stratigraphy. The suggested lithostratigraphic scheme is fundamentally a compilation of the works of Abdallah & El Adindani (1965) and Kora (1992, 1995a, b). The stratigraphy adopted here is partly based on and supported by some palaeontological and palynological studies carried out by the author as well as other workers on the Palaeozoic of Egypt and adjacent countries. The Carboniferous clastic succession of Sinai is subdivided into the Abu Thora Formation and the overlying Abu Durba Formation. Equivalent rocks exposed on the western side of the Gulf of Suez are overlain by the Permo-Carboniferous Aheimer Formation. The following comments summarize the characteristics of these lithostratigraphic units.

Abu Thora Formation

Nomenclature

This unit refers to the Late Carboniferous sandstone described by Ball (1916) from west-central Sinai. It was given different names including Ataka Series (Kostandi 1959), upper sandstone formation (Omara & Schultz 1965), Ataqa Formation (Weissbrod 1969; Said 1971; Klitzsch 1990), Ataqa Group – El-Hashash, Magharet El Maiah and Abu Zarab formations (Soliman & El Fetouh 1969) –, lower part of El Tih Sandstone (Omara 1971), Abu Thora Formation (Weissbrod 1980; Kora 1984) and Abu Thora Member of Rod El Hamal Formation (Beleity *et al.* 1986). In the Northern Wadi Qena-Wadi El-Dakhel, equivalent deposits were named Gilf Formation (Issawi & Jux 1982) and Somr El Qaa Formation (Klitzsch 1990).

Recently, the name Abu Thora Formation has gained wide acceptance and was subsequently used by most investigators, *e.g.* El Sharkawi *et al.* (1990), Morsy *et al.* (1992), Abdallah *et al.* (1992), El-Fawal (1994), Kora (1992, 1993, 1995a, b), El Agami (1996) and El Sherbini (1996).

Type section and locality

Wadi Abu Thora (lat. 29°02'N and long. 33°24'E), near Um Bogma, west-central Sinai with a thickness of 190 m. Weissbrod (1969) distinguished two members of the formation: a sandy-clayey member at base and a sandy-quartzitic member at top.

Reference sections

Abu Rodeiyim boreholes on the southern side of Wadi El Hommur, north of Um Bogma (200 m thick). A second reference section is measured near Wadi Sidri (80 m thick) and a third one (68 m thick) is studied from Wadi Nidia El Samra on the southern side of Wadi Feiran. A fourth less developed reference section (50 m thick) is recorded from Gabal Ekma in the Abu Durba area (Fig. 3).

Boundaries

In the Um Bogma area, the Abu Thora Formation overlies conformably the Early Carboniferous dolostones of Um Bogma Formation and underlies unconformably the Permo-Triassic red beds of Qiseib Formation with a local basaltic intrusion in-between. The basaltic rocks of Farsh El-Azraq, Wadi Abu Natash and Wadi Budra are related to Early Triassic-Middle Jurassic volcanic phases (Weissbrod 1969; Saleeb-Roufaiel *et al.* 1989).

In Abu Durba and Wadi Nidia El Samra to the south of Wadi Feiran, the Abu Thora Formation overlies unconformably Early Palaeozoic sandstones with a thin conglomeratic bed at the contact. In that particular area, the formation is overlain conformably by the Carboniferous shaly succession of Abu Durba Formation (Fig. 3). In Wadi El-Dakhel of the north Eastern Desert, the Abu Thora Formation is unconformably overlain by Early Cretaceous clastics of the Malha Formation (Fig. 4), reflecting a wider time gap of the unconformity than that present in the type area (Abdallah *et al.* 1992).

Description

This is a dominantly light-coloured sandstone succession with occasional dark brown and yellowish brown layers, alternating with silty shales and kaolinitic claystones, carbonaceous in places. The formation could be subdivided into a lower "kaolin/coal-bearing" member and an upper "glass sand" member.

The lower member is distributed all over west-central Sinai, decreasing in thickness from 140 m in the Um Bogma area to about 70 m in the Wadi Feiran area and 50 m in the Abu Durba area (Fig. 3). This member is made up of pinkish

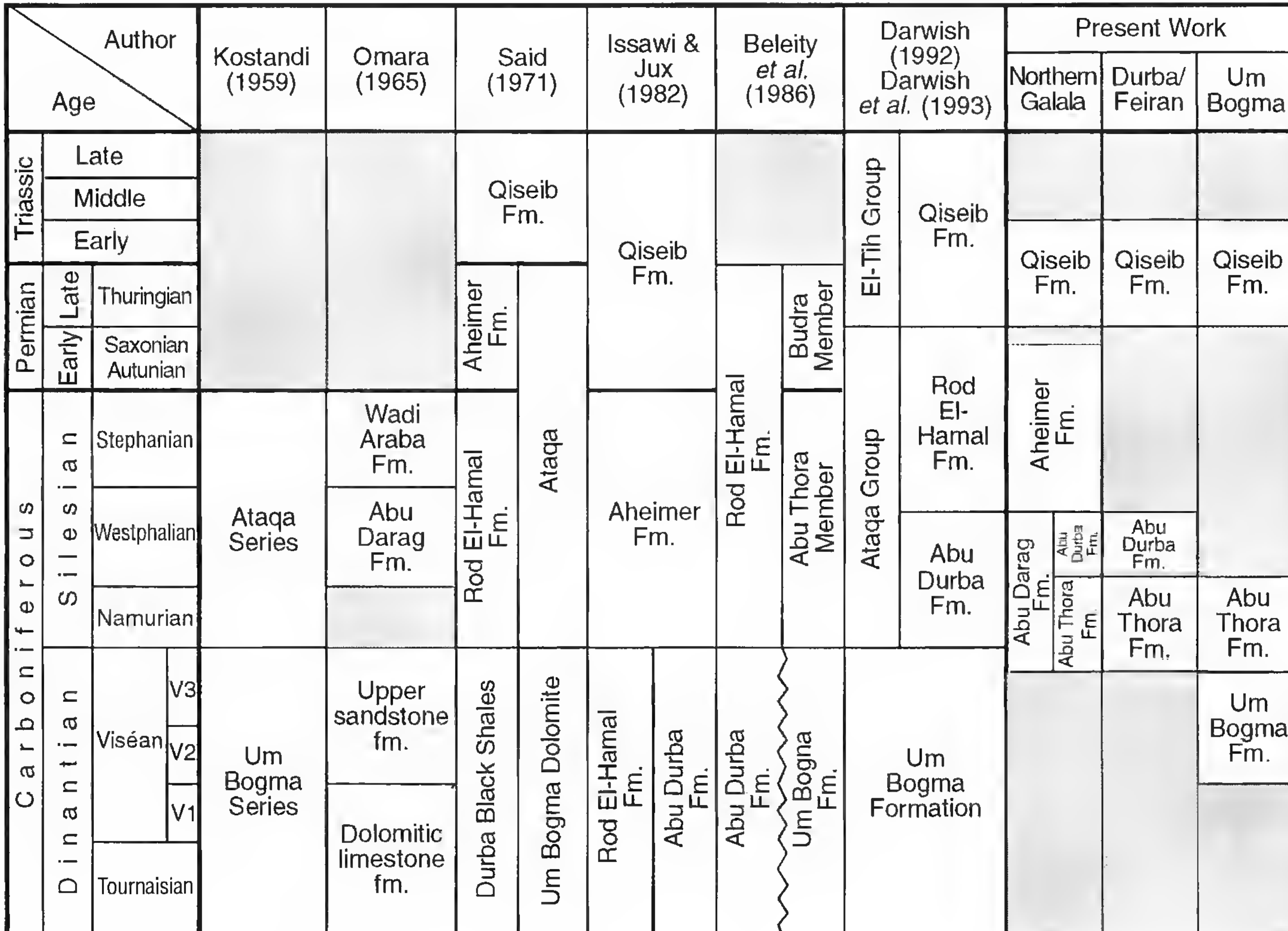

FIG. 2. — Stratigraphic classification schemes used for the Late Palaeozoic succession in the Gulf of Suez region.

white and yellow thick-bedded sandstones intercalating some mudstones and shales. Cross bedding, mainly of the tabular-planar type, but also wedge and convolute bedding are observed. The planar sets are 50-100 cm in thickness, 2-3 m in length and generally dip 20°-30° towards north. Ripple marks and flat horizontal laminations are observed in the fine silty intercalations near the top of the member. At Wadi Nidia El Samra to the south of Wadi Feiran, the basal part of this member includes 3 m thick biturbated shale layer overlying directly the conglomeratic band separating the Abu Thora Formation from the Early Palaeozoic clastics.

Two carbonaceous shale horizons with coal streaks were recorded from the continuously cored succession of the Abu Rodeiyim boreholes in the northern Um Bogma area. The lower level is about 17 m thick directly overlying the marly dolostones of Um Bogma Formation. A kaolinitic claystone bed (3 m thick) is recorded in an interval about 20 m above it. The upper carbonaceous shale bed is 100 m above the lower one. It varies in thickness between 3 and 20 m and is underlying directly the upper "glass sand" member. At Wadi Abu Thora, the lowet carbonaceous shale intercalation (9 m thick) appears some 70 m above the Um Bogma dolostones and the upper clay is 30 m above it. The kaolin beds exploited at Wadi Khaboba and Gabal Hazbar in the Um Bogma area are stratigraphically lower than that in Wadi Sidri area. This indicates that the kaolinitic claystones and carbonaceous shale horizons in the Abu Thora Formation are not confined to a certain level in the formation.

The sandstone-kaolinitic mudstone facies of the lower member of Abu Thora Formation in the Um Bogma and Wadi Feiran areas yielded badly preserved brachiopods and marine ichnofossils indicating a remnant of the shallow marine conditions that prevailed earlier in the Carboniferous during deposition of the Um Bogma carbonates. The carbonaceous shale horizons yielded lepidodendroid flora and miospores of pteridophytic affinity. Thus, the litho- and biofacies encountered reflect gradational environments between coastal marine, swampy deltaic and fluviatile (Fig. 5).

The upper "glass sand" member is recorded essentially from the central and northern parts of the Um Bogma area with an average thickness of 60 m. Glass sand is currently exploited at Um Rodeiyim, El Qor and Wadi Khaboba. It is also quarried from the notthern Wadi Qena-Wadi El-Dakhel stretch in the Eastern Desert. This member was not recorded from Wadi Feiran and Abu Durba areas due to erosion or even non-deposition. The quarried white sand interval is usually in the range of 4-10 m of friable clean well-sorted and rounded medium to fine grained quatzitic sandstone. Many sandstone beds are structureless, deeply weathered and contain neither clays nor carbonates, but enclose some granules and coarse sand grains. The white sandstones are in places irregularly- to tabular-planar cross bedded. Badly preserved moulds and casts of indeterminate pelecypod and brachiopod remains were recorded from the weakly consolidated bioturbated sandstones of Wadi Khaboba near Um Bogma and Wadi El-Dakhel in the northern Eastern Desert, reflecting the dominance of marginal marine and fluviatile depositional environments.

Fossil content and age

The Abu Thora Formation contains faunal and floral elements. A Late Visean-Early Namurian marine macroinvertebrate fauna including the brachiopod *Orthotetes subglobosus* Girty (Fig. 5) and the hydrozoan *Plectodiscus* sp. was described from the kaolinitic mudstone horizon at Wadi Khaboba in the Um Bogma area (Kora 1992). A marginal marine thanatocoenosis was recorded from the white sandstone of Wadi El-Dakhel in the north Eastern Desert (Jux & Issawi 1983). Most common is the brackish to fresh-water pelecypod *Anthraconaia* Trueman *et* Weir; next comes typical marine molluscs (*Bellerophon* Montfort, *Cypricardella* Hall, *Edmondia* De Koninck, etc.) and rare brachiopods (*Dictyoclostus* Muir-Wood, *Schizophoria* King and *Rhipidomella* Oehlert).

In the Wadi Feiran area, the Abu Thora Formation has yielded a broad variety of trace fossils of which three forms do have stratigraphic potential: *Cruziana carbonaria* Seilacher, ?*Cruziana costata* Seilacher and *Margaritichnus reptilis* (Bandel). According to Seilacher (1990),

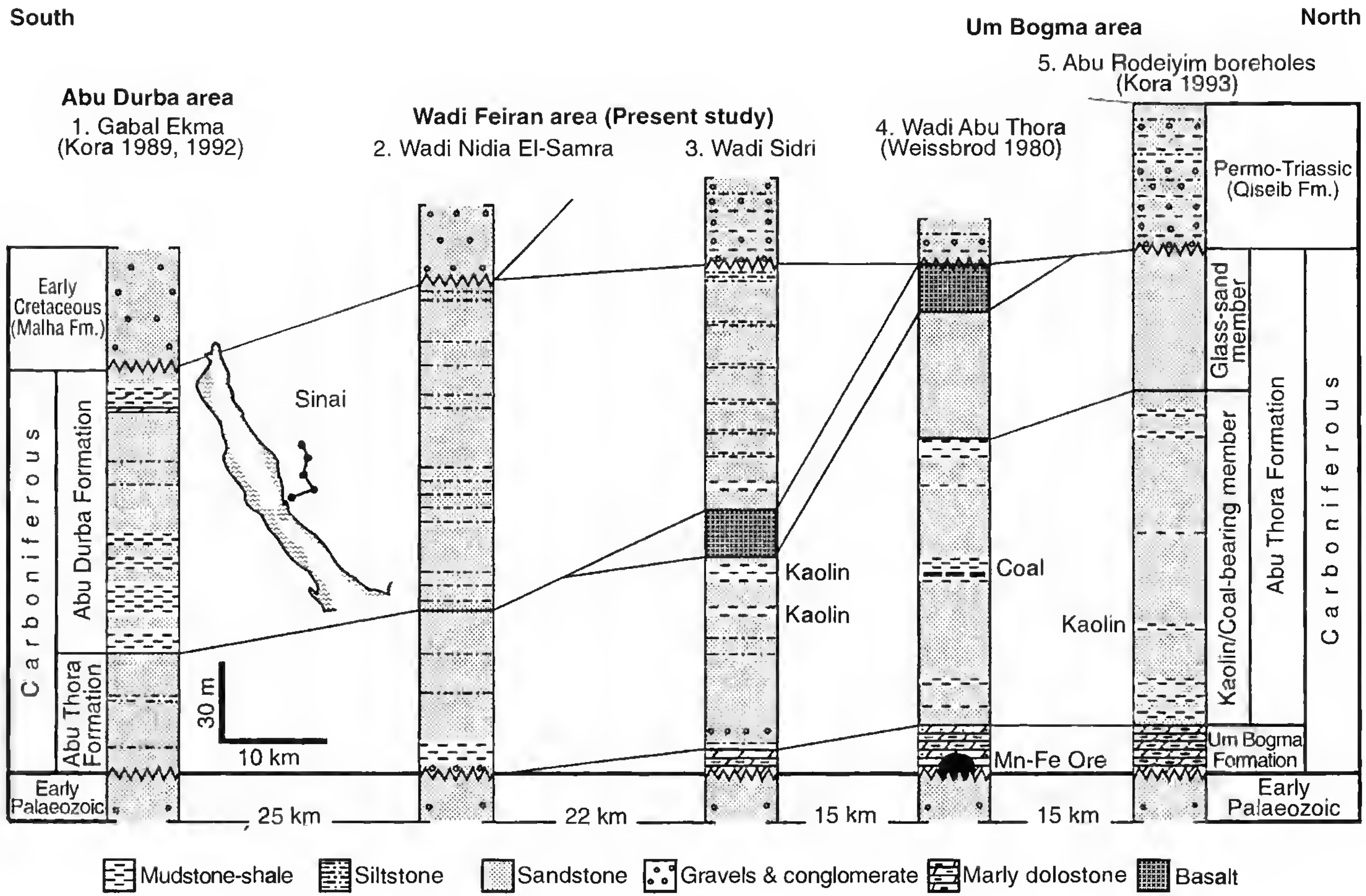

FIG. 3. — Stratigraphic correlation chart of the Carboniferous successions in south-western Sinai.

the *Margaritichnus* specimen from Sinai is identical in form and size with material from the Late Carboniferous of North America.

In the Um Bogma area, the argillaceous horizons of the Abu Thora Formation yielded rare finely agglutinated to granulated calcareous foraminifers belonging to species of *Lugtonia* Cummings, *Nodosinella* Brady and *Earlandinita* Cummings which range through most of the Carboniferous. However, an archaediscid foraminiferal assemblage was described from equivalent deposits included in the basal part of the Abu Darag Formation on the western side of the Gulf of Suez (Kora 1995b). The fossil spectra in that interval include *Archaediscus karreri*, *A. spira*, *A.* ex gr. *akchimensis* and *Asteroarchaediscus* ex gr. *rugosus*, pointing to a latest Visean-earliest Namurian transition.

Plant remains have long been known from the Abu Thora Formation (Fig. 5). These consist essentially of stem, root and leaf impressions of *Lepidodendron*, *Lepidodendropsis*, *Lepidophloios*, *Knorria*, *Sigillaria*, *Calamites*, *Bathrodendron*, *Noeggerathia*, etc. and were recorded mainly from the Um Bogma area in Sinai. Seward (1932) reported that the Sinai fossils might belong to a flora that flourished not far from the southern shore of the Tethys Sea in the latter part of the Early Carboniferous or in the early stages of the Late Carboniferous. Similarly, Lejal-Nicol (1990) concluded a Late Visean-Namurian age for a similar assemblage recorded at Wadi Mukattab in the Wadi Feiran area.

Palynomorphs were repeatedly recorded from the Abu Thora Formation. Recently, Kora (1993) described two miospore assemblages from the carbonaceous shale horizons intercalating the lower member of the formation in the Abu Rodeiyim boreholes. Assemblage Zone A is restricted to the basal part of the formation and is characterised by the common presence of *Raistrickia nigra*, *Spelaeotriletes owensi*, *Dibolisporites montuosus*, *Retusotriletes incobatus* and *Vallatisporites ciliaris* suggesting a Late Visean age. Assemblage Zone B is restricted to the 20 m interval just below the glass sand member with a rich microflora including *Raistrickia fulva*, *Laevigatosporites vulgaris*, *Endosporites globiformis*, *Lophotriletes gibbosus* and *Verrucosisporites donarii* indicating an age ranging from Namurian C to Westphalian A.

Geographic distribution and local correlation

The Abu Thora Formation is widely distributed in the Gulf of Suez region. In west-central Sinai, it is best developed in the central and northern parts of the Um Bogma area where it attains its maximum thickness (200 m). It extends from Wadi El Hommur and the upper reaches of Wadi Khaboba, covering the broken plain of El Qor, and stretches across Gabal Hazbar and Gabal Ghorabi but decreases to a thickness of 60 m in Gabal Raqaba eastwards. It is also well exposed in a rather narrow strip extending southwards through Wadi Budra, Wadi Sidri, Wadi Mukattab and crossing Wadi Feiran to Wadi Nidia El Samra. The Abu Thora Formation is reduced in thickness to about 50 m in the Abu Durba area (Fig. 3).

In the western side of the Gulf of Suez, the Abu Thora Formation as described herein, corresponds to the lower member (50 m thick) of the formation described by Abdallah *et al.* (1992) from Wadi El-Dakhel in the environs of Southern Galala. Their upper member (20 m thick) is mostly coeval with the Abu Durba Formation described below. Similarly, the lower two units (100 m thick) of the Abu Darag Formation (Abdallah & El Adindani 1965) are timewise equivalent to the present Abu Thora Formation; the overlying two units (75 m thick) represent essentially the shaly succession of the Abu Durba Formation. Moreover, equivalent deposits to the Abu Thora Formation were penetrated by drilling in Wadi Araba borehole-1, represented mostly by unit 3 of Hermina *et al.* (1983). This interval corresponds to the upper part of Nubia "C member" in the classification adopted by oil companies for the Gulf of Suez wells.

Abu Durba Formation

Nomenclature

A formation status for this unit was introduced by Said (1971) who named it Durba Black Shales or Durba Formation (166 m thick), after a lithologic description given by Hassan (1967) to a 122 m thick sandstone and fossiliferous

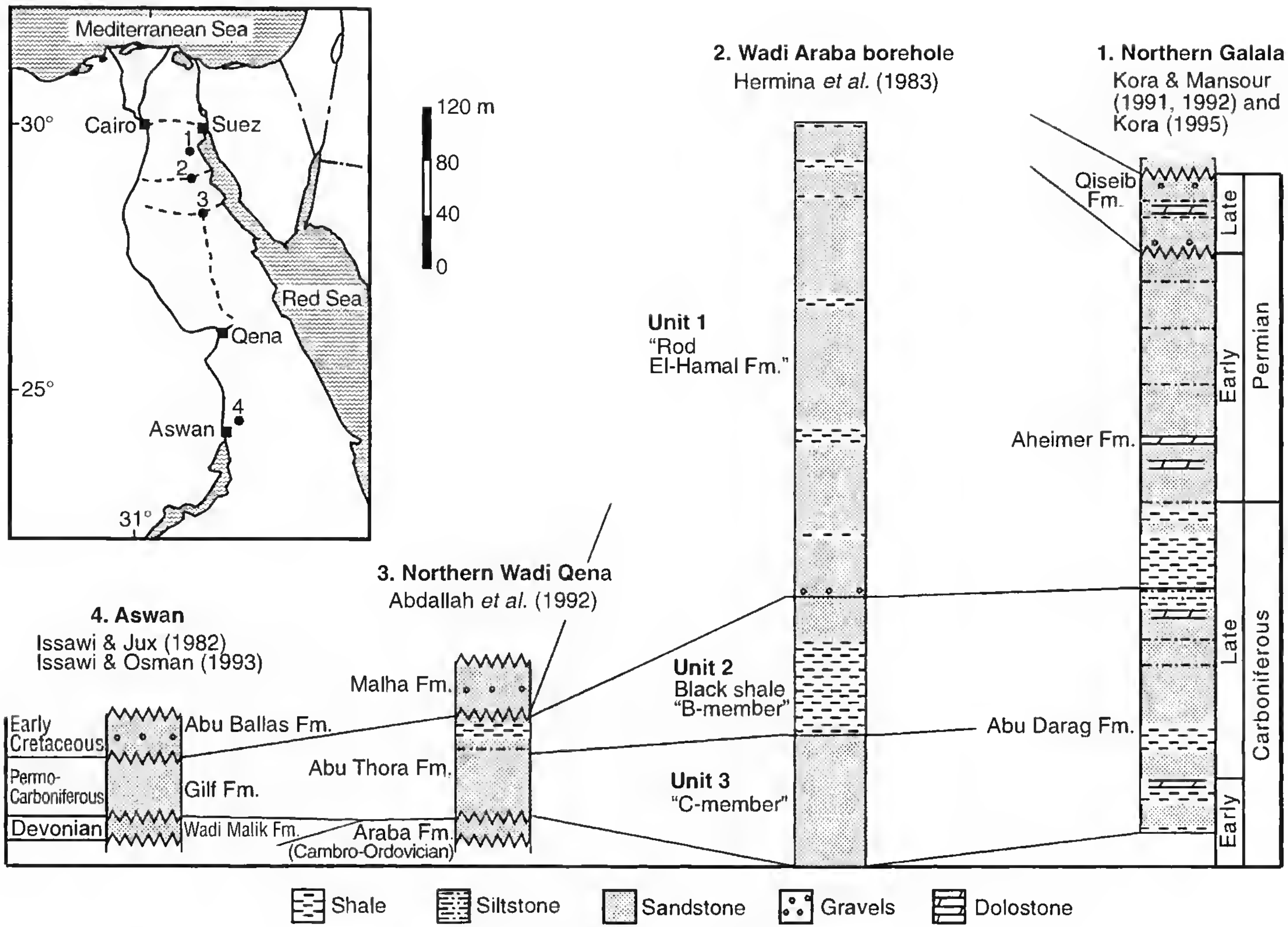

FIG. 4. — Stratigraphic correlation chart of the Carboniferous-Permian successions in the Eastern Desert of Egypt.

shale succession exposed in the Abu Durba area, Sinai. It is a synonym with the Nubia "B member" of the oil companies classification. This unit was incorrectly referred to as Aheimer Formation by Weissbrod (1980), Issawi & Jux (1982) and Allam (1989). Currently, the name "Abu Durba Formation" is commonly used by most investigators (Klitzsch 1990; Kora 1989, 1992; El Agami 1996; El Sherbini 1996 and Issawi 1996).

Type section and locality
East of El Belayim Bay, in the vicinity of Gabal Abu Durba, southwestern Sinai (lat. 28°34' N and long. 33°17' E). Another minor locality was also found near the mouth of Wadi Feiran on the eastern coast of the Gulf of Suez (Hassan 1967).

Reference sections
Two sections were studied from the type area (Kora 1989). The first (125 m thick) extends through the southern slopes of Gabal Ekma, immediately to the east of El Belayim Bay. The other section (120 m thick) was studied on the right hand side at the entrance of Wadi Feiran, facing the Petrobel oil fields. Two additional sections are studied throughout the present work in the Wadi Feiran area. The first (105 m thick) is measured near Wadi Sidri at its junction with the southern Wadi Budra. The second (140 m thick) was collected from Wadi Nidia El Samra near the contact with the basement rocks on the southern side of Wadi Feiran (Fig. 3).

Boundaries
In the type area and to the south of Wadi Feiran, the Abu Durba Formation overlies conformably the Abu Thora Formation and is unconformably overlain by Early Cretaceous pebbly sandstones of the Malha Formation. To the north of Wadi Feiran, near Wadi Sidri and Wadi Budra, the Abu Durba Formation is separated from the Abu Thora Formation by a basaltic sill and is overlain by the Permo-Triassic red beds of the Qiseib Formation (Fig. 3). In Wadi Araba borehole-1 on the western side of the Gulf of Suez, the Abu Durba Formation (unit 2 of Hermina *et al.* 1983) is underlying conformably a Late Carboniferous succession referred to as Rod El-Hamal Formation. In the Abu Darag area, deposits equivalent to the Abu Durba Formation which are represented by the upper two units of the Abu Darag Formation (Abdallah & El Adindani 1965) are overlain unconformably by Permo-Triassic red beds of the Qiseib Formation. At Wadi El-Dakhel in the northern Eastern Desert, rocks equivalent to the Abu Durba Formation (upper member of the Abu Thora Formation of Abdallah *et al.* 1992) were overlain unconformably by the Malha Formation (Fig. 4).

Description
In the Abu Durba area, the formation could be differentiated lithologically into three horizons (Fig. 3). The lower part is made up of dark grey to black shales interbedding few laminated siltstone and thin-bedded grey sandstone beds. An environment dominated by brackish water or estuarine conditions is indicated from the presence of only arenaceous foraminifers of low diversity (Fig. 5). The middle part is essentially composed of white or multicoloured medium to coarse grained sandstones ranging from thin bedded to tabular-planar cross bedded. The tabular sets are 20-30 cm in thickness and 3-4 m in length. The upper part of the formation is characterised by the presence of a dark grey to green fossiliferous shale horizon with two sandy dolostone/dolomitic sandstone interbeds. The shale contains varied marine fauna dominated by bryozoans and brachiopods. A conspicuous unfossiliferous reddish brown fine sandstone bed separates the Abu Durba Formation from the overlying light-coloured Cretaceous sandstones of the Malha Formation in that area. However, in the Wadi Feiran area, the differentiation of the Abu Durba Formation into three parts is not possible, since the dark grey siltstone and shale beds alternate with the ferruginous sandstones throughout the whole succession. Also, the fossiliferous marine sandy dolostone interbeds are not encountered (Fig. 3).

Fossil content and age
The lower part of the Abu Durba Formation in the type area is characterised by an assemblage of arenaceous foraminifers dominated by *Glomospira diversa* Cushman *et* Waters and *Nodosinella aegyptiaca* Said *et* Eissa (Fig. 5).

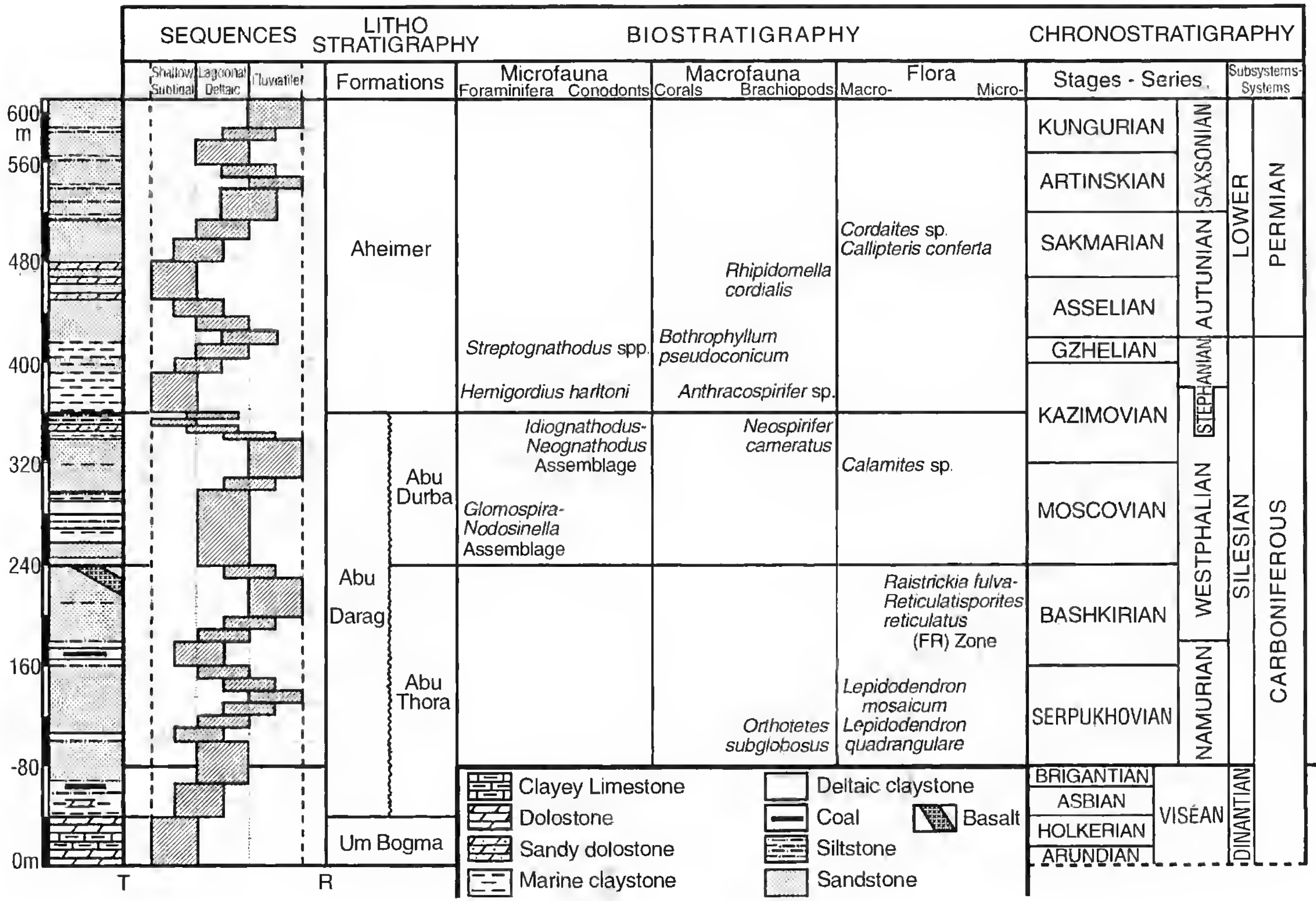

FIG. 5. — The Late Carboniferous-Early Permian stratigraphic sequence in the Gulf of Suez region (the biostratigraphy was compiled from different sources mentioned in the text).

Similar foraminiferal association is encountered from the succession studied at Wadi Sidti. Plant remains in the form of drifted logs of *Lepidodendron* and *Calamites* were recorded from the middle sandy interval of the formation, whereas bryozoans cover almost the entire bedding plane surfaces of some shale beds in the upper part and include species of *Fenestella*, *Polypora*, *Fistulipora* and *Ascopora*. These are associated with the Middle Pennsylvanian brachiopod *Neospirifer cameratus* (Morton) together with species of *Reticulatia*, *Choristitella* and *Choristites*. Bryozoans and brachiopods of similar affinity were recorded from the Wadi Araba borehole-1 (Hermina *et al.* 1983). This interval is characterised by the presence of a conodont assemblage dominated by *Idiognathodus delicatus* Gunnel and *Neognathodus medexultimus* Merrill (Fig. 5), suggesting an Early Moscovian age equivalent to Westphalian B-C (Kora 1989).

Geographic distribution and local correlation

The Abu Durba Formation is recorded from both sides of the Gulf of Suez. On the eastern side, it is well-developed and best exposed in the Abu Durba-Wadi Feiran area, particularly along the western slopes of Gabal Ekma. It is not encountered in the central and northern parts of the Um Bogma area (Fig. 3). This fossiliferous mainly black shale succession is described from Wadi Araba borehole-1, on the western side of the gulf (Said 1971; Hermina *et al.* 1983). It has been also recorded from many wells drilled by oil companies in the Gulf of Suez, *e.g.* in the Gharib, Bakr Ramadan, July, Ras Budran and Belayim oil fields, and is usually referred to as Nubia "B member".

The present study considers the fossiliferous dark coloured upper part (20 m thick) of the Carboniferous succession exposed at Wadi El-Dakhel in the northern Eastern Desert overlying the workable glass sand (the upper shale-sandstone member of the Abu Thora Formation of Abdallah *et al.* 1992) to represent the Abu Durba Formation in that area. Deposits equivalent to the Abu Durba Formation do occur in the Abu Darag area and are included in the upper part (75 m thick) of the Abu Darag Formation of Abdallah & El Adindani (1965). This interval yielded Westphalian microfossils (Omara 1965). However, the succession cannot be collected from a single outcrop. The complicated fault pattern and the wide distribution of Plio-Pleistocene terraces in the Abu Darag-Wadi Araba area make the distinction between the clastics building up the Abu Thora and the Abu Durba formations rather arbitrary. The present study suggests to keep applying the name Abu Darag Formation for the Carboniferous succession exposed around the Abu Darag Lighthouse in the Northern Galala which is equivalent to both the Abu Thora and the overlying Abu Durba formations in Sinai (Figs 4, 5).

AHEIMER FORMATION

Nomenclature

This unit was first named by Abdallah & El Adindani (1965), coeval with the Ataqa Formation (Saïd 1971; Beleity *et al.* 1986) and with the upper part of the Ataqa Group or the Rod El Hamal Formation as used by Darwish (1992).

Type section and locality

Wadi Aheimer, about 10 km S-SE of Ain Sukhna on the eastern footslopes of the Northern Galala massif (lat. 29°31' N and long. 32°29' E); the thickness is approximately 250 m. It was subdivided into 3 units; a lower unit: Shale member (60 m), a middle unit: Limestone member (90 m) and an upper unit: Silt-sandstone member, 100 m thick (Said & Eissa 1969; Said 1971).

Reference sections

The Aheimer Formation is studied by the present writer in the cliffs bordering Bir Aheimer between road marks 67 and 68 km of the Suez-Gharib road (162 m thick); another reference section is well exposed at road mark 79 km. The formation ranges in thickness from 65 m around Wadi Qiseib to more than 200 m slightly to the south of Ain Sukhna. The thickness of these highly faulted sequences varies greatly from place to place within short distances.

Boundaries

In the study area, the base of the Aheimer Formation is not exposed, but it has been considered to rest conformably over or to interfinger with the Abu Darag Formation (Klitzsch 1990) or the Rod El Hamal Formation (Said 1971). It underlies without visible unconformity the Permo-Triassic red beds of the Qiseib Formation. In places where the red beds were removed, *e.g.* on the northern footwalls of Wadi Aheimer and the northern face of Northern Galala, the Aheimer Formation is overlain unconformably by the Early Cretaceous Malha Formation (Swedan & Kandil 1990; Darwish 1992).

Description

The Permo-Carboniferous exposures in the Northern Galala form a narrow strip of dark-coloured sandstones alternating with a number of fossiliferous shale and dolostone beds, often in a cyclic manner. Several fining upward sequences of 10-20 m thickness were described by Bandel & Kuss (1987). Fluviatile sandstones commonly form the base of the cycle while the top is dominated by mudstones and dolomitized limestones with diverse shallow marine fauna. It can be subdivided into three members (Kora & Mansour 1992).

Lower member

This member is composed mainly of dark grey-black fossiliferous papery shales. They are slightly calcareous and intercalated with some yellow calcareous sandstone beds. It is most thick (60 m) south of Bir Abu Darag. About 34 m of this unit are exposed in the cliffs overhanging the asphaltic road of Suez-Gharib in two localities studied at road marks 68 and 79 km. The basal shales are rich in crinoidal columnals, bivalves, corals, brachiopods and bryozoans, reflecting shallow normal marine conditions. A low energy environment is suggested by the presence of delicate fenestrate bryozoans as well as the preservation of most crinoids in growth position. Trace fossils in the form of simple vertical and deep burrows are frequently encountered in the silty shale facies near the top of this member, indicating a marginal "intertidal" environment. So, a sheltered shallow marine environment changed to intertidal "lagoonal-deltaic" conditions during the deposition of the upper part of the lower member (Fig. 5).

Middle Member

This unit is made up of yellowish brown sandstones intercalated with few grey siltstone and calcareous sandstone beds. Along the measured section at road mark 68 km three to four thin hard brown crinoidal dolostone beds are encountered in this member which yielded some thin shelled brachiopods. According to Abdallah & El Adindani (1965), this member is best developed (106 m thick) in the cliffs that border Wadi Aheimer. There, it is characterised by the presence of six crinoidal limestone horizons and five fossiliferous sandy limestone beds. These rocks are associated with sandstones showing common small-scale herringbone cross bedding. The angle of inclination is 15-20° in two opposite directions forming chevrons. This suggests a partly intertidal depositional environment for the basal and top beds of this member. The characteristic microfacies of this member is an alternation of calcareous siltstone, sandy crinoidal dolostone and dolomitized algal grainstone. Within the carbonate facies, characteristic thali of encrusting phylloid (leaf-like) algae have been observed associated with rare calcareous foraminifers. These dolostone thin beds have yielded thin-shelled brachiopods together with other shell fragments in a clean, grain-supported fabric. This association indicates deposition in a shallow, well-lighted subtidal environment (Fig. 5).

Upper member

This member is composed of yellow-grey thick-bedded fine-medium grained sandstones with few light to dark grey siltstone interbeds. The unit attains an average thickness of 100 m at Wadi Aheimer. It thins to only 40 m in the northern face of the Northern Galala. Tabular-planar cross bedding is the dominant sedimentary structure observed. The sandstones are mostly quartz arenite, partly ferruginous and partly argillaceous. Rare badly preserved agglutinated foraminifers are the only microfossils which could be separated from the intercalating silt-shale horizons. These indicate a marginal environment containing some brackish lagoons and swamps. This environment might have been changed to fluviomarine conditions near the base and top of the succession (Fig. 5), where large-scale tabular bedding is more conspicuous in coarse ferruginous pebbly sandstones.

Fossil content and age

The Permo-Carboniferous succession of the Aheimer Formation yielded a variety of macro- and microfaunal and floral associations. The lower member is the richest fossil-bearing horizon encountered. It yielded an interesting rugose coral fauna described by Herbig & Kuss (1988) and Kora & Mansour (1991). The coral fauna includes typical Late Carboniferous "Westphalian D-Stephanian" forms e.g. *Roti-phyllum sokolovi* (Fomichev) and *Bothrophyllum pseudoconicum* Dobtolyubova, in addition to species belonging to the genera *Paraduplophyllum* Wu *et* Zhou, *Lytvolasma* Soshkina, *Verbeekiella* Penecke and *Assimulia* Fedorowski, which are known to cross the Carboniferous/Permian boundary. These corals are associated with characteristic Late Carboniferous brachiopods like *Anthracospirifer* sp. and *Rugosochonetes californicus* Watkins. Moreover, a rare Late Carboniferous conodont fauna dominated by *Streptognathodus* spp. was described from this interval (Omara & Kenawy 1966; Said & Eissa 1969). Some important calcareous foraminifers including *Hemigordius harltoni* Cushman *et* Waters, *Pseudobradyina* cf. *pulchra* Reitlinger, etc. were also recorded (Herbig & Kuss 1988) from this member (Fig. 5).

The middle member of the Aheimer Formation yielded an Early Permian association dominated by *Rhipidomella cordialis* Grant in addition to species of the genera *Composita* Brown and *Dielasma* King. On the other hand, a fossil flora derived from rocks overlying the Carboniferous dolostones of the Aheimer Formation at Bir Qiseib was determined by Lejal-Nicol *in* Bandel & Kuss (1987). The flora includes abundant branches of Coniferophyta and less common leaves of Pteridophylla; the stratigraphic range of which is uppermost Carboniferous-Early Permian. A typical Permian flora dominated by *Callipteris conferta* (Sternberg) and *Cordaites* sp. were described by Lejal-Nicol (1990) from deposits belonging to the upper member of the Aheimer Formation in the Wadi Araba area. These deposits yielded also Early Permian fossil algae including *Ortonella morikawai* Endo, *Solenopora texana* Johnson and *Osagia incrustata* Twenhofel (Omran & Khalifa 1988).

Thus, the Aheimer Formation ranges in age from the Late Carboniferous in its lower member to the Early Permian in the upper member (Fig. 5). This age assignment is quite accepted by almost all investigators, except Issawi (1996) who claims that the Aheimer Formation is Triassic in age.

Geographic distribution and local correlation

The Aheimer Formation is recorded in outcrops only from the western side of the Gulf of Suez. It is well exposed in the low cliffs facing the Gulf of Suez between Wadi Qiseib and Wadi Maà Sweilim. The rocks of this formation are upthrown against Cretaceous-Tertiary strata to the north of Wadi Aheimer. The landscape changed drastically in the last few years. The area is being prepared for investment; the infrastructures of many industrial and tourism projects were already constructed. Consequently, several faultblocks are destroyed and partly removed. The northernmost known outcrop (166 m thick) is that described by Swedan & Kandil (1990) from Wadi Um Reseis in the northern face of the Northern Galala. Equivalent rocks are recorded from the subsurface of the northern part of the Gulf of Suez *e.g.* Ataqa-1 and GS9-1 wells. The southernmost outcrops belonging to this unit are described from Wadi Araba along the southern footslopes of the Northern Galala Plateau. This locality was considered as the type section of the Rod El-Hamal Formation (Abdallah & El-Adindani 1965).

The "transitional strata" exposed in the cliffs between Wadi Bir Abu Darag and Wadi Bir Abu Sandug show a general resemblance with – and are equivalent to – the upper member of the Aheimer Formation (Said & Eissa 1969). However, Abd El Shafy & Abd El Azeam (1990) placed the "transitional strata" on top of the Aheimer Formation in spite of the absence of diagnostic fossils that may confirm such stratigraphic position. Moreover, Darwish (1992) prefered to relate all the Late Palaeozoic rocks exposed in the Northern Galala Plateau to one formal unit; the Rod El Hamal Formation, rather than to two or three formations (Fig. 4).

He considered this upper member of the Aheimer Formation to overlie unconformably the middle member, contrary to all other investigators, and correlated it with the Jurassic-Early Cretaceous sequence of Malha Formation.

DEPOSITIONAL HISTORY AND REGIONAL CORRELATIONS

The oldest adequately dated Carboniferous deposits exposed in the Gulf of Suez region are the marine carbonates (40 m thick) of the Um Bogma Formation known only from west-central Sinai. The Early Carboniferous faunas within this phase are of subtropical character. Oxygen isotope values suggest that the water temperature was 25°-28°C (Kora 1984). Based on isopach contour maps, litho- and biofacies, it has been suggested that the Um Bogma area was submerged during Middle-Late Visean time by a shallow transgressive sea with a shoreline running generally NE-SW and an open sea towards the NW (Kora *et al.* 1994).

From the faunal assemblages, there is evidence suggesting free communication with other areas in the Tethyan Realm, even though marine time-equivalent rocks have not yet been recorded in eastern Sinai, southern Israel-Palestine nor Jordan. The probable reason for the absence of this unit from most Near East localities is a major epeirogenic uplift during the Hercynian structural event. Erosion removed most of the Early Palaeozoic and a greater part of the Early Carboniferous from eastern Egypt. Regional stratigraphic evidence indicates that this Late Devonian-Early Carboniferous event was confined to a relatively narrow belt extending from the Gulf of Suez area to the vicinity of NE Syria and SE Turkey (Kohn *et al.* 1992). Although subsequent marine transgressions affected northern Egypt, probably only marginally, no major Late Devonian-Early Carboniferous erosion is recorded in the north Western Desert of Egypt and eastern Libya (Keeley 1989).

The Um Bogma carbonates are followed by a 200 m thick clastic sequence of the Abu Thora Formation. It is a sandstone-dominated succession intercalated with some kaolinitic claystone and carbonaceous shale beds, recorded from both sides of the Gulf of Suez. The litho- and biofacies encountered reflect gradational environments between coastal marine-swampy deltaic and fluviatile (Fig. 5). The association of badly preserved brachiopods and marine trace fossils in the kaolin/coal-bearing lower member refers to a remnant of the shallow marine conditions that prevailed earlier. The carbonaceous shale intervals yielded palynofloras of Late Visean-Early Westphalian (= mostly Serpukhovian-Bashkirian) age associated with some reworked Early Palaeozoic acritarchs (Kora & Schultz 1987) and chitinozoans which may be derived originally from Late Devonian Sinaitic-Negev palaeo-high (Zaslavskaya *et al.* 1995).

The Abu Thora Formation thins towards the Abu Durba area in the south and is conformably overlain by a black shale-sandstone succession (125 m thick) of the Abu Durba Formation. This fluvio-marine to marine facies contains conodonts and brachiopods indicating a Middle Westphalian (= Early Moscovian) age. A more or less similar Carboniferous succession (175 m thick) is exposed along the western coastal plain of the Gulf of Suez in the Abu Darag area. Marine influence becomes less clear southwards and the equivalent deposits in the Wadi El-Dakhel section (Southern Galala) are the southernmost marine exposures in NE Africa (Jux & Issawi 1983). In the subsurface of the Gulf of Suez region, this unit is usually referred to as Nubia "B member" by most oil geologists. Fluvial sandstones increase towards Aswan and Gilf Kebir areas and the Permo-Carboniferous Gilf Formation (Fig. 4) is the equivalent rock unit in southern Egypt (Issawi & Jux 1982; Issawi & Osman 1993).

The swampy-lagoonal and deltaic intervals have yielded microfloral elements which are represented in the North African (particularly Libya, Loboziak & Clayton 1988), central and northern Saudi Arabian (Clayton 1995; Owens & Turner 1995), Western European (Clayton *et al.* 1977), North American (Ravn & Fitzgerald 1982) and Western Ausrralian (Playford & Powis 1979) palynofloras by identical or closely similar forms. This suggests that the Carboniferous vegetation

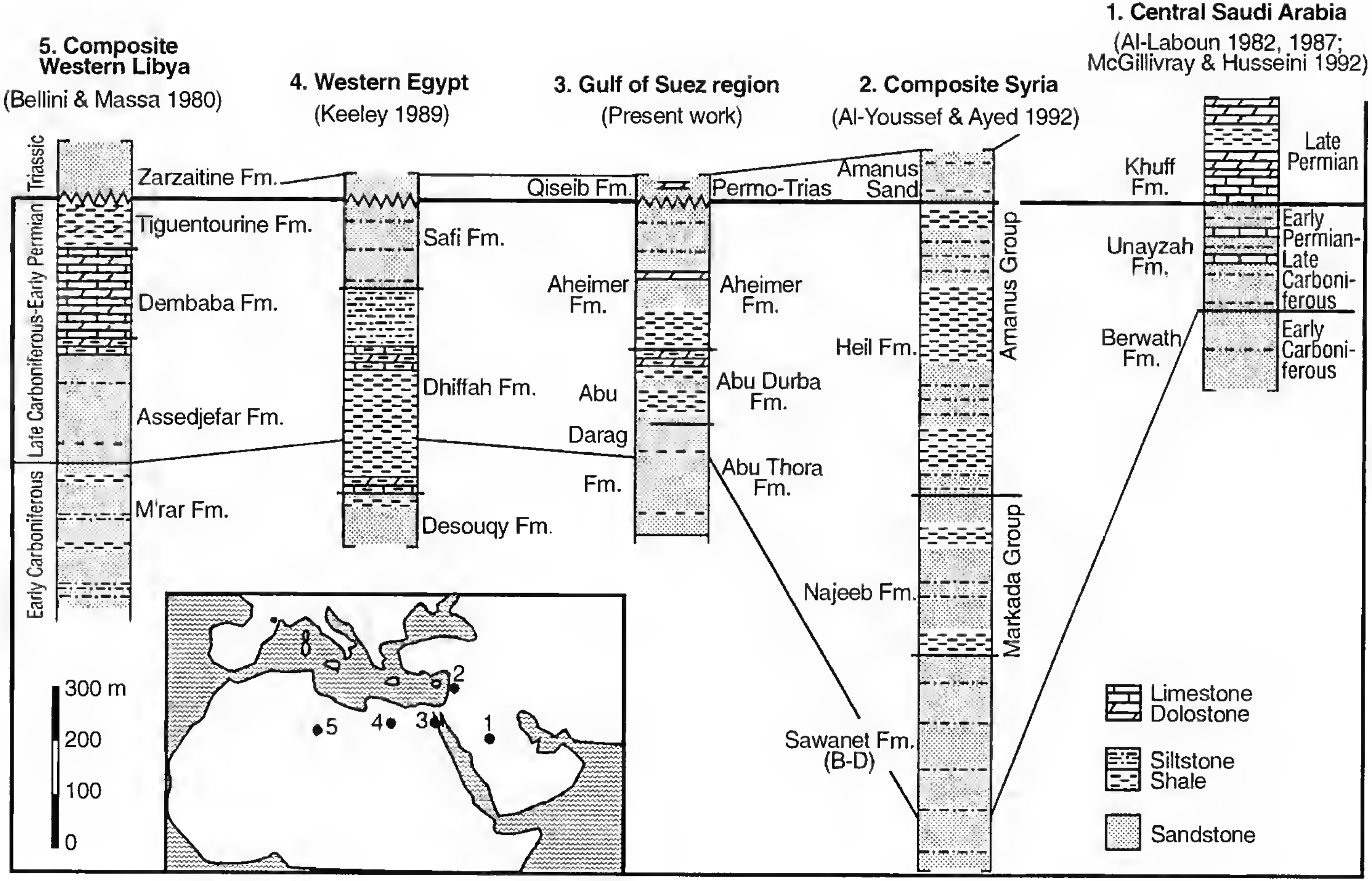

FIG. 6. — Correlation chart of the Permo-Carboniferous successions in Egypt and in some neighbouring countries.

of the Abu Thora and Abu Durba formations was of cosmopolitan nature and flourished before the Late Carboniferous glaciation in Gondwana which marked the beginning of provincialism in the floras (Kora 1993).

Outcrops in the Northern Galala are evidently of younger Carboniferous (Kazimovian-Gzhelian) and Early Permian ages. These deposits (250 m thick) reflect shallow subtidal-prograding shoreline and fluviatile conditions of the Aheimer Formation. This unit is recorded from the western side of the Gulf of Suez only and is overlain mostly by continental red beds of the Late Permian-Triassic Qiseib Formation. Equivalent deposits of the Ataqa Formation are restricted to the subsurface of the northern Gulf of Suez and central Sinai boreholes. The litho- and biofacies (Fig. 5) encountered indicate that the Aheimer Formation was deposited from a shallow transgressive-regressive sea, representing probably the last major invasion of the Tethys Sea to the area during the Palaeozoic times.

The absence of the Aheimer Formation from southern Sinai points to another uplift that took place in the region at the end of the Carboniferous or during the Early Permian. Much of the just deposited Permo-Carboniferous sediments were removed by erosion as were the remaining older deposits. The removal of the older deposits of the Abu Durba Formation from the central and northern parts of the Um Bogma area, Sinai suggests that this area was deeper truncated than the western side of the Gulf of Suez. Moreover, Carboniferous rocks have not yet been recorded in eastern Sinai, southern Israel-Palestine nor Jordan. In the Negev Desert, Early Permian clastics of the Saad Formation were recorded from the subsurface overlying the Precambrian basement and underlying thick Permo-Triassic succession (Zaslavskaya *et al.* 1995) reflecting even more deeper truncation.

In the subsurface of the northern Western Desert, Permo-Carboniferous paralic clastics equivalent to those of the Gulf of Suez include the Dhiffah and the overlying Safi formations (Fig. 6). Similar deposits are recognised from Cyrenaica in northeastern Libya (Vachard *et al.* 1993). The style of Late Palaeozoic deposition in southern Libya and into Algeria seems quite unlike that in Egypt (Keeley 1989). Equivalent deposits in western Libya basins include partly the Mrar, Assedjefar, Dembaba and Tiguentourine formations (Bellini & Massa 1980). Palaeobiogeographic relations with Tunisia, Morocco and the Algerian Sahara were stronger in the Early Carboniferous than in the Permo-Carboniferous time (Kora 1995a).

In central Saudi Arabia, the Permo-Carboniferous Unayzah Formation was recorded from Al Qasim Province and Widyan Basin (Al-Laboun 1982, 1987; Khalifa 1993). These swampy-deltaic deposits overlie conformably older Carboniferous clastics (Fig. 6) equivalent to the Khalata-Berwath formations (Owens & Turner 1995), and underlie conformably also the well-known Late Permian marine rocks of the Khuff Formation (McGillivray & Husseini 1992; Al-Aswad & Kamel 1992). These carbonate rocks represent one of the largest outcrops of marine Permian in the world, with clastics increasing southwards.

The Permo-Carboniferous sandstones are recorded also in the Mosandam Peninsula of northern Oman (Gharif Formation) and from western Iran (Faraghan Formation), underlying conformably Late Permian carbonates (Khalifa 1993). In the Western Iraqi Desert, equivalent Permo-Carboniferous clastics have been described as the Gaara Formation (Nader *et al.* 1993, 1994) reflecting also swampy-fluviatile conditions. Time-equivalent rocks in Syria (Fig. 6) include shallow marine-deltaic subsurface deposits of the Markada Group (Sawanet and Najeeb formations) and continental clastics of the Amanus Group (Hejl Formation). If the thicknesses estimated by Al-Youssef & Ayed (1992) are correct, then the Syrian Permo-Carboniferous deposits (>1000 m in the Palmyrid Trough) will be the thickest succession ever recorded in the Middle East. Equivalent less developed deposits have also been recorded from SE Turkey and northern Iraq.

CONCLUSION

A unified lithostratigraphic scheme for the Late Palaeozoic succession in the Gulf of Suez region

is proposed, including from base to top:
– Um Bogma Formation: Middle-Late Visean,
– Abu Thora Formation: mostly Serpukhovian-Bashkirian,
– Abu Durba Formation: Moscovian,
– Aheimer Formation: Kazimovian/Gzhelian-Early Permian,
– Qiseib Formation: Late Permian-Triassic.

The Um Bogma Formation is known only from the eastern side and the Aheimer Formation is recorded only from the western side of the gulf; all other formations are distributed on both sides.

In spite of the fact that both the Abu Thora and the overlying Abu Durba formations, which are originally described from Sinai, do occur on the western side of the Gulf of Suez, the complicated structural pattern of the Abu Darag-Wadi Araba area makes it difficult to differentiate in the field between the clastics building up these two formations. In that case, the name Abu Darag Formation can be applied for the Carboniferous succession exposed in that particular area.

The Carboniferous-Permian succession in the region is bounded by two unconformities; a pronounced lower one, coinciding with the Hercynian structural event, resulted in the removal of most of the underlying Early Palaeozoic and the basal Early Carboniferous deposits. The second uplift took place mostly during the Early Permian and led to subsequent erosion of a part of the Late Carboniferous and all the Early Permian successions from Sinai. It seems that the Late Permian sea transgression which covered wide areas in the Near East had not affected Egypt, since continental red beds (the Qiseib Formation) of Late Permian-Triassic age overlie unconformably the Permo-Carboniferous succession.

The fossil communities indicate that the Permo-Carboniferous succession of the Gulf of Suez region was deposited during transgressive/regressive cycles of a subtropical epicontinental sea which might have covered the northern parts of the Eastern and Western Deserts of Egypt, eastern Libya and greater areas in North Africa. The swampy-lagoonal and deltaic intervals in the Late Carboniferous succession can be correlated with equivalent deposits from northern and central Saudi Arabia, Syria and other countries in the Near East. Since no marine Permo-Carboniferous deposits are recorded south of the study area, it can be concluded that the Gulf of Suez region and greater areas in North Africa and the Near East were situated not far from the southern shore of the Tethys Sea during most of the Permo-Carboniferous time.

The current knowledge of the Permo-Carboniferous fauna of the Gulf of Suez region, though containing enough elements pointing to a free communication with the thicker marine Tethyan sequences, is still far from complete. Excessive investigation of the marine layers in the Abu Thora, Abu Durba and Aheimer formations may result in the recognition of more distinctive fossils. Conodonts and calcareous foraminifers are necessary microfaunas in calibrating the biostratigraphic and palaeogeographic interpretations.

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Quelques données stratigraphiques sur le Permien inférieur du Salt Range (Pakistan)

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MOTS CLÉS
Péri-Téthys, stratigraphie, palynologie, Permien, Salt Range, Pakistan.

RÉSUMÉ
L'association palynologique de la base de la formation de Warcha appartiendrait à la biozone à *Kingiacolpites subcircularis.* La formation de Warcha serait d'âge sakmarien à artinskien. Du Rajasthan en Inde en position autochtone en passant par le Salt Range allochtone jusqu'à l'Afghanistan, s'étendait un vaste bassin continental avec quelques passées marines au Permien inférieur sur la marge nord du Gondwana bordant la Téthys.

ABSTRACT
Some stratigraphic data on the Early Permian of the Salt Range (Pakistan). The palynological association at the base of the Warcha Formation would belong to the *Kingiacolpites subcircularis* biozone. The Warcha Formation would be dated the Sakmarian to Artinskian. From the Rajhastan in India in an autochtonous position to the Salt Range in an allochtonous position and to the Afghanistan extended a wide continental basin with some marine bands during the Early Permian on the North margin of the Gondwanaland fringing the Tethys.

KEY WORDS
Peri-Tethys,
stratigraphy,
palynology,
Permian,
Salt Range,
Pakistan.

INTRODUCTION

La chaîne du Salt Range représente la première nappe de charriage de la chaîne de l'Himalaya à matériel sédimentaire allant de l'Éocambrien à l'Actuel, décollée au niveau du sel d'âge éocambrien. Nous présentons dans cette note quelques données lithostratigraphiques (Iqbal 1993) et biostratigraphiques nouvelles sur le Permien inférieur. Les seuls échantillons traités ayant livré des palynomorphes proviennent d'une couche de charbon du Permien inférieur de l'ouest du Salt Range à Burrikhel près de l'Indus (Fig. 1), les autres essais sur les argilites rouges ayant été négatifs.

DONNÉES LITHOSTRATIGRAPHIQUES ET SÉDIMENTOLOGIQUES

Le Permien inférieur comprend les formations de Tobra, Dandot, Warcha, Sardhai et Amb et le Permien supérieur, les formations de Wargal et Chidru (Fig. 1). Ces formations ont été définies par Fatmi (1974) et Shah (1977). Cinq coupes ont été levées de l'ouest vers l'est à Burrikhel, Katha, Nila Wahan, Ghandala et Pidh. La formation de Tobra, formée d'argilites à galets et de conglomérats est interprétée comme un dépôt de tillite. La formation de Dandot est formée de siltites et d'argilites marines à *Eurydesma*. La formation de Warcha est constituée d'alternances décamétriques de grès et d'argilites rouges (Fig. 1). Son épaisseur décroît de l'ouest (200 m) vers l'est (67 m). Elle est connue au nord dans l'allochtone et au sud dans l'autochtone par forages pétroliers. À Burrikhel et Katha, les barres gréseuses présentent des bases érosives avec des galets et des litages obliques courbes ou sigmoïdes à courants opposés. À Burrikhel, un conglomérat et une couche de charbon est observée à la base de Warcha, qui repose directement sur la formation de Tobra. Une datation palynologique a pu être réalisée à ce niveau. Ce sont des dépôts fluviatiles à l'amont dans des rivières à méandres. À Nila Wahan et Ghandhala, les faciès gréseux à litage oblique sigmoïde sont associés à des faciès hétérolithiques de type siltites à rides et drapage argileux. À Pidh, les siltites et argilites dominent. Ce sont des dépôts fluviatiles à influences tidales à Nila Wahan et Ghandhala et estuariens à Pidh. Un passage latéral de faciès s'observe donc entre l'ouest et l'est du Salt Range, du domaine continental au domaine marin. La formation de Sardhaï est formée d'argilites bleu lavande. Les formations suivantes sont marines : gréseuse et carbonatée pour la formation d'Amb, carbonatée pour la formation de Wargal, gréseuse et carbonatée pour la formation de Chidru (P.J.R.G. 1985).

DONNÉES BIOSTRATIGRAPHIQUES ET CHRONOSTRATIGRAPHIQUES

La formation de Tobra (Fig. 3) est d'âge assélien présumé par comparaison avec la formation de Talchir en Inde (Pareek 1981; Casshyap & Tewari 1984). Elle contient des plantes, *Glossopteris* et *Gangamopteris* (Wopfner & Casshyap 1997). La formation de Dandot est datée par *Eurydesma* du sommet de l'Assélien-

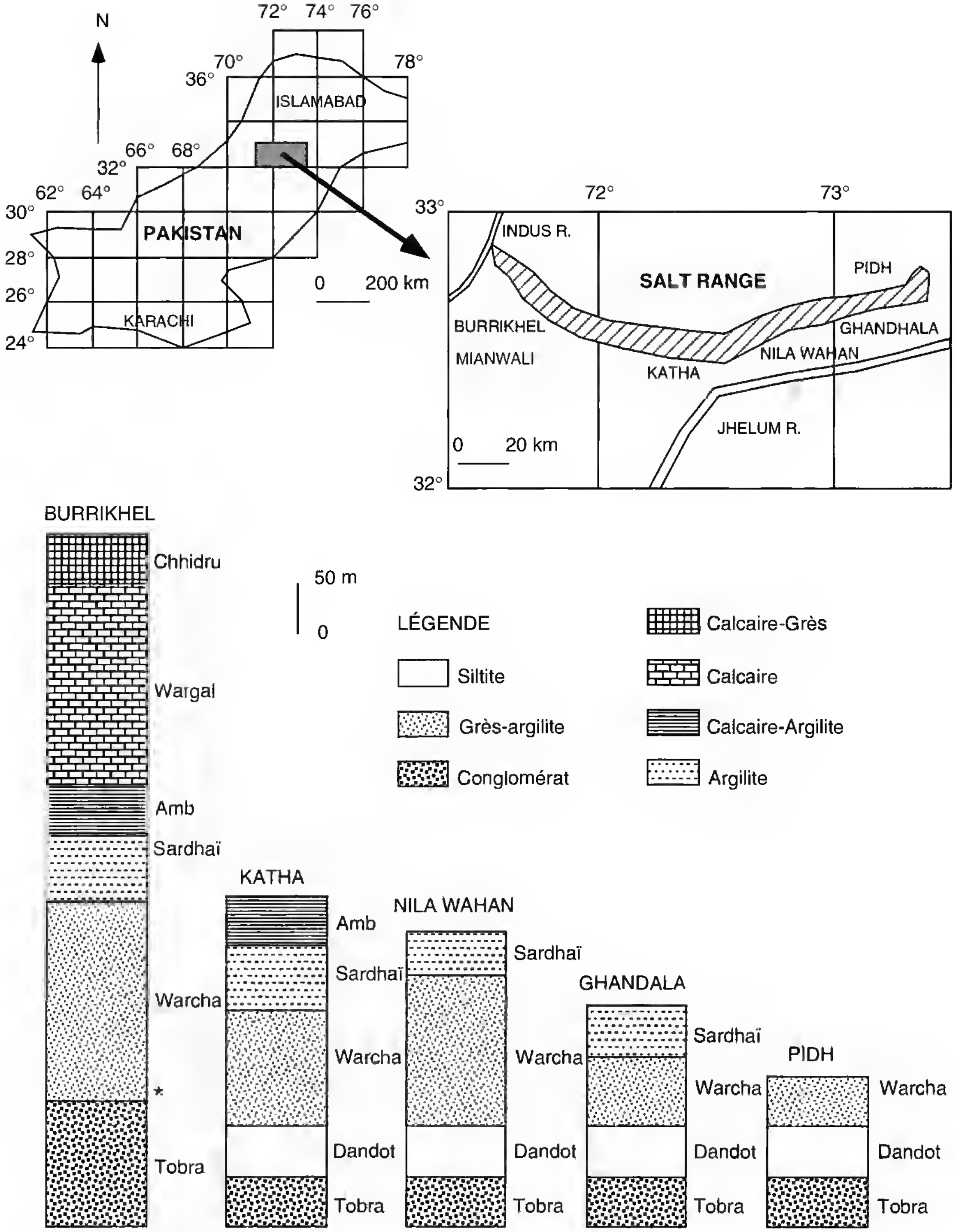


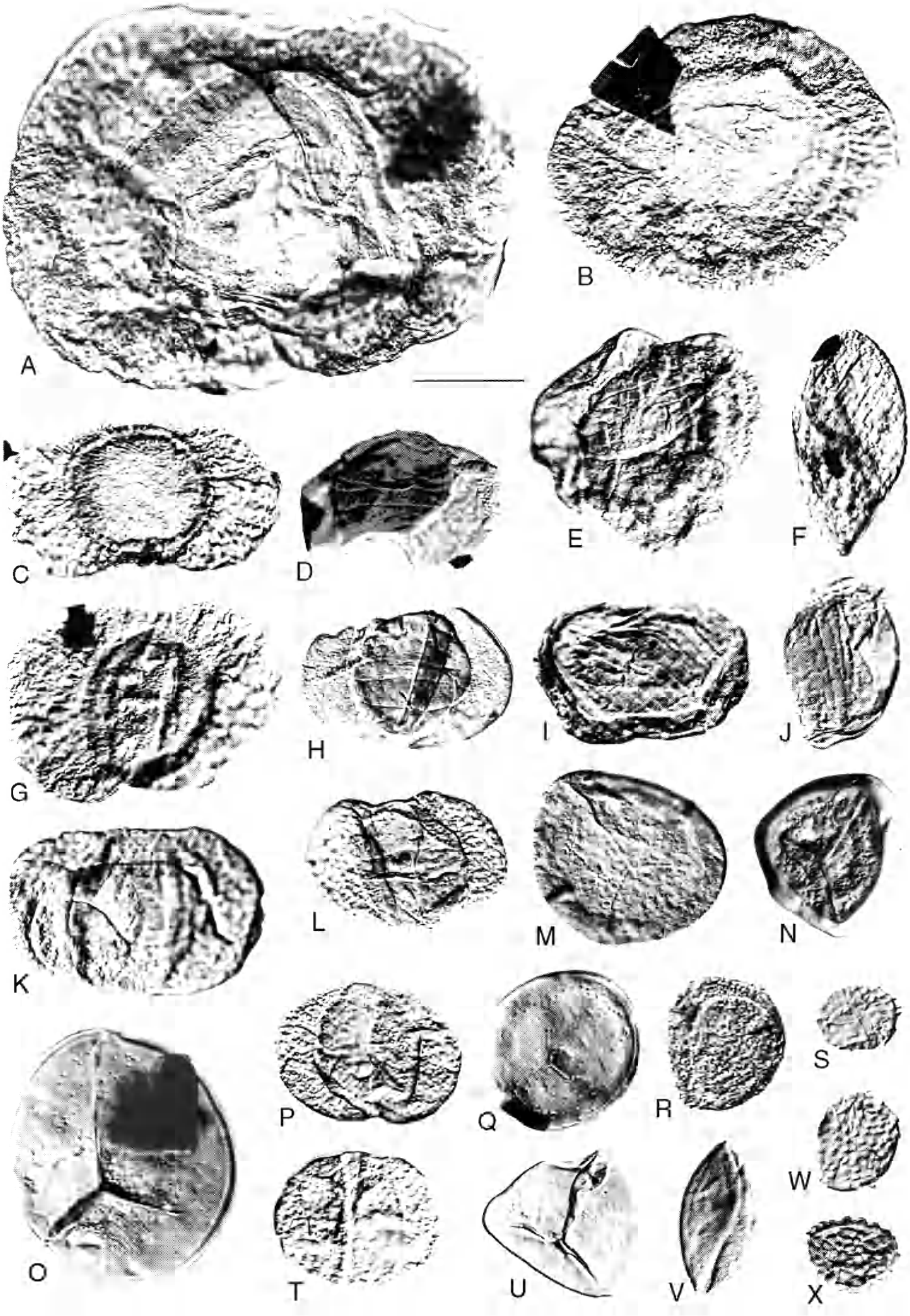
FIG. 1. — Colonnes stratigraphiques du Permien inférieur du Salt Range avec cartes de situation. * : localisation de l'échantillon palynologique.

base du Sakmarien par comparaison avec des faunes d'Inde, d'Australie ou d'Amérique du sud (Veevers & Powell 1987) et d'Afghanistan (Vachard 1980).

Seul le charbon situé à la base de la formation de Warcha a pu être daté par la palynologie (Fig. 2). Citons parmi les spores : *Leotriletes directus* Balme *et* Hennely, *Calamospora* sp., *Punctatisporites* spp., *Punctatisporites fongosus* Balme, *Phyllothecotriletes* cf. *golatensis* Staplin, *Retusotriletes diversiformis* (Balme *et* Hennely) Balme & Playford, *Brevitriletes cornutus* (Balme *et* Hennely) Backhouse, cf. *Iraqispora labrata* Singh, *Verrucosisporites* sp., *Densoisporites solidus* Segroves, *Jayantisporites* sp. B Backhouse, *Laevigatosporites vulgaris* Ibrahim, *Laevigatosporites* spp. et *Thymospora* cf. *ipsvicienis* (de Jersey) Jain. Citons parmi les grains de pollen Monosaccites : *Florinites eremus* Balme *et* Hennelly, *Potonieisporites novicus* Bhardwaj, *Caheniasaccites* cf. *ellipticus* Bose *et* Maheswari, *Cannanoropolis janakii* Potonié *et* Sah, *Striomonosaccites* sp. A Foster. Citons parmi les grains de pollen Disaccites : *Scheuringipollenites ovatus* (Balme *et* Hennely) Foster, *Scheuringipollenites* cf. *maximus* (Hart) Tiwari, *Alisporites* sp., *Sahnites* sp. *sensu* Backhouse. Citons parmi les grains de pollen Disaccites striatiti : *Protohaploxypinus limpidus* (Balme *et* Hennely) Balme *et* Playford, *Protohaploxypinus* sp., *Striatopodocarpites cancellatus* (Balme *et* Hennely) Hart, *Striatopodocarpites solitus* (Bharadwaj *et* Salujah) Foster, *Striatopodocarpites gondwanensis* Lakhanpal, Sah *et* Dube. Citons parmi les grains de pollen Plicates : *Tiwariasporis simplex* (Tiwari) Maheswari *et* Kar, *Vittatina fasciolata* (Balme *et* Hennely) Bharadwaj, *Vittatina* sp. Citons parmi les grains de pollen Praecolpates : *Marsupipollenites* cf. *triradiatus* Balme *et* Hennely, *Marsupipollenites striatus* (Balme *et* Hennely) Foster. Citons parmi les grains de pollen Monocolpates : *Cycadopites cymbatus* (Balme *et* Hennely) Segroves.

Cette association est composée de formes provenant de plantes vivant sous climat tempéré dans le biome 6 tempéré frais (Ziegler 1990 ; Ziegler *et al.* 1997). Cette association est très similaire aux cortèges palynologiques décrits dans le Permien inférieur gondwanien, de l'Inde et d'Australie en particulier. L'absence totale de formes caractéristiques telles que *Lueckisporites*, *Corisaccites*, *Lunatisporites* ou *Densipollenites* exclut toute attribution au Permien supérieur, quel que soit le système de référence adopté. *Potonieisporites novicus*, souvent considéré comme cantonné à la base du Permien, n'est représenté que par un seul spécimen. Les grains de pollen bisaccates sont, par contre, abondants et variés, notamment les bisaccates striés comme *Protohaploxypinus limpidus* et *Striatopodocarpites cancellatus*. Des formes habituellement décrites en Australie occidentale, *Marsupipollenites striatus*, *Jayantisporites* sp. B, *Vittatina fasciolata* ont une extension stratigraphique couvrant la période Arrinskien-Sakmarien (Backhouse 1991). Love (1994) a décrit en Oman différentes biozones : la biozone à *Potonieisporites* sp. et *Punctatisporites* sp., attribuée au Westphalien supérieur-Stéphanien inférieur, la biozone à *Microbaculispora* sp., *Cristatisporites* sp. et *Parasaccites* spp. attribuée au Stéphanien, la biozone à *Cycadopites cymbatus*, *Protohaploxypinus* sp. et *Vittatina* sp., attribuée à l'Assélien et au Sakmarien, la biozone à *Kingiacolpites subcircularis*, attribuée au Sakmarien supérieur à Artinskien, connue également en Inde dans la formation Barakar (Lele & Srivastava 1977). Cette association serait donc similaire à la biozone à *Cycadopites cymbatus*, attribuée à l'Assélien et au Sakmarien. Comme la formation de Dandot serait d'âge sommet de l'Assélien-base du Sakmarien, la formation de Warcha serait donc d'âge sakmarien à artinskien et pourrait corres-

FIG. 2. — L'assemblage palynologique de la base de la formation de Warcha. **A**, *Potonieisporites novicus* Bhardwaj ; **B**, *Cannanoropolis janakii* Potonié *et* Sah ; **C**, *Caheniasaccites* cf. *ellipticus* Bose *et* Maheswari ; **D**, *Striopodocarpites solitus* (Bharadwaj *et* Salujah) Foster ; **E**, *Striomonosaccites* sp. A Foster 1979 ; **F**, *Tiwariasporis simplex* (Tiwari) Maheswari *et* Kar ; **G**, *Sahnites* sp. *sensu* Backhouse 1990 ; **H**, *Striatopodocarpites* cf. *cancellatus* (Balme *et* Hennely) Hart ; **I**, *Marsupipollenites triradiatus* (Balme *et* Hennely) Foster ; **J**, *Vittatina* sp. ; **K**, *Protohaploxypinus* sp. ; **L**, *Protohaploxypinus limpidus* (Balme *et* Hennely) Balme *et* Playford ; **M**, *Punctatisporites* sp. ; **N**, cf. *Iraqispora labrata* Singh ; **O**, *Punctatisporites fongosus* ; **P**, *Alisporites* sp. ; **Q**, *Phyllothecosporites* cf. *golatensis* Staplin ; **R**, *Densoisporites solidus* Segroves ; **S**, **W**, *Brevitriletes cornutus* (Balme *et* Hennely) Backhouse ; **T**, *Scheuringipollenites ovatus* (Balme *et* Hennely) Foster ; **U**, *Leiotriletes directus* Balme *et* Hennely ; **V**, *Cycadopites cymbatus* (Balme *et* Hennely) Segroves ; **X**, *Thymospora* cf. *ipsviciensis* (de Jersey) Jain. Échelle : 4 µm.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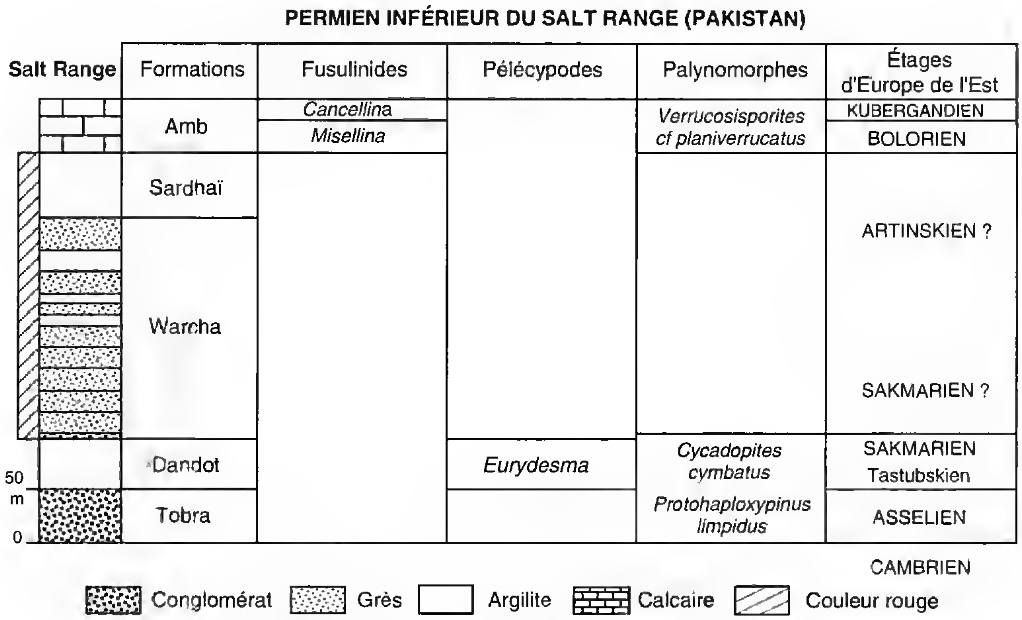

FIG. 3. — Tableau stratigraphique du Permien inférieur du Salt Range (d'après Iqbal 1986).

pondre à la formation P2 d'Afghanistan (Vachard 1980). La formation de Sardhaï serait alors d'âge artinskien.

La formation d'Amb serait, d'après les petits foraminifères et les fusulines (Haq 1987), d'âge bolorien, baigenzinien tardif ou artinskien tardif (zone à *Misellina*), mais d'après Vachard (communication orale) ces foraminifères sont endémiques et cette datation reste imprécise. Il n'est donc pas possible d'infirmer ou de confirmer un hiatus important à la base de cette formation. Si ce hiatus existe, la formation d'Amb pourrait ne représenter qu'une partie de l'Artinskien. La partie supérieure de la formation d'Amb présente des plantes, *Glossopteris* et *Gangamopteris* (Wopfner & Casshyap 1997) et des microflores, *Luckeisporites singhii, Corisaccites* sp. (Balme 1970), ce qui donne un âge kungurien-ufimien-kazanien à la limite Permien inférieur et supérieur et serait équivalent à la biozone à *Cancellina*. La formation de Wargal présente à la base des petits foraminifères et fusulines (*Neoschwagerina margaritae*) d'âge murgabien et au sommet des fusulines (*Nanlingella simplex*) d'âge dzhulfien supérieur. Elle présente *Luckeisporites singhi* et *Luckeisporites virkhiae* (Balme 1970), ce qui donne un âge Permien supérieur avec des formes provenant de plantes vivant sous climat chaud. La formation de Chidru montre des petits foraminifères et des fusulines (*Colaniella*) du Dzhulfien. Elle présente *Vitreisporites signatus, Cedripites priscus, Protohaploxypinus microcorpus*. Cette association est similaire à la zone à *Protohaploxypinus microcorpus* définie en Australie (Backhouse 1991) d'âge permien supérieur. La formation de Wargal est corrélable avec les formations carbonatées 7 à 9 d'Afghanistan et la formation de Chidru avec la formation 10 d'Afghanistan (Vachard 1980). On observe là, entre le Salt Range et l'Afghanistan, un passage latéral entre des faciès continentaux avec quelques intercalations marines à des faciès marins de la Téthys. Les flores du Permien supérieur du Pakistan et d'Oman sont des flores mixtes à éléments gondwaniens, européens et cathaysiens (Broutin *et al.* 1990, 1995). La formation de la Gharif d'Oman (Broutin *et al.* 1995), qui présente une association similaire à la zone à *Protohaploxypinus microcorpus* définie en Australie (Backhouse 1991), pourrait être

contemporaine de la formation de Wargal plutôt que de celle de Chidru.
En Inde, Chandra & Chandra (1987), Tiwari & Tripathi (1987), Navale & Saxena (1989) ont suivi le changement paléoclimatique à partir des flores et des microflores depuis la formation de Talchir (Assélien) à *Gangamopteris*, *Glossopteris* et microflores monosaccates de climat froid (biome 8), en passant par les formations de Karharbari et Barakar (Sakmarien à Artinskien) à charbon, flore à *Gangamopteris* dominant, puis *Glossopteris* dominant et microflores monosacates, puis dissacates non striées et striées montrant le passage d'un climat tempéré frais (biome 6) à un climat tempéré chaud (biome 5), jusqu'aux formations des Barren Measures, Raniganj et Kamthi du Permien supérieur à *Glossopteris* dominant et microflores disaccates striées de climat tempéré chaud soit sec soit humide (biome 5).

CONCLUSION

Si le Permien supérieur est bien daté par les foraminifères (P.J.R.G. 1985 ; Haq 1987), le Permien inférieur continental restait mal daté et ces données palynologiques apportent quelques précisions stratigraphiques nouvelles. L'association palynologique de la base de la formation de Warcha appartiendrait à la biozone à *Cycadopites cymbatus*. La formation de Warcha serait d'âge sakmarien à artinskien. Du Rajasthan en Inde en position autochtone (Pareek 1981) en passant par le Salt Range allochtone jusqu'à l'Afghanistan, s'étendait un vaste bassin continental avec quelques passées marines au Permien inférieur sur la marge nord du Gondwana bordant la Téthys. L'assemblage palynologique est un assemblage de climat tempéré frais (biome 6) sous une latitude de 40°S d'après l'hypothèse de Scotese & Langford (1995). Par contre, le Permien supérieur présentait un assemblage de climat tempéré chaud sous une latitude de 25°S.

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