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OUTLINE OF THE PERMIAN PALEOGEOGRAPHY IN THE CENTRAL AND EASTERN PART OF THE BALKAN PENINSULA

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Key words – Paleogeography; facies; sedimentology; terranes; Balkans; Carpathian; Upper Paleozoic; Carboniferous; Permian.

Abstract – Upper Carboniferous formations are preserved within the present territory of the Balkan Peninsula in a system of paleogeographical zones: (1) the very high "Paleo-Balkan" mountain range running in a WNW-ESE direction (Variscan orogeny); (2) the rolling plain north of the range; (3) intermontane hills west and south of the orogenic belt; (4) high mountains further west and south of the orogenic belt (to the present Serbian-Macedonian and Thracian massifs); (5) a shallow sea basin west and south of the massifs. Principal paleogeographical zones changed slightly in configuration through the Early Permian times. Sedimentation covered large, still isolated, areas.

The Thracian and Serbian-Macedonian massifs were preserved, as well as the high orogenic features, in and around which were deposited separate, often very thick cones of dominantly coarse proluvial-colluvial clastics. North of the orogenic belt, towards the Moesian region, layers of fine sediments continued to form. On the southern and western piedmont of the Variscan range, coarse clastics and volcaniclastics were deposited in intermontane zones, and finegrained beds at high levels more distant from range.

The Variscan mountain range was lower through the Late Permian, and locally covered with deltaic sediments that extended northeastwards into a larger continental basin. Terrigenous deposits in the Provadia Depression pass into evaporites formed in sabkha facies. Another large basin was formed in the intermontane zone. There is not a facial transition between the continental and marine Permian (and Upper Carboniferous) sedimentary rocks. This fact can been explained by a separation of the two sedimentation areas, because of paleorelief existing between them.

Parole chiave – paleogeografia; facies; sedimentologia; *terranes*; Balcani; Carpazi; Paleozoico superiore; Carbonifero; Permiano.

Riassunto – Il Carbonifero superiore è presente nella Penisola Balcanica all'interno di un sistema di zone paleogeografiche: (1) l'alta catena montuosa Paleo-Balcanica che decorre secondo una direzione WNW-ESE (dovuta all'orogenesi varisica); (2) la pianura ondulata a nord della catena; (3) le colline intramontuose ad ovest e a sud del *belt* orogenico; (4) le pronunciate montagne poste più oltre ad ovest e a sud del *belt* orogenico (sino agli attuali massicci Serbo-Macedone e Tracio); (5) un bassofondo marino sviluppato ad ovest e ad est dei suddetti massicci. Le principali zone paleogeografiche modificarono leggermente la loro configurazione nel corso del Permiano inferiore. I processi di sedimentazione si attuarono all'interno di ampie, ancora isolate aree. I massicci Tracio e Serbo-Macedone furono preservati, come pure i più pronunciati lineamenti orogenici entro e attorno ai quali si depositarono, tra loro separati, conoidi di materiali clastici spesso assai potenti e in prevalenza grossolani, di natura proluviale e colluviale. A nord del *belt* orogenico, in direzione della Piattaforma Moesia, continuarono ad aversi sedimenti fini. Nelle aree pedemontane a sud e ad ovest della catena varisica confluirono, in aree intramontuose, apporti detritici grossolani e prodotti vulcanoclastici, nonché, a livelli stratigraficamente alti e in luoghi relativamente più distanti dalla catena, sedimenti clastici fini. I lineamenti morfologici della catena varisica si attenuarono nel corso del Permiano superiore, e localmente furono ricoperti da depositi deltizi che si estesero verso nordest a formare un più ampio bacino continentale. Nella depressione di Provadia, depositi terrigeni passano a evaporiti di sabkha. Un secondo ampio bacino si generò nella fascia intramontuosa. Non si osserva alcuna transizione di facies tra Permiano (e Carbonifero superiore) continentale e marino. Ciò si può spiegare ammettendo una separazione tra le due aree di sedimentazione, determinata dalla presenza di un paleorilievo.

PRE LATE PALEOZOIC DEVELOPMENT

The Late Paleozoic development and paleogeography of the present central part of the Balkan Peninsula were largely predetermined by the Early Paleozoic evolution (Fig. 1). The eastern part of the region (on Bulgarian territory) consists of three large Lower Paleozoic tectonostratigraphic superterranes (composite terranes): Moesian, Balkan and Thracian (Yanev, 1993, 1997, and references therein). The Balkan superterrane is composed of several lower-rank

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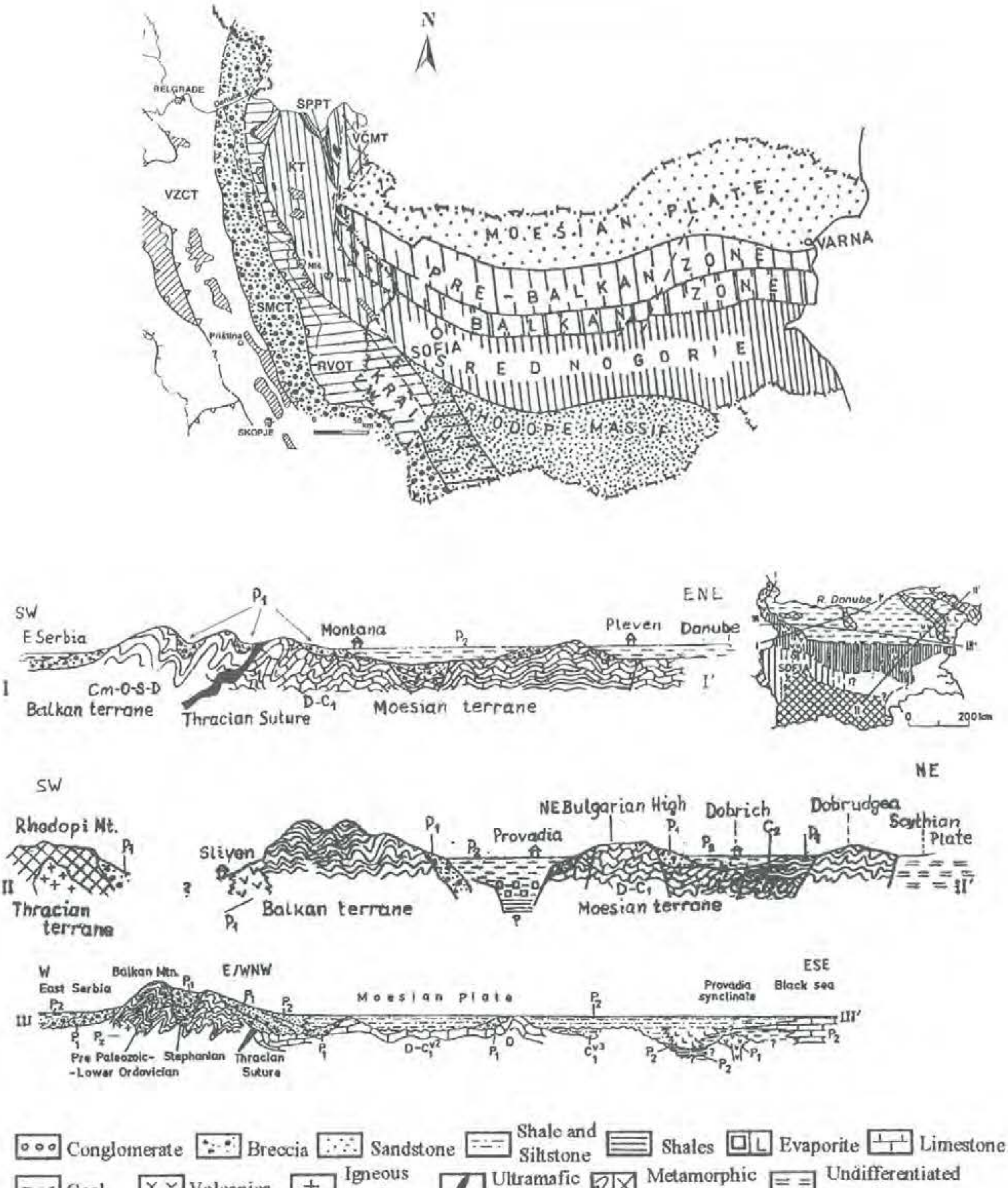

Fig. 1 – Scheme for the relationship between the main Bulgarian and Serbian tectonostratigraphic units. The abbreviations from east to west: MP - Moesian Plate; VCMT - Vrska Chuka-Miroc Terrane; SPPT - Stara Planina -Porec Terrane; KT - Kuchaj Terrane; RVOT - Ranovac-Vlasina-Osogovo Terrane; SMCT - Serbian-Macedonian Composite Terrane; VZCT - Vardar Zone Composite Terrane; E KRAI. and W KRAI.– Eastern and Western Kraishte, respectively. Moesian Plate – Moesian Terrane; Pre-Balkan Zone, Balkan Zone, Srednogorie and Kraishte – Balkan Composite Terrane; Phodope massif – part of the Serbo-Macedoniam-Thracian Composite Terrane. (The Serbian part after Krstic & Karamata, 1992; the Bulgarian part after Bonchev, 1986 – see Yanev & Cassinis, 1998).

Chronostratigraphical abbreviations in the sections: Cm - Cambrian; O - Ordovician; S - Silurian; D - Devonian; P_Z - Paleozoic *s.l.*; C_1^{v2} - Lower Carboniferous, Middle Visean; C_1^{v3} - Lower Carboniferous, Upper Visean; C_2 - Upper Carboniferous; P_1 - Lower Permian; P_2 - Upper Permian.

units, including the Western Kraishte, Eastern Kraishte and Sakar-Standja zones. Within the boundaries of ex-Yugoslavia, as well as the extensions of the Moesian and Balkan (Carpatho-Balkan) superterranes, are the Serbian-Macedonian, the Vardar and the Dalmatian-Hercegovinan, and between the latter two are the Jadar, Drina – Ivanjica and Dinaridic ophiolite belts, East Bosnian-Durmitor, and Central Bosnian terranes (Krstic & Karamata,1992; Karamata & Krstic,1996; Fig. 2).

The latter seven units extend over to Greece and partly to Albania. The Serbian-Macedonian superterrane is definitely connected with the Thracian one, the Balkan with Carpathian in Romania (Krautner *et al.*, 1981), and the Moesian superterrane forms the Paleozoic basement beneath the Walachian depression of Romania to the fault bounding the northern Dobrogea. Boundaries between the mentioned tectonostratigraphic units are tectonic and repeatedly active, including the significant Alpine overthrust. It is noteworthy that the sediment origin data for adjacent blocks sometimes distinctly indicate that these crustal blocks, although their contacts have been later tectonised or individual blocks rotated, were placed a similar order and only mutually displaced (drawn closer and in places thrust one over another). At the present time the terranes form a complex collage of peri-Gondwana blocks that successively docked from the south during the Late Paleozoic and Early Carboniferous (Visean).

LATE PALEOZOIC PALEOGEOGRAPHY

The most important explanation of the Late Paleozoic paleogeography of the region (Balkan Peninsula), and especially of its continental sedimentation, is the collision of the Balkan-Carpathian and Moesian superterranes, in the interval between the Early and Late Carboniferous epochs, which produced the Variscan range. The Thracian and Serbian-Macedonian massifs also collided with the Carpatho-

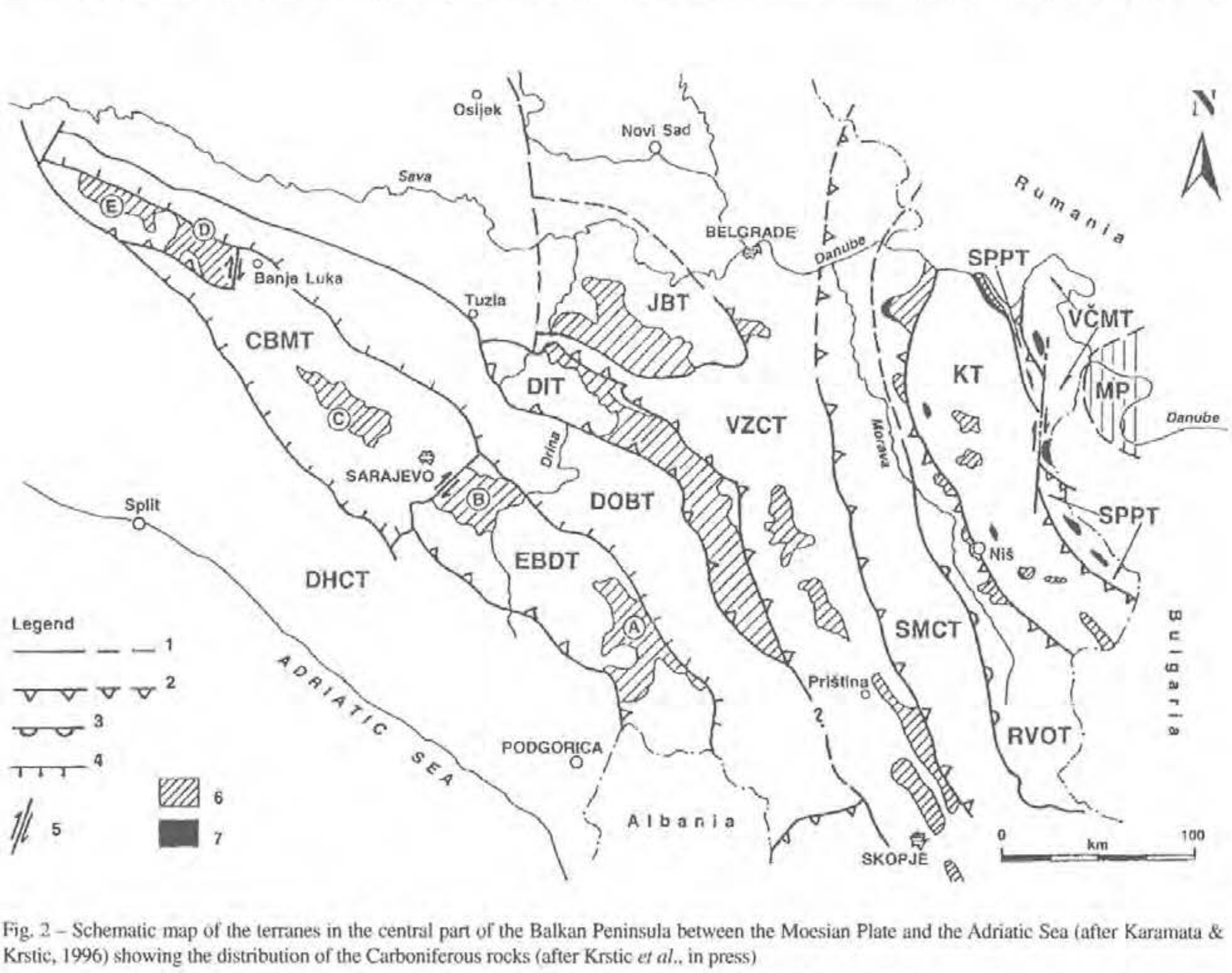

Fig. 2 – Schematic map of the terranes in the central part of the Balkan Peninsula between the Moesian Plate and the Adriatic Sea (after Karamata & Krstic, 1996) showing the distribution of the Carboniferous rocks (after Krstic *et al.*, in press)

Legend: 1 - fault, observed and covered; 2 - overthrust, observed and covered; 3 - unclear relationship; 4 - tectonised boundary; 5 - major strike-slip faults; 6 - marine Carboniferous; 7 - continental Carboniferous. Abbreviations for the Yugoslavian area (corresponding partly to that in Fig. 1) from east to west: MP - Moesian Plate; VCMT - Vrska Chuka-Miroc Terrane; SPPT - Stara Planina-Porec Terrane; KT - Kuchaj Terrane; RVOT - Ranovac-Vlasina-Osogovo Terrane; SMCT - Serbian-Macedonian Composite Terrane; VZCT - Vardar Zone Composite Terrane ; JBT - Jadar Block Terrane; DIT - Drina-Ivanjica Terrane; DOBT - Dinaric Ophiolite Belt Terrane; EBDT- East Bosnian-Durmitor Terrane (A - Lim and Tara catchment area, B - Praca region); CBMT - Central Bosnian Mts. Terrane (C - Central Bosnian Mts region, D - Sana region, E - Una region); DHCT - Dalmatian-Herzegovinian Composite Terrane.

Balkan superterrane, but this hypothesis cannot beverified due to a lack of Upper Paleozoic sediments on the massifs. Ophiolites of the pre-existing oceanic crust are compressed between these three superterranes in many places (Haydoutov, 1987; V. Quadt *et al.*, 1998).

The region is paleogeographically reconstructed using biostratigraphy, as well as the spatial distribution of facies and the thickness variations of series, stages, and lithic bodies, petrographic compositions with respect to the source area of derived material, and paleotransport measurements (Figs 3, 4, 5 and 6) (Janev, 1969; Yanev, 1970, 1979, 1981, 1989; Maslarevic & Protic, 1975). The principal criterion is the facial character of the Upper Paleozoic sediments. Information on the types and distributions of continental sediments and facies in the Upper Paleozoic series of Serbia is given by Maslarevic & Krstic (1999), and for Bulgaria by Yanev in Yanev & Adamia (1999), Cassinis & Yanev, 1999 and Yanev *et al.*, (1999) in the volume of abstracts of the Brescia congress, and in this book.

Late Carboniferous paleogeography

Upper Carboniferous formations are preserved on the present territory of the Balkan Peninsula in a system of different paleogeographical zones: (1) the high "Paleo-Balkan" mountain range running in a WNW-ESE direction (Variscan orogeny); (2) the rolling plain north of the range; (3) intermontane hills west and south of the orogenic belt; (4) high mountains further west and south of the orogenic belt (to the present Serbian-Macedonian and Rila-Rhodope massifs); (5) a shallow sea basin west and south of the massifs (Fig. 4). Theprevious zones, according to the available data, were areas only of denudation, not deposition. Isolated depressions of the paleo-Balkan zone contain continental, often coal deposits, varying in thickness from 0 to 1700 m in the Westphalian of Svoge; from 0 to 850 m. in the Stephanian between Ozirovo and Lyutadzik, NW Bul-

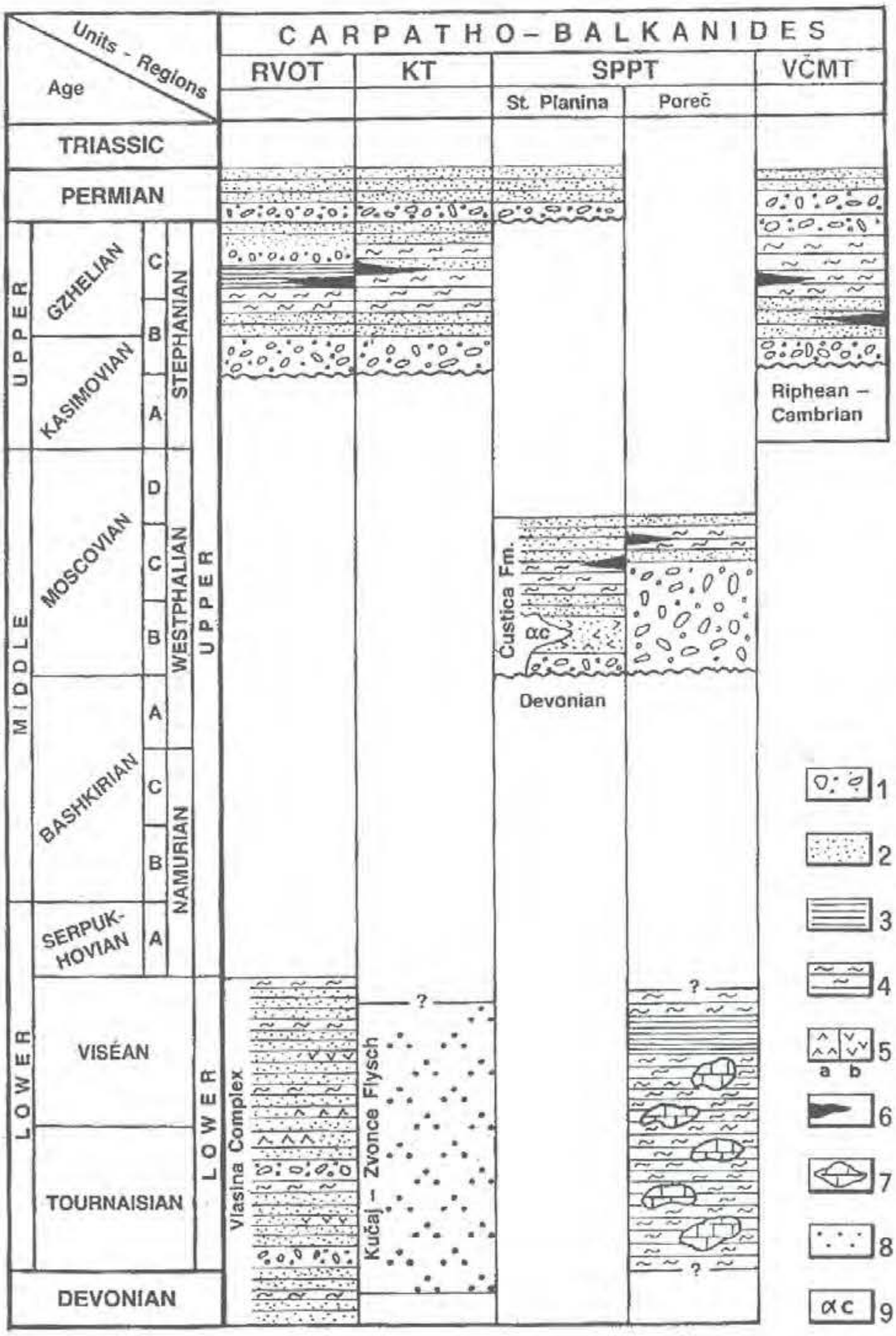

Fig. 3 – Schematic column for the Carboniferous successions in their main zones of distribution in East Serbia (after Krstic *et al.*, in press). Legend: 1. Conglomerate; 2. Sandstone; 3. Shale; 4. Siltstone; 5a. Basic volcanic rocks; 5b. Acidic volcanic rocks; 6. Coal; 7. Olistostromes; 8. Flysch; 9. αc: Paleoandesite.

garia; and from 0 to 360 m in East Serbia (Maslarevic, 1961; Yanev, 1985) (Fig. 5). Basins are supplied with rock clasts derived from the basement and adjacent areas (Lower Paleozoic sediments and low-crystalline metamorphic rocks). The paleo-rivers of the western Stara Planina Mountain drained to the north and northeast, and those of Eastern Serbia to the southwest (Vrshka Chuka). Late Carboniferous tectonic movements, mainly block displacements (Late Variscan?), transformed some of the Namurian-Westphalian depressions from depositional into denudational areas (Svoge), and formed new grabens (seven in Bulgaria and three in Serbia) during the Stephanian. A Westphalian volcano-sedimentary formation was formed in the Stara Planina-Porecka zone of Eastern Serbia only, unconformably overlain by Permian rocks (Krstic & Maslarevic, 1970). Westphalian deposits are lacking to the ENE and WSW of this zone, where Stephanian sediments lie unconformably over crystalline schists or over Lower Paleozoic rocks and pass upwards into Permian deposits (Krstic *et al.*, in press; Fig.3). The trough-bounding faults often were courses for subsequent volcanic flows. Reliable Upper Carboniferous sediments in the Moesian region are known from boreholes, but so far only at Kavarna-Balchik, Southern Dobrogea. More than 1600 m of Namurian-Westphalian clastic and coal deposits of alluvial plains are met by a marine basin to the east (or SE?). The larger part of the Moesian region was probably a major sediment bypass zone during the Late Carboniferous. Intermontane valleys in Bulgaria bear records

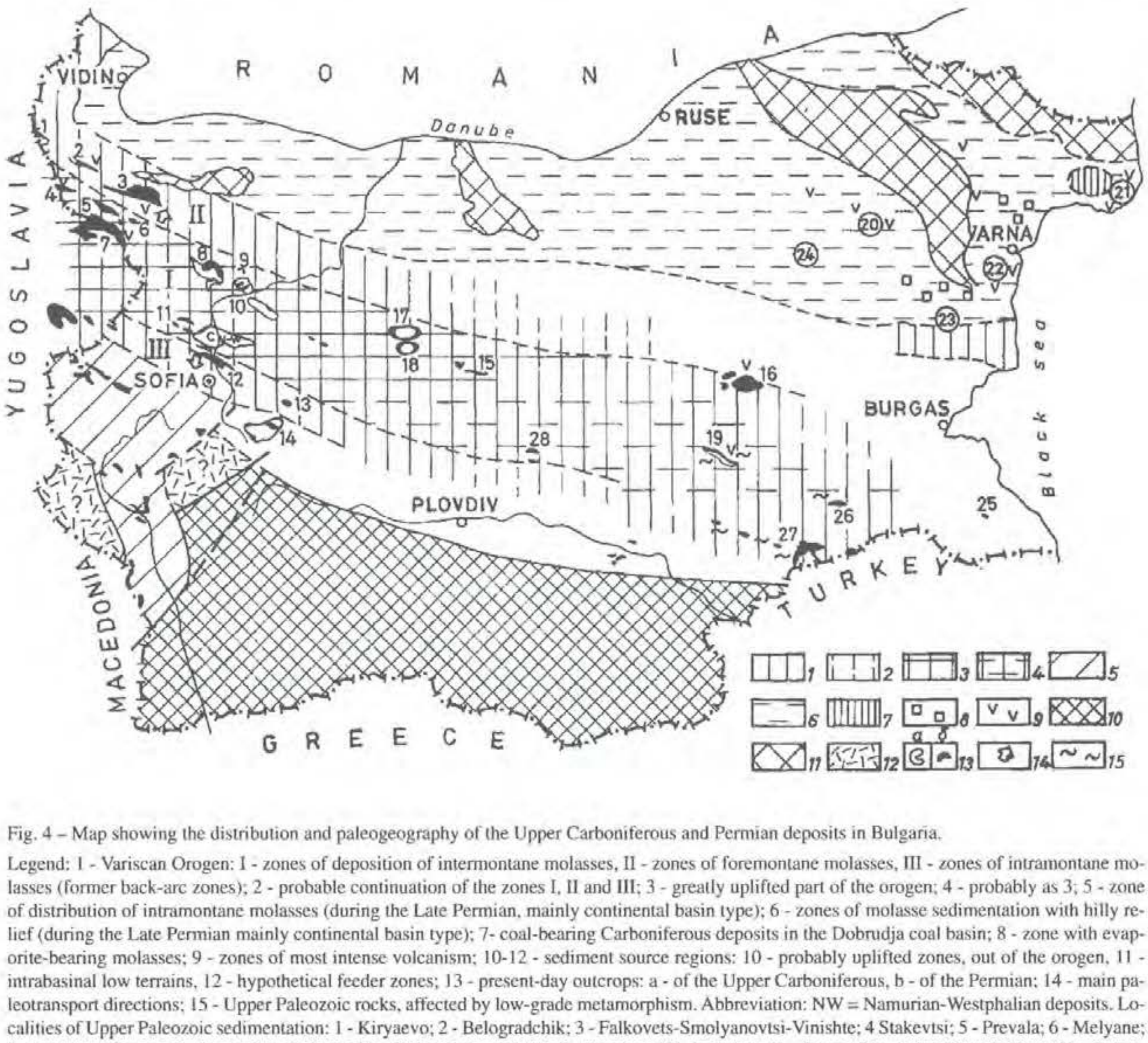

Fig. 4 – Map showing the distribution and paleogeography of the Upper Carboniferous and Permian deposits in Bulgaria.

Legend: 1 - Variscan Orogen: I - zones of deposition of intermontane molasses, II - zones of foremontane molasses, III - zones of intramontane molasses (former back-arc zones); 2 - probable continuation of the zones I, II and III; 3 - greatly uplifted part of the orogen; 4 - probably as 3; 5 - zone of distribution of intramontane molasses (during the Late Permian, mainly continental basin type); 6 - zones of molasse sedimentation with hilly relief (during the Late Permian mainly continental basin type); 7- coal-bearing Carboniferous deposits in the Dobrudja coal basin; 8 - zone with evaporite-bearing molasses; 9 - zones of most intense volcanism; 10-12 - sediment source regions: 10 - probably uplifted zones, out of the orogen, 11 - intrabasinal low terrains, 12 - hypothetical feeder zones; 13 - present-day outcrops: a - of the Upper Carboniferous, b - of the Permian; 14 - main paleotransport directions; 15 - Upper Paleozoic rocks, affected by low-grade metamorphism. Abbreviation: NW = Namurian-Westphalian deposits. Localities of Upper Paleozoic sedimentation: 1 - Kiryaevo; 2 - Belogradchik; 3 - Falkovets-Smolyanovtsi-Vinishte; 4 Stakevtsi; 5 - Prevala; 6 - Melyane; 7 - Midzhur-Kopren; 8 - Draganitsa-Bela Rechka-Ozirovo-Lyutadzhik; 9 - Zverino; 10 - Ignatitsa; 11 - Svoge (Namurian-Westphalian); 12 - Sofioter Stara Planina Mts; 13 - Bunovo; 14 - Lozen Planina Mts-Bakarel Hills; 15 - Troyan; 16 - Sliven; 17 - Glozhene; 18 - Vasilyovo; 19 - Sveti Ilia Hills; 20 - Borehole Vassil Levski; 21 - Borehole Kaliakra; 22 - Boreholes Varna-Ravna Gora; 23 - Boreholes Mirovo; 24 - Borehole Vetrino; 25 - Kondolovo - Strandja (marine Lower Permian in allochthonous position?); 26 - Klokotnitza (Upper Carboniferous?); 27 - East Rhodopi (redeposited pebbles from marine Upper Permian); 28 - Chernogorovo. (In circles - after drill-hole data; the others, after outcrop data).

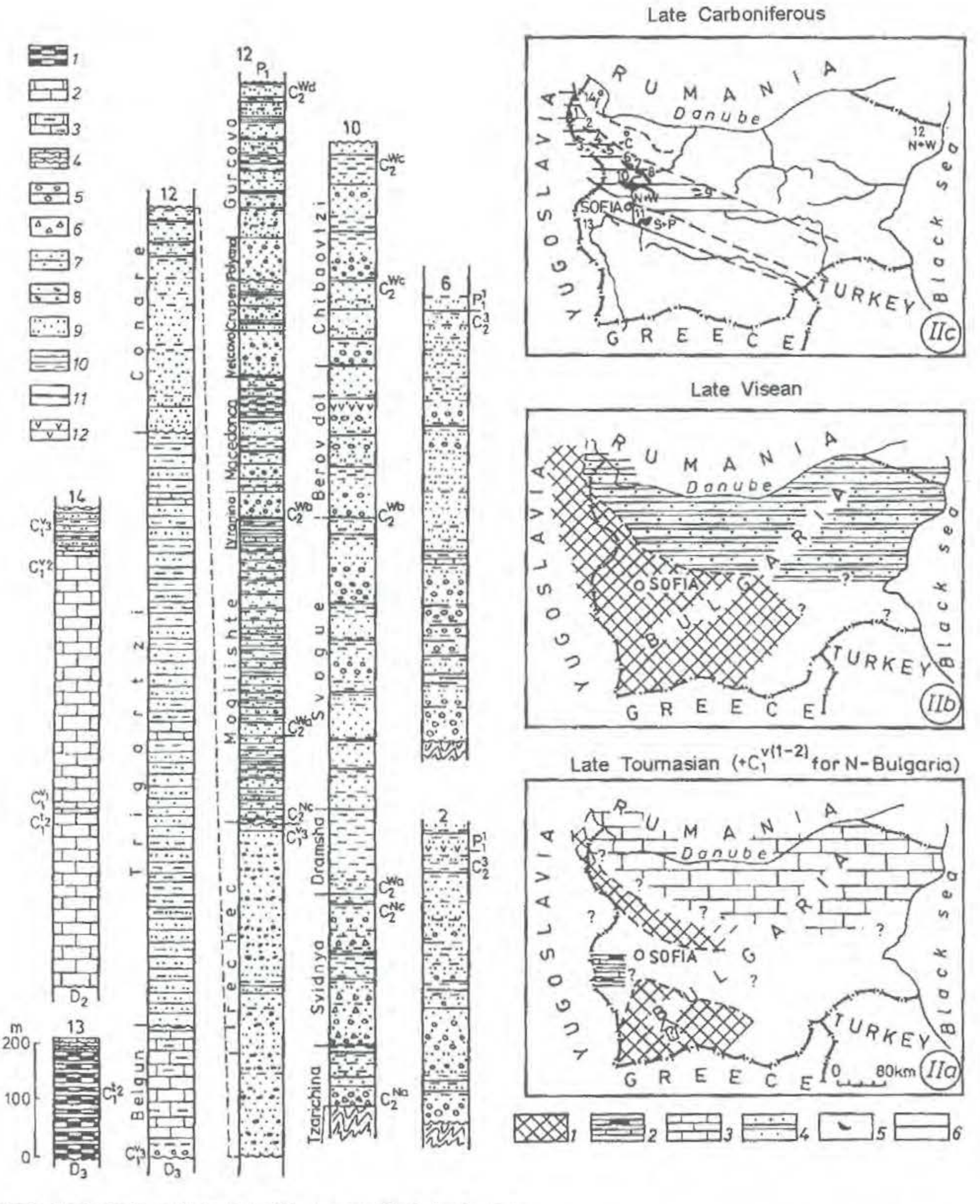

Fig. 5 - The Carboniferous System in the Bulgarian part of the Balkan Peninsula.

Legend: I. Lithological columns: 1 - Cherts; 2 - Limestones; 3 - Shaly limestones; 4 - Wave shaped and nodular limestones and marls; 5 - Conglomerates; 6 - Breccias; 7 - Sandstones; 8 - Sandstones with coal fragments; 9 - Siltstones; 10 - Shales; 11 - Coal.; 12 - volcanic rocks. II. Lithological-paleogeographical schemes for Bulgaria during the Carboniferous times. IIa - Late Tournaisian: 1 - dry lands; 2 - area with flint-carbonate-shaly sedimentation; 3 - area with shallow marine carbonate sedimentation. IIb - Late Visean: 4 - area with terrigenous-shaly sedimentation. IIc - Late Carboniferous: 5 - present day outcrops; 6 - distribution of continental sediments (see Fig. 4 for more detail). Abbreviations in the columns: D_3 - Upper Devonian; C_1^{t2} - Upper Tournaisian; C_1^{v1} - Lower Carboniferous, Lower Visean; C_1^{v2} - Lower Carboniferous, Middle Visean; C_1^{v3} - Lower Carboniferous, Upper Visean; C_2^{Na} - Upper Carboniferous, Namurian A; C_2^{Nc} - Upper Carboniferous, Namurian C; C_2^{Wa} - Upper Carboniferous, Westphalian A; C_2^{Wb} - Upper Carboniferous, Westphalian B; C_2^{Wc} - Upper Carboniferous, Westphalian C; C_2^{Wd} - Upper Carboniferous, Westphalian D; C_2^3 - Upper Carboniferous, Stephanian; P_1^1 - Lower Permian. Abbreviations in the schemes: $C_1^{v(1-2)}$ - Lower Carboniferous, Lower to Middle Visean.

of Stephanian, dominantly alluvial-lacustrine sedimentation on Lozen Mt. (south of Sofia). The deposited materials were derived from the Thracian massif. Stephanian sediments in the East-Serbian extension of this zone are interpreted as colluvial-alluvial and lacustrine deposits. There is no evidence of Late Carboniferous sedimentation in the Thracian and Serbian-Macedonian massifs.

Permian paleogeography

The principal paleogeographical zones changed slightly in configuration through the Early Permian. Sedimentation covered large, still isolated areas. The Thracian and Serbian- Macedonian massifs were preserved, as well as the high orogenic features in and around which were deposited separate, often very thick (up to more 3000 m) cones of dominantly coarse proluvial-colluvial clastics. North of the orogenic belt, toward the Moesian region, bands of fine sediments (cones tapering toward the periphery, often in playa facies) continued to form (or formed around new highs). On the southern (and western?) piedmont of the Variscan range, coarse clastics and volcaniclastics were deposited in intermontane zones (*e.g.* the Sofian Stara Planina Mt. and Sveti Iliya Heights, in Bulgaria, and the Serbian part of the Stara Planina Mts.), and finegrained beds at high levels more distant from the range. The Lozen Planina Mt. provides evidence (composition of fragments and paleotransport measurements) of material supply from the Thracian terrane (Kozhoukharov *et al.*, 1980). A connection with a sea basin could have existed on the extreme southeastern periphery of the zone (Strandzha Mt.) where the Thracian massif ended. The small outcrops of Lower Permian marine sediments here (Malyakov & Bakalova, 1978) could even be allochthonous. Material in Eastern Serbia was washed down from the Serbian-Macedonian massif, as indicated by conglomerates (fragments of gneisses and various schists, including muscovite and amphibole-bearing).

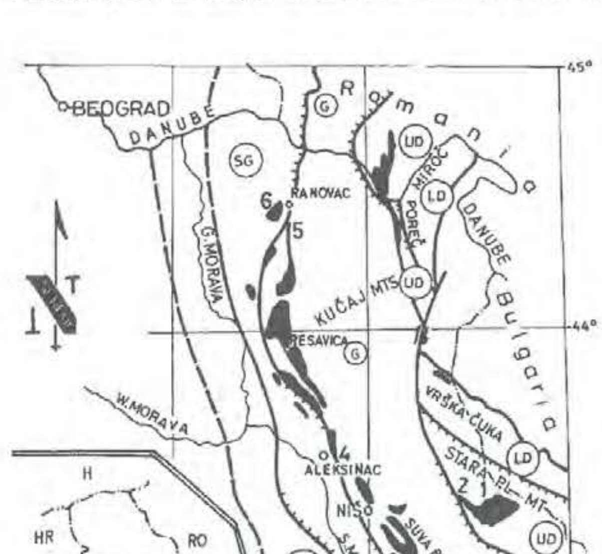

Fig. 6 – Distribution scheme of the continental Permian sediments in East Serbia (after Maslarevic & Krstic, Fig 1, this volume). The stratigraphy and lithologies of the various Permian successions are presented by Maslarevic & Krstic in Fig. 2, this volume). Abbreviations for the tectonic units: LD - Lower Danubicum; UD - Upper Danubicum; G - Gethicum; SG - Supragethicum; SMM - Serbian-Macedonian massif.

The Variscan mountain range was lower through the Late Permian and locally covered (*e.g.* between Kopren peak and Montana town) with deltaic sediments that extended northeastward into a larger continental basin. This basin covered a large part of the Moesian superterrane over Lower Permian and older rocks. Another large basin was formed in the intermontane zone. It is well studied in Bulgarian Kraishte (Yanev, 1979) and a large part of Eastern Serbia, the so-called Inner Belt of Eastern-Serbian red sandstones, where two zones of Permian rocks are recognised: the western, which is part of the Supragethicum (between the Mlava and Pek rivers), and the eastern, which belongs to the Gethicum (Gornjak-Suva Planina Mts. zone) (Maslarevic, 1967; Fig.6).

Deposits of these two continental basins are predominantly finegrained red terrigenous sediments; locally, coarser material was deposited or parts of the basins were temporarily dry. Coarse clastic sediments from alluvial fans prevail at the top of the Permian in the extreme north of the Supragethicum towards the Danube (Krepoljin) (Maslarevic & Krstic, 1999).

Terrigeneous deposits at Provadiya (in NE Bulgaria) pass into evaporites (mainly halite) formed in sabkhas facies, indicating a probable periodic seawater incursion on the basin periphery. One hypothesis is that the extreme southeastern parts of the zone, equivalent to the southern basin, had some communication with the Late Permian sea, because Mesozoic conglomerates near Mandrica (easternmost Rhodope Mts) include redeposited carbonate clasts with Upper Permian fauna (Trifonova & Boyanov, 1986). Data are lacking for Upper Permian, either continental or marine, sedimentary rocks over the Thracian and Serbian-Macedonian massifs. Extending west and south of the massifs, in the Jadar terrane of northwestern Serbia, are marine sediments of the Middle and Upper Permian (Pantic & Pesic, 1975).

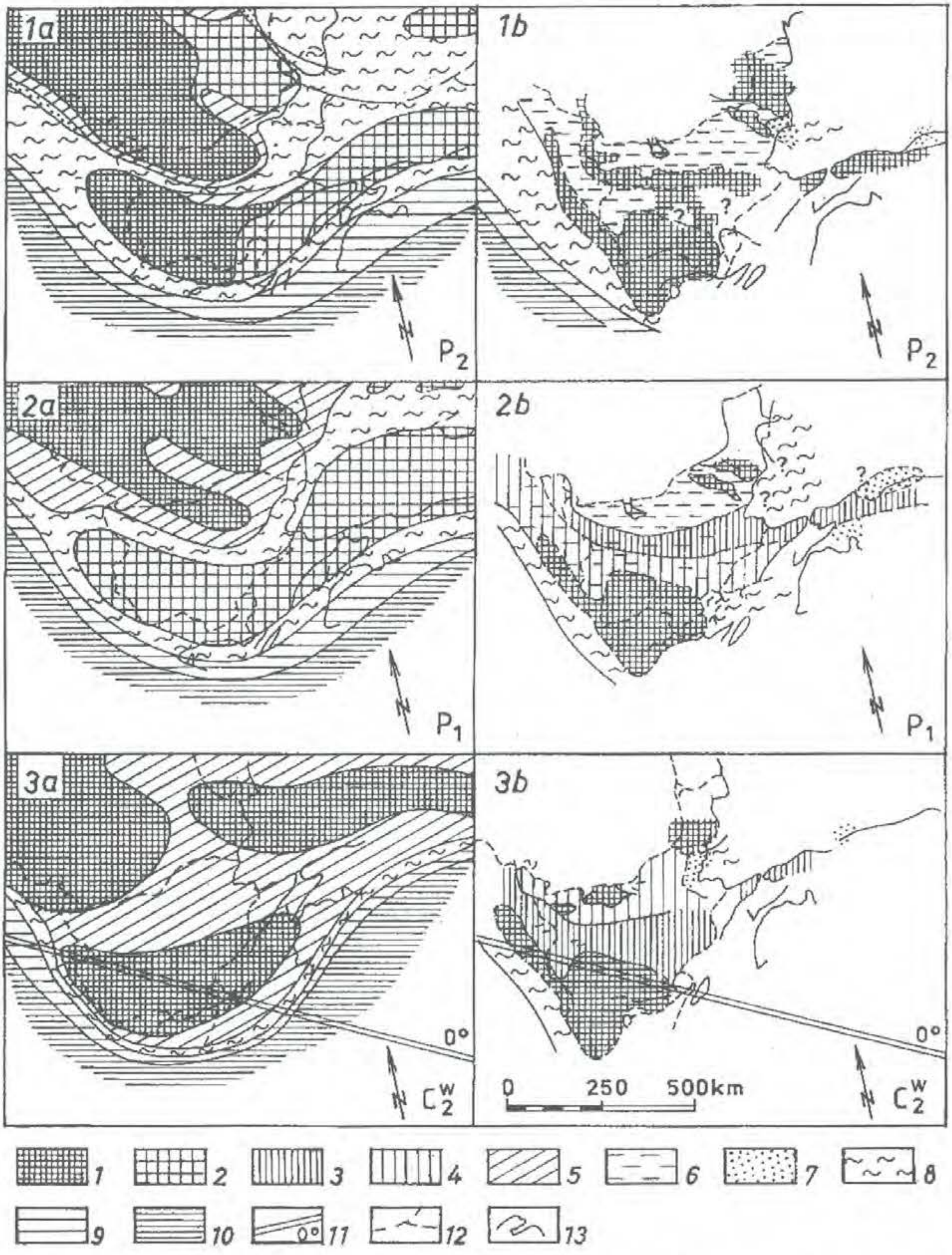

Fig. 7 – Comparative paleogeographical schemes for part of southeastern Europe during the "Westphalian" (C_2^w), Early (P_1) and Late Permian (P_2) times. 1a, 2a, and 3a: fragments from the maps of Ylmaz *et al.* (1996); 1b, 2b, and 3b: after Yanev (in print).

Legend: 1 - continental highlands (zones without deposition, sediment sources); 2 - continental lowlands (sediment bypass); 3 - continental highlands with intramontane (very limited) sedimentation; 4 - continental intermontane deposition; 5 - continental, fluvial, lacustrine deposition; 6 - continental basin deposition; 7 - deltaic and coastal plain deposition; 8 - marine shelf deposition; 9 - basin or slope deposition; 10 - deep ocean deposition; 11 - equator; 12 - state boundaries; 13 - block and coastline.

These shallow-water sediments, transgressive over the pre-existing rocks, consist of dolomites and clastics (Middle Permian) and limestones abounding with megafaunal associations of mixed Alpine, east-European and Indo-Armenian species (Late Permian). Shallow marine deposits are exposed in a limited area of the Thracian massif on some of the Greek islands (Lesvos, Skiros, etc), and further southeast in Turkey.

CONCLUSION

It should be mentioned in conclusion, that there is no facial transition between the continental and marine Permian (and Upper Carboniferous) sedimentary rocks. This fact can be explained by a separation of the two main sedimentation areas, due to the paleorelief existing between them. The position of this paleorelief corresponds of the location of the Thracian and Serbo-Macedonian massifs and is confirmed by the rock distribution and facies assemblages around the uplifted domains.

The revised paleogeographic picture of the Late Paleozoic of the Balkan Peninsula, based on numerous studies and regional generalisations (Maslarevic & Protic, 1975; Protic, 1978; Yanev, 1981; Yanev & Cassinis, 1998), essentially differs from any of the generalised reconstructions published to date (Vai, 1994, 1997; Yilmaz *et al*., 1996; and others). The last-mentioned publication, for instance, describes a marine basin exactly where the range of the Variscan mountain chain was the highest (Fig.7).

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CONTINENTAL PERMIAN AND LOWER TRIASSIC RED BEDS OF THE SERBIAN CARPATHO-BALKANIDES

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Key words – Continental sediments; Permian; Lower Triassic; East Serbia.

Abstract – Permian continental clastics in the Serbian part of the Carpatho-Balkan Mountains are post-orogenic sediments formed on the Hercinian land.

The clastics lie unconformably as overstep sequences on various pre-existing magmatic, metamorphic and sedimentary rocks, or are gradually derived from Upper Carboniferous (Stephanian) continental beds. Transitional between the Stephanian C and the Permian are the so-called Mottled Series with *Callipteris conferta*.

The Permian rock system is present as a component of four large Alpine geotectonic units: Vrska Cuka - Miroc (Lower Danubicum), Stara Planina-Porec (Upper Danubicum), Kucaj (Gethicum) and Ranovac-Vlasina-Osogovo (Supragethicum). Permian rocks of the Lower and Upper Danubicum contain andesite and quartz-porphyry extrusions, rarely including pyroclastics.

Generally, Permian clastics are immature deposits of ortho- and para-conglomerates, sandstones (arkoses and impure arkoses, rarely greywackes), siltstones and shales with organic markings. They are red or purple, rarely grey, in colour.

Permian clastics are deposited mainly in intramontane depressions with unstable tectonic regimes, in alluvial fans and meandering rivers; the Permian also includes thick alluvial plain, flood plain, and shallow lake deposits.

Palaeomagnetic data for Permian beds locate the primary depositional area at about latitude 8°N.

Continental deposits of the Lower Triassic lie unconformably over various units of the Permian red beds at a low angle (about 12°) and over Lower Paleozoic schists. The formation is composed of quartz and sub-arkose conglomerates (usually organised) and sandstones, then arkoses, siltstones, and shales mainly in the youngest member. Moreover, these clastics include fossil macroflora.

Lower Triassic rocks were deposited in braided rivers showing diverse sedimentary structures, in a more stable tectonic situation and lower-relief environment. The sediments are purple, white or red in colour.

The stratigraphic boundary between the Permian and Triassic Systems is not recognised everywhere, but is inferred mainly from sedimentological features.

Parole chiave – sedimenti continentali; Permiano; Trias inferiore; Serbia orientale.

Riassunto – I depositi clastici continentali permiani nella parte serba dei Monti Carpato-Balcani corrispondono a sedimenti post-orogenici formatisi sul basamento ercinico. Queste clastiti giacciono in discordanza come sequenze sovrapposte su varie rocce magmatiche, metamorfiche e sedimentarie preesistenti, o sono state gradualmente alimentate a seguito dell'erosione di strati continentali appartenenti al Carbonifero superiore ("Stefaniano"). La così chiamata "Serie Screziata" (*Mottled Series*), con *Callipteris conferta*, rappresenta una successione di transizione tra lo "Stefaniano" C e il Permiano.

Il Permiano è presente in quattro ampie unità geotettoniche alpine: Vrska Cuka-Miroc (Danubico inferiore), Stara Planina-Porec (Danubico superiore), Kucaj (Getico) e Ranovac-Vlasina-Osogovo (Supragetico). Rocce permiane appartenenti al Danubico inferiore e superiore contengono estrusioni di andesite e di porfido quarzifero, raramente commiste a depositi piroclastici.

Generalmente, i depositi clastici permiani sono depositi immaturi di orto- e paraconglomerati, arenarie (arcose e arcose impure, raramente grovacche), siltiti e shales con tracce organiche. Essi risultano di colore rosso o porpora, e raramente grigio.

Le clastiti permiane si sono soprattutto accumulate in depressioni intramontane controllate da regimi tettonici instabili, sotto forma di coni alluvionali e di depositi fluviali governati da meandri; il Permiano, pure, include potenti piane alluvionali, piane di inondazione e depositi lacustri poco profondi. Dati paleomagnetici raccolti negli strati permiani posizionano l'originaria area di deposione di quest'ultimi ad una latitudine di circa 8°N.

I depositi continentali del Triassico inferiore poggiano in discordanza, a basso angolo (circa 12°), sui vari membri che costituiscono i *red-beds* permiani e sopra scisti del Paleozoico inferiore. Essi consistono di quarzo, conglomerati sub-arcosici (in genere organizzati) e arenarie, inoltre di arcose, siltiti e *shales* soprattutto in corrispondenza dei livelli stratigrafici più recenti. Vi è anche presente una macroflora fossile. Il Trias inferiore si depositò in fiumi *braided* che mostrano varie strutture sedimentarie, nell'ambito di una situazione tettonica più stabile e in seno ad un ambiente caratterizzato da una topografia scarsamente pronunciata. I sedimenti sono di colore porpora, bianco o rosso. Il limite stratigrafico tra Permiano e Trias non è dovunque riconosciuto, ma è essenzialmente dedotto in base a caratteristiche sedimentologiche.

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INTRODUCTION

Permian and Lower Triassic rocks are found in two large Alpine orogenic systems in Serbia: the Carpatho-Balkanides and the Dinarides, which are very dissimilar (Fig. 1). The sequence in the Carpatho-Balkanides consists of Permian continental rocks (the so-called "Red Sandstone Formation"); in part of the Dinarides, the Permian system of rocks is lacking, so that Lower Triassic continental clastics lie unconformably over Lower Carboniferous flysch; Triassic marine limestones are transgressive over Lower Carboniferous volcanosedimentary units. Marine sedimentary rocks of the Middle and Upper Permian are found in other parts of the Dinarids,in NW and SW Serbia, transgressive over the pre-existing rocks.

Permian continental clastics in the Serbian part of the Carpatho-Balkanides are post-orogenic products laid over the Hercynian land. They are unconformable over various magmatic, metamorphic and sedimentary rocks, or derive from Upper Carboniferous ("Stephanian") beds. The Permian system crops out in four large Alpine geotectonic units: Vrska Cuka - Miroc, Stara Planina - Porec, Kucaj, and Ranovac-Vlasina-Osogovo.

Generally, Permian clastics are immature deposits of ortho- and para-conglomerates, sandstones (arkoses and impure arkoses, rarely greywackes), siltstones and shales with organic markings. They are red or purple, rarely grey, in colour. The sequence varies in thickness from 50 to 700 metres or more, formed in an arid or semi-arid climate.

Permian and Lower Triassic continental sediments were studied by Protic (1934, 1959, 1967, 1978), Petkovic (1937), Antonovic (1958), Pantic & Protic (1960), Maslarevic (1961, 1967, 1970, 1980), Maslarevic & Protic (1975), Bogdanovic (1980) and Maslarevic & Cendic (1995), and palaeomagnetism was investigated by Milicevic (1998).

PERMIAN CONTINENTAL SEQUENCES

The Vrska Cuka-Miroc Unit (Lower Danubicum)

This Unit is the extreme eastern part of the Carpatho-Balkanides of eastern Serbia (Figs 1, 2). Lower Paleozoic and Lower Carboniferous rocks are lacking there, whilst Permian rocks are largely eroded, preserved only over a small area, and corresponding to the Lower Rotliegend. Permian strata lie conformably over Upper Carboniferous ("Stephanian") continental deposits with coal beds, and consist of conglomerates, sandstones, siltstones and shales. Conglomerates lie lowest in the column and include pebbles of pre-Permian limestones, quartz porphyry, and Lower Paleozoic sandstones. Beds of conglomerates are quite thin and pass upwards into a sequence of sandstones and prevailing siltstones and shales which include quartz porphyry exstrusions. The sediments were deposited at first in river valleys, and later between river channels, mainly in shallow lakes.

The Stara Planina-Porec Unit (Upper Danubicum)

This Unit is found to the southwest of the Lower Danubicum (Figs 1, 2). Permian rocks in the Stara Planina part of the Unit lie unconformably over Riphean/Cambrian schists of the Crni Vrh Formation, Devonian rocks of the Inovo Formation, and "Westphalian" volcanosedimentary products of the Custica Formation, and are referred to in the geological literature as "the outer belt of Permian Red Sandstones" (Maslarevic & Protic, 1975).

Two localities, Sugrin and Topli Do, have outcrops of the Toplodolska Formation. The lowest-lying rocks are basal conglomerates, several metres thick at Sugrin; much coarser conglomerates and breccias up to 200 metres thick occur at Topli Dol (Babin Zub). These are para- and orthoconglomerates alternating with sandstone and rarely siltstones. The conglomerates are massive, rarely stratified, occasionally repeatedly graded, often of disorganised and unsorted subangular material which includes sills of porphyrite, quartz-porphyry and tuff.

Conglomerates are composed of porphyrite, quartz-porphyry, granite pebbles, limestone cobbles, schist, quartz and feldspar in a sandy matrix. Porphyrite fragments prevail in places. Upwards in the sequence, porphyrite disappears and the rock is arkosic in type. Conglomerates are clast- to matrix- supported. The sequence fines upwards; coarse-grained rocks are overlain by variably sized arkoses, a few tens of metres thick. Arkosic rocks are medium- to thick-bedded, graded in places, composed mainly of quartz, feldspar, and granite fragments; the minor constituents are porphyrite and rarely mica, schist, diabase, acid volcanic rocks and chert fragments. Arkoses are clast- to matrix- supported rocks with an illite matrix and hematite or calcite cement.

The rocks at Sugrin were interpreted as river-bed deposits and those at Topli Dol as alluvial fan deposits from proximal parts including debris-flow sediments and from the middle part with Gm and Sh lithofacies (Miall,1977), deposited in high relief on intermontane slopes.

The rapid, irregular deposition of the lowermost Permian ("Lower Rotliegend") is followed by deposition of better-sorted finegrained sediments. Upwards, finegrained sandstones and siltstones prevail, and then shale to a total thickness of nearly 400 metres (Sugrin). There are also thin beds of medium-grained sandstones or arkoses. The finegrained rocks are often horizontally laminated bearing symmetrical ripple-marks, organic markings, and limestone, rarely dolomite concretions. Mud chips in parallel orientation are common. Shales are marly in places with $CaC0_3$ to 28%. These are dominantly interchannel, flood plain, lake, and playa sediments. Scarce thin beds of coarser rocks are the probable remains of crevasse splays.

Finegrained rocks of the Topli Dol Formation are overlain by coarse deposits of a new sedimentary cycle in the Upper Permian. These are immature arkosic conglomerates and coarse, rarely medium-grained, arkoses of subangular unsorted material, either in beds of less than 60 cm or massive, about 30 metres in thickness. Horizontal and gently inclined tabular cross-bedding and asymmetrical ripple-marks can be found, and the series fines upwards. Arkosic rocks contain intraclasts from the base in calcite and haematite cement with scanty dolomite and clay matrix, deposited in the middle part of alluvial fans, possibly from braided channels and river-beds. Magnetite and ilmenite, locally epidote, are the dominant heavy minerals in Permian rocks, whereas stable tourmaline, rutile and zircon are scanty, all subangular to subrounded.

Palaeotransport is dispersed, but mainly towards the east, less to the west.

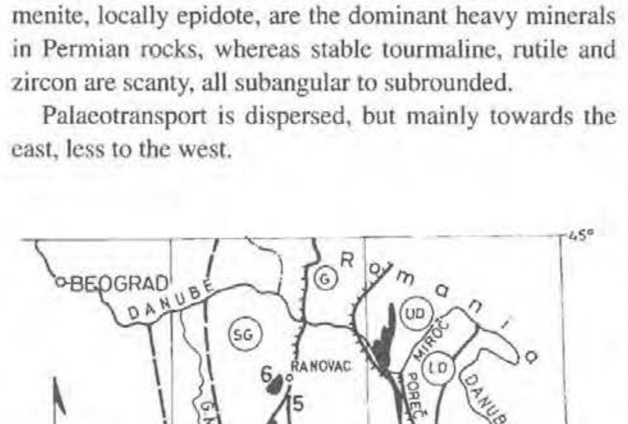

Fig. 1 – Main geotectonic units of eastern Serbia: SMM - Serbian-Macedonian massif; SG - Ranovac-Vlasina-Osogovo Unit (Supragethicum); G - Kucaj Unit (Gethicum); UD - Stara Planina - Porec Unit (Upper Danubicum); LD - Vrska Cuka - Miroc Unit (Lower Danubicum). Lithological columns: 1. Temska (UD); 2. Sugrin (UD); 3. Suva Planina (G); 4. Budina (G); 5. Zdrelo (G); 6 Ranovac (SG).

Similar Permian deposits are situated in the northern, Porec part of the unit. It is composed of conglomerates, sandstones and shales, alternating with pyroclastics and volcanic rock flows, which lie transgressively over pyroxene gabbro of Glavica (at Donji Milanovac), and green schists on the left side of the Porecka reka. Bogdanovic (1980) distinguished two Permian horizons: sedimentary and volcanosedimentary. The terrigenous horizon forms the lower part of the Permian sequence, from conglomerate and conglomerate breccia at the base to red sandstone and shale intercalated with freshwater limestone at the top. The volcanosedimentary horizon is composed of red sandstone, shale, volcanic breccia, tuff, and quartz porphyry and porphyrite extrusions.

The Kucaj Unit (Gethicum)

This Unit has a central and western position in eastern Serbia (Figs 1, 3). It includes several continental basins of graben or semi-graben type. Permian (and Lower Triassic) continental rocks extend discontinuously from the Danube in the north to Ruj Mt. in the south, over 200 km. It is referred to in the literature as "the Inner belt of Permian Red sandstones of eastern Serbia"(Maslarevc & Protic,1975). The system is unconformable over the older metamorphosed rocks at the base, or passes from Upper Carboniferous ("Stephanian") beds. It is believed to form the complete Permian sequence between the underlying ("Stephanian") and overlying (Lower Triassic) units.

Permian rocks make up a thick sequence of clastics, from 50 to 700 metres or more in thickness. Its constituents are sandstones and conglomerates, siltstones and shales. Dolomite and limestone are scanty. Rocks are red or purple, rarely grey or green, in medium to thin beds, rarely thick or massive. Horizontal bedding and lamination, thick tabular cross-bedding and asymptotic bedding are common, and current lamination can be seen. Conglomerate-sandstone grading with lower bed-surface erosion and clay chips also occur. Bed surfaces show fine symmetrical and asymmetrical ripple-marks. Finegrained rocks bear concretions of calcite and dolomite, rarely hematite, organic markings, raindrop imprints, and rarely desiccation cracks. There are many bleached marks around active centres (organic matter). Rocks show characteristic fluvial fining-upward sequences.

The southernmost Permian rocks of this Unit are those of Ruj Mt. and at the Vlaska and Greben mountains, unconformably overlying the older amphibolites or Devonian-Lower Carboniferous flysch. The entire Permian sequence (and the basal Unit) is fining upwards: disorganised, quite thin basal conglomerates that alternate with coarse sandstones, medium-grained sandstones which pass into a succession of finegrained sandstones and siltstones, for a total thickness of more than 100 metres.

These are unconformably overlain by Lower Triassic quartz conglomerates and sandstones. The Permian sequence is interpreted as alluvial fan clastics passing upwards into sediments filling river channels, topped by plain rivers and lake (playa) deposits.

The Permian stratigraphic sequence in this Unit is almost complete in the Suva Planina region (Fig. 2). It begins with pebbly sandstones and partly conglomerates, unconformable over Upper Devonian-Lower Carboniferous flysch or progressively developed from Upper Carboniferous ("Stephanian") rocks. Upwards follow coarse and medium-grained sandstones, and subsequently hundreds of metres of a monotonous succession of siltstones alternating with finegrained sandstones. The coarsest constituents are interpreted as river channel deposits that rapidly pass upwards to finer-grained sediments of plain rivers and further to shallow lake and playa deposits, which dominate.

Although thin (about 100 m), the sequence is complete in the Budina stream near Aleksinac, between the underlying "Stephanian" and the overlying Lower Triassic rocks with megafloral remains (Fig. 2). Constituent rocks are siltstones and shales with scarce sandstone beds and lenses and a few coarse-grained sandstone and conglomerate interbeds: deposits of meandering rivers and finegrained interchannel deposits of alluvial plain, flood plain, and playa sediments deposited from suspension.

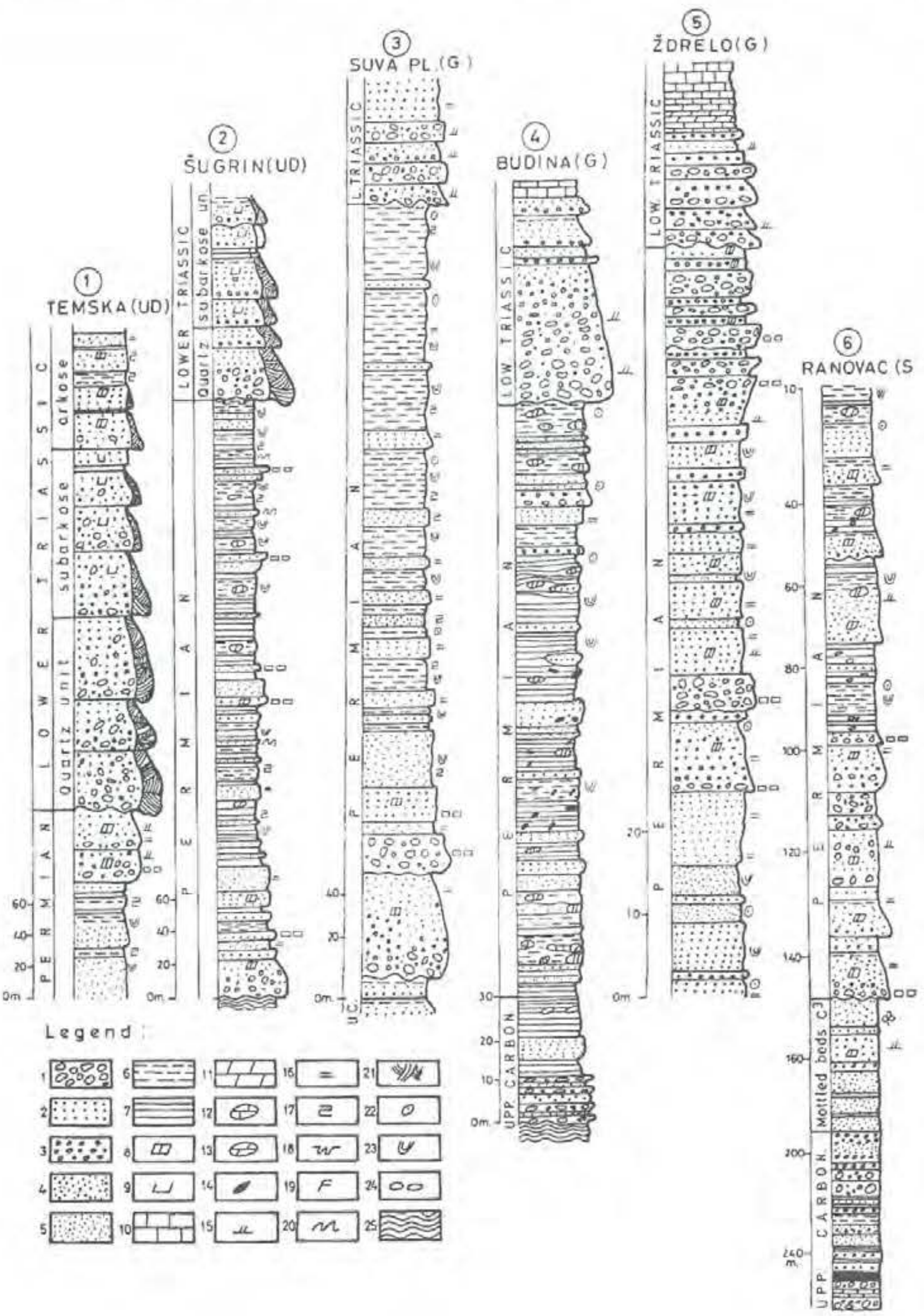

Fig. 2

Legend: 1. Conglomerate; 2. Coarse-grained sandstone; 3. Pebbly sandstone; 4. Mediumgrained sandstone; 5. Finegrained sandstone; 6. Siltstone; 7. Shale; 8. Subarkose; 9. Arkose; 10. Limestone; 11. Dolomite; 12. Concretion of limestone; 13. Concretion of dolomite; 14. Concretion of hematite; 15. Crossbedding; 16. Horizontal bedding; 17. Horizontal lamination; 18. Convolute lamination; 19. Crosslamination; 20. Wave marks; 21. Trough cross-bedding; 22. Trace of raindrop imprints; 23. Organic markings ("bioglyphs"); 24. Concretion of spheroidal siderite; 25. Schists.

Two zones of Permian rocks, divided by regional dislocations, are recognised to the north around Resavica and between Donja Mutnica and Rujevica, southwest of Samanjac.

Rocks mostly from the middle of the Permian sequence, composed of medium- to finegrained sandstones, siltstones and coarse-grained sandstones, rarely conglomerates and shales, are found in the Resavica-Josanica zone.

These rocks contain limestone and dolomite concretions. The sequence consists of thin, medium, and locally thick beds (tens of metres) beds. The bedding is horizontal, rarely cross-bedded (unidirectional fluvial sets), and the lamination in finegrained rocks is horizontal, cross-laminated or convolute. These are fining-upwards sequences from meandering rivers and bars, with gravel lag and cross-bedded sandstones. Permian rocks in this zone are transgressively overlain by Middle Jurassic rocks.

Rather thin conglomerates, locally with cobbles, and coarse-grained sandstones in the Donja Mutnica-Rujevica zone, associated with the lower part of the Permian stratigraphic sequence, correspond to scanty alluvial fans (sometimes with debris-flow sediments). These rocks pass upwards to thin river-channel deposits and further into quite widespread flood plain and playa deposits with dolomite concretions and scarce beds.

The Upper Permian sequence is well developed in the northern part of the Unit, *i.e.* in the Zdrelo and Krepoljin region (Fig. 2). It is characterised by a succession of ortho- and paraconglomerates, and of coarse-grained and rarely medium-grained sandstones. Rocks are stratified, graded with distinctly erosional lower surfaces, or else form large homogeneous masses. They show gently inclined tabular and asymptotic bedding, through to cross-bedding and horizontal bedding. The sequence is either fining or coarsening upwards. The coarsening sequence ranges from a quite thick succession of medium- and finegrained sandstones to ortho- and paraconglomerates and coarse sandstones (progradation of proximal over distal sediments). The fining sequence ranges from orthoconglomerate to sandstone with scattered pebbles, and tabular cross-beds gently inclined to horizontally bedded medium-grained sandstone. Besides fluvial transport, the sediments also indicate eolian transport desert-polished dreikanter pebbles.

These rocks are interpreted as deposits of an alluvial fan proximal to mid-slope, and partly of a braided river with bars. The imbrication, cross-bedding, and often erosional base suggest traction currents that carried pebbles as the bed load.

The Ranovac-Vlasina-Osogovo Unit (Supragethicum)

This Unit is part of the western Carpatho-Balkanides of eastern Serbia (Figs 1, 2), where unmetamorphosed Upper Carboniferous ("Stephanian") rocks lie unconformably over metamorphosed pre-existing rocks. The Permian system (Ranovac Formation) is conformable over "Stephanian" coal-bearing rocks (Fig. 2). Stephanian deposits, over the so-called "Mottled Series" (alternating grey, green, and red sandstones), 30 to 100 m thick, gradually pass into a formation of Permian red beds. The Carboniferous/Permian boundary is marked by beds with *Callipteris conferta.* Permian rocks are best studied in the Ranovac area (Maslarevic, 1961).

The Lower Permian-Rotliegend sequence is represented by conglomerates and breccia-conglomerates, coarse- to finegrained sandstones, and pyroclastic breccia of andesite-dacite type (Fig. 2). The upper part of the sequence includes siltstone and shale, and scanty thin limestone and dolomite beds. Rocks are stratified, thick or massive, exhibiting horizontal and cross-bedding produced by unidirectional flow, wavy bedding, and trough cross-lamination. Bed contacts are often sharp and erosional at the base of the coarser bed.

These rocks are channel with bar deposits in a fining-upward sequence. The upper part of the sequence consists of alluvial plain, flood plain, lake, and playa suspension deposits, composed dominantly of fine- to medium-grained sandstones, siltstones and shales with structures similar to those of the Lower Permian. The siltstones and shales are thinly bedded. Limestone concretions, raindrop prints, rarely desiccation cracks and bleaching around small plant remains are found throughout the sequence. Thin limestone and dolomite beds are scanty.

To the south, at Plazane near Despotovac, the Upper Carboniferous is conformably overlain by a Lower Permian unit of coarse- to finegrained sandstones, finegrained conglomerates, and scantier siltstone.

Permian clastics of the Gethian and Supragethian regions are immature, poorly sorted and subangular with a significant unstable component and a clay matrix. These are mainly arkoses or impure arkoses, or feldspathic greywackes and feldspathic subgreywackes (*sensu* Folk, 1954) as in the Budina brook. Arkoses and impure arkoses consist of quartz, feldspar, albite, oligoclase, andesine, potassium feldspar, rare mica, abundant granitic rock fragments (which contain purple feldspar in the Ranovac Formation), some quartzite, low-crystallinity schists, green schist (Ranovac), rarely gneiss, Lower Palaeozoic sandstone, diabase, tuff, keratophyre, lydite, andesitic and rhyolitic rocks, amphibole schist, and common fragments from the same sequences. Schist fragments are common in the Donja Mutnica-Rujevica area. Sedimentary rocks are clast- to matrix-supported, clasts being bound by a mixture of illite, montmorillonite, occasionally kaolinite in calcite, (secondary) quartz, and rarely dolomite cement.

Permian rocks are rich in heavy minerals, only some of which are important for the correlation. Dominant in older Permian rocks are the stable heavy minerals: tourmaline, zircon and rutile, occasionally also magnetite (and ilmenite), and garnet in younger beds.

Authigenic minerals include hematite, barite, pyrite, rarely gypsum, and anhydrite.

PROVENANCE AND PALEOTRANSPORT

The mineral compositions of rocks, rock fragments, and the directions of paleotransport indicate the pre-Hercinian Serbo-Macedonian Massif, and partly the Hercinian land of the Kucaj and Homolje Mts (Lower Paleozoic sedimentary and volcanic rocks), as the provenance of the deposited materials. The angularity of clasts in the Permian sediments of the Supragethicum suggests short transport distances, and those of the Ranovac Formation as deriving from underlying rocks of Permian/Carboniferous and the granite massif of Neresnica and Brnjica. In the northern and southern parts of the Kucaj Unit, paleotransport was northward from the south and SSW-NNE, respectively. The paleotransport and dispersal for the Ranovac Formation was dominantly westward (from Hercynian land).

PALAEOMAGNETISM

Paleomagnetic data for the Permian beds of the Carpatho-Balkanides (Milicevic, 1998) locate the primary depositional area at about latitude 8°N. The general magnetisation direction is $D = 350°$, $I = 5\text{-}30°$. Coordinates of the palaeopole are: latitude $\varphi = 52{,}6°N$, longitude $\lambda = 227°E$ (radius of confidence circle $\alpha_{95} = 13{,}4°$).

IMPLEMENTATIONS OF CLIMATE AND TECTONISM

The climate prevailing in the Permian was arid or semi-arid, with storm rainfalls and flash floods. As a result of high rates of evaporation, basins in arid areas were alkalic, and saw the formation of concretions and thin beds of calcite and dolomite, with occurrences of barite, gypsum, and anhydrite. The clay component contains 3000 ppm strontium, indicating increased salinity in the basins. The cementation of syntaxial quartz is due to precipitation of silica from alkaline ground-water. Subaerial features such as raindrop prints are common, with occasional desiccation cracks. The environment was oxidising, intermittently reducing (grey sandstone), with conditions favouring the presence of authigenic pyrite.

Deposition of the thick Permian sequence can be associated with the Hercynian post-orogeny that formed strong relief and contributed to rapid erosion, short transport distances and, often, rapid deposition in intermontane depressions. The coarsening-upwards sequences indicate local uplift of the source areas and depositional slopes during tectonic events. Very thick fining-upwards megasequences might result from gradual decreases in basin-margin faulting. Both fining- and coarsening-upwards sequences were subjected to less violent tectonic fluctuations. Alluvial fans are often associated with normal faults and the evolution of grabens and subgrabens. Thick, finegrained deposits (interchannel, flood plain, etc.) are generated from suspension in stable, subsiding tectonic situations (Reineck & Singh, 1973).

LOWER TRIASSIC CONTINENTAL CLASTICS

Continental deposits of the Lower Triassic are found in the Stara Planina - Porec and Kucaj Units. They are best developed at Stara Planina Mountain, where they are identified as the Temska Formation (Maslarevic & Cendic, 1995).

Sedimentary rocks of this formation lie unconformably over various units of the Permian red beds at a low angle (about 12°) and over Lower Palaeozoic schists. The formation is dated using fossil macroflora: *Equisetites mougeoti, Schisoneura paradoxa, ?Neuropteridium intermedium, Woltzia heterophylla, Yuccites sp.*, and so on, characteristic of the Lower Triassic (Pantic & Protic, 1960). The formation is divided into three members: the lower quartzite, the middle subarkose, and the upper arkose.

The Temska Formation marks a new megasequence of fluvial sedimentation that began in the Permian. It is equivalent to gravel-sand and sand deposits from braided rivers, and at the beginning possibly also from the middle part of an alluvial fan. The contributing rivers were mostly large with lower flow regimes, and sometimes with slight bends. Younger finegrained constituents of the arkosic member correspond to meandering rivers. The major facies are channels with bars (longitudinal and tranverse), and interchannel finegrained facies (flood plain, natural level, crevasse, and crevasse splay) in younger beds. Sediments form beds 10-50 cm thick with diverse structures (horizontal bedding, variable cross-bedding: through, tabular, planar, asymptotic, and in finegrained rocks: horizontal and cross-laminations and convolution, showing bioturbation and raindrop prints). Sedimentary material was carried by traction currents, seldom being suspensed load.

The formation is made up of quartz and subarkose conglomerates (organised, rarely disorganised) and sandstones, then arkoses, siltstones, and shales mainly in the youngest member. Basal conglomerates often contain large (50 x 40 cm) fragments of Permian red siltstone. Sediments on the whole fine upwards in several similar sequences. These are supermature and mature clastics, with the textural maturity decreasing upwards to the younger beds. Clastics are characterised by mineralogical maturity (dominant quartz and stable heavy minerals: tourmaline, zircon, rutile), comprising rounded grains without or with a low clay matrix. The maturity is a result of prolonged fluvial transport and effective redeposition. The sediments are clast-supported, cemented by quartz and hematite, and in upper layers have a hydro-mica matrix with calcite and hematite cement. Depending on the amount of hematite cement, the rocks are red, purple or white in colour.

Lower Triassic sediments were deposited in semi-arid or arid climate with storm episodes of heavy rain. The paleotransport analysis shows dispersion in two directions, to the SE and the SW. The formation exceeds 400 metres in thickness. It is overlain by Lower Triassic shallow marine sediments of the Zavoj Formation.

Lower Triassic continental sediments in the Gethian domain do not lie over Permian rocks in all Permian localities. In many places, the overlying deposits are Middle Jurassic. Lower Triassic sequences are found in Ruj Mt., Suva Planina Mt., the Budina brook near Aleksinac, in Zdrelo and Krepoljin, where they unconformably overlie (at a low angle) various Permian members. Lower Triassic rocks are represented by basal quartz conglomerates and white or pink sandstones that pass upwards into a subarkosic rock member. Upper parts of the Lower Triassic sequence contain fossil macroflora. The sequence fines upwards (conglomerate to coarse- and medium-grained sandstone) and has features characteristic of gravel- and sand-dominated braided rivers. It resembles the Temska Formation. Continental clastics are overlain by Lower Triassic shallow-marine limestones and dolomites.

PERMIAN / TRIASSIC BOUNDARY

The stratigraphic boundary between the Permian and Triassic Systems is not recognised everywhere, but is inferred mainly from sedimentological features:

– Permian rocks are mainly red, while Lower Triassic rocks are purple, white or red in colour.

– Permian rocks are immature, poorly sorted with subangular grains, dominantly arkosic in type, with many unstable constituents such as feldspar and granitic rock fragments. Lower Triassic clastics are mature; supermature quartz conglomerates and subarkose sandstones have well-rounded or rounded grains and are well-sorted. There is evidence of humidisation during the Early Triassic.

– Grains of Permian rocks are set in a clay matrix and cemented by hematite and calcite. Lower Triassic rocks are cemented by quartz with hematite, rarely with clayey material.

– Dominant heavy minerals are garnet, sometimes also magnetite, in the uppermost Permian, but stable tourmaline, zircon and rutile in the Lower Triassic.

– Upper Permian rocks are fossil-free, and Lower Triassic rocks contain fossil macroflora.

Permian and Lower Triassic rocks were the products of two separate megacycles of fluvial sedimentation. Permian clastics were deposited mainly in intermontane depressions, in unstable tectonic situations, in alluvial fans and meandering rivers; they are thick alluvial plain, flood plain, and shallow lake deposits. Lower Triassic rocks are braided river products with diverse sedimentary structures, deposited in a lower relief environment with more stable tectonics. The Permian/Lower Triassic stratigraphic boundary consists of Lower Triassic basal quartz conglomerates, similar to western Bulgaria and Romania. The Lower Triassic rocks overlie the Permian at a low-angle unconformity. The boundary layer surface is often erosional, with cobbles in erosional pockets.

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UPPER CARBONIFEROUS AND PERMIAN CONTINENTAL DEPOSITS OF BULGARIA AND ITALY: A REVIEW

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Key words – Late Carboniferous; Permian; continental and marine deposits; geological events; Bulgaria; northern Italy.

Abstract (extended) – We give a short but updated synthesis of some Upper Paleozoic continental, sedimentary and volcanic, and locally also marine successions in Bulgaria and Italy.

– *Bulgaria*. Following the Variscan collision, the assembled and varied terranes of the Bulgarian basement generally shared the same Late Paleozoic evolution. A basin-and-swell topography occurred locally from the Early Carboniferous, or almost so, and spread gradually throughout the present territory. Namurian, Westphalian and Stephanian fossiliferous, coarse- to fine detrital sediments have been recognised, at intervals with calcalkaline intermediate-to-acidic volcanic products. Extensional and transtensional tectonic regimes seemingly began in the "Stephanian".

The Lower Permian is characterised by the alluvial-to-lacustrine clastic German Rotliegend, of which the lower part also consists, in places, of very thick igneous, mainly volcanic deposits. In contrast, the upper Rotliegend (locally interpreted as subsequent to the Saalian phase) seems to be marked by the disappearance of this effusive activity, and by the development of red beds. During the Late Permian, these red beds spread laterally and vertically, giving rise to a marked unconformity with the older rocks.

Towards the east, near the Black Sea, sabkha and marine fossiliferous sediments also occur. In Strandzha, however, the shallow-water carbonates of Kondolovo have been ascribed so far to Early Permian times (due to the presence of algae such as *Epimastopora piae*, *E. alpina*, etc.); in contrast, in the eastern Rodhope, an Upper Jurassic-Lower Cretaceous olistostrome highlighted, in the clasts, some Late Permian foraminifers. But the present position of these outcrops is still a matter of controversy; according to some authors, they are interpreted as resulting from tectonic movements from southern undefined sectors.

The boundary between the Permian succession and the overlying Lower Triassic Buntsandstein is sealed by a very important unconformity, which is marked by a gap. From a primary position slightly above the P/T boundary, the latter unit stepped down unconformably, by erosion, on to all the older rocks, including the Variscan basement.

– *Italy*. The Southern Alps, western Ligurian Alps, and Tuscany, thanks to a large number of studies, display the best examples of Late Carboniferous and Permian interregional correlation with continental areas. The South-Alpine domain clearly shows two main well-differentiated tectonosedimentary cycles, separated by a marked unconformity and a gap of as yet unknown duration. The lower one (1), as much as 2000 m thick, consists of acidic to intermediate volcanics and fluvial to lacustrine sediments, both infilling intramontane fault-bounded subsiding basins delimited by metamorphic and igneous structural highs. Normally, these deposits range from early to late Early Permian, but in some places (*e.g.* in the Tregiovo Basin) they also rise up to early Late Permian. However, as in the "Lake Volcanic District" (western Lombardy-Canton Ticino), the onset of this first cycle could also be ascribed to older times. In fact, it is noteworthy that the local Logone, Manno and other "aporphyric" and non-metamorphic molasses are interpreted as pertaining to the "Westphalian". In contrast with the above continental conditions, in the Carnic Alps, where development clearly took place from the Middle Carboniferous (late Moscovian) up to latest Artinskian or slightly younger (Bolorian), the cycle in question is made up only of shallow-marine and transitional deposits. The Lower Permian basins were controlled by strike-slip tectonics accompanied by a progressive thinning of the Variscan crust.

The Upper Permian cycle is characterised by the continental clastic Val Gardena/Verrucano Lombardo Fms and, east of the Adige Valley, by the coastal to shallow-marine Bellerophon Fm.; both units are in turn followed by the Lower Triassic Werfen/Servino deposits, which mark an overall transgression on the Alpine domain. This cycle was widespread outside the previous Permian basins, and stepped down unconformably on to the older rocks, to the Variscan basement.

In the Ligurian Alps also, two second-order cycles have been generally recognised, from Namurian-Westphalian to Early Triassic times. The older cycle consists of siliciclastics and volcanics; the latter has been subdivided into three episodes, of which the main one is related to the Early Permian. On the top, through a distinct unconformity, the Upper Permian cycle consists of Verrucano clastics.

The Upper Paleozoic of Tuscany displays continental and marine environments. The former, represented by siliciclastic sediments and volcanic products, are mostly developed in northern areas, while the latter show a more widespread distribution along the Farma Creek, near Siena. However, the age assessment of all these deposits is still debated. In general, paleontological evidence seems to assign the onset of the northern continental sedimentation to "Westphalian" times, stretching up to the Early Permian (Artinskian?). The shallow-marine sedimentation of the southern sector probably began in the late Early Carboniferous, but certainly developed up to latest Carboniferous times; the additional presence of Lower Permian clasts within the Triassic Verrucano, and of early Late Permian foram-bearing strata in the

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M. Amiata drill-cores, seem to indicate that marine conditions persisted locally throughout the Permian. However, further research is still required in these Tuscan areas.
In conclusion, from the above overview, we can identify some striking affinities between the Late Paleozoic evolution of Bulgaria and northern Italy. Consequently, we need to emphasise the validity of some events in a wider geological context.

Parole chiave – Carbonifero Superiore; Permiano; depositi continentali e marini; eventi geologici; Bulgaria; Italia settentrionale.

Riassunto (esteso) – È data una breve, ma aggiornata sintesi di alcune successioni continentali, sedimentarie e vulcaniche, nonché localmente anche marine, relative al Paleozoico superiore della Bulgaria e dell'Italia.
– *Bulgaria*. Dopo la collisione varisica, i basamenti bulgari in cui affiorano condivisero di norma un'evoluzione tardo-paleozoica piuttosto simile. Bassi ed alti strutturali si attuarono localmente in concomitanza, o quasi, al Carbonifero inferiore, e portarono a condizioni topografiche che si estesero progressivamente a gran parte del territorio. All'inizio s'ingenerarono sedimenti clastici da fini a grossolani, con fossili attribuibili al Namuriano, Westfaliano e Stefaniano, e con saltuarie intercalazioni di prodotti vulcanici, ritenuti per lo più calcalcalini, a composizione da acida a intermedia. Questi depositi vulcano-sedimentari presero probabilmente posto, a partire dallo "Stefaniano", nell'ambito di un regime tettonico estensionale/transtensivo.
Il Permiano inferiore è caratterizzato da facies ricollegabili al Rotliegende tedesco, cioè da clastiti per lo più alluvio-lacustri, che includono nella porzione inferiore masse ignee, anche cospicue, di origine prevalentemente vulcanica. Viceversa, il Rotliegende superiore (che è considerato, in Bulgaria, posteriore alla cosiddetta fase tettonica Saaliana) risulterebbe contraddistinto dalla scomparsa di questa attività estrusiva e da una sedimentazione a *red-beds*. Nel corso del Permiano superiore, questi *red-beds* si svilupparono ampiamente nella regione, raggiungendo anche notevoli spessori, e dando origine ad una marcata discontinuità stratigrafica con i preesistenti depositi.
Verso est, in prossimità del Mar Nero, sono inoltre presenti sedimenti fossiliferi evaporitico-marini. In Strandzha, i carbonati di mare basso posti in corrispondenza del villaggio di Kondolovo sono stati ascritti al Permiano inferiore (per la presenza di alghe quali *Epimastopora piae*, *E. alpina*, ecc.), mentre nella parte orientale dei M.ti Rodope un olistostroma riferito al Giurassico superiore e al Cretaceo inferiore ha evidenziato, all'interno dei clasti, la presenza di alcuni foraminiferi tardo-permiani. Tuttavia, l'attuale posizione di questi affioramenti marini è ancora oggetto di controversie; secondo alcuni autori, infatti, essi sarebbero da riferire ad unità tettoniche provenienti da settori meridionali, non meglio precisati.
Il limite tra le successioni permiane e il sovrastante Buntsandstein del Trias inferiore è sigillato da una discontinuità stratigrafica anch'essa assai significativa, in quanto include una lacuna di varie proporzioni; da una posizione stratigrafica che può essere ritenuta inizialmente più o meno prossima al limite P/T, il Buntsandstein viene tuttavia spesso a contatto, a seguito di una nutrita attività d'erosione permotriassica, con rocce relativamente più antiche, sino a raggiungere il basamento coinvolto nei movimenti collisionali varisici.
-*Italia*. Le Alpi Meridionali, le Alpi Liguri occidentali e la Toscana, grazie a innumerevoli studi, offrono ottimi esempi per una correlazione interregionale tardo-carbonifera e permiana tra aree prevalentemente continentali. Il dominio sudalpino è rappresentato da due maggiori, ben differenziati cicli tettono-sedimentari, separati da una decisa discontinuità stratigrafica e una lacuna di durata ancora sconosciuta. Il ciclo inferiore (1), potente fino a 2000 m, consiste di vulcaniti acide-intermedie e di sedimenti fluvio-lacustri, entrambi localmente accumulatisi in bacini intramontani subsidenti e delimitati da faglie, che li affiancano ad alti strutturali metamorfici e ignei. Normalmente questi depositi appartengono al Permiano inferiore, ma in talune aree (ad es. a Tregiovo) essi includerebbero anche parte del Permiano superiore. Tuttavia, come nel "Distretto Vulcanico dei Laghi" (Lombardia occidentale-Canton Ticino), l'inizio di questo primo ciclo potrebbe essere anche ascritto a tempi precedenti. Infatti, i depositi molassici a piante di Logone, Manno e di altre vicine località, che poggiano sul basamento metamorfico varisico, sono riferiti (almeno nelle prime due citate località) al "Westfaliano". In contrasto con le suddette condizioni ambientali, nelle Alpi Carniche il primo ciclo è rappresentato unicamente da depositi di mare basso e di transizione ad altri ambienti, sviluppatisi tra il Carbonifero medio (Moscoviano superiore) e l'Artinskiano sommitale, o in tempi leggermente più recenti (Boloriano). Secondo alcuni autori, la sedimentazione nei suddetti bacini sarebbe stata controllata da una tettonica a *strike-slip*, concomitante ad un progressivo assottigliamento della crosta ispessita dall'orogenesi varisica.
Il ciclo relativo al Permiano superiore è caratterizzato dalle formazioni clastiche del Verrucano Lombardo e/o dell'Arenaria di Val Gardena, che, ad est della Val d'Adige, s'interdigita ed è sovrapposta dalla Formazione a Bellerophon, di ambiente costiero e marino. Tutte queste unità sono a loro volta ricoperte dai depositi triassico-inferiori delle formazioni di Werfen e del Servino, che segnano l'inizio di una generale trasgressione marina sul dominio alpino. I prodotti di questo secondo ciclo si estesero al di là dei limiti dei precedenti bacini permiani, sovrapponendosi in discordanza su rocce relativamente più antiche, sino a raggiungere il basamento.
Nelle Alpi Liguri sono stati analogamente riconosciuti, tra il Namuriano-Westfaliano e il Trias inferiore, due maggiori cicli. Il primo tra essi consiste di depositi silicoclastici e vulcanici, quest'ultimi suddivisi in tre episodi, di cui l'episodio maggiore è quello più recente, assegnato di norma al Permiano inferiore. Più sopra, il ciclo pertinente al Permiano superiore, che è delimitato da una marcata discontinuità stratigrafica col sottostante ciclo, è caratterizzato anch'esso dal Verrucano clastico.
Il Paleozoico superiore della Toscana è contraddistinto da ambienti continentali e marini. I primi, costituiti da sedimenti silicoclastici e prodotti vulcanici, sono soprattutto evidenti nelle aree settentrionali, mentre i secondi affiorano essenzialmente lungo il Torrente Farma, presso Siena. Tuttavia, l'inquadramento cronostratigrafico di tutti questi depositi è ancora dibattuto. In genere, le evidenze paleontologiche porterebbero ad assegnare l'inizio della sedimentazione continentale al "Westfaliano", ed a farla proseguire, anche se interessata plausimibilmente da discontinuità stratigrafiche, sino al Permiano inferiore (Artinskiano?). La sedimentazione di mare basso nella Toscana meridionale probabilmente iniziò nel tardo Carbonifero inferiore, ma certamente si sviluppò sino al Carbonifero più tardo; l'ulteriore presenza di clasti del Permiano inferiore all'interno del Verrucano triassico, così come il rinvenimento di foraminiferi attribuibili alla base del Permiano superiore nei sondaggi del M. Amiata, sembrano inoltre voler indicare che le condizioni marine persistettero localmente, almeno in parte, anche nel corso del Per-

miano. Tuttavia, da questo incerto e discontinuo quadro cronostratigrafico emerge chiaramente la necessità di attuare più accurate ricerche nella successione toscana indagata.
In conclusione, in base alla rassegna svolta, è possibile riconoscere alcune strette affinità tra l'evoluzione tardo-paleozoica della Bulgaria e dell'Italia settentrionale. Ciò, pertanto, ci induce a verificarne il grado di validità di alcuni eventi riscontrati nell'ambito di un contesto geologico più ampio.

The paper gives a short but updated outline of the Upper Carboniferous and Permian continental, sedimentary and magmatic rocks in Bulgaria and Italy. These deposits are widespread in the former country, while in the latter they crop out only in the Alps, in some parts of Tuscany, and, much further south, in Calabria and northeast Sicily. Sardinia is also exclusively made up of continental deposits; however, as the evolution of this island and of the "Calabro-Peloritan arc" pertains to far western paleogeographical domains, the omission of both these regions from the present review appears justified in order to understand better the most suitable Bulgarian and Italian continental successions, which is the aim of this work.

BULGARIA

The Basement

The Variscan basement of Bulgaria has been interpreted as a collage of two large and considerably different tectonic blocks: the Protomoesian and the Thracian microcontinents. Protomoesia consists of two different parts: a nucleus, *i.e.* the Moesia terrane (with a Precambrian metamorphic substratum and an incomplete Paleozoic sedimentary cover), and a southwestern outer zone, *i.e.* the Balkane terrane (with Precambrian ophiolite and a Cambrian island-arc assemblage basement, unconformably capped again by an almost regular succession of Paleozoic sediments that differ significantly from the Moesian ones). Sedimentological, paleontological, biostratigraphical, paleobiogeographical, paleoclimatological and paleomagnetic research has supported a peri-Gondwanian origin for both these terranes (Yanev, 1990, 1993 b; Lakova, 1993; Boncheva, 1997; Haydoutov & Yanev, 1997). Generally, the Moesia microplate came into contact with the Laurussia continent at the end of the Late Devonian, whereas the Balkan terrane collided with Moesia in later times, probably between the Visean and Namurian.

The Thracian microcontinent, which corresponds to the present-day Rhodope and Serbo-Macedonian massifs, is made up of metamorphic and migmatised rocks, in which an ophiolite association again occurs (Kozhoukharova, 1984; Kolceva & Eskenazy, 1988), but with differing features from that of the Balkan complex.

We also wish to point out that the Protomoesian and Thracian superterranes were separated by a marked Variscan suture, which was in turn involved in the Alpine orogeny (Haydoutov & Yanev, 1997).

The (late) post-Variscan cover

Upper Carboniferous

At the end of the Variscan collision, the assembled and varied block fragments of the Bulgarian basement generally shared the same Late Paleozoic evolution. However, on the basis of the available dates, we can also state that the pre-Variscan plate configuration played an important role in the definition of the younger fundamental structural and sedimentary lineaments of the country. In the relatively stable Moesia, the Upper Carboniferous, found only by drilling, consists of some more or less complete and sparse clastic successions. The clearest example is represented, in the east, by the "Dobrudgea Coal Basin", where a Devonian or Lower Carboniferous basement is unconformably overlain by Namurian A (partly marine) and C sediments, up to a thick Westphalian plant-bearing clastic succession, intercalated with volcanics. Like everywhere in Moesia, there is no evidence of "Stephanian" rocks (Haydoutov & Yanev, 1997).

The Balkan Upper Carboniferous is well-developed in intramontane fault-bounded subsiding basins. The Svoge Trough includes Namurian to B/C Westphalian alluvial-lacustrine, fine to coarse detrital sediments, up to about 1700 m thick. They contain lithics of the non-metamorphic substrate and subordinately of Variscan granitoids in the upper part (Yanev, 1965). Coal layers and calcalkaline andesitic products also occur. Westphalian B is documented by the presence of *Calamites* and *Lepidophytes* (Tenchov, 1966).

In the Balkan Mts, there are also Stephanian plant-bearing clastic sediments, up to a maximum of 1000 m in thickness, which infill a number of narrow basins. In places, these deposits are associated with calcalkaline andesitic-dacitic volcaniclastics and lava flows (Yanev, 1981). Generally such igneous activity, which is greatly evidenced in some areas (Belogradcik, Berkovica, etc.), developed mainly during the Early Permian.

It is also noteworthy that the Stephanian basins of the Balkan region do not generally coincide with the slightly older ones, which appear less widespread. Normally, their sediments lie directly on a folded and metamorphic basement and pass gradually to the Permian deposits.

In the Srednogorie region, the post-Variscan succession of Mount St. Iliya shows some basal conglomerates, which have been dubiously ascribed to the Carboniferous-Permian transition (Catalov, 1985).

In Kraishte (SW Bulgaria), "Stephanian"-"Autunian" slightly metamorphosed, grey and red clastic sediments, which unconformably rest on a Lower Paleozoic or older basement, have also been recorded in the Vukovo area (Yanev, 1982).

In conclusion, from the above overview, we are led to believe that a fault-bounded basin-and-swell framework developed from the early Late Carboniferous, but most of the examples originated in slightly younger times, spreading progressively throughout Bulgaria. As in other parts of Europe, this geological setting seems to be connected to tensile tectonism, apparently lacking in marked compressional stresses. In an interregional context, the opening of the "Stephanian" basins could have been linked to transtensional movements, which were consistent with, and followed by, during the Early Permian, an extensional regime. Probably, the depicted geological evolution of the Moesia and Balkan

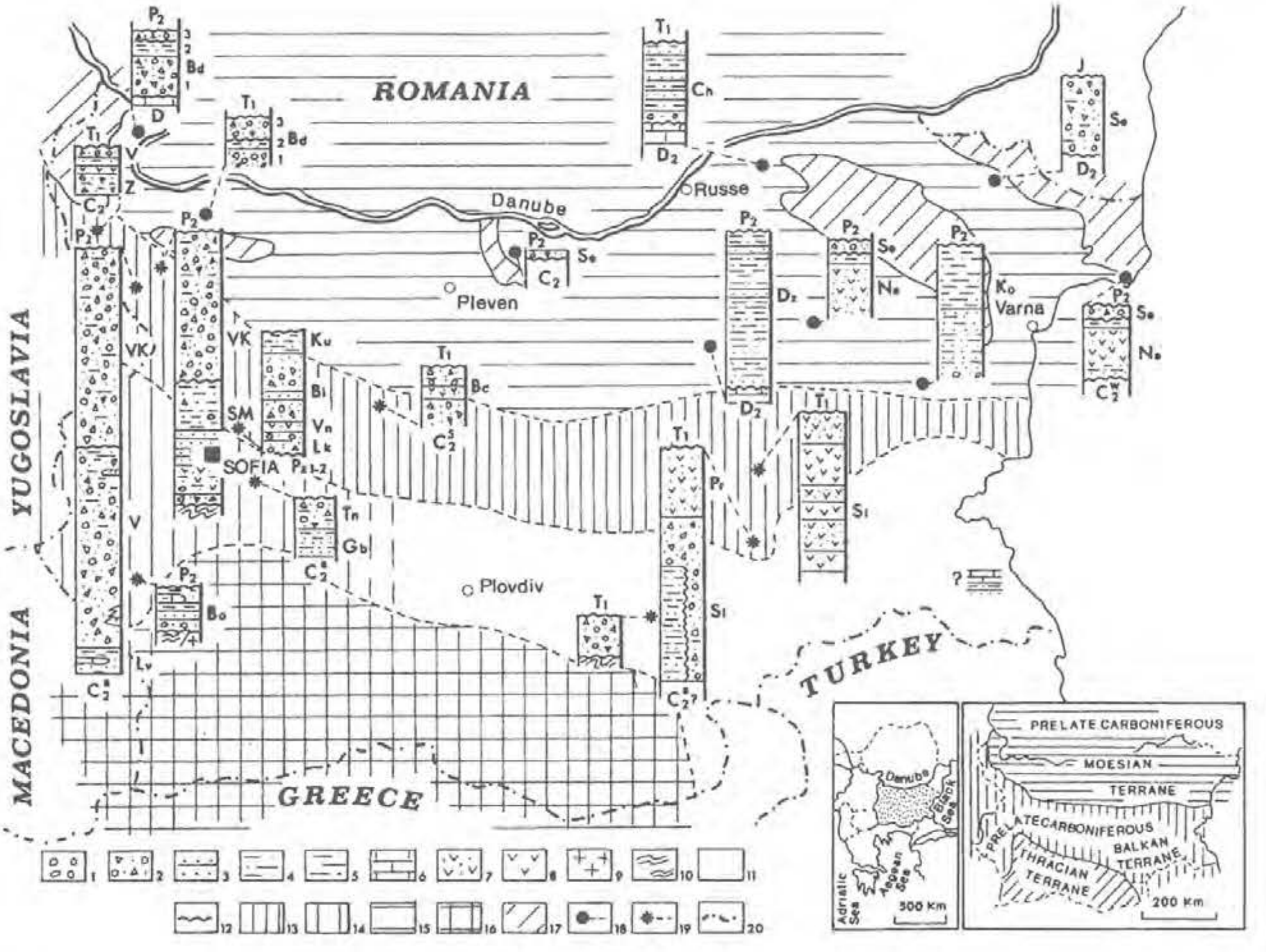


Fig. 1 – Main paleogeographic zones during the Early Permian in Bulgaria and some their typical stratigraphic sections. On the inset maps: left - Bulgaria in the Balkan geographic context; right – Basement: pre-Late Carboniferous terranes of the Bulgarian basement (after Yanev, 1990).

Legend. Lithology: 1. conglomerates; 2. breccia-conglomerates; 3. sandstones; 4. mudstones and siltstones; 5. shales; 6. limestones; 7. pyroclastics; 8. volcanics; 9.plutonics; 10. metamorphic rocks. Paleogeographic zones: 11. Areas lacking in Permian data (Meso-Cenozoic cover); 12. Erosive contact; 13. High dry land with isolated intramontane basins infilled by coarse clastic deposits; 14. Hilly terrains with isolated basins (generally sediment by-pass zone); 15. Isolated basins covered by Meso-Cenozoic deposits (from drilling data); 16. Dry land lacking in Lower Permian sediments; 17. Low dry land with Lower Permian deposits (Meso-Cenozoic cover); 18. Position of stratigraphic columns based on drilling data; 19. Position of Lower Permian sequences based on outcrop data; 20. State boundary. *Abbreviations* (in alphabetic order). – Lithostratigraphic units: Bc, Vasilyovo Fm.; Bd, Bdin Fm. (1, Bononia Mb., 2, Deleina Mb., 3, Rasovo Mb.); Bi, Birimirtzi Fm.; Bo, Boboshevo Fm.; Dz, Dalna Zlatitza Fm.; Gb, Gabra Fm.; Lk, Lokovsno Fm.; Lv, Levitza Fm.; Ko, Komunari Fm.; Ku, Kurilo Fm.; Na, Nanevo Fm.; Pr, Prohorovo Fm.; Si, Sveti Iliya Fm.; Sl, Sliven Fm.; Sm, Smolyanovtzi Fm.; Sv, Severtsi Fm.; Tn, Tarnava Fm.; V, Vranska Fm.; Vk, Vranski Kamak Fm.; Vn, Voinezhka Fm.; Z, Zelenigrad Fm. – Chronostratigraphic units: D, undivided Devonian; D_2, Upper Devonian; C_2, undivided Upper Carboniferous; C_2^w, Westphalian; C_2^s, Upper Stephanian; P_2, Upper Permian; T_1, Lower Triassic; J, Jurassic.

Upper Carboniferous outcrops could also be interpreted as inherited by the differing primary conditions of both these terranes, as well as by the weakness of their joint lines.

Permian

Throughout the Permian, a Rotliegend-type clastic sedimentation spread progressively over vast regions of Bulgaria, and was locally accompanied by significant volcanism (Fig. 1). However, according to the literature (Yanev, 1992; Yanev & Cassinis, 1998; etc.), this eruptive activity took place only during the Early Permian, and was mainly concentrated at the beginning of this epoch. Most of these examples are recorded in the Balkan areas; in particular near Sliven, in the east, this igneous activity gave rise to volcanic, subvolcanic and plutonic products. Generally, the volcanics consist of calcalkaline rhyolitic rocks, whereas the relatively deeper bodies are made up of granophyres, micrograntes and granodiorites (Zhukov *et al.*, 1976).

In Moesia, Permian rocks have so far been detected only by drill-cores (Fig. 1). Some sections of the eastern area (Kaliakra, Targovishte and other places), similarly to a very large part of Bulgaria, can be divided into two sedimentary cycles. Only the first cycle (I), which coincides with the "North Bulgarian Lower Group" of Yanev (1992), is defined as typical Rotliegend, in turn subdivided by the same author into two parts, respectively indicated as "Lower Rotliegend" (P_1^1) and "Upper Rotliegend" (P_1^2), and both are generally ascribed to the Early Permian.

Along coastal Dobrudgea, the Permian begins with the sedimentary and volcanic Nanevo Fm., which is also recorded in the southern part of the same region and around the Permian "paleo-horst" of northeast Bulgaria (Fig. 1). In contrast, in these and nearby areas, and in the extreme NE part of the country, the unconformably overlain coarse detrital deposits of the Severci Fm. lack volcanic products. Generally, the fanglomerates of the two aforementioned Rotliegend-type units include Lower Paleozoic metamorphic and Devonian-Lower Carboniferous carbonate rock-fragments, deriving from the same Moesia Platform.

Locally, in the Bulgarian "Dobrudgea Coal Basin", the Lower Permian appears to be confined between two main unconformities, respectively, below, with Devonian rocks, and above with the Lower Triassic Buntsandstein or Jurassic sediments (Fig. 1).

In central and western Moesia, the Lower Permian clastic deposits are grouped as the Bdin Formation (Fig. 1). This unit spread throughout the northwestern part of the present Bulgaria, approximately from Vidin to Pleven, where it unconformably rests on a Lower Carboniferous (Visean) or Devonian substratum. On the top, near the village of Rasovo, the Bdin Fm. comes directly into unconformable contact with the Lower Triassic Buntsandstein or similar red beds.

Along the southern margin of Moesia, the Lower Permian is well developed south of the "Tarnovo Depression" and a little to the west. It consists of fanglomerates, breccias and finer clastics. These latter deposits, known as Dolna Zlatitsa Fm., pass laterally, in the eastern Vetrino area, to the coarse sediments of the Komunare Fm., which also occur near Varna (Fig. 1).

In the Balkan region, the Lower Permian is made up again of continental Rotliegend-type sediments and volcanics (Fig. 1). The latter products, which crop out in the pre-Balkan (Belogradcik, Teteven) and western and central Balkan (Berkovica, Levskj peak) areas, generally display a calcalkaline acidic composition, are irregularly distributed in the field, and can reach about 1000 m in thickness. The Rotliegend fine- to coarse-grained sediments infilled a number of fault-bounded basins, and locally onlapped outside. The lithoclasts commonly consist of metamorphic, Variscan and older intrusive rocks, as well as Permian volcanic fragments.

In the Balkan region, as in other Bulgarian areas, the presence of an unconformity between the Lower and Upper Rotliegend is probably related to the disappearance of the Early Permian magmatic activity. Furthermore, in some places, the latter unit is missing and the Lower Rotliegend comes directly into contact with the Lower Triassic Buntsandstein (Petrohan Group). In the Svoge area, the Permian was probably never deposited.

In Srednogorie, just above a Lower Palaeozoic and older basement, the Rotliegend of Mount St. Iliya, which consists of coarse- to fine clastics topped by volcaniclastic products both of presumed Early Permian age (Fig. 1), is unconformably capped by the red beds of the Upper Rotliegend.

In southeastern Bulgaria, the presence of Permian deposits is still the subject of controversy. In Strandzha, the Kondolovo area displays some algae-bearing carbonate rocks (Fig. 1), including *Epimastopora piae*, *E. alpina* and *Mizzia velebitiana*, which have been related to the Early Permian (Malyakov & Bakalova, 1978; Bakalova, 1988). However, these local marine, shallow-water sediments have also been interpreted as the result of tectonic displacement from southern sectors.

As already stated, in southwestern Bulgaria (Kraishte) a narrow fault-bounded basin near Vukovo was infilled by Upper Carboniferous ?-Lower Permian grey and red clastics, which unconformably overlie a Lower Paleozoic or older basement (Yanev, 1979; Ellenberg *et al.*, 1980; Fig. 1).

A second Permian cycle (II), corresponding to the "Lower Danube Upper Group" of Yanev (1993 a), is clearly developed in North Bulgaria, especially in the Moesia region (Fig. 2). This Group is generally represented by alluvial, partly deltaic massive clastic red beds (Targovishte Fm.), which unconformably overlie the Lower Permian or older rocks, reaching more than 1000 m in thickness. In the Provadia syncline, these deposits are affected by intercalation of evaporites and carbonate fossiliferous bodies (Vetrino Fm.; Fig. 2), which seem consistent with the presence of marine conditions towards the east, in the position of the present-day Black Sea.

Palynological data (Schirmer & Kurze, 1960; Pozemova *et al.*, 1972 in Yanev, 1993 a), such as the discovery of *Lueckisporites virrkiae*, *L. platysaccoides*, *Klausipollenites schlaubergeri* and *Falcisporites zapfei* in basal pelitic levels (Mirovo Fm.), suggest that this younger cycle (II) developed during Late Permian times. These Upper Permian deposits are more widely distributed than those of the Lower Permian cycle. In some places, however, they lack evidence.

Over a large part of Moesia, the Targovishte Fm. is overlain by well-bedded varicoloured, finegrained sediments, which yield palynomorphs (Pozemova *et al.*, 1972 in Yanev, 1993 a) related to the latest Permian (in part equivalent to the Upper Tatarian of the Russian platform). This Totleben Fm. is unconformably capped by the Lower Triassic red clastics of the Buntsandstein, which covered all the country's rocks and led to a new sedimentary cycle (Fig. 2). This regional discontinuity marks a time gap of unknown duration which, according to some authors (*e.g.* Yanev, 1981), seals the Permian-Triassic (P/T) boundary.

The influence of transitional to marine environments towards the Black Sea has also been recorded in the eastern part of the Rhodope Massif, near the Bulgarian-Greek bor-

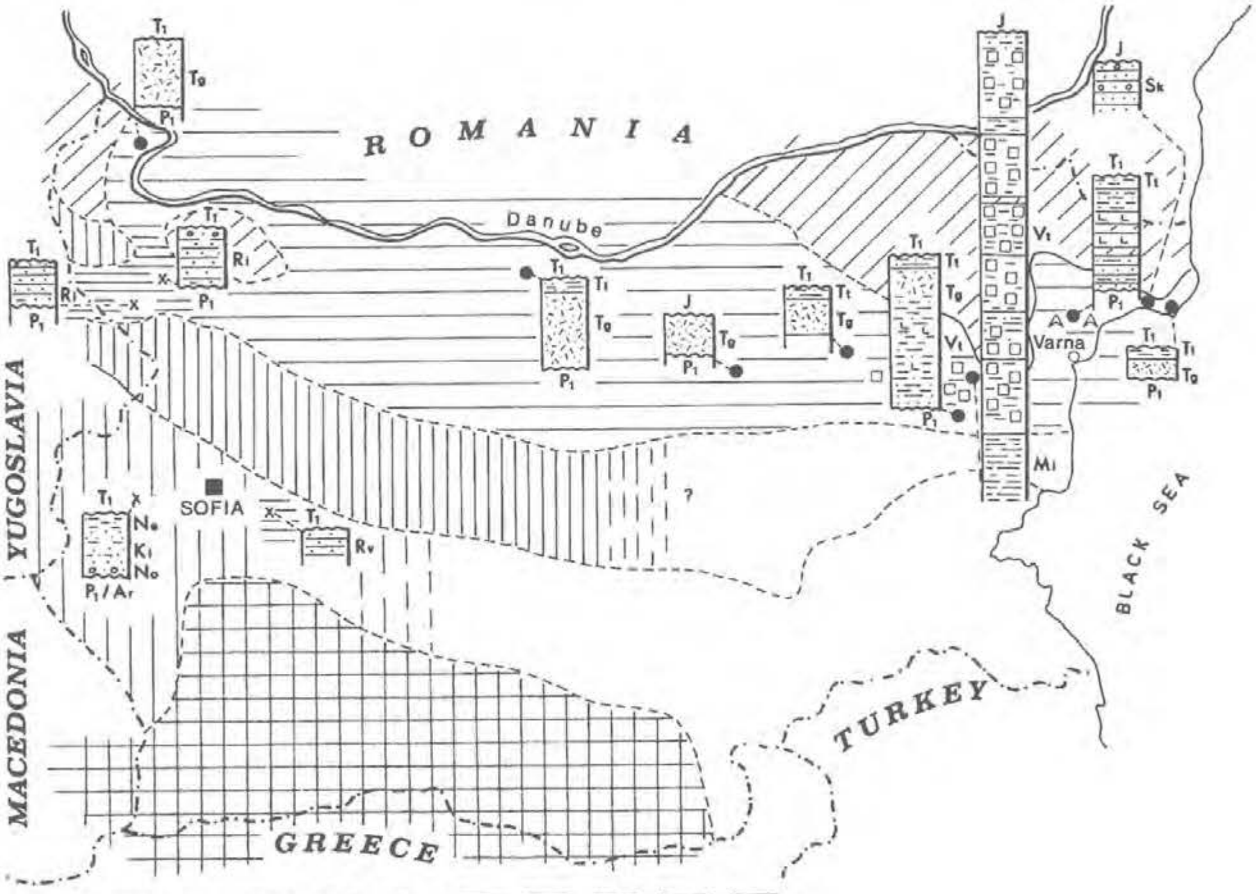


Fig. 2 – Main Late Permian paleogeographic zones of Bulgaria and some typical stratigraphic sections.

Lithology: 1. conglomerates; 2. sandstones; 3. mudstones and siltstones; 4. shales; 5. Very low sorted sediments; 6. anhydrites; 7. halites; 8. dolostones. Facial and paleogeographic zones: 9. Dry land with moderate relief; 10. Probably as 9; 11. Northern continental basin covered by Meso-Cenozoic deposits (drilling data); 12. Anhydrite-bearing zone pertaining to the same basin; 13. "Sabkha" sedimentation; 14. Lower dry land; 15. Delta connected to continental basin; 16. Southern continental basin, 17. Probably as 16; 18. Dry land lacking in Upper Permian deposits; 19. Zone without any information on the Permian sedimentation (Meso-Cenozoic cover); 20. Local section based on drilling data, 21. Local section based on outcrop data; 22. State boundary. *Abbreviations* (in alphabetic order) – Lithostratigraphic units: Ki, Kiselichka Fm.; Mi, Mirovo Fm.; Ne, Nepraznentzi Fm.; No, Noevtzi Fm.; Ri, Rinovska Fm.; Rv, Pavulya Fm.; Sk, Sokolare Fm.; Tg, Târgovishte Fm.; Tt, Totleben Fm.; Vt, Vetrino Fm. – Cronostratigraphic units: Ar, Archean; P_1, Lower Permian.

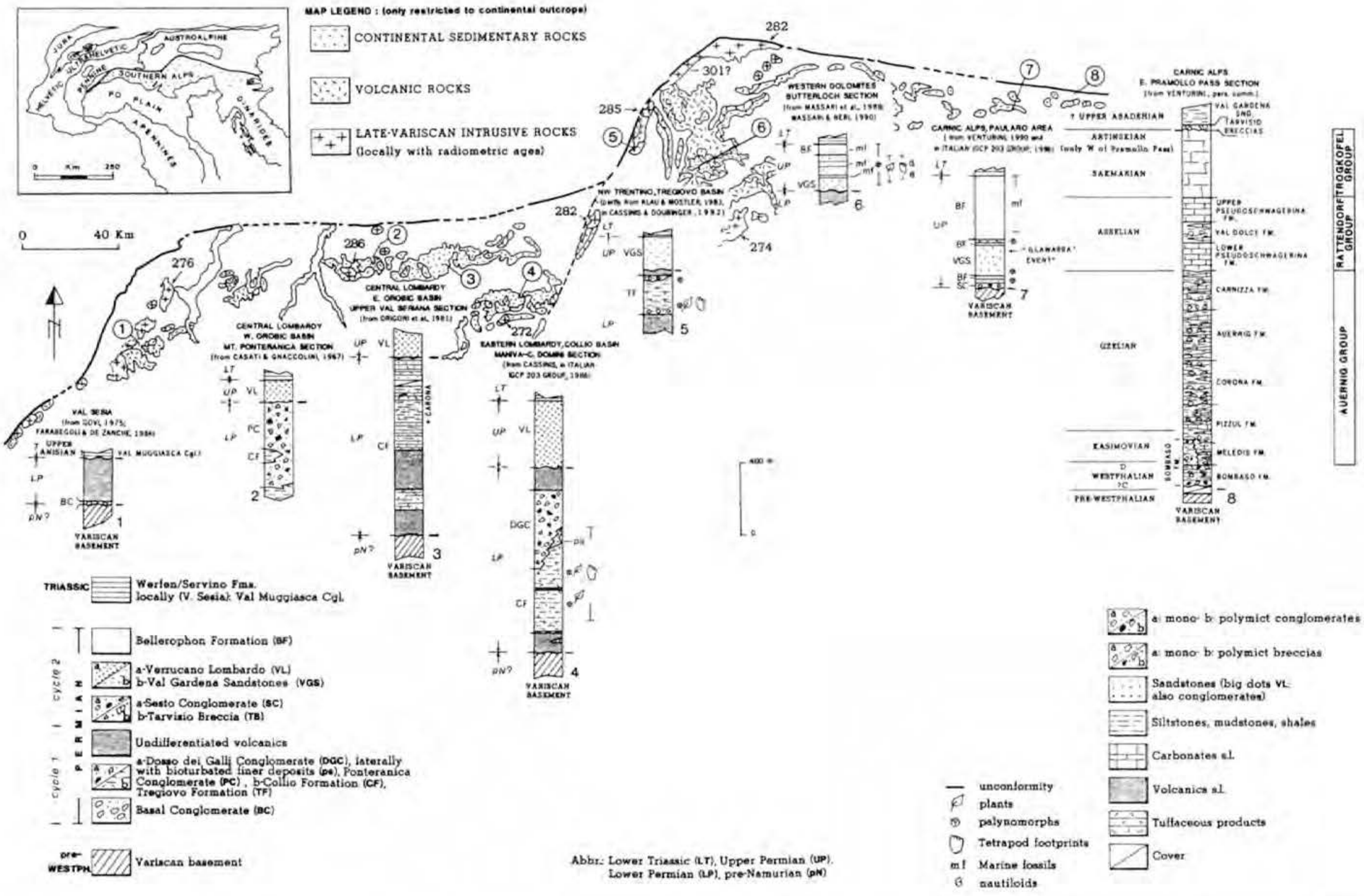


Fig. 3 – Selected and schematic Upper Carboniferous-Permian stratigraphic sections in the Southern Alps. Data from the authors cited above the columns; radiometric ages of intrusive bodies from A. Del Moro (Pisa, CNR) and G. Liborio (Milano Univ.), pers. comm.; Permian, very simplified continental map from Cassinis, unpublished. (After Cassinis, 1996).

der. Silicified carbonate rock fragments, reworked into an Upper Jurassic-Lower Cretaceous terrigenous olistostrome cropping out to the north of Dolno Lukovo, uncovered Upper Permian foraminifers (Trifonova & Boyanov, 1986), such as *Agathammina pusilla*, *Bradyina novizkiana*, *Neoendothyra parva* and *Colaniella* sp.; however, as for the Lower Permian of Strandzha, the paleogeographical-structural source-area of this unit could be envisaged to the south.

ITALY

The Alps and Apennines show a very differentiated and complex history for their generally folded and/or metamorphic substrata, but further research and careful evaluation are still necessary for a better understanding of these rock basements. Therefore, as this paper focuses on the most significant features of some Upper Paleozoic continental areas of Italy, our overview starts from this time. An inheritance of the substratum on the post-Variscan cover is, as in Bulgaria, very plausible in the light of the following data.

The Alpine Upper Paleozoic

Upper Carboniferous and Permian

In the Southern Alps, excluding Carnia, Permian sedimentary and volcanic continental rocks rest above a crystalline basement affected by a Variscan metamorphism, of which the last event can be assigned approximately to the Visean/Namurian boundary (Sudetian phase), or to slightly more recent times. The Carboniferous crops out only between Lakes Como and Maggiore, with some "aporphyric" fluviolacustrine-to-fluviopalustrine sediments bearing middle Westphalian (Venzo & Maglia, 1947; Jongmans, 1950, 1960) up to perhaps, locally, Stephanian megafloras. Intrusive bodies also occur, generally concentrated along important Alpine tectonic lines or close thereto (Fig. 3).

Therefore, from the Late Carboniferous (Moscovian), but mainly during the Early Permian, a basin-and-swell topography dominated the region. This structural framework can be interpreted as the result of a general collapse of the Variscan orogen, accompanied and followed by the outpouring of significant volumes of magma, as well as by transtensional-transpressional movements acting in a progressively extensional regime (*e.g.* Arthaud & Matte, 1977; Ziegler, 1984, 1988; Vai, 1991; Broutin *et al.*, 1994; Cassinis & Perotti, 1994, 1997; Cassinis *et al.*, 1997; Cortesogno *et al.*, 1998).

In the western and central sectors of the Southern Alps, the Lower Permian consists of continental acidic-intermediate volcanics and alluvial-lacustrine deposits (Collio and Tregiovo Fms, Ponteranica and Dosso dei Galli Cgls, etc.), both infilling intramontane fault-bounded subsiding basins delimited by metamorphic and igneous structural highs. Basal polymict conglomerates and breccias, together with fine siliciclastic products (Basal Cgl., Ponte Gardena Cgl., etc.), may be present (Fig. 3).

Paleontological data from the macroflora, palynomorphs and tetrapod footprints generally indicate an Early Permian or, locally, a slightly younger age (Haubold & Katzung, 1975; Remy & Remy, 1978; Kozur, 1980 a; Cassinis & Doubinger, 1991, 1992; Conti *et al.*, 1991, 1997; Pittau, 1999 a, b; Cassinis *et al.*, in press). Radiometric investigations also agree with the above dating (in Cassinis *et al.*, 1999 and in press).

During the Late Permian, new paleogeographical and structural conditions occurred, due to a plate reorganisation probably connected with the opening of Neotethys (Ziegler & Stampfli, this volume). In the Southern Alps, this new cycle includes the fluvial red clastics of the Verrucano Lombardo and the Val Gardena Sandstone as well as, to the east of the Adige Valley, the sulphate evaporite to shallow-marine carbonate sequences of the Bellerophon Fm. (Fig. 3). The above-mentioned red sediments, which in places are preceded by mono- or polymict ruditic units (Daone and Sesto Cgls, Tarvisio Breccia), at least in part regarded as scarp-foot fan deposits, form a widespread blanket up to 600 m thick which covers the Early Permian basins and the surrounding highs. The contact with these underlying rocks is delimited by a gap of as yet unknown duration. Moreover, the new cycle marks the extinction of the volcanic activity.

Paleontological data suggest, for this upper succession, a very Late Permian age, generally beginning from Tatarian times (*e.g.* Italian IGCP 203 Group, 1986; Massari *et al.*, 1988, 1994; Cassinis *et al.*, 1995, 1998, 1999).

On the basis of recent research, the boundary between the Upper Permian red beds and the overlying Lower Triassic Werfen/Servino Fms, in the area from central Lombardy to Slovenia, is seemingly devoid of a consistent stratigraphic gap.

In the Carnic Alps, where Variscan metamorphism is lacking, or almost so, the tectonic climax linked to this orogeny occurred during Moscovian ("Westphalian") times (*e.g.* Venturini, 1990). As a consequence, the overlying succession (Pontebba Supergroup) made up of a cyclic alternation of marine, deltaic and paralic sediments is very different from the coeval succession west of Comelico and resembles that of nearby former Yugoslavia. In contrast, the Upper Permian of the Dolomites shows continuity, even if in Carnia and Cadore the relative sections are characterised by basal clastics, and probably a different temporal shift of the formations.

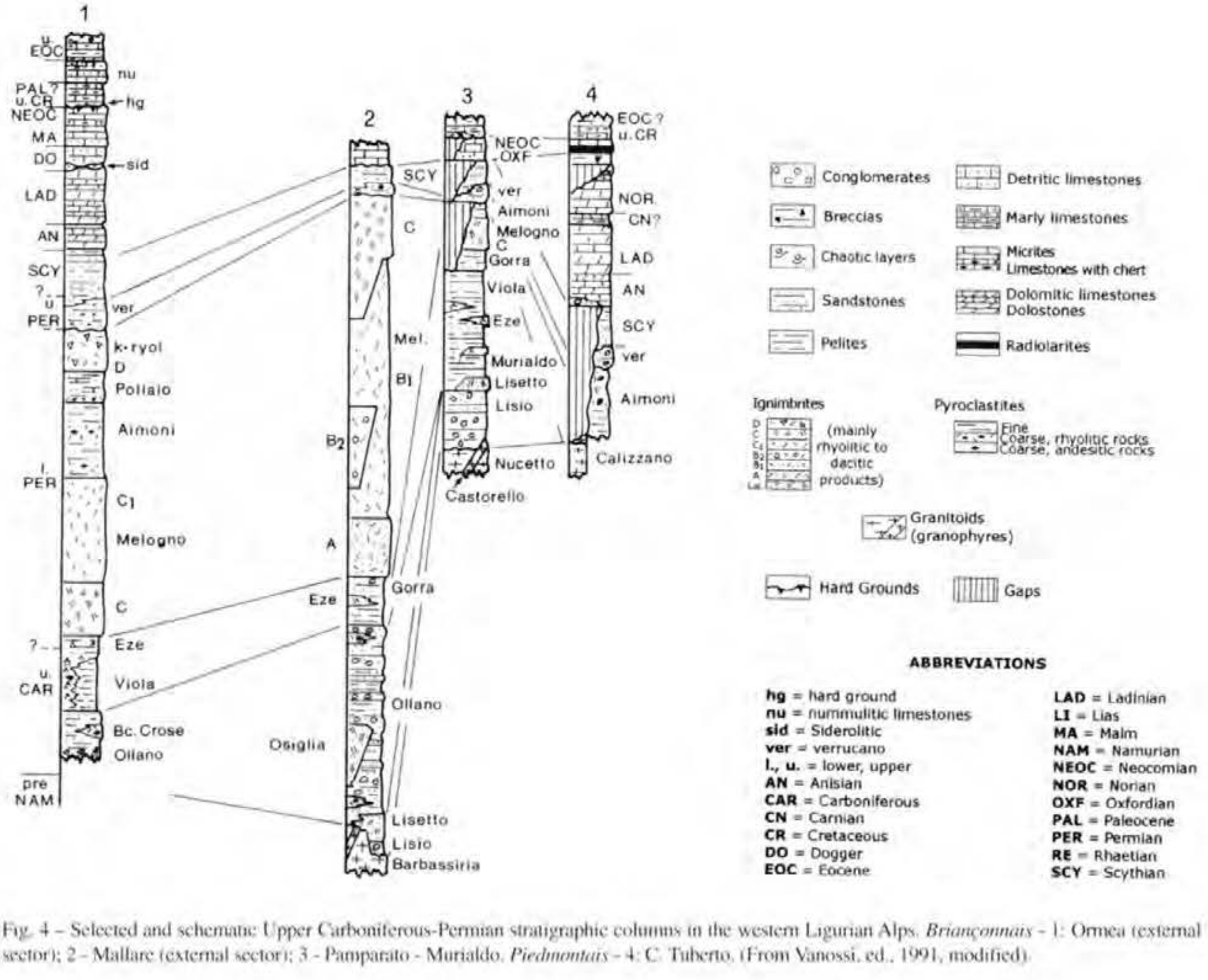
In the other sectors of the Italian Alps, the only useful and updated studies on the Upper Paleozoic have been carried out in western Liguria (Vanossi, 1991; Fig. 4). In this area, the "internal Briançonnais" is represented by Namurian and younger fluvial to lacustrine clastic sediments associated with volcanic products, both infilling fault-bounded basins. As regards the volcanics, early calcalkaline rhyolitic ignimbrites are followed upwards by andesitic pyroclastics and lavas with subalkaline affinities, and, mainly during the Early Permian, by calcalkaline acidic ignimbrites and tuffs. Normally these latter products, ending with subalkaline, high-K rhyolites, represent the most important post-Variscan magmatic episode of the investigated sector, with deposits estimated at over 1000 m in thickness. The overlying Upper Permian Verrucano Fm. is marked by an erosive surface and a gap of uncertain duration. On the top, Lower-to Middle (*p.p.*) Triassic fine detrital sediments crop out. The "external Briançonnais" deposits of the Ligurian Alps are not substantially different to those of the internal sectors.

The Apennine Upper Paleozoic, up to the overlying Triassic

Upper Carboniferous, Permian and younger Triassic times. In the northern Apennines, only Tuscany includes Upper Palaeozoic outcrops. Conforming to a differing geographical distribution, they consist of continental and marine deposits (Fig. 5). As a consequence, for easier correlation with the previously described Alpine framework, we wish to initiate this regional review from the former domains, which display a wider development in the north.

Following the Variscan orogeny, of which the main tectonometamorphic event seems to be connected with the Sudetian phase, a basin-and-swell topography probably began during Moscovian (late "Westphalian"?) times and lasted up to as-yet-undefined Permian times (Remy in Rau & Tongiorgi, 1974; Vai & Francavilla, 1974; etc.). Fluvio-deltaic and lacustrine sediments accumulated in some troughs, later overstepping their boundaries and taking on a reddish colour (Rau & Tongiorgi, 1974, 1976). The onset of this event is unknown, due to a lack of paleontological data and the difficulties of stratigraphic reconstruction within a region strongly affected by the Alpine orogeny; however, a Permian post-"Autunian" time (more or less corresponding to the "Saxono-Thuringian" of the French Authors) may be reasonably assumed.

Volcanic products occurred during, and perhaps also af-



ABBREVIATIONS

hg = hard ground
nu = nummulitic limestones
sid = Siderolitic
ver = verrucano
l., u. = lower, upper
AN = Anisian
CAR = Carboniferous
CN = Carnian
CR = Cretaceous
DO = Dogger
EOC = Eocene
LAD = Ladinian
LI = Lias
MA = Malm
NAM = Namurian
NEOC = Neocomian
NOR = Norian
OXF = Oxfordian
PAL = Paleocene
PER = Permian
RE = Rhaetian
SCY = Scythian

Fig. 4 – Selected and schematic Upper Carboniferous-Permian stratigraphic columns in the western Ligurian Alps. *Briançonnais* - 1: Ormea (external sector); 2 - Mallare (external sector); 3 - Pamparato - Murialdo. *Piedmontais* - 4: C. Tuberto. (From Vanossi, ed., 1991, modified).

ter, the Early Permian (*e.g.* Barberi, 1966; Bagnoli *et al.*, 1979; Costantini *et al.*, 1991, 1998; Pandeli, 1998). However, in places, the clasts deriving from some covering units (such as the Castelnuovo sandstones at Larderello) testify to a wider development of this activity. In any case, the impressive aspects of the Corsican-Sardinian plutonism and volcanism are lacking in Tuscany.

The Verrucano, of which the early sedimentation is generally related to the Middle Triassic but must be regarded as diachronous, "covers" a gap of as yet undefined duration. Between Punta Bianca and the Argentario promontory, it rests on deposits of different ages, locally laid down directly on the Variscan crystalline basement (Rau & Tongiorgi, 1972, 1976; Pandeli, in press; others).

In Tuscany, marine sediments crop out within or near the above-mentioned continental deposits in the form of thin intercalations or very thick sequences authors (Vai, 1978; Cocozza *et al.*, 1987; Costantini *et al.*, 1988). The latter are present near Siena, showing facies of shallow- and deeper water, including turbidites and olistoliths (Farma Fm.). The ages of all these marine sediments, as well as of others which are found either in the boreholes of the Amiata geothermal field or among the lithic clasts from the Monticiano-Roccastrada tectonic unit, generally extend, according to some authors (*e.g.* Costantini *et al.*, 1988; Engelbrecht *et al.*, 1989; Pasini, 1980, 1991; Pandeli & Pasini, 1990; Elter & Pandeli, 1991), from a presumed late Visean age up to the beginning of the Late Permian (Kubergandian *Cancellina* Zone). However, to be precise, this marine sedimentation seems to be discontinuous in Tuscany from the latest Carboniferous. Post-Kubergandian deposits have not been recorded so far in the country.

LATE PALEOZOIC SCENARIOS FOR BULGARIA AND ITALY: A COMPARISON

From Late Carboniferous to Permian times, the investigated areas of Bulgaria and Italy show some affinities, which can be summarised as follows.

Depositional events

Carboniferous p.p.

In both countries, post-Variscan sedimentation began in some places from late Visean or the Namurian times. It consisted of continental and local marine deposits. On the basis of paleontological data, the best examples are found in some Moesian ("Dobrudgea Coal Basin") and Balkan (Svoge) areas, in the Carnic and western Ligurian Alps, and in southern Tuscany (Farma Valley, near Siena). The earliest deposits unconformably overlie metamorphic or non-metamorphic rocks, generally related to the Devonian/Early Carboniferous or, in places, to older times.

– Bulgaria

In this region, sedimentation spread progressively during the Late Carboniferous and Permian. Thanks again to floral and faunal investigations, "Westphalian-Stephanian" and Lower Permian siliciclastic deposits have been identified in a large number of regions, which were affected by a different evolution. Once more, Moesia and the Balkan Mts are the only Bulgarian areas where the Upper Carboniferous is widespread and well developed within intramontane fault-bounded narrow and subsiding basins. The Dobrudgea and Svoge areas represent the clearest examples. However, as already stated, there is no evidence of "Staphanian" deposits in Moesia.

– Italy

In Italy, the Upper Carboniferous is, often paleontologically, recorded in the southern and western Alps, and in the northern Apennines. Continental siliciclastic deposits bearing Westphalian and/or Stephanian plants occur in western Lombardy (Logone, etc.) and in the nearby Canton Ticino (Manno, etc.), in the Ligurian Briançonnais (associated with volcanics) and in Tuscany (Pisan Mts. and Jano). In contrast, in the Carnic Alps the onset of the Pontebba Supergroup is related to Moscovian times, and the basal, transitional to marine deposits (essentially pertaining to the Auernig Group) have yielded some indicative foraminifer assemblages, Kasimovian and Gzhelian in age (see Venturini in Cassinis *et al.*, 1998).

Permian

– Bulgaria

The Lower Permian of Bulgaria consists of, as in Italy, Rotliegend-type alluvial-lacustrine, coarse to fine clastic sediments. The basal part, which is marked by consistent volcanic products, passes upwards to more or less similar sediments, locally through an unconformity. These relatively upper deposits, in which volcanics seem missing, have so far been regarded as Lower Permian (Yanev, 1981 and other works).

Upwardly, the abundant clastic red beds of the Targovishte Fm. or of other lateral deposits unconformably cover all the preceding rocks, and locally step down on to the pre-Lower Carboniferous basement. We also wish to point out, in eastern Bulgaria, that some Upper Permian deposits of Moesia (Vetrino Fm.) containing evaporite and carbonate bodies seem to be connected with marine conditions in the position of what is now the Black Sea.

On the basis of palynological data and regional correlations (Yanev, 1993 a), the upper cycle mentioned above is ascribed to Late Permian times. Furthermore, as already stated, the presence of a new regional unconformity by the overlying Lower Triassic Buntsandstein (or Petrohan Group) supports the opinion that the P/T transition is marked by a gap of uncertain duration. The direct overlapping in some places of such Lower Triassic deposits on the Variscan basement of Bulgaria greatly increases the importance of this unconformity, from which a relatively wider sedimentary cycle began.

– Italy

As in Bulgaria, some central and western Alpine areas of Italy were also generally affected by a roughly similar evolution of the Permian succession. In fact, the underlying alluvial-lacustrine varicoloured sediments and the associated volcanic products are unconformably followed by the Verrucano and Val Gardena Sandstone fluvial red beds (Italian IGCP 203 Group, 1986; Cassinis *et al.*, 1999). In many places, the above volcanics appear widespread and well developed, so that, locally, the lower Rotliegend clastics are very subordinate or almost missing (such as in the "Bolzano-Trento porphyric plateau", the "Volcanic Lake District", and so on). Also the Ligurian Alps were not substantially different, during the Permian, from this stratigraphic framework in which the Verrucano was deposited unconformably on abundant volcanics.

According to palaeontological and radiometric data, the units underlying the Verrucano or the more or less coeval Val Gardena Sandstones have been so far related to Early Permian and locally also to slightly later times. However, some contrasting chronostratigraphical results obtained from the above research, and in part undoubtedly emphasised by the different time-scales currently in use, are still the object of controversy (Schaltegger & Brack, 1999; Cassinis *et al.*, 1999 and in press). Consequently, further investigations are necessary in order to interpret this age difference better.

In contrast, the overlying deposits of the Verrucano-Val Gardena Sandstone agree with Late Permian times. In fact, the macroflora, palynomorphs and tetrapod footprints discovered in the latter formation, which, to the east of the Adige Valley, passes laterally and upwards into the marine

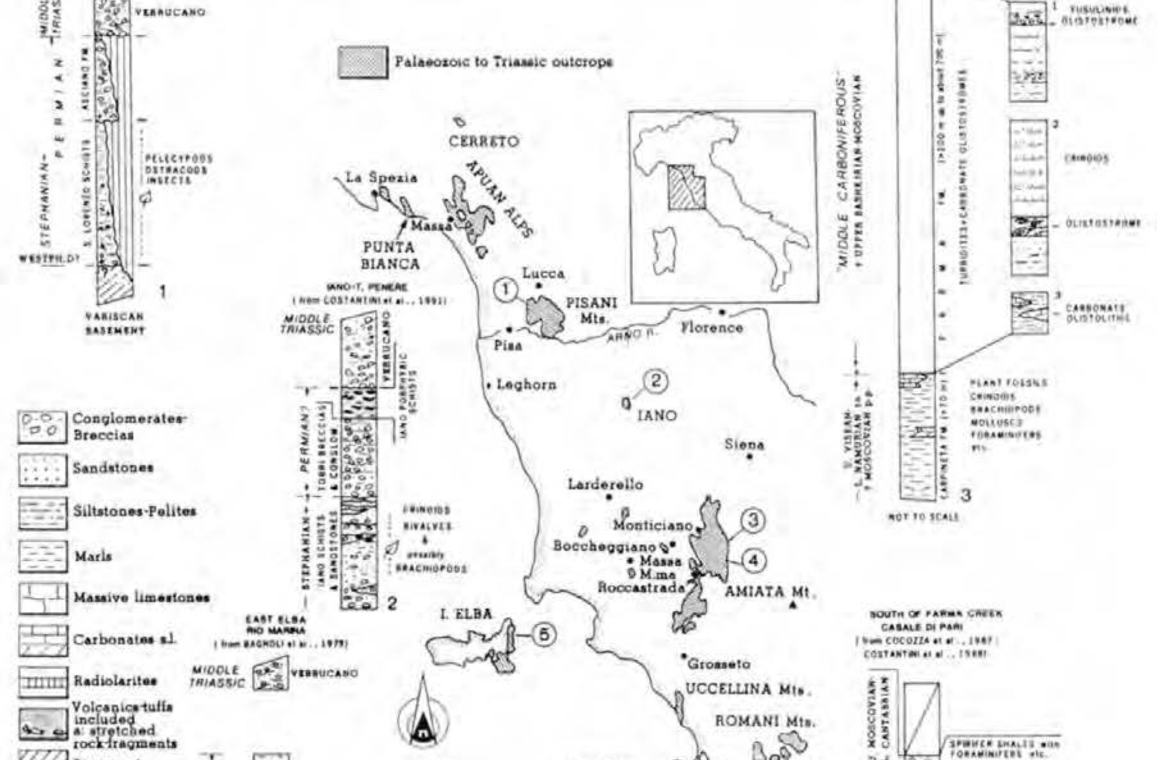


Fig. 5 – Schematic Carboniferous-Triassic stratigraphic sections in the northern Apennines. Data from the authors cited above the columns; map from Elter & Pandeli, 1990. (After Cassinis, 1996).

Bellerophon Fm. yielding algae, molluscs and *Paratirolites* sp. (Posenato & Prinoth, 1999), on the whole affirm resolutely this age assessment. According to Massari *et al.* (1988, 1994) and Pittau (in Conti *et al.*, 1997 and Cassinis *et al.*, 1999), this Upper Permian succession might be considered coeval with the Central European Zechstein or, in part, with the Tatarian of Russia.

The stratigraphic break between the above two Permian successions shows significant chronological differences (in the central-eastern Southern Alps, probably from approximately 14 to 27 Ma; Cassinis *et al.*, in press). The most consistent values are reached where the Verrucano-Val Gardena blanket lies directly on the pre-Upper Carboniferous basement, due to the progressive spreading of the post-Variscan sedimentation.

In Tuscany, the Alpine Carboniferous and Permian conditions could be again highlighted in some continental areas, in spite of their discontinuity and not being well known. In the Pisan Mts area, the S. Lorenzo schists and the Asciano breccias generally show good affinity with some units found in Liguria and in the central South-Alpine region between the end of the Carboniferous and the onset of the Early Permian. The lack of volcanic rocks, which are only present in the form of clasts within the overlying unconformable Verrucano, could be caused by erosion of magmatic products now occurring in Jano and other sites (*e.g.* Pandeli, in press).

As already stated, Permo-Carboniferous marine strata are also recorded in the Tuscan region (Elba Isl., Jano, etc.), but the bulk of these shallow-water marine deposits seem to match the one cropping out along the Torrente Farma and in nearby areas. In southern Tuscany, on the basis of few but significant paleontological data, the marine sedimentation developed, perhaps irregularly, throughout the Early Permian up to the beginning of the Late Permian.

In this context, therefore, we are forced to suggest that an important gap exists between the Lower Permian (or even slightly younger) deposits and the overlying ones, probably encompassing diachronously the Late Permian and perhaps, in part, the earliest Triassic. The Tuscan Verrucano could have been formed later, normally beginning from the Middle Triassic, as indicated by many authors in the type-locality of the Pisan Mts, above all on the basis of its stratigraphic position.

Igneous events

– Bulgaria

The Upper Palaeozoic igneous, extrusive and intrusive products of Bulgaria need further research, because of the lack of an updated synthesis for interregional correlation. These conditions, therefore, forced us to promote some investigations, which are still in progress, on the Permo-Carboniferous volcanism of the Balkan region.

From the literature (*e.g.* Tchounev & Bonev, 1975; Zukof *et al.*, 1976), the first igneous event occurred during the Variscan orogeny, probably at the end of the Early Carboniferous, through the intrusion of granitoids in the basement. The following event took place throughout the Middle Carboniferous ("Westphalian") and was essentially characterised by calcalkaline andesitic products. A third event was bracketed between the latest Carboniferous and the earliest Permian, again distinguished by the previous deposits. The subsequent episode occurred during the Lower Rotliegend, giving rise locally to the most developed examples. As already mentioned, calcalkaline dacitic to rhyolitic volcanic rocks near Sliven are associated with intrusive and subvolcanic rocks of acidic composition. Later, up to the Triassic, no igneous activity was recorded in Bulgaria.

– Italy

In Italy, the Carboniferous and Permian igneous activity of the areas examined shows some affinities with that of Bulgaria. In the Southern Alps, intrusive bodies were probably initiated at the end of the Carboniferous and continued intermittently up to the early Late Permian (see synthetic data in Cassinis, 1996; Cassinis *et al.*, 1999 and in press). Huge volcanics were widespread only to the west of the Comelico region, probably pertaining to pre-Verrucano-Val Gardena Permian times. Carnia did not experience any manifest plutonic and volcanic activity.

In contrast, the "internal Briançonnais" of the Ligurian Alps includes a first Late Carboniferous episode of calcalkaline rhyolitic ignimbrites which rest unconformably upon a pre-Namurian polymetamorphic basement. Upwards, associated with the finegrained clastics of the Murialdo Fm., there is a second episode formed by andesitic pyroclastics and lavas, generally assigned to latest Carboniferous times (Cortesogno *et al.*, 1982). These volcanics display a subalkaline affinity. Above, during the Early Permian, calcalkaline rhyolitic-to-dacitic ignimbrites and pyroclastics generated the third and last main episode. In the uppermost part, unconformably below the Upper Permian Verrucano, these rhyolitic products show a subalkaline potassic composition.

In the "external Briançonnais", above the aforementioned first Late Carboniferous episode, the coarse- to finegrained Ollano Fm. bearing a late Westphalian megaflora (Block, 1966) includes rhyolitic and andesitic volcanics slightly metamorphosed. The Lower Permian metavolcanics are mainly represented by calcalkaline ignimbrites and are unconformably capped by the Verrucano deposits.

From the above Alpine overview, we are led to remark on the similarity of magmatic events, especially in petrographic and chemical composition, between the Ligurian Alps and Bulgaria.

In Tuscany, the available data on Permo-Carboniferous magmatism are insufficient to provide clear correlations. Apparently, only Permian volcanism can be ascertained so far. This striking difference in the igneous development of this and other Italian and Bulgarian regions is still a matter for speculation, and consequently further research is required.

Tectonic events

– Bulgaria and Italy

Following the Variscan collision, during early to middle Late Carboniferous times, Bulgaria and Italy were locally affected by the onset of an irregular topography, which gave rise to as-yet-uncertain tectonic activity. Some continental basins (*e.g.* in Dobrudgea and western Liguria), partly infilled by magmatic rocks, could be interpreted as fault-bounded subsiding basins that have collapsed in the general geological setting of the Variscan orogeny. This basin-and-swell framework spread progressively, from the latest Late Carboniferous, throughout the above territories and reached its peak of development during the Early Permian. Furthermore, these basins show sedimentary and structural features which are consistent with an extensional regime; they evolved from narrow zones to wider depositional areas. Presumably, transtensional movements determined the inception and in part the subsequent development of this structural scenario. Subsidence, sedimentation and volcanism, in the framework of pronounced tectonism, marked such times.

Subsequently, during the Late Permian, the spread of a more or less ubiquitous red sedimentation (Targovishte Fm., Verrucano Lombardo, Val Gardena Sandstone) and the extinction of any magmatic activity are compatible with a new tectonic framework, probably connected to a marked extensional regime. This led to anorogenic conditions (*e.g.* Bonin, 1988; Cortesogno *et al.*, 1998), as clearly documented by the further presence of bimodal alkaline volcanic products in nearby areas (such as southern France, northern Spain, the Corsican-Sardinian massif), and highlighted by the geological scenarios described in this paper. French authors (Toutin-Morin in Cassinis *et al.*, 1992, 1995) interpret this event as the birth of the Alpine cycle.

The gap to the underlying Lower Permian or older rocks represents a striking tool for subdividing the post-Variscan Late Carboniferous to Permian evolution of southern continental Europe into two tectonosedimentary cycles of the second order (Italian IGCP 203 Group, 1986; and so on). The first cycle is irregularly developed from Moscovian or older ages up to about the Early-Late Permian; the second one encompasses the Late Permian and the Early Triassic, locally ending in later times.

However, other unconformities within these megasequences (*e.g.* in Bulgaria and the northern Apennines) could also allow us to establish other cycles, but, in the authors' opinion, the two above-mentioned cycles are the only ones recognisable on an interregional scale, although they probably acted according to diachronic trends. In other European regions, their boundary is placed at about the Lower-Upper Permian transition, and the consequent discontinuity has been identified with the "Palatine" tectonic phase (*e.g.* Kozur, 1980 b), and with the "post-Saalian" or the "Altmark" phases (*e.g.* Hoffmann *et al.*, 1989). It probably marked the birth of new geodynamic conditions, probably connected with an active reorganisation of plates in Mediterranean and circum-Mediterranean regions.

CONCLUDING REMARKS

In conclusion, the Late Paleozoic evolution of Bulgaria and Italy could be generally interpreted as the result of two main sedimentary cycles, separated by a marked unconformity. The older cycle developed irregularly from a "generic" Middle Carboniferous up to about the onset of the Late Permian; where present, the second cycle began during the Late Permian and continued, at least in some places, up to Triassic times. However, throughout their development, these cycles seem to have been affected by an as-yet-imprecise number of more or less protracted phases of non-deposition and/or erosion. Furthermore, their deposits, which are essentially made up of continental siliciclastic and volcanic products, and also subordinately by marine sediments, often display uncertain ages and prevent clear correlations. A varied and complex geological scenario commonly arose, emphasised once again by the important role played by the Alpine orogenesis in the investigated regions.

In spite of these complications, the unconformity between the two cycles generally appears to have been a very significant event in Permian evolution, which could be related to the opening of Neotethys. Thus, after the Gondwana-Eurasia Variscan collision and the subsequent rearrangement and structuration of the European areas between, a Permo-Triassic extensional regime resolutely developed.

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OVERVIEW OF THE CONTINENTAL PERMIAN DEPOSITS OF BULGARIA AND ROMANIA

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Key words – Permian; stratigraphy; tectonic evolution; correlation; Bulgaria; Romania.

Abstract – Continental Permian deposits show widespread development within the territories of Bulgaria and Romania. The Prebalkan Unit of Bulgaria can be correlated with the Danubian Unit of Romania, while the Balkan and Srednogorie Units may correspond to the Getic Nappe of Romania. This paper presents a short lateral and temporal overview of the lithostratigraphy and sedimentology of the Permian continental sedimentation in the Balkan Mountains, Moesia, Kraishte, the South Carpathians and Apuseni Mountains. Many characteristics were inherited from the Late Paleozoic paleogeography. A Variscan Balkan – Carpathian system coincides with the Variscan orogenic chain and with the adjacent lowlands. In all domains of the Balkan area, the Permian System can be divided into two well-differentiated sedimentary groups (cycles), separated by a clear unconformity. Many similarities with the Romanian territory are established. In both countries, the Lower Permian in particular shows mostly molasse features. Terrigenous, volcanic, volcaniclastic and locally evaporitic sediments accumulated in various depositional systems, such as fluvial, alluvial-plain to palustrine, lacustrine, proluvial, playa, colluvial and sabkha facies.

Parole chiave – Permiano; stratigrafia; evoluzione tettonica; correlazione; Bulgaria; Romania.

Riassunto – I depositi continentali permiani mostrano un esteso sviluppo nei territori della Bulgaria e della Romania. L'unità pre-Balcanica della Bulgaria può essere correlata con l'unità Danubica della Romania, mentre le unità dei Balcani e di Srednogorie possono corrispondere alla falda Getica della Romania. Questo lavoro presenta un breve panorama spaziale e temporale della litostratigrafia e sedimentologia relative alla sedimentazione continentale permiana nei Monti Balcani, in Moesia, in Kraishte, nei Carpazi meridionali e nei Monti Apuseni. Molte caratteristiche furono ereditate dalla paleogeografia tardo-paleozoica. Un sistema balcano-carpatico varisico coincide con la catena orogenica varisica e con le basse terre limitrofe. In tutti i domini dell'area balcanica, il Permiano può essere suddiviso in due ben differenziati gruppi sedimentari (cicli), separati da una chiara discontinuità stratigrafica. Sono precisate molte somiglianze col territorio romeno. In entrambi i paesi, in particolare il Permiano inferiore mostra soprattutto aspetti molassici. Sedimenti terrigeni, vulcanici, vulcanoclastici e localmente evaporitici si accumularono in vari sistemi deposizionali, come facies fluviali, di piana alluvionale, palustri, lacustri, proluviali, di playa, colluviali e di sabkha.

INTRODUCTION

This paper presents a short overview of the Permian continental sedimentation in the Balkan Mountains, Moesia, Kraishte, the South Carpathians and Apuseni Mountains. The continental Permian deposits show widespread development in the study area – the present day territories of Bulgaria and Romania.

OCCURRENCE OF PERMIAN DEPOSITS IN BULGARIA AND ROMANIA

In Bulgaria, the Permian deposits occur mainly in five of the present-day morphotectonic units (from north to south): the Moesia, Prebalkan, Balkan, Sredna Gora and Kraishte units (Fig. 1). In Romania, Permian deposits are recorded in the South Carpathians (with Getic and Danubian units), the Apuseni Mountains (with Bihor Autochthonous and Codru Nappe systems), North Dobrogea, and the Moesian and Scythian Platforms (Fig. 1). Sedimentation took place in several basins – Resita (Getic Nappe), Sirinia and Presacina (Danubian Units) in the South Carpathians, Codru-Bihor Basin in the Apuseni Mountains, Carapelit Basin in North Dobrogea, the Scythian Basin (with Aluat and Lower Danube sub-basins) and the Moesian Basin within the Carpathian foreland.

Surrounded by the Carpathians and the Balkans, the

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Moesian Platform extends over both Romania and Bulgaria (Figs 2, 3). The variations of Permian sedimentation in the Bulgarian part of the Moesian Platform can be distinguished, based on borehole data (Yanev, 1992, 1993a) from the following areas: Vidin-Rasovo (west), Pleven-Tarnovo-Targovishte (centre), Mirovo-Komunari (southeast) and South Dobrogea (northeast).

The Prebalkan Unit of Bulgaria can be correlated with the Danubian Unit of Romania, while the Balkan and Srednogorie Units may correspond to the Getic Nappe of Romania (Figs 2, 3). During the Permian, the Prebalkan Unit represented the former foredeep of the Variscan orogen. In the best exposed, western part of Bulgaria, this unit comprises the localities of Vrashka chuka, Belogradchik, Smolyanovtsi and Vratsa (Tenchov & Yanev, 1963; Yanev & Tenchov, 1978).

The Balkan and Sredna Gora Units coincide with the position of the Variscan orogenic belt, crossing the Balkan Peninsula from WNW to ESE (Figs 2, 3). Within these units occur intramontane basins separated by grabens and half-grabens. They are confined to several diagonally extended, tectonically bounded belts. Within the northern belt (from northwest to southeast) the following localities occur: Stakevtsi, Prevala, Melyane, Draganitsa-Lyu-

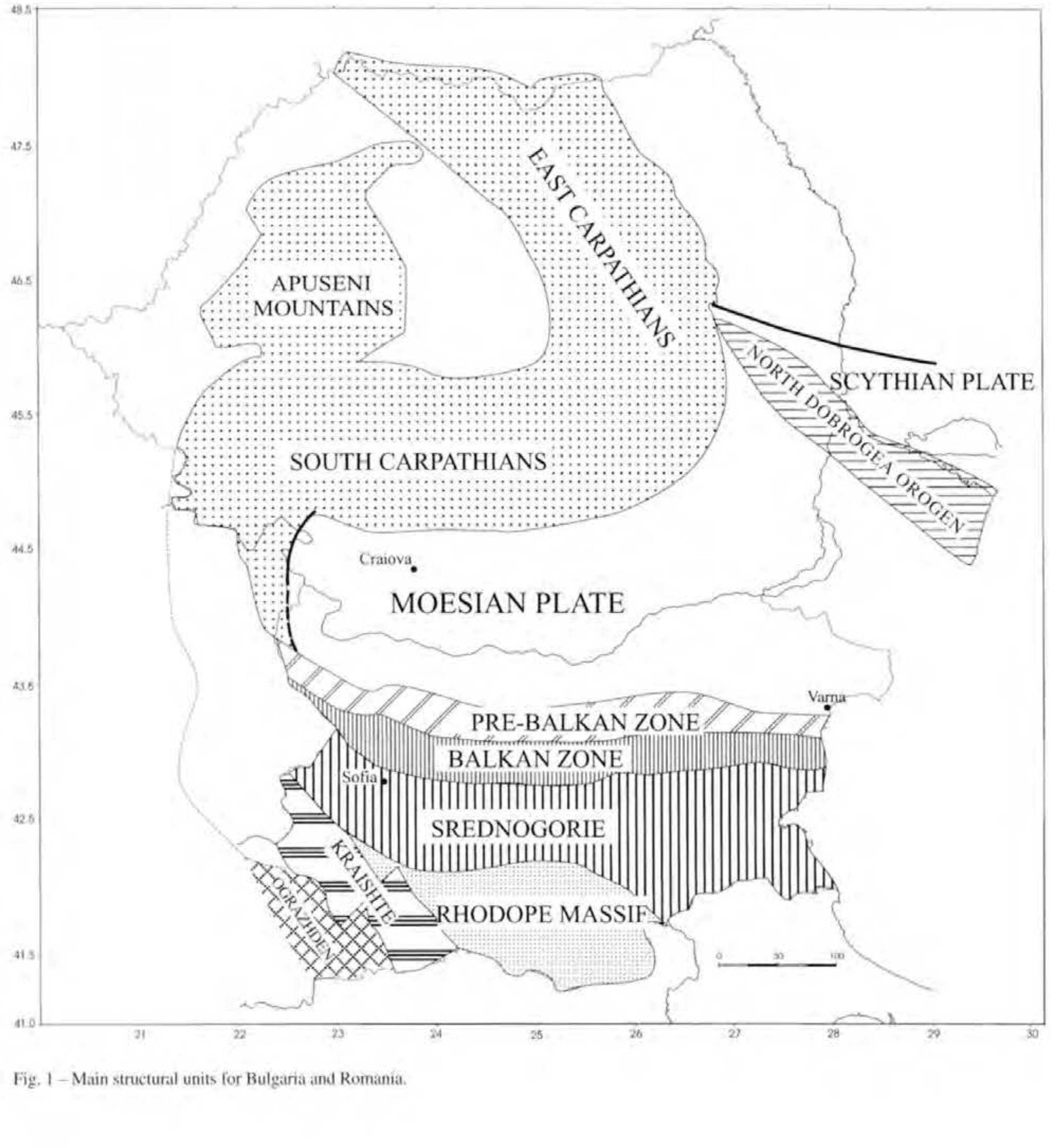

Fig. 1 – Main structural units for Bulgaria and Romania.

tadzhik, Zverino-Ignatitsa, Teteven, Troyan Mountain, and Sliven (Spassov & Zafirov, 1961; Yanev & Tenchov, 1962, 1972, 1978; Chatalov *et al.*, 1962, 1963; Zhukov *et al.*, 1971). The peaks of Midzhur-Kopren, Godech-Buchino Pass, Svoge, and the Sveti Iliya Hills mark the middle zone (Tchumacenko & Shopov, 1965; Yanev, 1981, 1982 a; Chatalov, 1985). The next belt includes localities in Sofioter Stara Planina Mountain, Bunovo area, Lozenska Mountain area, and Chernogorovo (Kulaksazov *et al.*, 1966; Kozhukharov *et al.*, 1980; Yanev, 1982 a).

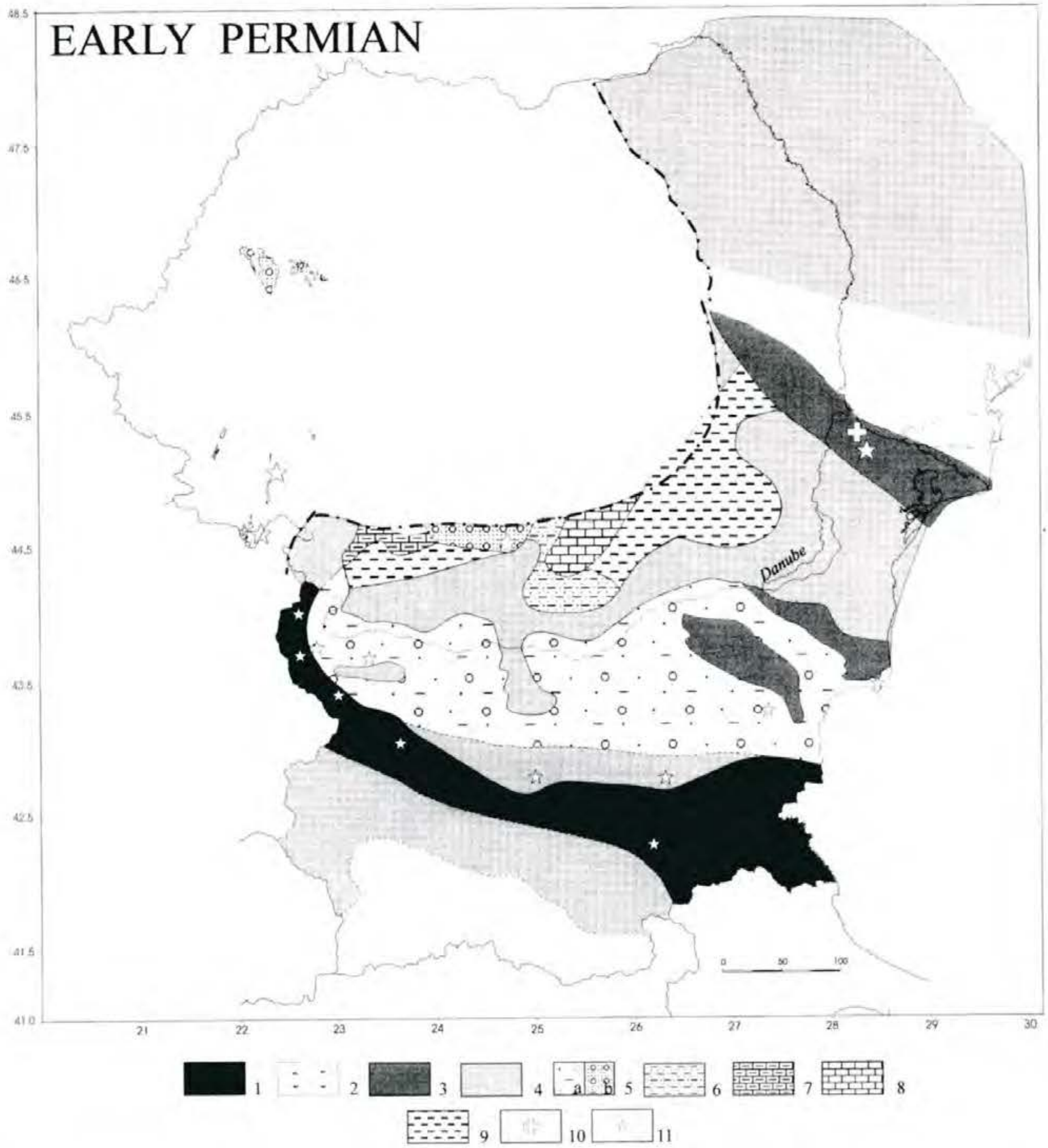

Fig. 2 – Scheme for the main palaeogeographic zones during the Early Permian and their dominating lithology. 1 to 5: Zones of continental sedimentation. 1 - high relief, deposition in intramountain basins of conglomerates, breccia-conglomerates, sandstones and siltstones or non-deposition. 2 - coal bearing deposits in the intramountain basins; 3 - moderate relief, deposition in grabens and half-grabens of conglomerates, sandstones, siltstones, mudstones; 4 - low relief with deposition of more fine grained clastics (mainly sediment by-pass); 5 - low-land with isolated basins: a - with variegated lithology; b - mainly conglomerate and sandstone - bearing; 6 - deltaic, coastal and shallow marine clastics; 7 - shallow marine carbonates and shales; 8 - marine carbonates; 9 - marine shales; 10 - batholiths; 11 - volcanics.

Permian deposits in the Bulgarian Kraishte Unit (in the opinion of S.Y.) may be compared partly with the Romanian Apuseni Mountains. The main difference is the lack of intensive volcanism in the Kraishte area. Present Lower Permian outcrops in the Kraishte are confined only to the Boboshevo-Vukovo area (Yanev, 1982 b), but the earliest distribution of the Upper Permian sediments was larger since their relicts are well exposed between Tran, Noevtsi, Batanovtsi, Boboshevo, Stanke Lisichkovo, Padesh and other villages (Yanev, 1979) (Figs 2, 3).

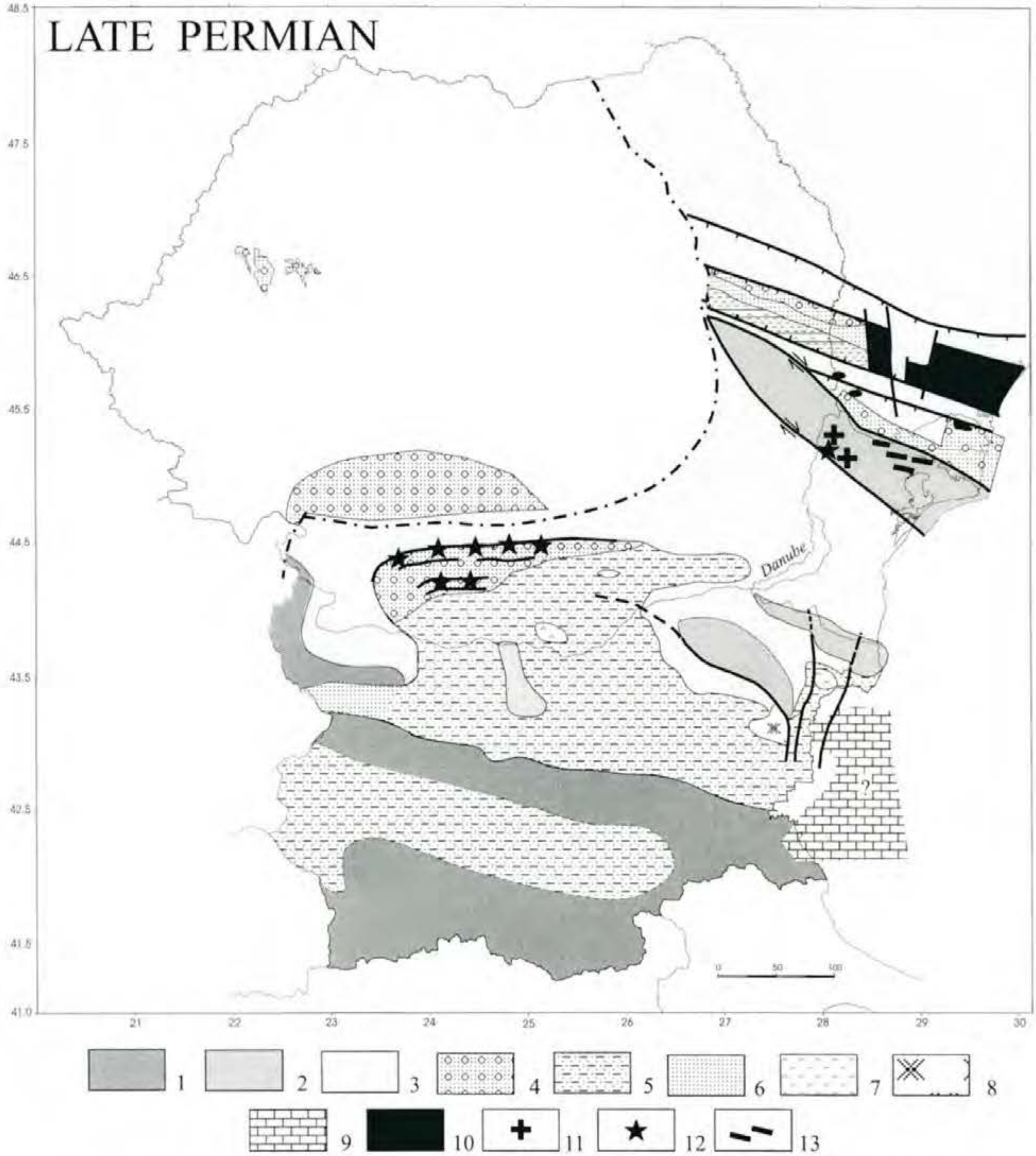

Fig. 3 – Scheme for the main palaeogeographic zones during the Late Permian and dominating their lithology. 1-3: Zones without Late Permian sedimentation - generally sediment by-pass terranes. 1 - with moderate to relatively high relief; 2 - with moderate relief; 3 - with low relief; 4 - continental coarse sedimentation of conglomerates, sandstones, mudstones (proluvial fan, alluvial fan and other facies); 5 - continental basins sedimentation (generally poorly graded red beds: mudstones, sandstones, siltstones, etc.); 6 - deltaic sediments, related with the continental basin delta - mainly sandstones; 7-8 - zones of evaporite sedimentation: 7- sulphate-bearing deposits; 8 - halite-bearing sabkha deposits; 9 - zone of supposed marine carbonate sedimentation; 10 - plateau basalts; 11 - batholiths; 12 - volcanics; 13 - dyke systems.

Permian deposits are lacking in the Rhodope Unit and the Serbo-Macedonian ("Dardan") Massif and so cannot be correlated with any Romanian units.

LITHOSTRATIGRAPHY AND STRATIGRAPHIC CORRELATION OF THE PERMIAN DEPOSITS IN ROMANIA AND BULGARIA

In all domains of the Balkan area, the Permian System can be divided into two well-differentiated sedimentary groups (cycles), separated by a marked unconformity (Yanev, 1981).

From the above general palaeogeographical schemes (Figs 2, 3) and the following Bulgarian stratigraphical successions (Figs 4, 5 and 6), some correlations could be suggested. The NW Balkan prolongation of the Variscan belt is recognised through the western part of the South Carpathians (Banat area). Here, low-scale unconformities occur at the "Stephanian"/Lower Permian ("Autunian") boundary (Secu area), while sedimentary gaps are recorded between the upper "Westphalian" - "Stephanian" sequences (as in the West Balkan domain). The Permian successions are unconformably overlain by Lower Jurassic deposits.

In both the Getic and Danubian Units, only Lower Permian deposits are known. The succession begins with black shaly sediments (fossiliferous, Early Permian in age

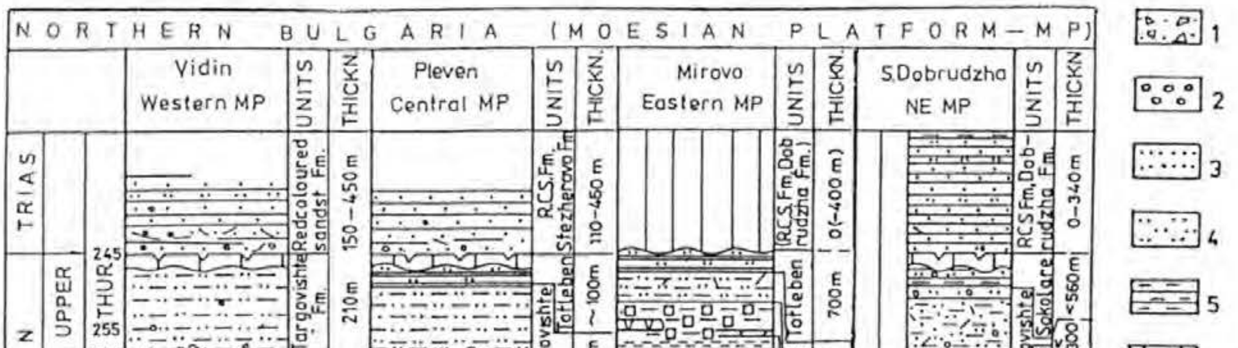

Fig. 4 - Scheme for the lithology, stratigraphic position and thicknesses of selected typical successions of the Upper Paleozoic in the boreholes from the Bulgarian part of the Moesian Plate (see Figs 2-5 in Seghedi *et al.*, this volume). The presented lithostratigraphic units are comparable with some units in the Romanian part of the Moesian Plate.

Symbols (for Figs 4, 5 and 6): 1 - breccia; 2- conglomerate; 3 - sandstone; 4 - siltstone; 5 - shale; 6 - limestone; 7 - dolomite; 8 - anhydrite; 9 - halite; 10 - coal; 11 - volcanics; 12 - volcaniclastics; 13 - carbonate concretions; 14 - anhydrite concretions; 15a - unconformity; 15b - erosional surface; 16 - stratigraphic gaps.

with Autunian type flora), conformably overlain by red beds and volcaniclastic facies, at least late Early Permian (late "Autunian") in age (Raileanu, 1953; Nastaseanu, 1975, 1987; Nastaseanu *et al.*, 1973; Stan, 1987; Stanoiu & Stan, 1986). So far, no paleontological evidence from the red beds of the upper part of the Lower Permian ("Saxonian - Thuringian" age) has been recorded (Antonescu, 1980; Antonescu & Nastaseanu, 1976).

These basins can be correlated with their Bulgarian counterparts. Along the Danube, in the Svinita zone, the Lower Permian Ieliseva Formation can be correlated with the Zelenigrad Formation ("Autunian"; Yanev & Tenchov, 1972) and both the Vranska Formation and the lower two members of the Smolyanovtsi Formation (Variscan orogen zone, Lower Permian; Yanev, 1981). The volcaniclastic sequences of the Sirinia Basin exposed along the Romanian tributaries of the Danube (*e.g.* Staristea Valley) are similar to part of the Vranska Formation near the Vrashka Chuka Hill, the town of Belogradchik and the village of Ozirovo, to the Gyurgich Member of the Smolyanovtsi Formation, and especially to volcanogenic units in the Central Balkan Mountains (Zhukov *et al.*, 1971, 1976; Yanev, 1981, 1982 a).

The Permian sequences of the Resita Basin (Getic Nappe) can be correlated with their Bulgarian counterparts in the following way: the Ciudanovita Formation, mainly the basal Girliste Member (lowest Lower Permian - lower "Autunian", mainly black pelites) is similar to the Levitsa Formation (cropping out around Stakevtsi and Prevala), the Dalgi Del Formation (cropping out near Melyane village), the Lyutadzhik Formation cropping out in the Ozirovo-Lyutadzhik areas) and the Buk Formation (cropping out in the Zverino-Ignatitsa areas). The topmost member of the Ciudanovita Formation, the Lisava Member (at least the upper part of the Lower Permian - upper "Autunian"), in red-bed facies, is rather similar to some sequences of the Milinska Formation (Tchumacenko & Shopov, 1965) and the Koritarska Member of the Smolyanovtsi Formation (Yanev, 1981). For the Upper Carboniferous sequences in Resita Basin (Resita Formation), the similarity points to the Starchovdol Formation (Stakevtsi area), the Melyane Formation (near the village of Melyane), the Ekimska and Draganitsa formations (Draganitsa-Ozirovo-Byala Rechka areas) or the Ochindol Formation (Zverino and Ignatitsa areas).

The Permian of the Codru-Bihor Basin conformably overlies the Upper Carboniferous deposits, or unconformably covers various older basement rocks. The Per-

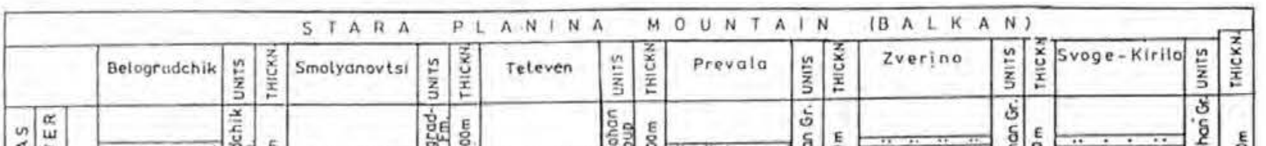

Fig. 5 – Scheme for the lithology, stratigraphic position and ticknesses of selected typical successions of the Upper Paleozoic related to the Variscan Orogen (Stara Planina Mountain System in Bulgaria). The presented lithostratigraphic units are compared with some units mentioned in the text for the Romanian part of the Variscan Orogen (Carpathian Mountain System) (symbols as in Fig. 4).

mian red-beds grade upwards (?) to Lower Triassic (Buntsandstein) quartzitic sandstones (Bleahu, 1963; Bleahu *et al.*, 1985; Bordea & Bordea, 1982; Mantea, 1985). The sequences can be correlated to the Permian from the southern basins in Bulgaria (the area south of the Balkan Mountains, including Kraishte and present-day Sredna Gora Units). The Lower Permian in this domain also conformably overlies upper "Stephanian" sediments or unconformably covers older basement rocks. The Upper Permian red-bed clastic and silty-shaly deposits are separated from the Lower Permian sediments by an erosional surface, or they lie unconformably on various older metamorphic, igneous or sedimentary rocks. In the Kraishte area a narrow unconformity between the Upper Permian and Triassic sediments is recorded (Yanev, 1964).

Facial similarities between the red beds of the Aries Valley (close to Arieseni) and their Bulgarian counterparts are the following: the upper part of the Gabra Formation - upper "Stephanian" to Lower Permian in age (transition between the "Autunian" and "Rotliegend" facies; Kozhukharov *et al.*, 1980), the Tarnavska Formation (Lower Permian) and the Ravulya Formation (Upper Permian) in Lozenska Mountain, the Boboshevo Formation (Lower Permian), in the Vukovo area (Yanev, 1982 b), the Skrino Formation (Zagorchev, 1980), or the Noevtsi, Kiselichka and Nepraznentsi formations (Upper Permian or (?) Upper "Rotliegendes" in Yanev, 1979).

The age and lithology of the Permian deposits from the northern part of the Moesian Platform (Romania) generally corresponds to those on the southern, Bulgarian part (Yanev, 1992, 1993 a). This is caused by the mirrored positions of both zones – in the foreland of the Variscan chain, relatively close to the Balkan part southwards and to the Carpathian part, northwards. The distribution of the coarse, proximal facies in the northern and southern areas of the "Platform" suggests tectonically controlled deposition, related to E-W to NW-SE trending extensional faults. A second control on Permian sedimentation was the active subaerial volcanism, which according to Bulgarian authors was developed only in the Early Permian (lower part of the Rotliegend facies). In the Romanian part of the Moesian Platform, bimodal volcanism continued during the Triassic, as indicated by boreholes.

For Bulgaria during Late Paleozoic times, two main cycles of continental sedimentation can be again envisaged in the whole eastern part of the Balkan Peninsula. The first group (generally spanning Late Carbonifer-

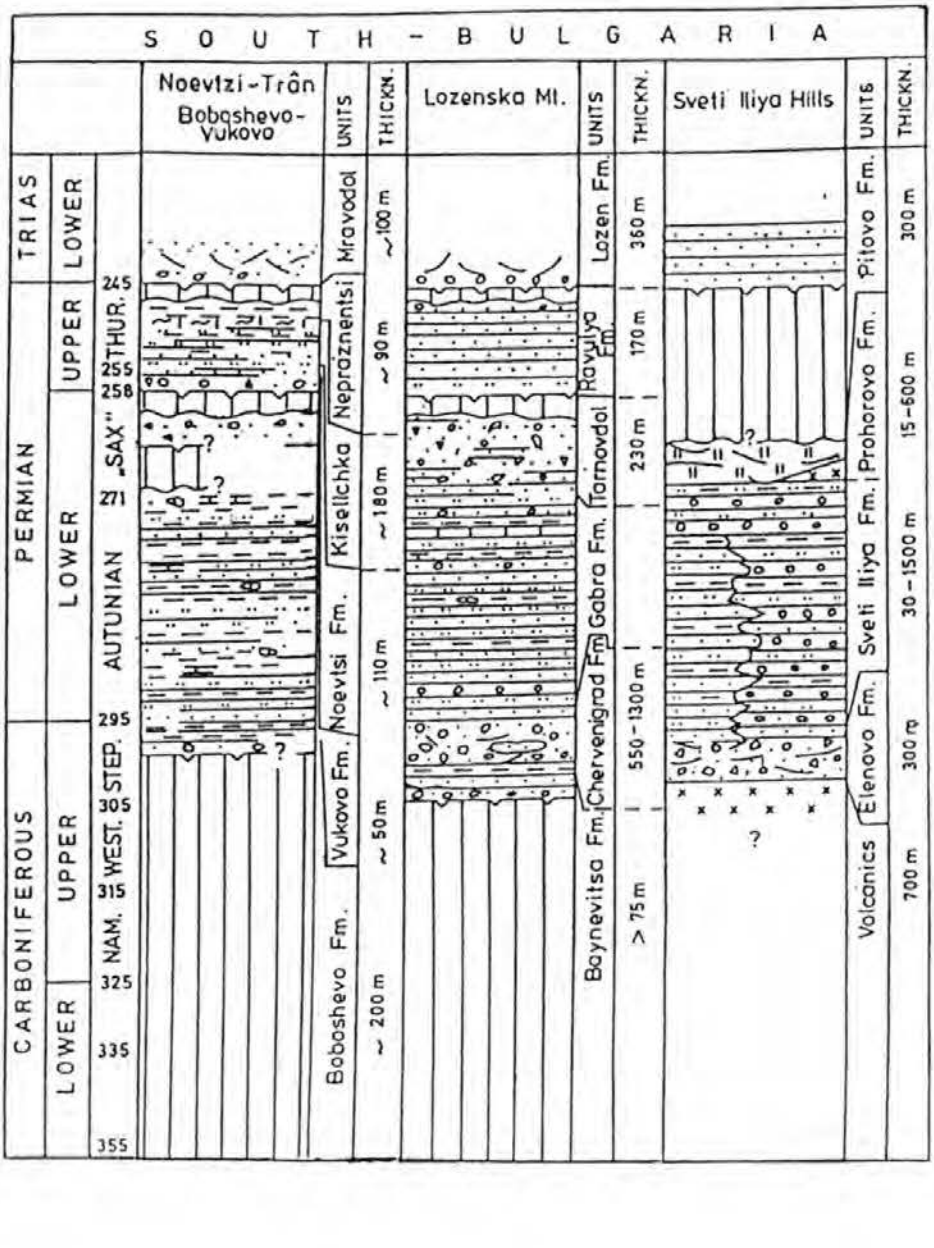

Fig. 6 - Scheme for the lithology, stratigraphic position and thicknesses of selected typical successions of the Upper Paleozoic in South Bulgaria (for symbols see Fig. 4)

ous, mainly late Stephanian to Early Permian times) consists of lacustrine, fluvial and proluvial fan deposits, as well as of volcanic rocks, both infilling intermontane and foremontane grabens or semigrabens (Yanev, 1969, 1988, 1989). The basins were separated by highs of Lower Paleozoic, metamorphic and igneous basement rocks. The boundary faults generally have WNW-ESE trends and often coincide with long-lived tectonic structures reactivated as late as the Alpine orogeny.

The second group (Late Permian, from the Tatarian (?) to the P/T boundary after data from Schirmer, 1960 and Yanev, 1993 a) is represented by deltaic and continental clastics and, only in the southeastern part of the Moesian domain (in the Provadia depression), by halite evaporites, as well as by sulphate evaporites in a zone north of the town of Varna (Yanev, 1993 a). These deposits form a widespread blanket, covering both basins of the first group and the surrounding highs of western Bulgaria (Moesian Platform). The continuity of tectonic control is documented by strong thickness variations - from a few metres (or total absence in many localities of the former Variscan Orogen, such as over the NE-Bulgarian Uplift) to more than 1200 m in the depocentres and in areas with evaporite sedimentation (former foremontane depression).

SEDIMENTOLOGY, FACIES AND SOME PALEOGEOGRAPHICAL ASPECTS OF THE PERMIAN DEPOSITS OF BULGARIA AND ROMANIA

Permian deposits in both Romania and Bulgaria generally show molasse features, mainly and more typically for the Lower Permian in the Balkan, the Prebalkan, the Sredna Gora, the Kraishte, the South Carpathians, the Apuseni Mountains and the Carapelit Basin. In the Moesian and Scythian Platforms, as well as in the Kraishte area, the molassic character, especially of the Upper Permian sediments, is not so obvious, since both continental-basins and partly transitional facies occur. The Permian sequences from the present-day Alpine fold-belts show clear Variscan molasse features. This evidence is related to sedimentation in relatively narrow, deeper intramontane basins and half-grabens within a folded terrain with steep relief. Those sequences from the Moesian and Scythian Platforms are fault-related, since deposition occurred in shallower, sometimes larger grabens and half-grabens inside a hilly terrain.

Terrigenous, volcanic, volcaniclastic, and locally evaporitic sediments accumulated in various continental environments: from fluvial, proluvial, playa, colluvial and alluvial-plain to palustrine, lacustrine, continental-basin and sabkha conditions (Yanev, 1970, 1989).

For Bulgaria, the chain of the Variscan Orogen extended NW-SE across Bulgaria, bordered by lowlands both to the north and the south. In intramontane valleys within the orogen, as well as to its borders were deposited clastic, shaly and coal-bearing sediments in river-beds, terrace, lacustrine, palustrine and other facies (Yanev, 1969, 1989). They follow from proluvial cones and playa sediments during the late Early Permian (two clastic successions separated by erosional surfaces, and as facies corresponding to the early Rotliegend and late Rotliegend). During the Late Permian, two larger continental basins formed to the north and the south, controlled by a lower-altitude main watershed (Yanev, 1981).

For Romania, the molassic character is well defined in intramontane basins in the South Carpathians (Resita, Sirinia and Presacina basins) and in the Apuseni Mountains. The molassic sedimentation was controlled by alluvial, fluvial, lacustrine, and swampy (with no significant coal seams as a result) depositional environments, to which volcanic and volcaniclastic material was added. For the South Carpathians, the ratio of clastic vs. volcaniclastic sedimentation is high in the Resita Basin and low in the Sirinia and Presacina basins, where volcanic and volcaniclastic rocks predominate.

In the Apuseni Mountains, terrigenous and volcaniclastic sedimentation occurs as well, the dominance of one sedimentological type over the other depending on area. The Permian deposits conformably overlie Upper Carboniferous deposits, the terrigenous facies often presenting typical red-bed features. The terrigenous vs. volcaniclastic sedimentation continued until the Triassic, the Permian/Triassic boundary being difficult to establish within the red-bed facies.

TECTONIC EVOLUTION OF THE PRE-LATE PALEOZOIC TERRANES DURING THE PERMIAN

The various regional, lithological, paleoclimatic, paleomagnetic, paleobiogeographical and other data show a peri-Gondwana provenance for the basement of the Upper Paleozoic successions in Bulgaria (Yanev, 1997 and cited references). Three Lower Paleozoic terranes (from north to south): Moesian, Balkan and Thracian are distinguished (Yanev, 1990, 1993 b, 1997). At the start of the Late Carboniferous, the *en echelon* movement from Gondwana to Paleo-Europa brought the Moesian and Balkan (+ Thracian?) terranes into collision. The building of the Variscan Orogen was related to the collisional accretion between both Moesian and Balkan terranes. The development of the Late Carboniferous and Permian molasse sedimentation took place in late-orogenic and post-orogenic conditions. During the Late Permian, the formerly variable relief decreased in energy and deposition was controlled particularly by transtensional movements. As a whole, the Perm-

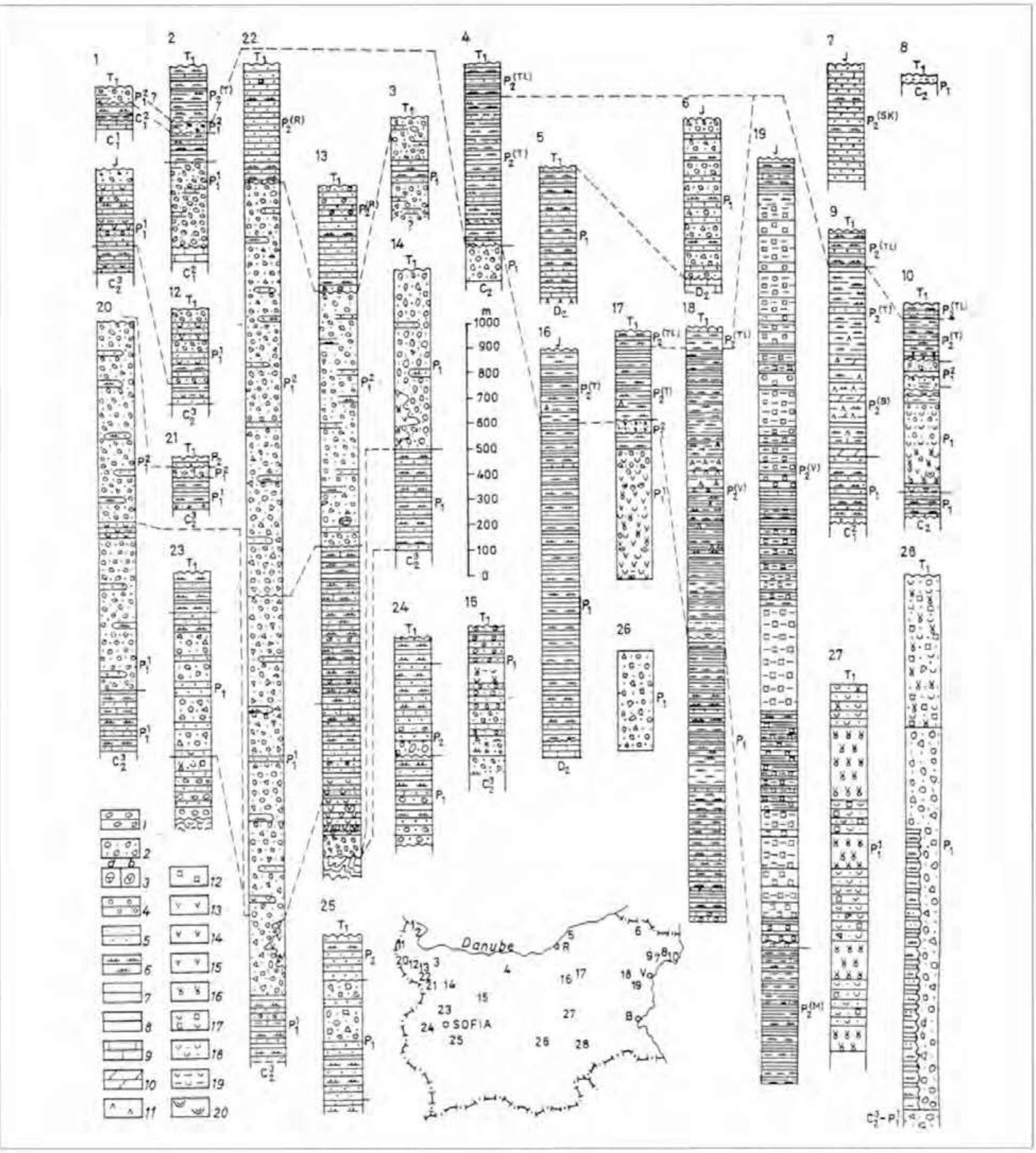

Fig. 7 – Schematic logs of some typical Permian successions in Bulgaria (based on outcrops and borehole data) presented with their comparable real thicknesses.

Lithological symbols: 1 - conglomerate; 2 - breccia; 3 - concretions: a - limey, b - anhydritic; 4 - gravelite; 5 - sandstone; 6 - siltstone; 7 - argillite; 8 - coal; 9 - argillaceous limestone; 10 - dolomite; 11 - anhydrite; 12 - halite (salt); 13 - andesite; 14 - trachyte; 15 - latite; 16 - dacite; 17 - xenotuffs; 18 - tuffs; 19 - tuffites; 20 - ignimbrites.

Stratigraphic symbols: D_2 - Upper Devonian; C_1 - Lower Carboniferous; C_1^1 - Lower Carboniferous, Tourniasian; C_1^2 - Lower Carboniferous, Visean; C_2 - Upper Carboniferous; C_2^3 - Upper Stephanian; P_1 - Lower Permian (Rotliegend); P_1^1 - Lower Rotliegend; P_1^2 - Upper Rotliegend; $P_2^{(T)}$ - Upper Permian, Targovishte Fm.; $P_2^{(TL)}$ - Upper Permian, Totleben Fm.; $P_2^{(R)}$ - Upper Permian, Rikovska Fm.; $P_2^{(V)}$ - Upper Permian, Vetrino Fm.; $P_2^{(M)}$ - Upper Permian, Mirovo Fm.; $P_2^{(SK)}$ - Upper Permian, Sokolevo Fm.; T_1 - Lower Triassic; J - Jurassic.

Sketch: distribution of sections. Localities: 1 - Gomotartsi; 2 - Vidin; 3 - Rasovo; 4 - Totleben ; 5 - Chereshovo; 6 - Severtsi; 7 - Sokolovo; 8 - Gurkovo; 9 - Bezvoditsa; 10 - Kaliakra; 11 - Kiryaevo; 12 - Belogradchik; 13 - Smolyanovtsi; 14 - Ozirovo; 15 - Teteven; 16 - Dolna Zlatitsa; 17 - Vasil Levski; 18 - Vetrino; 19 - Mirovo-Hrabrovo; 20 -Stakevtsi; 21 - 22 - Prevala; 23 - Kurilo; 24 - Kraishte (Boboshevo-Noevtsi); 25 - Lozen Mt.; 26 - Chernogorovo; 27 - Sliven; 28 - Sakar Mt.

ian basins evolved from narrow zones (the Variscan Orogen and locally the Moesian and Kraishte lowlands) into wider depositional areas, due to lower relief and the increase of accumulation areas at the expense of source areas.

CONCLUSIONS

As parts of the Carpathian-Balkan chain, Romanian and Bulgarian territories recorded the influence of Variscan and Alpine orogenies in the same way, with almost the same evolution, stratigraphy and depositional features. This fact is demonstrated by the possibility of correlation between the South Carpathians and the Balkans. In the Moesian Platform, shared by Romania and Bulgaria, the structure and stratigraphy could well be correlated, this prospect remaining valid for the Permian deposits presented here. At the same time, the comparison between Permian deposits from Apuseni Mountains and the Kraishte area is not so certain. Those from North Dobrogea and Bulgarian zones without Late Paleozoic sedimentation (Thracian and Dardan massifs) are difficult to correlate.

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THE PERMIAN SYSTEM IN ROMANIA

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Key words – Permian; sedimentology; paleontology; magmatism; tectonics; Romania.

Abstract – Permian deposits from major tectonic units in Romania (South Carpathians, East Carpathians, Apuseni Mountains, North Dobrogea, Moesian and Scythian Platforms) are mainly developed in continental facies, with molassic characteristics. Red beds are the dominant facies, but basal black and grey shaly deposits are present in the South Carpathians and Apuseni Mountains. In all areas, sedimentation took place mostly in alluvial fan, fluvial and lacustrine systems. Shallow-marine carbonate platform conditions were restricted to the northern part of the Moesian Platform in the Early Permian. Evaporites are associated with the red beds only within the platforms.

The sedimentary record of most basins includes volcano-sedimentary sequences. The Permian volcanism was bimodal, with an alkaline signature in the Apuseni Mountains, North Dobrogea and Scythian Platform. The basalt-rhyolite bimodal association typically occurs in the South Carpathians, Apuseni Mountains and the Moesian Platform, while the basalt-trachyte association is found in North Dobrogea and the Scythian Platform.

The South Carpathians (Getic Nappe and Danubian units) yielded by far the most fossiliferous Permian deposits in Romania, the fossil remains being represented by flora (compressed macroflora, microflora), and fresh water fauna (ganoid fishes, ostracods, bivalves). The Apuseni Mountains include deposits yielding flora (silicified woods, microflora), while the North Dobrogea has yielded no fossils to date. The Moesian and Scythian Platforms include faunal remains, but palynological evidence was also found in the latter.

An extensional tectonic setting, related to Late? Permian rifting, is suggested by both field evidence and the geochemistry of the volcanic rocks from the South Carpathians, Apuseni Mountains, Moesian and Scythian Platforms. Typical rift basins are those from the platforms. For North Dobrogea, magmatic associations illustrate the transition from a compressional, post-collisional setting in the Early Permian to a transtensional setting in the Late Permian, related to the tectonic collapse of the Hercynian crust.

Parole chiave – Permiano; sedimentologia; paleontologia; magmatismo; tettonica; Romania.

Riassunto – I depositi permiani delle maggiori unità tettoniche della Romania (Carpazi meridionali, Carpazi orientali, Monti Apuseni, Dobrogea settentrionale, Piattaforme Moesia e Scitica) sono rappresentati essenzialmente da facies continentali con caratteristiche di molasse. I *red beds* corrispondono alla facies dominante, ma peliti (*shales*) di color nero affiorano altresì, in posizione sottostante, nei Carpazi meridionali e nei Monti Apuseni. In tutte le sopra citate aree, la sedimentazione si espresse principalmente in sistemi di coni alluvionali, fluviali e lacustri. Condizioni di piattaforma carbonatica di mare basso furono limitate alla parte settentrionale della Piattaforma Moesia, nel corso del Permiano inferiore. Evaporiti si trovano associate a *red beds* solo all'interno delle piattaforme. Il record sedimentario della maggior parte dei bacini include sequenze vulcano-sedimentarie. Il vulcanismo permiano fu bimodale, con un marchio di natura alcalina nei Monti Apuseni, nella Dobrogea settentrionale e nella Piattaforma Scitica. L'associazione bimodale basalto/riolite ricorre tipicamente nei Carpazi meridionali, nei Monti Apuseni e nella Piattaforma Moesia, mentre l'associazione basalto-trachite è presente in Dobrogea meridionale e nella Piattaforma Scitica.

I Carpazi meridionali (Falda Getica e unità Danubiche) comprendono di gran lunga i maggiori depositi fossiliferi della Romania, con resti fossili rappresentati da flore (macroflore limitate, microflora) e faune (pesci ganoidi, ostracodi, bivalvi). I Monti Apuseni includono depositi a flore (legni silicizzati, microflora), mentre la Dobrugea settentrionale non ha ancora dato fossili utili per eventuali datazioni. Le Piattaforme Moesia e Scitica contengono resti faunistici; tuttavia, nella seconda di esse è stata anche riscontrata la presenza di elementi palinologici.

Un assetto tettonico estensionale riferito al *rifting* permiano è suggerito da evidenze di campagna e dalla geochimica delle rocce vulcaniche provenienti dai Carpazi meridionali, dai Monti Apuseni, e dalle Piattaforme Moesia e Scitica. Bacini tipici di *rift* sono quelli di piattaforma. Per quanto riguarda la Dobrogea settentrionale, le associazioni magmatiche segnano la transizione da un assetto compressionale e post-collisionale, durante il Permiano inferiore, ad un assetto transtensivo, riferito al collasso tettonico della crosta ercinica, nel corso del Permiano superiore.

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INTRODUCTION

In Romania, Permian deposits are exposed in the Alpine belts (East and South Carpathians, Apuseni Mountains and North Dobrogea orogen), but they are also known from boreholes in the Moesian and Scythian Platforms (Fig. 1). In the East Carpathians, scarce terrigenous sediments overlain by Lower Triassic sandstones are ascribed to the Permian within the Bucovinian, Sub-Bucovinian and Infra-Bucovinian Nappes. In the South Carpathians the Permian deposits are recorded in both the Getic and Danubian Nappe systems. The Permian occurrences are confined to the central part of the Apuseni Mountains (Codru and Biharia Nappe systems and Bihor "autochthonous" unit of the Codru Moma, Bihor and Padurea Craiului Mountains).

The Permian sedimentation took place in several basins in the South Carpathians – Resita and Pui (Getic Nappe), Sirinia and Presacina (Danubian units) (Codarcea, 1940; Raileanu, 1953; Stilla & Luta, 1968). Small patches of thin Permian red beds, mostly fanglomerates, initially described as "Verrucano" facies, are scattered locally in the area of the Danubian Window and in the Godeanu outlier of the Getic Nappe (Gherasi, 1937; Pavelescu, 1953).

The Resita Basin exposes the sedimentary cover of the Getic Nappe in the westernmost part of the South Carpathians (Banat region). It is a north-south elongated basin, faulted and folded longitudinally, its deposits belonging to a Variscan (Westphalian A?-B-Lower Permian - "Autunian") and an Alpine cycle (Hettangian-Albian). The Pui area is located within the Hateg Depression (central South Carpathians), which is dominated by Mesozoic and Tertiary deposits.

The Sirinia Basin represents the cover of the Upper Danubian units and lies in the southwesternmost Carpathians (Banat region), mainly within the Almaj Mountains. It is a north-south oriented basin, located eastwards of and parallel to the Resita Basin. The Presacina Basin, oriented north-south, lies eastwards of the Sirinia Basin. Both Danubian basins include products of two main cycles, a Variscan and an Alpine cycle.

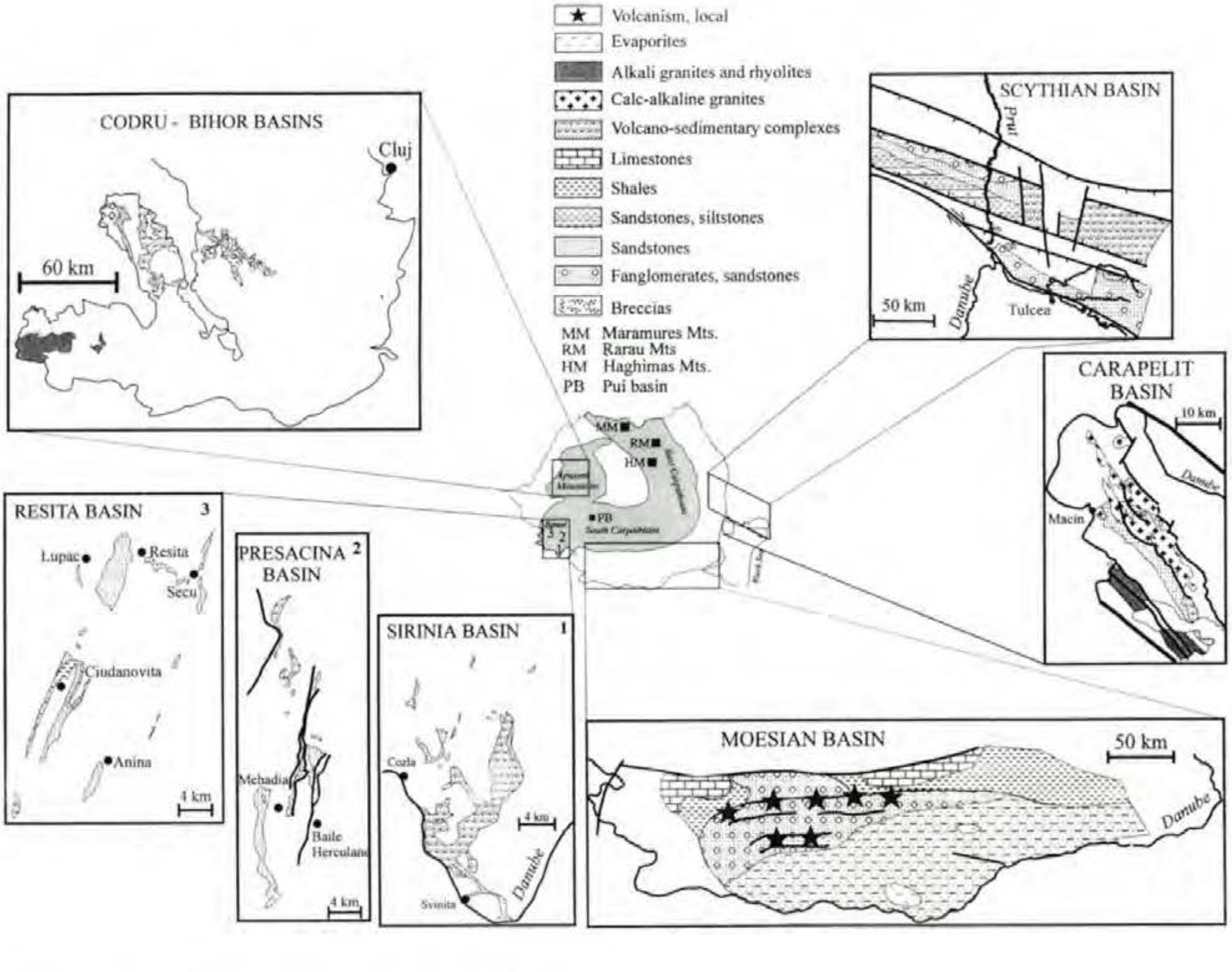

Fig. 1 – Location map and distribution of Permian deposits in Romania.

The Permian of the Apuseni Mountains is known in the Codru Nappe System (Dieva, Moma, Finis and Codru Nappes) of the Codru Moma Mountains, as well as in the Biharia Nappe System (Garda and Arieseni Nappes) and the Bihor Unit (Bihor "Autochthonous") of the Bihor and Padurea Craiului Mountains (Bleahu, 1963; Istocescu *et al.*, 1970; Patrulius, 1972; Bordea & Bordea, 1982; Bleahu *et al.*, 1985; Dimitrescu, 1988). Recent studies (Bordea & Bordea, 1993) revealed the presence of the Lower Permian bioturbated sandstones in the Highis Mountains (southwestern part of the Apuseni Mountains).

In North Dobrogea, Permo-Carboniferous continental sedimentation took place in largely E-W oriented, narrow piggyback basins related to back-arc thrusting (Seghedi & Oaie, 1995 a). The NW-SE elongation of the outcrop area of Carapelit Formation (Fig. 1) is the result of subsequent deformation, and preservation of the Upper Paleozoic sediments in the core of a Kimmerian syncline.

An E-W oriented rift basin controlled the Permian sedimentation in the northern part of the Moesian Platform. This was located south of an elongated basement high (Craiova - Bals - Optasi rise) (Paraschiv, 1979), which probably represented a rift shoulder. Other part of the Permian basin occurred in the southern part of the Romanian Moesian Platform and continued southwards into the present-day Bulgarian territory.

The Scythian Basin, bordered and fragmented by major faults, is oriented WNW-ESE and includes the Aluat-Sarata and Lower Danube sub-basins (Neaga & Moroz, 1987), separated by tectonic ridges or push-ups.

STRATIGRAPHY

Coarse-grained sediments (Haghimas Breccias) in the Bucovinian Nappe of the East Carpathians, consisting mainly of unsorted clasts of metamorphic rocks, were ascribed to the Permian in Rarau and Haghimas Mountains, based on palynological associations (Muresan, 1970). In the Bucovinian and Sub-Bucovinian Nappes from the Maramures Mountains, the Haghimas Breccia directly overlies the metamorphic basement and is unconformably overlain by red Permian siliciclastics; based on field relations, an Upper Carboniferous and possibly Lower Permian age was ascribed to these rocks, overlain in turn by Lower Triassic sediments (Sandulescu *et al.*, 1989). A Permian age was assigned to the red sandstones and conglomerates from the Infrabucovinian Nappes in the same area, by lithological correlation with the Rozis series from Ukraine (Sandulescu, 1985).

The Variscan molasse deposits of the Resita Basin are subdivided into the Upper Carboniferous ("Westphalian A?-B" – "Stephanian") Resita Formation and the Lower Permian ("Autunian") Ciudanovita Formation (Bucur, 1991); the latter consists of lower black deposits (the Gîrliste Member) overlain by red beds (the Lisava Member) (Fig. 2). The Ciudanovita Formation lies conformably (west-

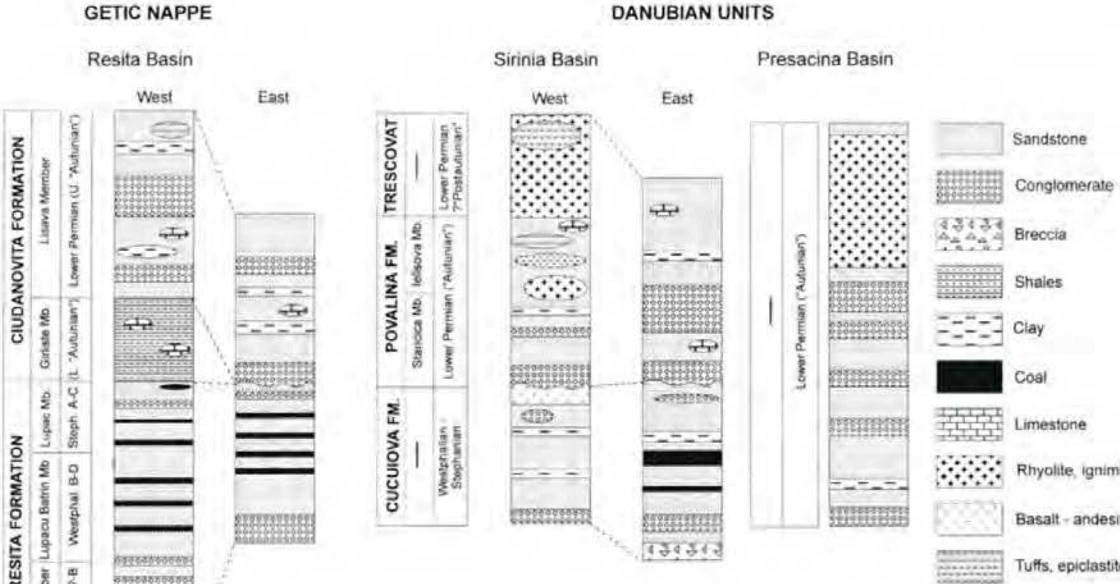

Fig. 2 – Variscan molasse deposits of the South Carpathians. Data compiled from Raileanu (1953), Nastaseanu *et al.* (1981), Stanoiu & Stan (1986) and Stanoiu *et al.* (1996).

wards) or unconformably (eastwards) on the Upper Carboniferous deposits of the Resita Formation, and it is unconformably overlain by the Lower Jurassic deposits of the Steierdorf Formation (the first unit of the Alpine cycle). The typical molasse characteristics suggest that the continental deposits of the Ciudanovita Formation accumulated in an intramontane depression. During Late Carboniferous and Early Permian times, the lateral shift of the depositional centre of the basin explains the numerous heteropic, partially juxtaposed Upper Paleozoic sequences in the Resita Basin (Stanoiu *et al.*, 1996). The Girliste Member is the lowest sequence of the Lower Permian, dominated by lacustrine deposits. Its thickness (150-300m) decreases from the west (Lupac, Ciudanovita and Jitin areas) to the east, disappearing in the Secu area. This member consists of black pelites with sandstone and freshwater limestone interlayers; rare microconglomerates or thin coal layers also occur. The Lisava Member is represented by red beds (red, green and grey sandstones, clays, conglomerates), with freshwater limestone interbeds; rare volcanic tuff and tuffite interlayers occur westwards in Lupac area. Its thickness varies between 1000-1500m. The paleontological data recorded within the middle part of the succession indicate an upper Lower Permian ("Autunian") age, but there are no markers for younger ages ("Saxonian"-"Thuringian"?) recorded for the uppermost sequences of the Lisava Member (Antonescu, 1980).

Below the Lower Jurassic deposits in the Pui area, scarce outcrops of grey sandstones recovered close to the Cioclovina Cave yielded palynological assemblages ascribed to the Lower Permian (Stilla & Luta, 1968; Stilla, 1980).

The Variscan cycle of the Sirinia Basin (Fig. 2) is represented by "Westphalian-Stephanian" clastics overlain by

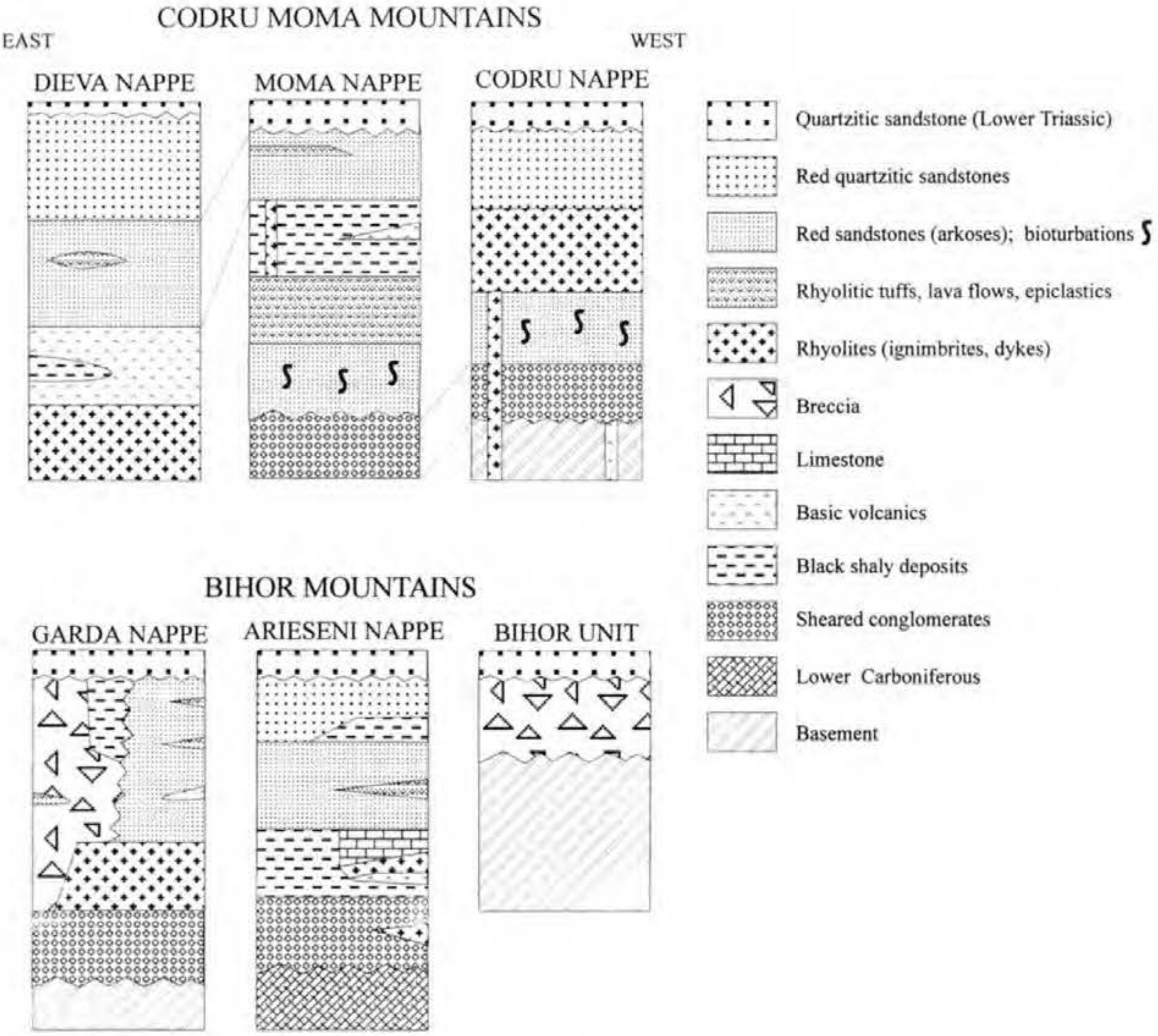

Fig. 3 – Permian logs of the Apuseni Mountains, after Bleahu *et al.* (1979, 1981, 1985) and Dimitrescu *et al.* (1977).

the Lower Permian sediments of the Povalina Formation; this Permian sequence unconformably rests on the lower-middle "Stephanian" deposits, upper "Stephanian" being absent. The Povalina Formation includes black and grey shales (Staricica Member) overlain by red beds (Ielisova Member) (Stanoiu & Stan, 1986). The Ielisova Member conformably overlies the Staricica Member in the central areas of the basin, and unconformably rests on the basement towards the marginal parts of the basin, mainly eastwards (Stanoiu *et al.*, 1996). The red beds are dominated by thick volcano sedimentary sequences, with local lacustrine limestones (Raileanu, 1953). Paleosol layers with caliche concretions often occur in the red bed sequence. The volcano-sedimentary dominance is very strong within the western part of the Sirinia Basin, while to the east the sedimentation is more terrigenous. The black fine clastics of the Staricica Member are thin and fossiliferous.

Within the Presacina Basin, the Lower Permian deposits show both terrigenous (red beds) and volcaniclastic deposits (Codarcea, 1940; Nastaseanu *et al.*, 1973; Nastaseanu, 1975, 1987) (Fig. 2).

Volcaniclastic, volcanic and terrigenous Permian sequences are exposed in various units of the central Apuseni Mountains (Fig. 3). The discovery of Lower Permian ("Autunian") rocks is based on geometric and facies criteria; a possible "Saxonian" or even younger Permian age is indicated by silicified wood remains. The basal phyllitic sequence of the Permian corresponds to the black bituminous pelites and is overlain by red beds with tuffaceous interbeds. To the east, in the Bihor Mountains, the Lower Permian consists of sheared conglomerates; the Upper Permian sequence starts either with ignimbritic rhyolites, or with breccias and fanglomerates sourced from the nearby metamorphic basement. The fanglomerates interfinger with coarse sandstones or fine shale sequences, as well as with ignimbritic rhyolites and occasionally with basalts.

The stratigraphy of the Permo-Carboniferous continental deposits (Carapelit Formation) of North Dobrogea includes a lower member of grey alluvial fan - alluvial plain sediments (loosely ascribed to the Carboniferous), unconformably overlying older metamorphic basement or Silurian-Lower Devonian sediments; the succession continues upsequence with red beds (0-900 m thick), overlain in turn by an upper volcanosedimentary member (Oaie, 1986; Seghedi & Oaie, 1986, 1995 b; Seghedi *et al.*, 1987) (Fig. 4).

In both the Moesian and Scythian Platforms, the Permian overlies older Paleozoic sequences (Fig. 5); the Permo-Triassic boundary is often difficult to trace, since both Permian and Triassic sediments show Germanic facies development. Evaporites occur in red beds devoid of carbonate sediments, suggesting a desert or coastal sabkha environment. In the Moesian Platform, red continental deposits prevail, but recent micropaleontological evidence suggests the presence of shallow-marine, Lower Permian carbonate facies in some parts of the platform (Pana, 1997) (Figs 1, 5). The red beds are interbedded with products of bimodal volcanism, with rhyolitic and basaltic rocks prevailing in the Moesian Platform, and the basalt-trachyte association well represented in the eastern part of the Scythian Platform.

PALEONTOLOGICAL DATA

Paleontological data were recorded for the Resita and Pui basins of the Getic Nappe, the Sirinia Basin of the Danubian units, the Codru-Biharia Nappes of the Apuseni Mountains, and the Moesian and Scythian Platforms. No paleontologi-

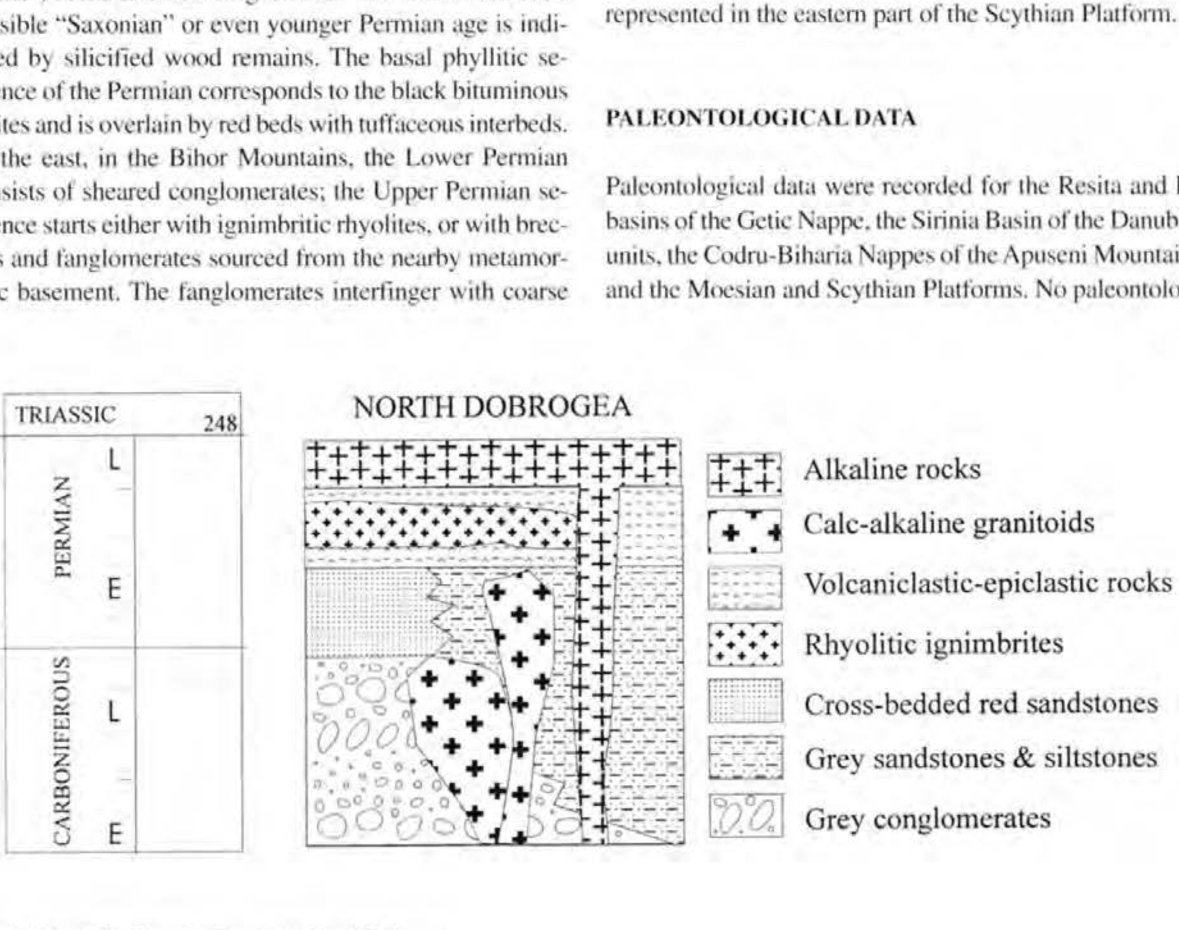

Fig. 4 - Log of the Carapelit Formation, North Dobrogea.

cal evidence has been recorded so far for the Presacina Danubian Basin of the South Carpathians, the Bihor Autochthon or the Carapelit Basin in North Dobrogea.

The first paleobotanical data from the Resita Basin were recorded by Stur (1870) and Telegd (1890), citing various Permian and Upper Carboniferous megaflora taxa. These taxa were later cited by Schreter (1910), Bitoianu (1973, 1974, 1987, 1988), Antonescu & Nastaseanu (1976) and Dragastan *et al.* (1997). Popa (1999) undertook a taxonomic revision and has established for the first time the majority of the Permian megaflora taxa of the Ciudanovita Formation: *Calamites* sp., *Annularia* cf. *stellata*, *Annularia* cf. *sphenophylloides*, *Asterophyllites longifolius*, *Sphenophyllum oblongifolium*, *Autunia conferta*, *Autunia naumannii*, *Arnhardtia scheibei*, *Lodevia suberosa*, *Gracilopteris bergeronii*, *Rhachyphyllum schenkii*, *Neuropteris* cf. *cordata*, *Neuropteris* sp., *Odontopteris* sp., *Pecopteris polymorpha*, *?Linopteris* sp., *Cyclopteris* sp., *Pecopteris* cf. *polymorpha*, *Taeniopteris* sp., *Alethopteris zeilleri*, *Cordaites principalis*, *Walchia piniformis*, *Ernestiodendron filiciformis*, *?Otovicia* sp., *Carpolithes* sp. *A* and *Carpolithes* sp. *B*. For the Gîrliste Member, the paleoflora are diverse and well preserved, represented by pteridophytes, pteridosperms and conifers, recording some Late Stephanian taxa as well as Early Permian taxa. For the Lisava Member, the diversity of the flora decreases substantially, with only Walchiaceae conifers occurring.

The palynological associations of the Permian deposits of the Resita Basin (Beju, 1970; Antonescu, 1980; Antonescu & Nastaseanu, 1976), record an early assemblage with *Florinites*, within the lowermost part of the Gîrliste Member (black sediments), and an upper assemblage with *Potonieisporites*, in the upper part of the Gîrliste Member and within the Lisava Member (red beds).

The first assemblage, with *Florinites*, is dominated by *Florinites* div. sp. (*F. circularis*, *F.* cf. *junior*, *F.* sp., 60-90% of the assemblage), followed by *Potonieisporites novicus* and *P. bharadwaji* (8-15%) or *Reticulatisporites facetus*, *Platysaccus papillionis*, *Alisporites* div. sp. (*A. aequus*, *A. saarensis*, *A.* sp.), *Pityosporites* sp., with less than 1-2% (Beju, 1970, in the Gîrliste area). Antonescu & Nastaseanu (1976) cited the same assemblage from Vidra Valley (Gîrliste Member), correlating the zone with the zone A1 of Doubinger (1974). They also cited S. Luta (in Antonescu & Nastaseanu, 1976) who described a Lower Permian assemblage with *Urospora kosankei*, *Raistrikia microhorrida*, *Complexisporites chaloneri*, *Cordaitina rotata*, *C. uralensis*, *Florinites similis*, *F. volans*, *P. novicus*, *Vittatina simplex* and *Guthorlisporites verus* from the Secu-Lupac area.

The second assemblage, dominated by *Potonieisporites* div. sp. (*P. novicus*, *P. bharadwaji*, 30-70%), is also represented by *Florinites* div. sp. (*F. circularis*, *F.* cf. *junior*, *F.* sp., 15-30%), *Platisaccus papillionis*, *Alisporites* div. sp. (*A. aequus*, *A. saarensis*, *A.* sp., 3-10%), *Pityosporites* sp. (3-8%) and *Striatoabietites* sp. (Beju, 1970, in the Gîrliste zone). To this assemblage was added *Crucisaccites* sp. and *Vesicaspora wilsonii* by Antonescu & Nastaseanu (1976, from Vidra Valley), these authors correlating the assemblage with the zone A2 of Doubinger, and later, (Antonescu, 1980) *Leiotriletes* sp., *Verrucosisporites* sp., cf. *Concetricisporites* sp., *Halletheca reticulata* and cf. *Schopfipollenites* sp. in samples from the Jitin-Ciudanovita Veche Valleys. These assemblages were described from the basal or terminal sequences of the Gîrliste Member. Furthermore, from the median sequence of the Lisava Member (within the Permian red beds) Antonescu & Nastaseanu (1976) identified an assemblage with cf. *Punc-*

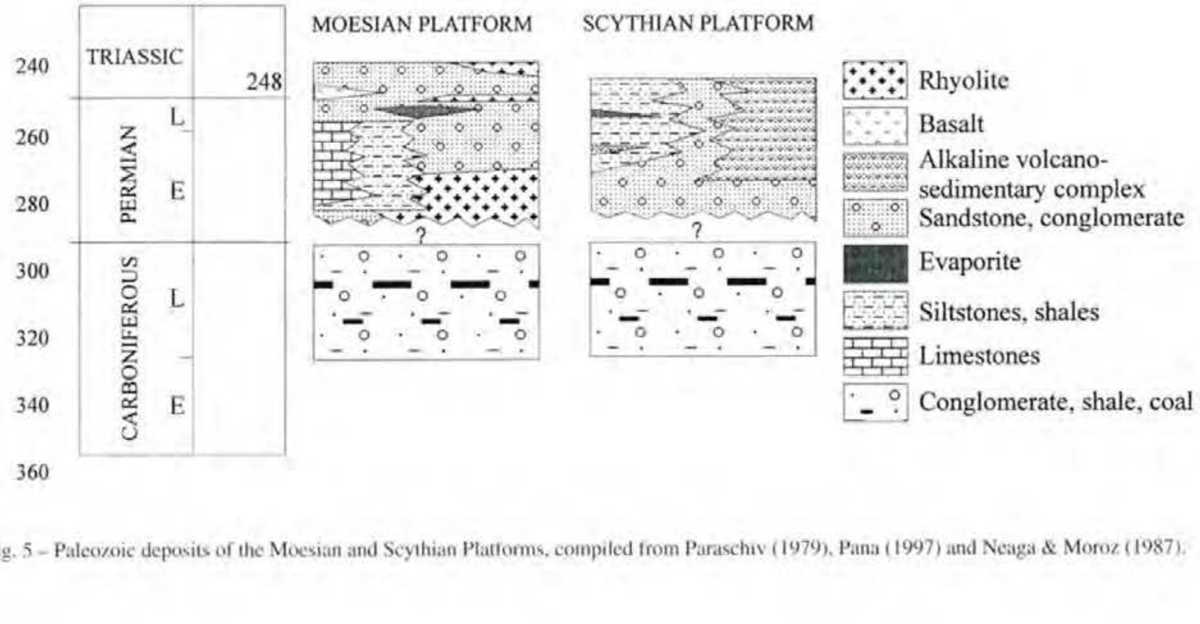

Fig. 5 – Paleozoic deposits of the Moesian and Scythian Platforms, compiled from Paraschiv (1979), Pana (1997) and Neaga & Moroz (1987).

tatisporites sp., *Granulatisporites* sp., *Lophotriletes* sp., cf. *Reticulisporites* sp., cf. *Neoraistrikia* sp., *Knoxisporites* sp., *?Speciosporites* sp., *Guthorlisporites* sp., *Potonieisporites* div. sp. (*P. novicus*, *P. bharadwaji*, *P.* cf. *microdens*, *P. neglectus*), *Florinites* sp., *Crucisaccites* sp., *Vittatina costabilis*, *Protohaploxypinus*, *Striatopodocarpites* sp., *Hamiapollenites* sp., *Ginkgocycadophytus* sp., cf. *Gardenasporites* sp., *Platysaccus* sp., *Alisporites* cf. *aequus* and *Vesicaspora wilsonii*. This is the uppermost palynological assemblage described within the red beds facies and it is considered Lower Permian ("Autunian") in age (zone A2 *sensu* Doubinger, 1974). In a paper discussing the age of the red beds of the Resita Basin, Antonescu (1980) attributed at least an Early Autunian age to the microflora from the basal sequences, but not excluding younger ages (Late Autunian?) for the upper sequences of the red beds, which lack paleontological evidence.

The fauna of the Resita Basin includes fish remains as *Palaeoniscus duvernoy* (Eufrosin, 1957) and the bivalves *Carbonicola carbonaria* and *Anthracomya* cf. *thuringensis*.

At Cioclovina, in the Pui area, Stilla & Luta (1968) mentioned and figured *Azonomonoletes vulgaris*, *Leiotriletes gulaferus*, *Punctatisporites* sp., *P. obliquus*, *P. spathulatus*, *Azonotriletes* cf. *tuberculatus*, *A. microrugosus*, *A.* cf. *rezistens*, *Laevigatisporites* sp., *Pemphygaletes minor*, *Reticulatosporites facetus*, *Punctatisporites marattioides*, *Cyclogranisporites leopoldi*, *Cycadopites* sp., *Vitrisporites* cf. *signatus*, *Ephedripites primus* and *Pityosporites* sp. This assemblage was considered Early Permian in age.

The megaflora of the Povalina Formation in the Sirinia Basin was cited by Telegd (1890) and Raileanu (1953). As their material is not yet revised, their lists include old designations (*Hymenophyllites semiallatus*, *Odontopteris obtusiloba*, etc.); however, *Walchia piniformis* and *Cordaites principalis* were mentioned.

Antonescu (1980) recognised from Sirinia well no. 22766/586 (Berzasca area), within the Povalina Formation, a palynological assemblage with *Leiotriletes* sp., *Dictyophyllidites* sp., *Calamospora breviradiata*, *C. mutabilis*, *Granulatisporites* sp. 1, 2, *Nigrisporites nigritellus*, *Punctatisporites obliquus*, *P.* sp., *Cyclogranisporites* cf. *palaeophytus*, *C.* sp., *Lophotriletes scotii*, *Knoxisporites* cf. *glomus*, *Crassispora* cf. *kosankei*, *Laevigatisporites* cf. *vulgaris*, *L. desmoinesensis*, *Spinosporites exiguus*, *Florinites* spp., cf. *Potonieisporites* sp., *Vittatina* sp., *Vesicaspora wilsonii* and *Ginkgocycadophytus* sp. The assemblage is dominated by *Laevigatisporites* and *Punctatisporites obliquus*, and it is considered Late Stephanian - Early Permian in age.

Faunal remains from the Sirinia Basin consist of the fresh-water bivalves *Carbonicola carbonaria*, *Anthracomya thuringensis* and the ostracod *Estheria* sp. (Raileanu, 1953).

The megaflora recorded for the Codru-Biharia Nappe System are very scarce, represented only by rare rachises, which are impossible to identify. Silicified woods, collected from the red bed sequences, were described by Arabu (1941) as *Dadoxylon* sp. Matyasi (1998) recorded silicified wood fragments identified by Popa (thanks to J. Galtier from Montpellier, France) as *Dadoxylon* of type III *sensu* Doubinger & Marguerier, 1975; they may represent a marker for a possible Late Permian age for the above-mentioned red-beds.

The palynological assemblage identified in the Codru Nappe (at Scarisoara) is represented by *Calamospora microrugosa*, *Turrisporites pyramidalis*, *Verrucosporites* sp., *Florinites* sp., *Cycadopites* sp., *Vittatina* sp., *Azonotriletes* cf. *nodosus*, *Zonotriletes* cf. *anubilus*, *Azonoletes similis*, *Stenozites compactus* and *S.* cf. *bulbiferus* (Visarion & Dimitrescu, 1971). This assemblage is related to a Late Carboniferous - Early Permian time interval.

The presence of ichnogenous *Planolites* is suggested to support an Early Permian age of the bioturbated sandstones from the Apuseni Mountains, as this ichnogenus is confined to the Lower Permian (Rotliegendes) from the Thuringerwald, in Germany, and widespread within coeval formations in continental facies from the Sudets (Poland) and West Carpathians (Slovakia) (Brustur, 1986, 1997). Moreover, identification of the resting trace of a primitiv aquatic amphibian of *Diplocaulus* type (*Hermundurichnus patruliusi*) within the bioturbated sandstones from the Finis Nappe (Padurea Craiului Mountains) enables their correlation with the Lower Permian from Thuringerwald (Brustur, 1997).

Within the central-eastern part of the Moesian Platform, paleontological data from wells Ileana, Hirlesti, Peretu, Peris and Amara indicate Early Permian marine environments (Pana, 1997). The author described Permian species of several foraminifer groups: Textulariina, Miliolina, Lagenina, Stafellidae (nine species), Ozowainellidae (six species), Schubertalidae (three species), Neoschwageridae, Earlandinidae, Nodosinellidae, Corallinellidae, Dagmaritinae, Louizettitinae. *Medlicottia* sp. was also cited. Among the conodonts, *Gnathodus defectus* and *Spathognathodus whitei* were identified in the Lower Permian, and *Anchirognathus typicalis*, *Neospathodus divergens* and *N. profundis* in the Upper Permian (Pana, 1997). As for ostracods, Pana found *Healdia* aff. *axensis*, *Coronakirbia fimbriata* for the Lower Permian and *Permiana oblonga* for the Upper Permian, among many other ostracod species (*Sishaella*, *Bythocypris*, *Tomiella*, *Iniella*, *Kirkybia*, etc.).

Paleontological and palynological studies of the red beds from the Scythian Platform identified a phyllopode association with *Pseudoestheria*, as well as spores indicating a Permian age (Kaptan & Safarov, 1965, 1966). Geochronological data show ages of 290-248 Ma for the associated volcanic rocks (Neaga & Moroz, 1987). However, as they are K-Ar ages, they represent cooling ages.

SEDIMENTOLOGY

Sedimentological studies on the Permian deposits of the South Carpathians and Apuseni Mountains are still in progress. The red-bed sequences from the Resita Basin (Lisava Member) and the Bihor Mountains show frequent cross-bedding, and their depositional features generally indicate alluvial to fluvial environments. The Lower Permian sequence of the Resita Basin coarsens upwards (Stanoiu *et al.*, 1996).

In North Dobrogea, the lower terrigenous members in-

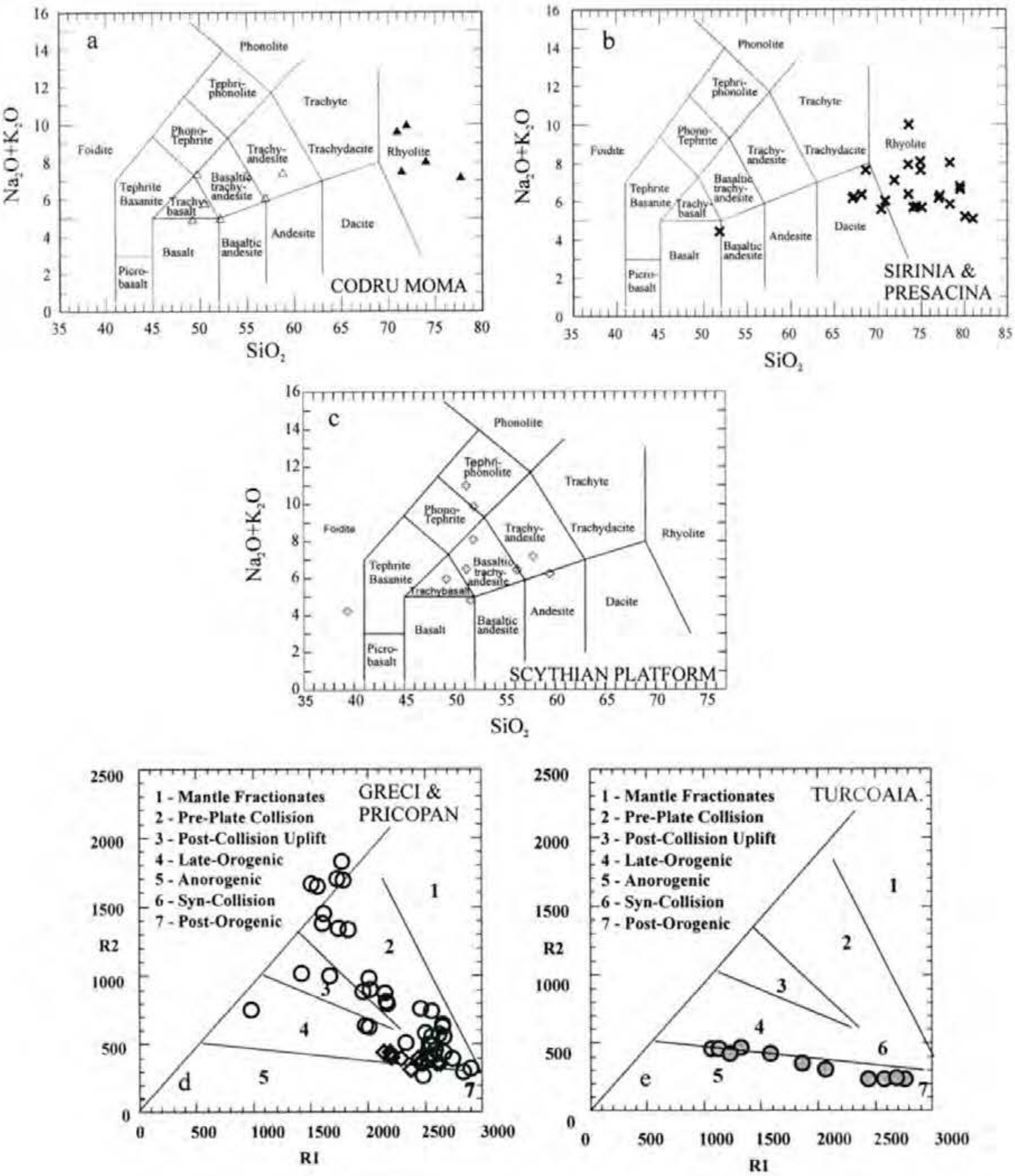

Fig. 6 – TAS diagrams for South Carpathian (Banat), Apuseni Mountain and Scythian Platform volcanics. Data compiled from papers of Stan (1984, 1987), Stan & Udrescu (1980), Stan *et al.*, (1986 a, b), Moroz *et al.* (1996) and unpublished data of the authors. Multication discriminant diagrams of Greci and Turcoaia massifs from North Dobrogea (modified from Tatu, 1999 and Tatu & Seghedi, 1999).

clude alluvial-fans to alluvial plain clastic wedges, with fanglomerates dominating the coarse members and sandstone-siltstone cycles in the flood-plain deposits (Seghedi & Oaie, 1986). Red beds make up a thick, upward-coarsening sequence, deposited by a sandy braided river with fluctuating discharge, showing upward progradation of coarse, longitudinal bar deposits over sand dunes with planar cross-beds (Oaie, 1986). Sandstone petrography suggests that the onset of red-bed deposition was related to a major climatic change, switching from a warm and humid climate which prevailed during alluvial fan sedimentation, to an arid, dry climate, controlling red-bed accumulation. The thick volcaniclastic successions from the upper part of the Carapelit Formation consist of superimposed cycles of pyroclastic deposits and coarse rhyolitic epiclastic sequences. Volcaniclastic rocks are dominated by large volumes of ignimbritic rhyolites (up to 1000 m in thickness), interbedded with airfall tuffs and base surge deposits, displaying the geometry of superimposed flow units (Seghedi *et al.*, 1987). Vertical facies associations suggest that the style of deposition was controlled by intermittent volcanic eruptions. Sedimentological, petrographical and mineralogical evidence reveals that accumulation of the Carapelit Formation was controlled by two major factors: a tectonically active source area, supplying metamorphic rocks, granites and earlier Paleozoic sediments and an active volcanic source, delivering large amounts of feldspars (mostly plagioclase feldspars) and volcanic lithoclasts (Seghedi & Oaie, 1986, 1994; Oaie, 1986; Seghedi *et al.*, 1987).

In the eastern part of the Aluat-Sarata half-graben from the Scythian Platform, several fining-upwards cycles are superimposed in the 1685 m-thick column of Permian volcanosedimentary sequences pierced by borehole 1 Furmanovka (Moroz, 1984; Neaga & Moroz, 1987). In the western part of the half-graben, the distribution of the coarse fanglomerates suggests sedimentation controlled by activity along the northern boundary fault (Fig. 1). Fanglomerates interfinger and grade upwards to a finegrained sequence of siltstones and mudstones, with thin, discontinuous layers of gypsum and anhydrite.

MAGMATISM

Permian magmatism was characterised by bimodal volcanism in the South Carpathians and Apuseni Mountains, as well as in both the Moesian and Scythian Platforms; volcanosedimentary sequences are typically developed in most areas, with the exception of the Resita Basin, where minor volcanism occurred. Granite intrusions took place only in the southern part of the Apuseni Mountains (Highis massif) (Tatu, 1998). In North Dobrogea a volcano-plutonic association with calcalkaline geochemistry is well represented, and the transition to alkaline magmatism probably occurred in the Late Permian, reflecting a change in geotectonic setting from compression to transtension.

Acid, rhyolitic volcanic and volcaniclastic deposits prevail in the Permian of the Danubian units (Banat). Rhyolitic and dacitic volcanics and volcaniclastic-epiclastic successions are variously interbedded with continental red beds, while thick bodies of ignimbritic rhyolites occur at the top of the Danubian sequences (Stanoiu & Stan, 1986; Stan *et al.*, 1986 a, b). The thickness of the volcanic sequences increases westwards. The volcanism was bimodal (Fig. 6 a), as basic dykes intrude the red beds in some areas (Pop, 1997), and basic flows are exposed below red beds from the right bank of the Danube (Serbia) (Grubic *et al.*, 1997). Trachytic rocks occur southward (A. Grubic, oral comm., 1997). An intraplate setting is suggested for these rocks, based on geochemical data.

In the Codru Moma Mountains (western Apuseni), the volumes of both ignimbritic rhyolites and basic rocks decrease eastwards (Dimitrescu *et al.*, 1977; Bleahu *et al.*, 1979, 1981, 1985). Thin dykes and elongate rhyolitic bodies cutting the older basement (Bleahu *et al.*, 1984) suggest that volcanic centres, aligned in a NNW-SSE direction, were located along the present western border of the massif. Several basic dykes, elongated in the same direction, may represent the feeder channels for the basic flows interbedded in the middle part of the Permian sequence. In the Bihor Mountains, the ignimbrite eruptions took place in the upper part of the Permian sequence (Dimitrescu *et al.*, 1977). These acid rocks, mostly rhyolites, occur as pyroclastic flows and lava flows, but also as tuffs (Dimitrescu *et al.*, 1973; Dimitrescu, 1975; Stan, 1983, 1984, 1987). Basic volcanic rocks include basalts and basaltic andesites as pillow lavas, minor pyroclastic sequences and dykes (Bleahu *et al.*, 1979, 1981,1985; Stan, 1987). Chemical analyses of the volcanic rocks reveal both the bimodality and the alkaline features of the basic rocks; the latter plot in the trachybasalt-trachyandesite field of the TAS diagram (Fig. 6 b). The bimodal character of the volcanism is explained by having two distinct magma sources (Stan, 1987).

In North Dobrogea, the volcano-plutonic association with a calcalkaline geochemistry is related to crustal convergence at the end of the Hercynian Orogeny. For the volcanosedimentary member of the Carapelit Formation, overall volcanological features indicate that the calcalkaline volcanism was subaerial, with calderas and plinian eruptions, and that volcanic products accumulated in both subaerial and subaqueous environments (fluvial and lacustrine) (Seghedi *et al.*, 1987).

Field relationships indicate that two major phases of granite emplacement occurred in North Dobrogea, one preceding and the other post-dating the deposition of the Carapelit Formation or at least its lower and middle members (Rotman, 1917; Mirauta & Mirauta, 1962). However, the age of the granites is not well constrained, since no reliable geochronological data exist. Younger generation intrusives thought to have been emplaced during the Early Permian represent a highly differentiated I-type calcalkaline suite, ranging from dioritic and gabbroic facies to leucogranites, but dominated by biotite-hornblende granodiorites and tonalites (Seghedi *et al.*, 1994 a). The suite of the Greci Massif was emplaced in lower members of the Carapelit Formation as high level, high temperature intrusives, with both cross-cutting and partly conformable contacts, producing large contact-metamorphic aureoles and local garnet-pyroxene skarns. Rocks are rich in xenoliths of hornfels inferred to have been country rocks, as well as in various types of cognate xenoliths. The discriminant multicationic diagram (Fig. 6 d) suggests a mantle source for the basic end members and a deep or mid-crustal conditions for the genesis of granitic magma, as well as a syncollisional geotectonic setting (Tatu & Seghedi, 1999).

In the Late Permian, products of alkaline, intraplate volcanism were emplaced along the crustal faults bordering North Dobrogea. They form both subvolcanic bodies (granites, syenites, rhyolites of the Turcoaia – Cîrjelari lineament) in the south and basalt-trachyte dyke swarms in the north (Fig. 7) (Seghedi *et al.*, 1994 b; Tatu & Teleman, 1997). For the Turcoaia massif, a crustal magma source is indicated by the $^{87}Sr/^{86}Sr$ values (Pop *et al.*, 1985), suggesting that crustal anatexis occurred in a continental, intraplate tectonic setting (Fig. 6 e) (Tatu, 1999). The geochemistry of Permian magmatic rocks suggests that this transition from calcalkaline to alkaline magmatism reflected a change in tectonic setting from compressional to (trans)tensional.

In the Moesian Platform, volcanic products belonging to a bimodal basalt-rhyolite association, interbedded at various levels of the Permo-Triassic sequence (Savu & Paraschiv, 1985) are obviously related to several episodes of extension and rifting of the Moesian Platform.

Products of a typical continental within-plate bimodal volcanism of the alkali basalt-trachyte association accumulated in the two major half-grabens from the Scythian Platform (Aluat and Sarata – Tuzla). Alkaline basalt flows, trachytes, rhyolites and various pyroclastic and epiclastic products make up volcanic-volcaniclastic sequences that are up to 300 m thick, interbedded with thick, synrifting continental clastics. The Permian volcanism was subaerial and effusive, displaying a subalkaline geochemical signature (Moroz, 1984; Neaga & Moroz, 1987). Trachy-

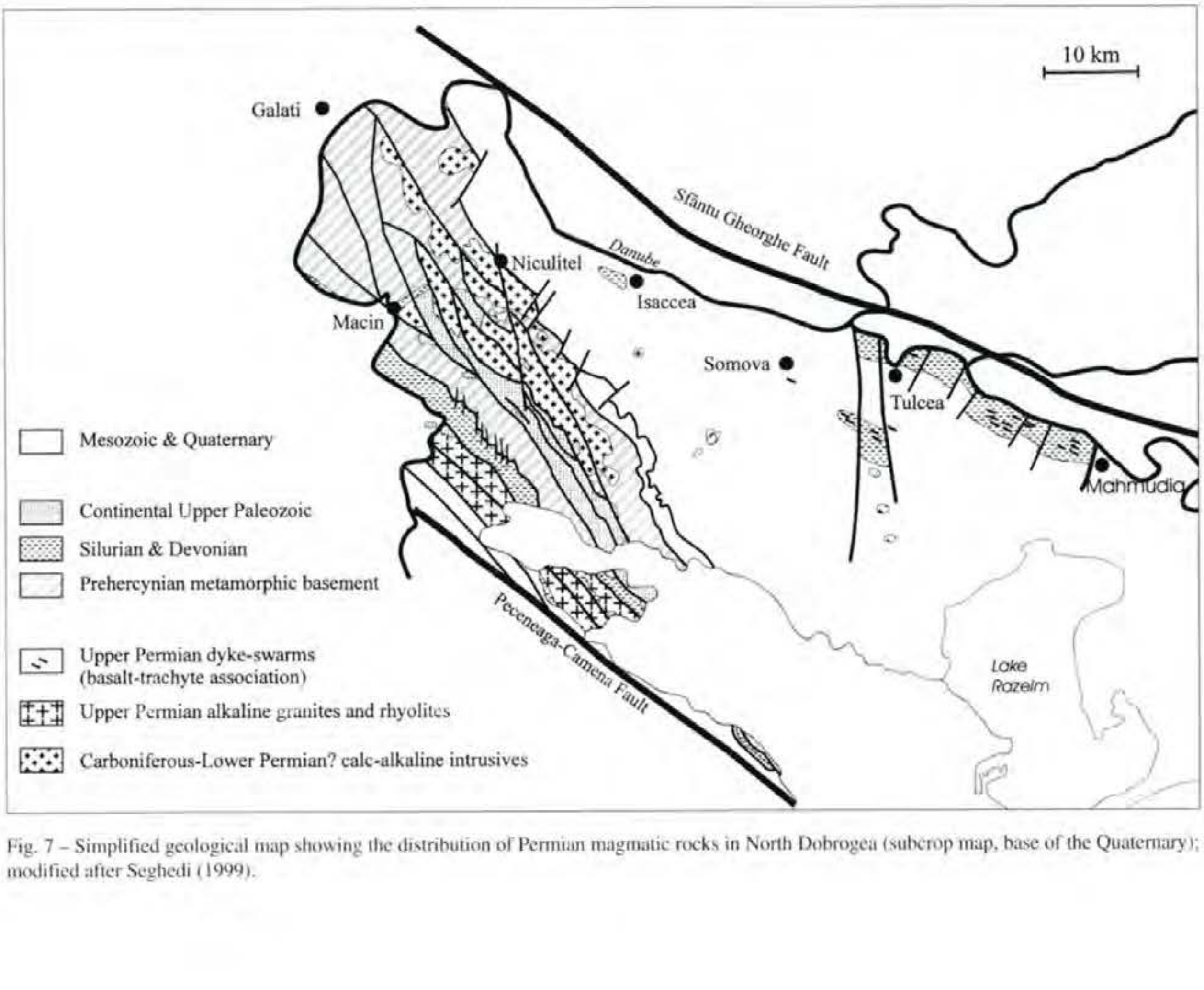

Fig. 7 – Simplified geological map showing the distribution of Permian magmatic rocks in North Dobrogea (subcrop map, base of the Quaternary); modified after Seghedi (1999).

basalts and trachyandesites prevail, most rocks showing a shoshonitic affinity (Fig. 6 c). Geochemical data suggest a great inhomogeneity of samples compared with the Codru-Moma volcanics. However, the intraplate setting is quite clear from the geological evidence.

CONCLUSIONS

The Permian deposits of Romania are mainly developed in continental facies, with molassic characteristics. The sedimentary record of most basins includes volcanosedimentary sequences. Red beds are the dominant facies, but the lower black shaly member of the Permian is present in the South Carpathians and Apuseni Mountains. Evaporitic sediments are associated with the red beds in both the Moesian and Scythian Platforms. In all areas, sedimentation took place mostly in alluvial fan, fluvial and lacustrine systems. Only in the northern part of the Moesian Platform do shallow-marine limestones occur. The South Carpathians (Getic Nappe and Danubian units) yield by far the most fossiliferous Permian deposits in Romania, the fossil remains being represented by both flora (compressed macroflora, microflora) and fauna (ganoid fishes, ostracods, bivalves). The Apuseni Mountains include deposits yielding flora (silicified woods, microflora), while North Dobrogea has no fossils recorded so far. The Moesian and Scythian Platforms include faunal remains.

The Permian volcanism was bimodal. The basalt-rhyolite association typically occurs in the South Carpathians, the Apuseni Mountains and the Moesian Platform, while the basalt-trachyte association is found in North Dobrogea and the Scythian Platform.

An extensional tectonic setting, related to Late? Permian rifting, is suggested by both field evidence and geochemical features of the magmatic rocks from the South Carpathians, Apuseni Mountains, Moesian and Scythian Platforms. For North Dobrogea, both magmatic associations and their geochemical features illustrate a transition from a calcalkaline post-collisional setting to a transtensional setting related to the collapse of the overthickened Hercynian crust, which was displaced along major wrench faults.

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UPPER PERMIAN TYPE SECTIONS OF THE EAST EUROPEAN PLATFORM AND THEIR CORRELATION

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Key words – Ufimian; Kazanian; Tatarian; stage; boundaries; fauna; flora; paleomagnetic zones.

Abstract – The authors describe zonal subdivision of the Upper Permian (Ufimian, Kazanian, Tatarian) on the East European Platform, and suggest stratigraphic levels for these stages for global correlation.

Parole chiave – Ufimiano; Kazaniano; Tatariano; piano; limiti; fauna; flora; zone paleomagnetiche.

Riassunto – Gli autori descrivono la suddivisione zonale del Permiano superiore (Ufimiano, Kazaniano, Tatariano) inerente alla Piattaforma Est-Europea, e suggeriscono livelli stratigrafici relativi a questi Piani utili per correlazioni globali.

INTRODUCTION

Upper Permian sediments occur on the East European Platform from the Middle Urals in the south to Novaya Zemlya in the north. Ufimian type sections are located in the Kama region near the town of Perm, Kazanian type sections in the Volga and Kama rivers region, and Tatarian type sections in the basins of the Volga, Vyatka, Sukhona and North Dvina rivers (Fig. 1).

CHARACTERISTICS OF THE BASIN

During Late Permian times, this vast basin occupied an area of over 2 million km^2 and ranged from 8°N to 32°N (Fig. 2). Numerous hiatuses/discontinuities of the Volga-Urals Permian sections are nowadays widely discussed. Some hiatuses are associated with the dispersion of sedimentation. The hiati are evenly distributed over all sedimentary basins, including marine ones, and reflect the alternation between continuous and discontinuous sedimentation. There are hiatuses caused by sedimentary cyclic recurrence. At the rhythmic boundaries, coarse basal sediments overlap calcareous formations, sometimes disrupting their structure and bedding. Such hiatuses do not distort the whole picture, provided there are more complete sections nearby.

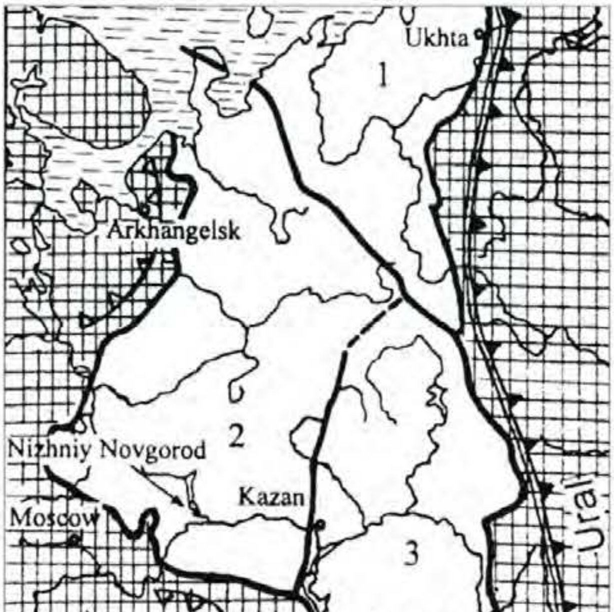

Fig. 1 – Late Permian sedimentary basins in European Russia.
1. Pechora Basin; 2. Dvina Basin; 3. Volga-Urals Basin; 4. Caspian Basin.

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There can be marginal disconformities associated with the oscillation of the sedimentary basin's margins. Thus, the Permian in the east of the basin overlies the Kungurian, but in the west the Artinskian, Sakmarian and Asselian. The Kazanian in the east conformably overlies the Ufimian Sheshminian red beds, but in the west the Sakmarian and Asselian. As for the profile running from Kazan to Nizhny, basal layers of the Tatarian Urzhum horizon near Kazan overlie the Upper Kazanian 'transitional' series, farther to the west the Podluzhnik series, then the Shikhany series, and so on up to the Lower Kazanian. In some sections, the Induan overlies the Severodvinian horizon. This unconformity is clearly recognised by the lack of some Permian paleomagnetic zones. It can be concluded that hiatuses that substantially distort stratigraphic sequences are developed at the margins, and are associated in the east with water erosion, and in the west with movement of the basin's margin caused by the development cycles. More complete sections can be found in central areas of the sedimentary basin.

UPPER PERMIAN FAUNA

We stick to a conventional two-part division of the Permian that globally indicates mostly marine sedimentation in Early Permian times, and transitional sedimentation in Late Permian times, while the Triassic is known to have mostly continental sediments. The Upper Permian is represented by marine, transitional and continental facies, and characterised by **normal marine** radiolarians, foraminifers, bryozoans, corals, bivalves, gastropods, cephalopods, nautiloids, ostracods, ichthyloids and conodonts, **freshwater** bivalves, ostracods, ichthyloids, stromatoliths and charophytes, and **continental** terrestrial vertebrates, macroflora and miospores. At the Permian Symposium in 1998, we had the opportunity to present detailed paleontological characteristics of the Ufimian, Kazanian and Tatarian (Proceedings..., 1999). In this report, we would like to examine several stratigraphic levels that can be used for global correlation.

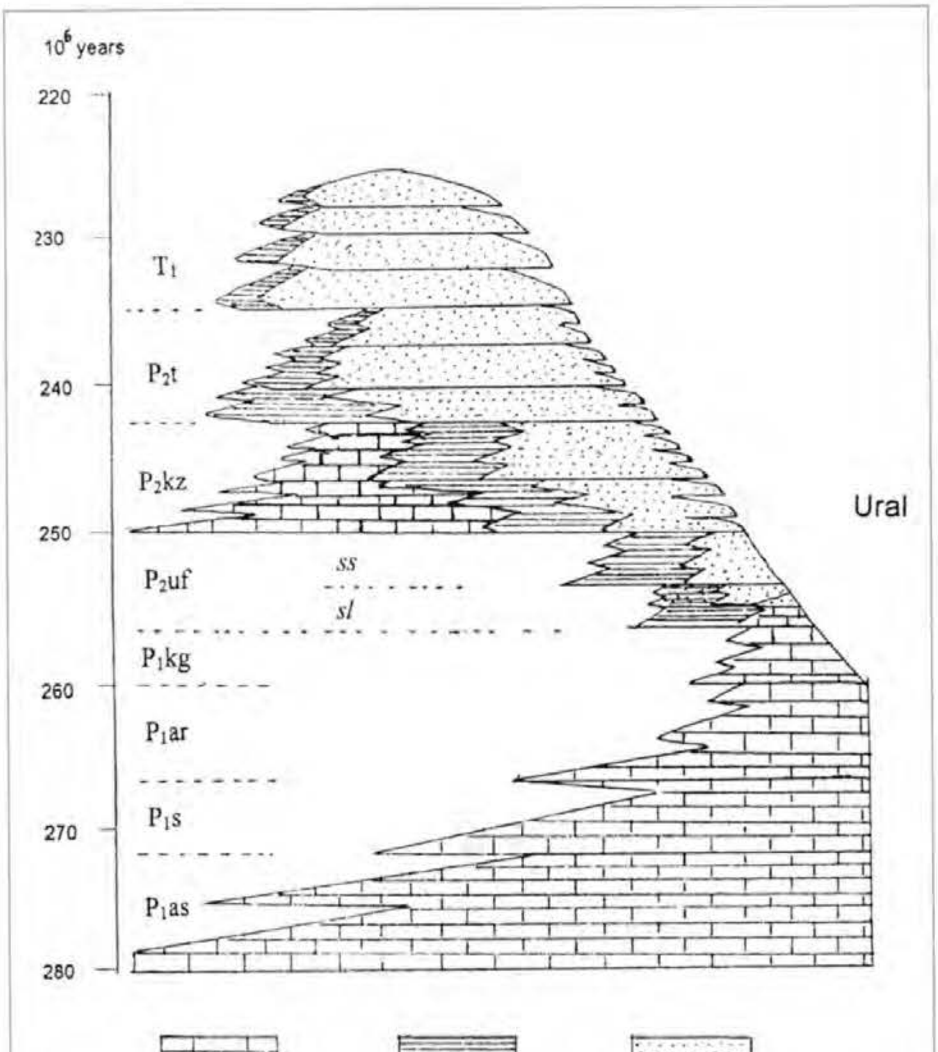

Fig. 2 – Permian sedimentary basin of the Volga-Ural region (Burov *et al.*, 1998).

Abbreviations: P_1 Lower Permian; as Asselian; s Sakmarian; ar Artinskian; kg Kungurian. P_2 Upper Permian; uf Ufimian (*sl*: *sensu lato*; *ss*: *sensu stricto*); kz Kazanian; t Tatarian. T_1 Lower Triassic.

In the Permian Cis-Urals region, the Upper Permian sediments (Solikamian horizon of the Ufimian) occur on gypsiferous carbonates of the Kungurian Irensky horizon, and contain stunted bivalves (Silantiev, 1998, p. 20). As a parastratotype of the Lower/Upper Permian boundary, we would like to propose a section on the Kazhim river since it has been described in detail using marine foraminifers, bryozoans, brachiopods, bivalves and gastropods (Biota…, 1998, Fig. 25). A gradual transition from deep-marine to shallow-marine facies is reflected by the change in faunal taxa at the boundary between the Kozhimian and Kozhimrudnitskian series. The boundary is observed throughout the basin, and can serve as a basis for inter-regional correlation. Moreover, Grunt (Biota…, 1998) has reported that brachiopods *Kochiproductus, Yakovlevia, Spirifirella* of the Solikamian Kozhimorudnitskian horizon have also been found at the Jisu-Hongora section of Inner Mongolia. Numerous *Monodixodina* associated, according to the viewpoint of Leven (pers. comm.), with *Armenia* and highly developed *Misselina* and *Parafusulina* which are peculiar to the Kubergandinian have also been found at this Mongolian site. This provides an adequate basis for the correlation of the Solikamian horizon of the East European scale with the Kubergandinian of the Tethyan scale. In our monograph (Biota…, 1998), we provide a detailed description of the Lower/Upper Permian boundary. The Ufimian Solikamian and Sheshminian in the Cis-Urals near the town of Perm are mostly characterized by shallow-marine sediments with marine and non-marine bivalves (Silantiev, 1998, p. 28). Marine bivalve sediments also contain foraminifers. The first foraminifer level is characterised by *Pseudonodosaria, Rectoglandulina* and *Langella*, and corresponds to the Solikamian horizon, while the second level corresponds to the Sheshminian horizon which is, according to Kotlyar (pers. comm.), characterised by a first appearance of *Dentalina* and *Lingulina*, with new species of *Nodosaria, Geinitzina* and *Frondicularia* corresponding to the Guadalupian Roadian of North America.

The Kazanian of the Volga-Urals basin is represented by marine, transitional and continental facies with diverse fauna and flora. Foraminifers from the region were studied by G. Pronina (1998, p. 163). They belong to 126 species of 43 genera . The third foraminifer level corresponds to the Lower Kazanian, the fourth to the Upper Kazanian, and the fifth to the Lower Tatarian. The Lower Kazanian contains *Frondicularia,* known from the Upper Ghizhiginsky horizon of the Omolon Massif and Polish Zechstein (Pronina, 1998). The Upper Kazanian also contains taxa known from other Boreal regions such as Omolon, Taimyr, Novaya Zemlya and Kolguev.

More than 35 brachiopod species of 20 genera of the Paleozoic taxa are known from the Kazanian stratotypes of the Volga region (Fig. 3).

Most characteristic of this complex are spiriferids represented by such boreal genera as *Licharevia, Blasispirifer, Odontospirifer* and *Tumarinia* (Gubareva, 1998, p. 30). In topotype sections along the Vyatka River, there are also *Permospirifer* and *Kaninospirifer*. Besides a single find of *Compressoproductus sp.,* the stratotype contains abundant productoids *Cancrinella, Terrakea, Globiella* and *Aulosteges. Stenoscisma, Rhynchopora, Cleiothyridina, Pinegathyris, Baituganía, Crurithyris* and *Spiriferellina* are also found in abundance. These brachiopods allow the correlation with Zechstein of Germany, Novaya Zemlya (New Land), northeastern Russia, Mongolia, China, and also Australia and New Zealand, within a single boreal area

BRACHIOPODS FROM THE PERMIAN SOLIKAMIAN HORIZON OF THE KAMA REGION

- *Lingula: L. orientalis* Gol.
- *Cancrnella: C. cancrini* (Vern)
- *Cleiothiridina: C. pectinifera* (Sow.)
- *Phrycodothyris: Ph. rostrata* (Kut.)

BRACHIOPODS FROM THE KAZANIAN STRATOTYPICAL AREA

- *Lingulina: L. orientalis* Gol., *L. credneri* Geinitz, *L. lawrskii* Netch.
- *Crania: C. orientalis* Netsch.
- *Orbiculoidea: O. konincki* (Gein.)
- *Streptorhnchus: S. pelargonatus* Schlot.
- *Cancrinella: C. canarini* (Vern.)
- *Terrakia: T. hemisphaeroidalis* (Netsch.)
- *Globiella: G. hemisphaerium* (Kut.)
- *Aulosteges: A. wangwnheimi* (Vern.), *A. horrescens horrescens* (Vern.), *A. horrescens sokensis* Grig., *A. fragilis* (Netsch.)
- *Compressoproductus: C.* sp.
- *Stenoscisma: S. superus* (Vern.), *S. globulina* (Phill.)
- *Rhynchopora: R. geinitzina* (Vern.), *R. globulina* (Phill.)
- *Cleiothyridina: C. pectinifera* (Sow.)
- *Pinegathyris: P. royssiana royssiana* (Keys.), *P. stuckenbergi* (Netsch.)
- *Baituganía: B. netschaevi* Grunt
- *Licharewia: L. rugulata* (Kut.), *L. stuckenbergi* (Netsch.), *L. schrencki* (Keys.)
- *Tumarinia: T. latiareata* (Netsch.)
- *Blasispirifer: B. multiplicoststus* (Netsch.)
- *Odontospirifer: O. subcristatus* (Netsch.), *O. parvula* (Netsch.)
- *Crurithyris: C. nucella* (Netsch.)
- *Spiriferellina: S. netschajewi* (E. Ivan.)
- *Beecheria: B. netschajewi* Grig., *B. angusta* (Netsch.),
- *B. elliptica* (Netsch.), *B. itiatubense* (Derby), *B. nikitini* (Netsch.)

Fig. 3 – Upper Permian brachiopods from the stratotypical area (Gubareva, 1998).

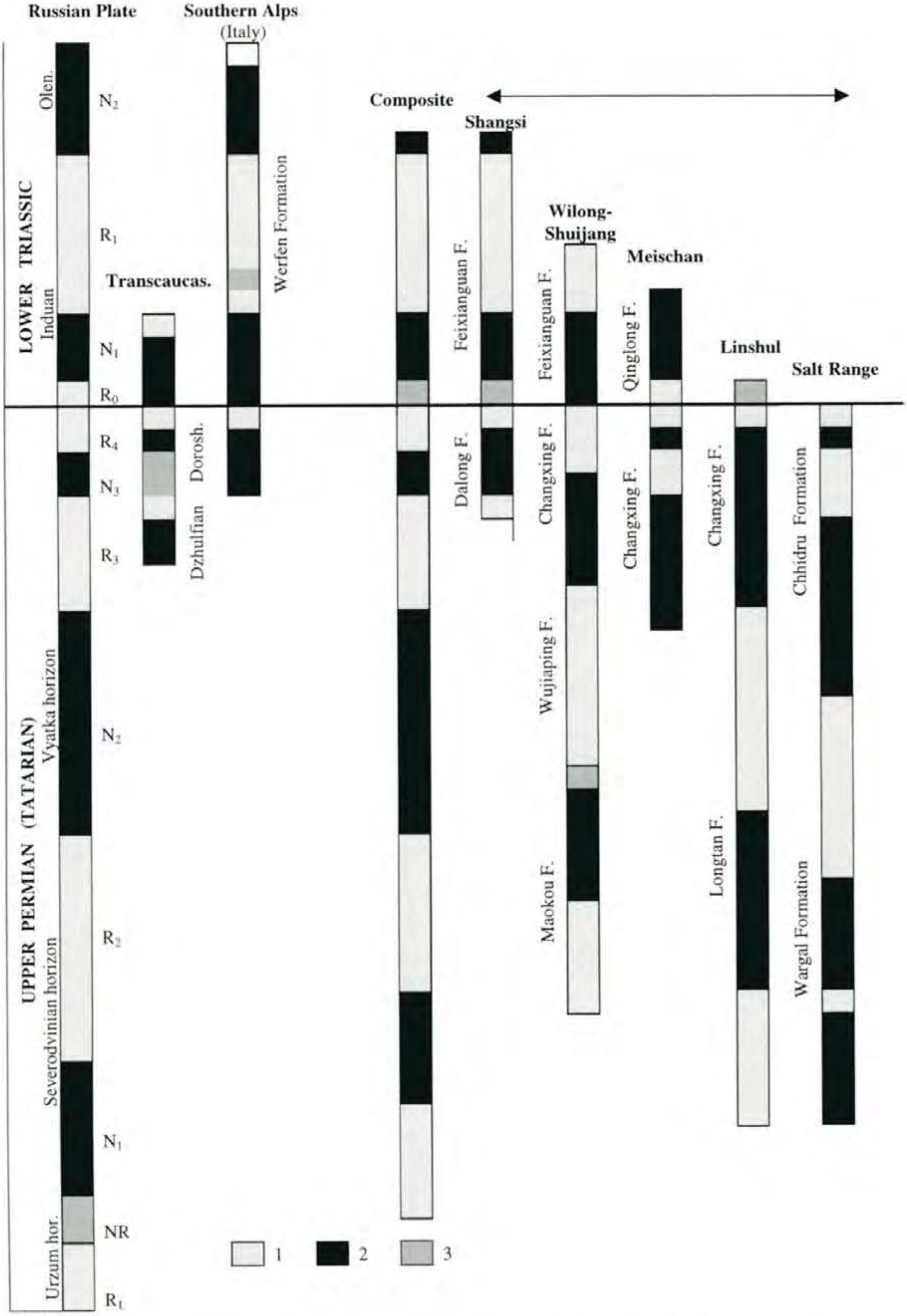

Fig. 4 – Scheme of paleomagnetic correlation of the Upper Permian Stratotype (the Volga-Kama region) with Tethyan sections. 1. reversed polarity magnetic zones; 2. normal polarity magnetic zones; 3. changing polarity zones.

(Gubareva, 1998). The complex can easily be recognised in the East European region where the Samaro-Tataro-Bashkir subprovince with the *Licharewia-Tumarinia-Blasispirifer* zone and the Kirov-Arkhangelsk subprovince with the *Licharewia-Tumarinia-Blasispirifer* + *Permospirifer* zones were outlined. At the same time, *Aulosteges* and *Compressoproductus* are known from the Tethyan sections of the northern Caucasus, and *Stenoscisma* and *Spiriferellina* from the Midian of the Eastern Tethys, allowing the correlation between various regions of the world.

The Kazanian basin, as a northward-opening intracontinental gulf, offered favourable living conditions for the development of bryozoans. The Kazanian association is characterised by 70 species of 40 genera, both cosmopolitan and endemic. In the Volga-Urals region, Lisitsin & Morozova (1998, p. 91) have studied 20 species of 16 genera. Eight of them are also found in the Kozhimian of the Pechora basin, nine in the Starostinian series of Spitsbergen, eleven in the Chandalazsky horizon of South Primorye, and ten genera in the Wordian Herster formation of northwest USA.

Nowadays, multi-element species of *Sweetina*, *Merrilina* and *Stepanovites* have been found throughout the Kazanian section. *Sweetina tritica* Wardlaw et Collinson in the Lower Kazanian allows correlation with the Upper Roadian and Lower Wordian. The Upper Kazanian of the East European Platform, according to *Stepanovites meyeni* and *Merrilina divergens*, corresponds to the Upper Wordian and Lower Capitanian.

An outstanding feature of the Late Permian Volga-Urals basin is a facies change from marine to continental, permitting co-occurrence of conodonts and macroflora within one section, although in different layers (Esaulova, 1998, pp. 206-208). Macroflora make possible the detailed zonal division and correlation of the whole Angarian region up to South Primorye (Esaulova, 1996, p. 470). It is noteworthy that the Chandalazsky horizon of the South Primorye has some elements of the

EASTERN EUROPE						TETHYS
				Tetrapod zones		
LOWER TRIASSIC			RYBINSKIAN		Thoosuches jakovlevi	LOWER TRIASSIC
			VOKHMIAN		Tupilakosaurus wetlugensis	DORASHAMIAN
UPPER PERMIAN	TATARIAN	U	VYATKIAN	Scutosaurus	Archosaurus rossicus	
					Scutosaurus karpinskii	DZHULFIAN
			SEVERODVINIAN		Proelginia permiana	
					Deltavjatia viatkensis	
		L	URZHUMIAN	Titanophoneus	Ulemosaurus svijagensis	MIDIAN
	KAZANIAN	U	POVOLZHIAN		Estemmenosuchus uralensis	MURGHABIAN
		L	SOKIAN		Parabradysaurus silantjevi	KUBERGANDINIAN
	UFIMIAN		SHESHMINIAN		Clamorosaurus nocturnus	BOLORIAN

Fig. 5 – Correlation of the Upper Permian deposits of the Boreal regions using vertebrates (Golubev, 1998).

Kazanian phylladodermic floristic complex as well as the Tethyan goniatites *Timorites markevichi* from the Lower Capitanian.

The Tatarian is represented by shallow-marine and freshwater facies characterised by diverse and rapidly-evolving fauna and flora, allowing the detailed division using bivalves, ostracods, fish, macroflora and miospores. All the biostratigraphical zones are correlated with paleomagnetic ones (Gusev *et al.*, 1993). The lithology of the Tatarian allows a detailed study of the structure of geomagnetic field. The paleomagnetic data from the Boreal Volga-Urals basin and the Salt Range of Pakistan permit their correlation (Burov *et al.*, 1998, p. 263) (Fig. 4).

Golubev (1998, p. 57) indicated tetrapod zones in the Upper Permian continental facies of the East European Platform. In Late Permian times, Eurasia and Gondwana were separated by Tethys. Vast regressions resulting in land bridges allowed the correlation between the East European and Tethyan vertebrate zones (Fig. 5).

CONCLUSION

Thus, we believe that the Lower/Upper Permian boundary, the Kazanian, and the Kiama/Illawarra boundary of the Tatarian can all serve as a basis for the global correlation of the Upper Permian according to the East European scale.

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TRANSITIONAL PERMIAN-TRIASSIC DEPOSITS IN EUROPEAN RUSSIA, AND NON-MARINE CORRELATIONS

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Key words – Permian; Triassic; stratigraphic correlation; fossil flora; palynology; magnetostratigraphy.

Abstract – A recent discovery of a relatively complete transitional Permian-Triassic (Tatarian-Vetlugian) sequence in the Vologda region, European Russia, bears on the problem of non-marine PTB correlation. It shows a zone of reversed polarity at the base of the Vetlugian.
The plant megafossil assemblage of the transitional interval is dominated by Tatarian survivors, with a few conifer species with affinities to the Zechstein flora.
The palynological assemblage is of mixed Upper Permian-lowest Triassic aspect.
The megaspore assemblage contains *Otynisporites eotriassicus*, a zonal index species of the lowermost Buntsandstein, occurring also in the Tesero Oolite, Southern Alps, with conodonts *Hindeodus praeparvus* (Kozur, 1998), as well as in the Upper Guodikeng Formation of the Junggar Basin with *Dicynodon* and *Lystrosaurus* (Liu, 1994).
These occurrences are considered to mark a stratigraphic level corresponding to the conodont zone *Clarkina meishanensis* of the Meishan section, south China.

Parole chiave – Permiano; Triassico; correlazioni stratigrafiche; flora fossile; palinologia; magnetostratigrafia.

Riassunto – Il recente rinvenimento di una successione relativamente completa in corrispondenza della transizione tra il Permiano e il Trias (Tatariano-Vetlugiano) nella regione di Vologda (Russia europea) porta al problema di una correlazione relativa al limite P/T in ambiente continentale. Essa mostra una zona di polarità inversa alla base del Vetlugiano. L'associazione fossilifera a piante dell'intervallo di transizione è dominato da organismi superstiti del Tatariano, con poche specie di conifere affini alla flora dello Zechstein. L'associazione palinologica mostra un aspetto misto tra quella del Permiano superiore e quella inerente alla parte più bassa del Trias. L'associazione a megaspore contiene *Otynisporites eotriassicus*, un indice zonale della parte più bassa del Buntsandstein, che è anologamente presente sia nell'Oolite di Tesero, delle Alpi Meridionali, dove sono stati recentemente rinvenuti conodonti del tipo *Hindeodus praeparvus* (Kozur, 1998), e sia nella porzione superiore della Formazione di Guodiken, del Bacino di Junggar, che include *Dicynodon* e *Lystrosaurus* (Liu, 1994). Questi eventi sono considerati come indicatori di un livello stratigrafico corrispondente alla zona a conodonti *Clarkina meishanensis* della sezione di Meishan, in Cina meridionale.

INTRODUCTION

In European Russia the Tatarian deposits are unconformably overlain by the Lower Triassic Vetlugian Series. Paleomagnetic correlation indicates a hiatus at the boundary encompassing most of the Changhsingian-Dorashamian stages (Lozovsky & Esaulova, 1998). Equivalents of the upper Zechstein seemed likewise lacking in the transboundary Tatarian to Vetlugian sections. A find of *Lystrosaurus (Paralystrosaurus) georgi* (Kalan.) in the lower Astashikhinsk Member of the Vetlugian Series was taken as evidence of the lowermost Triassic age (Lozovsky, 1998). Our new data indicate that relatively complete sequences, supposedly continuous over the PTB, occur in the central part of the Permian–Triassic basin at about the Volga–Severnaya Dvina watershed (Krassilov *et al.*, 1999). This conclusion is based on the results of paleobotanical and magnetostratigraphic studies, supplemented by a few faunistic finds, in the Nedubrovo Section, Vologda region.

TRANSBOUNDARY SECTION AT NEDUBROVO

The Nedubrovo Section is exposed in a series of large outcrops on the left bank of the Kichmenga River (left tributary

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of the Yug River), northeast of Vologda City between the Glebovo and Nedubrovo riverside villages. Here the uppermost Tatarian (Vyatkian) variegate marls and clays with small carbonate nodules are overlain, at a sharp contact, by: (1) the basal Vetlugian cross-bedded sands with gravel and pebbles, up to 8 m thick; (2) reddish-brown micaceous clays and siltstones about 3 m thick; (3) alternating thinly-bedded grey (in the lower part), greenish-grey and purple siltstones and silty clays, 2.5 m thick, with abundant plant debris on the bedding planes and with ostracods *Gerdalia* sp., conchostracans, aquatic beetles and a few remains of terrestrial insects (under study at present); (4) red clay containing thin interbeds of bluish siltstones, with crack-fill wedges penetrating the underlying deposits; (5) cross-bedded polymictic sand beds with gravel, more than 2.5 m thick, starting the second sedimentary cycle, with a few vertebra of amphibians *Tupilakosaurus* sp. and the *Procolophonidae* gen. sp. indet. (defined by M. A. Shishkin). These vertebrate fossils first appear in the latest Tatarian and are widespread in the Early Triassic.

MAGNETOSTRATIGRAPHY

Magnetostratigraphic studies of the Nedubrovo Section have shown a high magnetic susceptibility (mean χ 159.5 $\cdot 10^{-5}$) that is more typical of the Vetlugian deposits than of the Tatarian (Burov *et al.*, 1998). However, the polarity is reversed, while all the hitherto-studied lower Vetlugian sections fall in the direct polarity zone NPT (Lozovsky & Esaulova, 1998). We therefore designate the basal Vetlugian of Nedubrovo as a new reversed polarity zone R_0T, supposedly correlatable with the upper basalts of the Tchernyshov Ridge in the Timano-Petchorsk region.

A reversed polarity zone probably corresponding to R_0T at Nedubrovo was also found at the base of the Nyamunsk Formation in Lithuania, the stratigraphic equivalent of the lowermost Vetlugian, as well as of the basal Buntsandstein of Poland (Kisnerius & Saidakowsky, 1972; Katinas, 1997).

FOSSIL FLORA

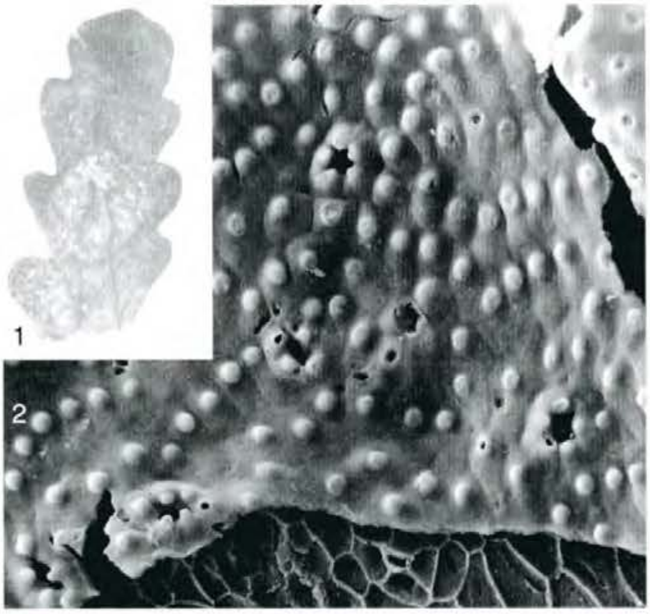
The plant mega- and mesofossils occur abundantly in the grey laminated siltstones and clays (bed 3). These accumulations of plant debris on bedding planes locally appear as a thin, lenticular coal. The plant remains are fragmentary but with well-preserved cuticles providing epidermal characteristics that are crucial for classification of the Permian and Triassic gymnosperms. A classification by S. Meyen (in Gomankov & Meyen, 1986; Meyen, 1992) is followed here for the sake of comparison with the Tatarian flora, although some generic assignments are in need of revision.

The plant megafossils constitute an essentially peltasperm–conifer assemblage with a few fern remains. The assemblage is dominated by peltasperms *Tatarina conspicua* S. Meyen, *T. lobata* S. Meyen, *Phylladoderma (Aequistomia) annulata* Meyen, *Raphidopteris antiqua* S. Meyen, *Peltaspermopsis buevichiae* (Gomankov et S. Meyen) Gomankov, and *Salpingocarpus variabilis* S. Meyen (Plate I). These species, with the single exception of *Tatarina lobata*, are known from the uppermost Tatarian (Vyatkian) localities (we accept the Vyatkian age for a controversial Aristovo locality with *Phylladoderma annulata* and *Peltaspermopsis buevichiae*). The cuticles of a

Fig. 1 – Sketch map of the Volga-Severnaya Dvina watershed region showing the geographical position of the Nedubrovo Section (black circle).

Plate I – Peltasperms from the fossil plant bed of Nedubrovo.

1. *Tatarina lobata* S. Meyen, leaf fragment, x15. 2, 3. *Tatarina (Tatarinopsis)* cuticle, x230, and stoma with hollow papillae, 1200. 4. *Rhaphidopteris antiqua* S. Meyen, pinna with decurrent pinnules, x10. 5. *Peltaspermopsis buevichiae* (Gomankov et S. Meyen) Gomankov, pelta with ovules, x20. 6, 7. *Tatarina conspicua* S. Meyen, cuticle, x110, and stoma, x700.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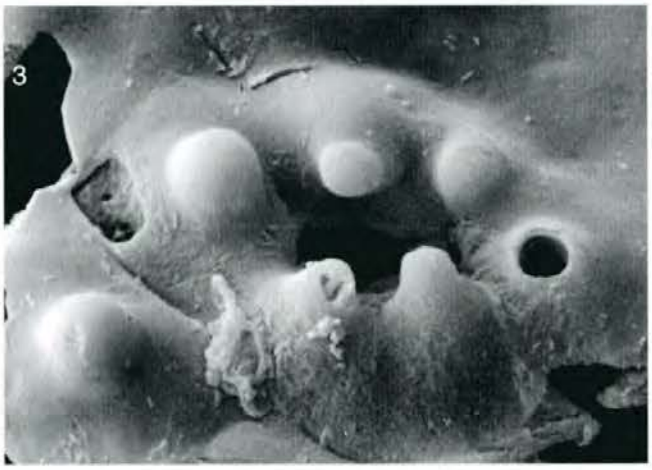
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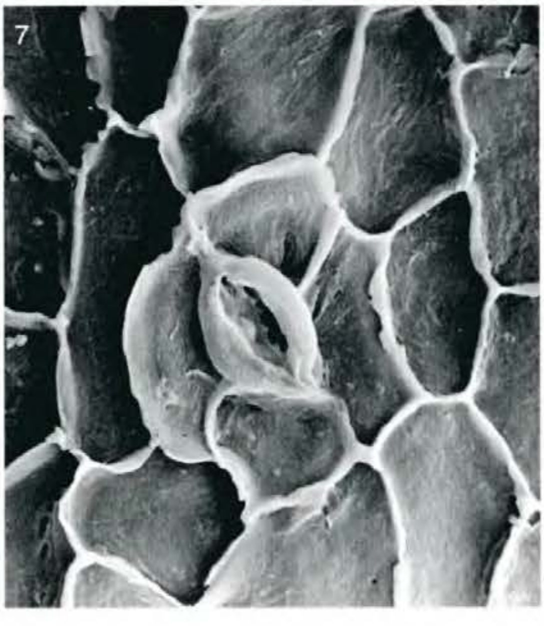
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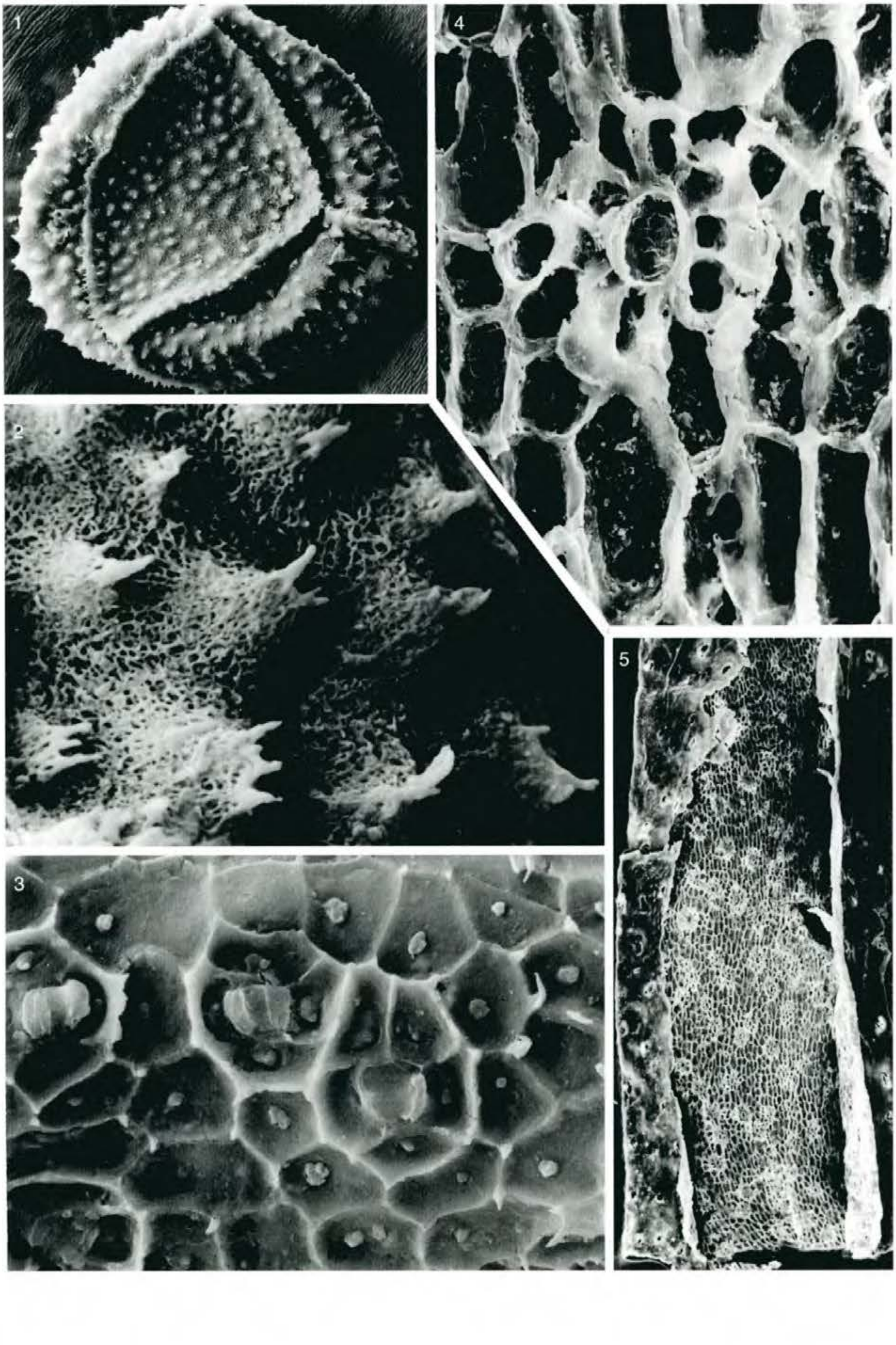
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dominant Tatarian species *T. conspicua* are also fairly common in the Nedubrovo locality. *T. lobata* was originally described from the Korvunchan Formation of the Tungusska Basin (Meyen & Gomankov, 1980). In Nedubrovo, the peltasperm leaves and reproductive organs are somewhat smaller than in typical Tatarian material and the cuticles often show anomalous cell patterns.

The conifers are represented by scattered leaves, the taxonomic assignments of which are based solely on epidermal characteristics (Plate II). Alongside a typically Tatarian *Quadrocladus dvinensis* S. Meyen there are *Ullmannia*. cf. *bronnii* Goepert and *Quadrocladus* cf. *solmsii* (Gothan et Nagalhard) Schweitzer, both comparable with the Zechstein conifers.

Thus the Nedubrovo megafossil flora is still essentially Permian, with a number of species surviving from the Tatarian. However, a few Zechstein and Korvunchan forms indicate a younger age than the uppermost Tatarian. It bears a general similarity to the late Changhsingian flora of Tieqiao Section, Laibin County, south China, dominated by the Permian peltasperms, gigantopterids and conifers, with conifer assemblages of Zechstein aspect (Jin *et al.*, 1998 and our unpublished data).

Prominent in the plant mesofossil assemblage of bed (3) is *Otynisporites eotriassicus* Fugl. (Plate II), the index species of a megaspore zone comprising the basal Suboolitic Member of Buntsandstein immediately above the Zechstein (Fuglewicz, 1977).

PALYNOLOGY

The spore-pollen assemblages were obtained from the beds (2-4), with insignificant variation from bed to bed (Plate III). They are dominated by *Klausipollenites schaubergeri* (Potonié et Klaus) Jansonius and *Cycadopites* sp., summarily including more than 50% of the palynomorphs. Non-taeniate pollen is also represented by the subordinate *Klausipollenites decipiens* Jansonius, *Alisporites nuthallensis* (Clarke) Balme, *A. grauvogelii* Klaus, *Falcisporites zapfei* Potonié et Klaus, and *Platysaccus queenslandii* de Jersey. The taeniate pollen grains are assigned to *Protohaploxypinus* cf. *pantii* (Jansonius) Orlowska-Zwolinska, *Lueckisporites virkkiae* Potonié et Klaus, *Lunatisporites noviaulensis* (Leschik) Foster, and *L. transversmundatus* (Jansonius) Fisher, ranging from 0.5% to 2% each, *Striatoabieites richteri* (Klaus) Hart, up to 3%, and *L. pellucidus* (Goubin) Helby, locally up to 12-15%. Occasional grains belong to *Ephedripites permasensis*, *E.* sp., *Striomonosaccites* sp. and *Triadispora* cf. *crassa* Klaus.

Spores are less diverse, with a few numerically prominent forms, such as *Apiculatisporis*, up to 30%, and *Limatulasporites fossulatus* (Balme) Foster, up to 15%. *Punctatisporites triassicus* Schulz, *Polycingulatisporites densatus* (de Jersey) Playford et Dettmann, *Leptolepidites jonkeri* (Jansonius) Yarosh. et Golubeva, *Proprisporites pocockii* Jansonius, *Densoisporites playfordii* (Balme) Dettmann and *Pechorosporites disertus* Yarosh. et Golubeva amount to 1-2% each.

Common in the assemblage are *Tympanicysta stoschiana* Balme as well as the planktonic prasinophytes *Pterospermella*, *Pilasporites* and *Inaperturopollenites nebulosus* Balme.

The association of the prevailingly Permian *K. schaubergeri* (with a few reliably-dated Early Triassic records in the early Griensbachian of Arctic Canada and the Induan Panchet Formation with *Lystrosaurus:* Fisher, 1979; Tiwari & Tripathi, 1992), *Lueckisporites virkkiae*, *Falcisporites zapfei* and *Alisporites nuthallensis* with the Early Triassic *Proprisporites pocockii*, *Leptolepidites jonkeri*, *Polycingulatisporites densatus*, *Densoisporites playfordii*, *Pechorosporites disertus*, *Lunatisporites pellucidus*, *L. transversmundatus*, *Ephedripites permasensis* and abundant *Cycadopites*, indicate a transitional uppermost Permian to lowermost Triassic age for the Nedubrovo palynological assemblage. It is closely comparable to palynofloras from the lowermost Buntsandstein of Poland (Orlowska-Zwolinska, 1984), *Otoceras* beds of western Canada (Jansonius, 1962), Arctic Canada (Fisher, 1979; Utting, 1994) and the *Protohaploxypinus* zone of eastern Greenland (Balme, 1979).

CORRELATION

A correlation of the major continental sequences is shown in Fig. 2. In a relatively complete Permian-Triassic sequence of the Junggar Basin, northern China, the fossiliferous transitional deposits are exposed in two limbs of the Dalongkou Anticline (Yang *et al.*, 1986; Cheng *et al.*, 1989). A graphical correlation made by the senior author has shown that the megaspore zone *Otynisporites eotriassicus* of the Upper Guodikeng Formation (Liu, 1994) comprises the interval of joint occurrences of *Dicynodon* and *Lystrosaurus* and extends upsection with *Lystrosaurus* alone. Thus the FAD of *Lystrosaurus* coincides with that of *Otynisporites eotriassicus*. Paleomagnetic zonation is not yet completed for Junggar Basin. However, the Upper

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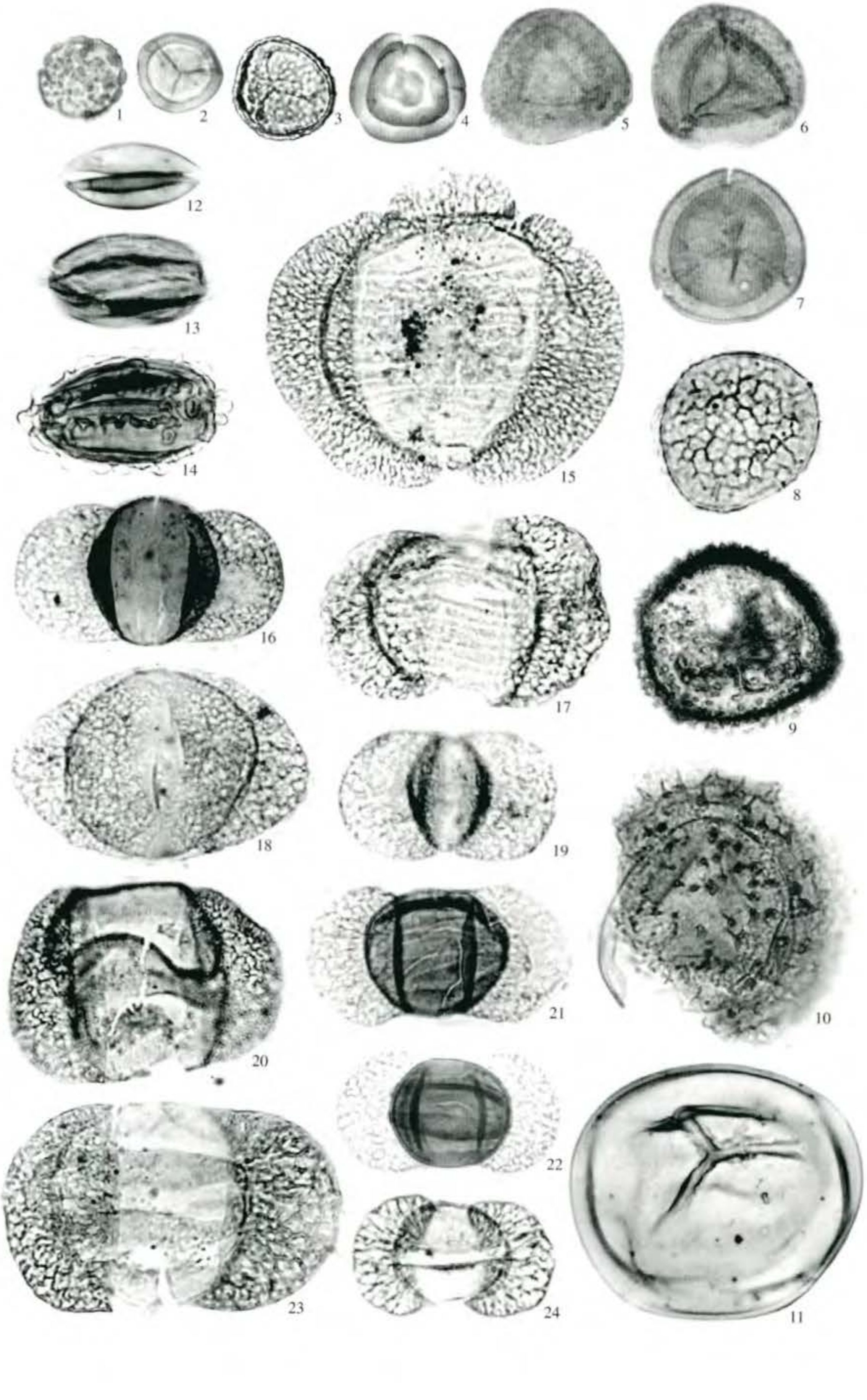
Plate II – Megaspore and cuticles from the fossil plant bed of Nedubrovo: 1, 2. *Otynisporites eotriassicus* Fugl., proximal aspect, x280, and distal appendages, x2000, 3. *Quadrocladus dvinensis* S. Meyen, group of stomata, x 480, 4, 5. *Ullmannia* cf. *bronnii* Goepp., stoma with a ring of subsidiary cells anomalously intruded by an ordinary cell, x800, and whole leaf cuticle showing the arrangement of stomata, x53.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Guodikeng, as well as the overlying basal Jiucaiyuan Formation, show a reversed polarity (Cheng *et al.*, 1989).

Of a certain importance for the non-marine to marine PTB correlations is the occurrence of *Otynisporites eotriassicus* in the marginal marine Tesero Oolite near the base of the Werfen Formation, Southern Alps, at about the PTB position as defined by Broglio Loriga & Cassinis (1992). According to Kozur (1989, 1998), the megaspores were found in the Tesero section about 1.8-2.2 m above the boundary with the underlying Bellerophon Formation. They associate with a palynological *Lundbladispora obsoleta-Lunatisporites noviaulensis* assemblage similar to that of the lower Buntsandstein, with a mass occurrence of *Tympanicysta stoschiana*, as well as with conodonts *Hindeodus praeparvus* Kozur and *Isarcicella? prisca* Kozur. These species indicate the conodont zone *Clarkina (Neogondolella) meishanensis-Hindeodus praeparvus* (Kozur, 1998), the base of which correlates with the first appearance of *Otoceras* (zone *O. concavum/latilobatum*). This level corresponds to the PTB as defined by Orchard & Tozer (1997) and Orchard & Krystyn (1998). In the Meishan Section of south China, the *Clarkina meishanensis* zone (Mei, 1996) falls in the interval of reversed polarity (Zhu & Liu, 1999). It should be noted that a previous report of direct polarity in the lower part of the *O. concavum* zone of Arctic Canada was not confirmed by the recent studies (Ogg & Steiner, 1991).

This level is also marked by the appearance of *Lystrosaurus* in continental facies (Lozovsky & Esaulova, 1998) and, in terms of event stratigraphy, by the onset of a widespread transgression, trap basalt eruptions, a peak of *Tympanicysta* and the prominent isotopic excursions (Fig.

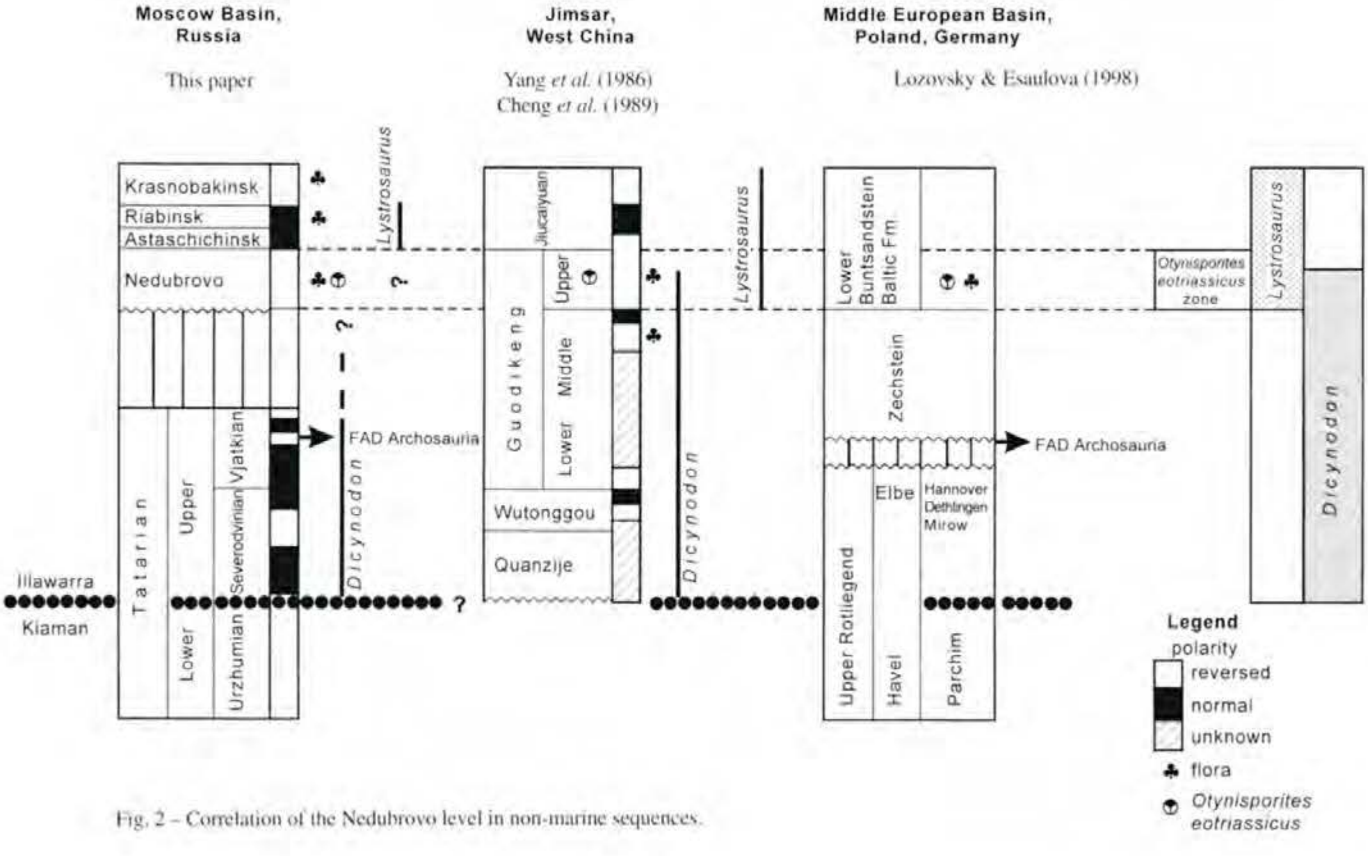

Fig. 2 – Correlation of the Nedubrovo level in non-marine sequences.

Plate III – Palynological assemblage of Nedubrovo, x625.

1. *Leptolepidites jonkeri* (Jansonius) Yarosh. et Golubeva, 2. *Limatulasporites fossulatus* (Balme) Helby et Foster, 3. *Apiculatisporis* sp., 4. *Polycingulatisporites densatus* (de Jersey) Playford et Dettmann, 5. *Densoisporites* sp., 6. *Densoisporites* sp., 7. *Densoisporites playfordii* (Balme) Dettmann, 8. *Proprisporites pocockii* Jansonius, 9. *Pechorosporites* sp., 10. *Pechorosporites disertus* Yarosh. et Golubeva, 11. *Punctatisporites triassicus* Schulz, 12. *Cycadopites* sp., 13. *Ephedripites* sp., 14. *Ephedripites permasensis* Yarosh., 15. *Striomonosaccites* sp., 16. *Falcisporites zaptei* Potonié et Klaus, 17. *Striatoabieites richteri* (Klaus) Hart., 18. *Klausipollenites schaubergeri* (Potonié et Klaus) Jansonius, 19. *Platysaccus* sp., 20. *Scutasporites* sp., 21. *Protohaploxypinus* sp., 22. *Lunatisporites noviaulensis* (Leschik) Foster, 23. *Lunatisporites pellucidus* (Goubin) Helby, 24. *Lueckisporites virkkiae* Potonié et Klaus.

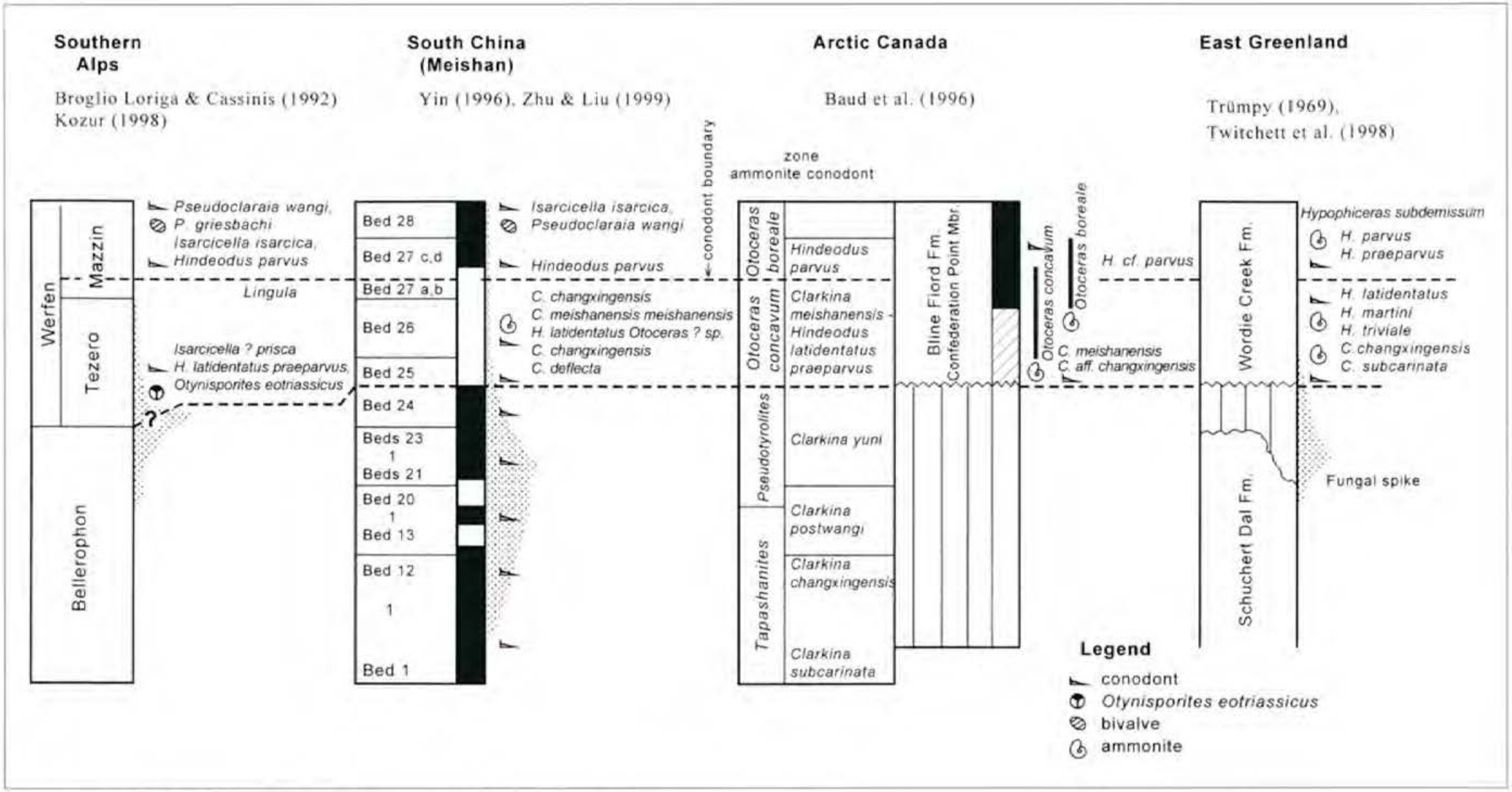

Fig. 3 – Correlation of the Nedubrovo (*Otynisporites eotriassicus*) level in marine sequences.

3). However, in the widely accepted conodont zonation, the PTB is drawn above this level, at the base of the next conodont zone *Hindeodus parvus*. Whatever the final decision on the PT GSSP, it has to be taken into consideration that at the level of the earliest *Otoceras*, *Lystrosaurus* and *Otynisporites* records, both marine invertebrate assemblages and terrestrial flora still retained the Late Permian aspect, with subordinate Triassic newcomers.

CONCLUSIONS

The Nedubrovo Section on the Kichmenga River, Vologda region, represents a relatively complete transboundary PT sequence, with the upper Tatarian overlain by the basal Vetlugian which contains a plant megafossil assemblage of Permian aspect, with most species having survived from the Late Tatarian, megaspores of *Otynisporites* zone (basal Buntsandstein of Poland), and a rich palynological assemblage of a mixed Zechstein-Lower Griesbachian character. The relatively diverse planktonic Prasinophyceae probably indicate a marine influence at a high stand of the end-Permian boreal transgression. A reversed polarity zone is established for these deposits. The Nedubrovo sequence thus appears older than the basal Vetlugian elsewhere in European Russia. It conceivably represents a stratigraphic interval missing in the less complete transboundary sections.

On the basis of the evidence, the Nedubrovo sequence is correlated with the upper Guodikeng Formation of the Junggar Basin in China, both showing a reversed polarity. It is stratigraphically equivalent to or somewhat older than the lowermost Buntsandstein of Western Europe. Probable marine correlates of Nedubrovo are the lowermost part of the *Otoceras* zone as well as the Tesero Oolite and the Transitional beds 1 and 2 below the *Hindeodus parvus* FAD in the Meishan Section of south China. This stratigraphic level is traceable by the joint occurrences of *Otynisporites*, the earliest *Lystrosauridae* and, in marginal marine deposits, conodonts of the *Clarkina (Neogondolella) meishanensis-Hindeodus praeparvus* zone. It is also marked by the onset of a widespread transgression, trap eruptions in Siberia and prominent isotopic anomalies. There may have been a certain time lag between these events and biotic change, since the biota was still of a prevailingly Permian character.

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THE CONTINENTAL PERMIAN OF NORTHEAST EUROPE

ELENA O. MALYSHEVA[1]

Key words – Facies; depositional environments; paleogeography; correlation; sequence stratigraphy; Pechora Basin.

Abstract – A sequence stratigraphy approach applied to the Upper Permian of northeastern Europe appeared to be very helpful in subdivision and correlation of complex marine to non-marine successions and identification of the intervals favourable for paleogeographical reconstructions. The biostratigraphically proven Kungurian-Ufimian stage boundary is interpreted as a sequence boundary marked by basinward facies shift and a change in parasequence stacking patterns. Each following sequence is characterised by further progradation of low-stand deltaic-nearshore facies to the north and northwest. By the end of Ufimian times, continental deposition dominated. Alluvial and lacustrine depositional environments, paleosols and calcretes have been interpreted within the continental complexes. Mature calcrete horizons have been used to mark sequence boundaries within the continental part of the section. The confidence in correlations and sequence identification decreases up the section.

Parole chiave – Facies; ambienti deposizionali; paleogeografia; correlazione; stratigrafia sequenziale; Bacino della Pechora.

Riassunto – Un approccio della stratigrafia sequenziale nell'ambito del Permiano superiore dell'Europa nord-orientale si dimostra assai utile nel suddividere e correlare complesse successioni marine e non-marine, nonché nell'identificare intervalli favorevoli per le ricostruzioni paleogeografiche. Il biostratigraficamente dimostrato limite Kunguriano-Ufimiano è interpretato come un limite di sequenza demarcato da uno spostamento di facies verso il bacino e da un cambio nei modelli di parasequenze accumulatesi. Ciascuna successiva sequenza è caratterizzata da un'ulteriore progradazione verso nord e nord-ovest di facies deltizie prossime alla spiaggia, in situazione di *lowstand*. Entro la fine dell'Ufimiano dominò una deposizione continentale. Ambienti deposizionali alluviali e lacustri, paleosuoli e calcrete sono stati interpretati all'interno di complessi continentali. Orizzonti di calcrete mature sono stati usati per tracciare limiti di sequenza entro la parte continentale della sezione. La sicurezza ad operare delle correlazioni e ad identificare delle sequenze decrescono verso l'alto.

INTRODUCTION

Continental deposits of Late Permian age are widespread in the Pechora sedimentary basin, located in northeastern Europe between the Urals in the east and the Timan Ridge in the west (Fig.1). Late Permian sedimentation was associated with the Urals orogeny and occurred in various depositional environments (from marine to non-marine), controlled by two major structural (Pechora Synclise and Pre-Ural Foredeep) and two climatic (northeastern humid and southwestern semi-arid) zones. F.I. Entzova, G.A. Ivanov, V.I. Chalyshev, L.L. Khaytzer, J.N.Lubina, A.V. Makedonov, I.S.Muravyev, N.I. Nikonov, N.S.Oknova, A.P.Rotay, G.M.Yaroslavtzev and others contributed to the facies study of the region. However paleogeographical reconstructions for epochs seem to be very uncertain because of complicated facies combinations caused by steady regression of the sea basin interrupted by short transgressions. Thus, the objectives of the current study were to produce paleogeographical reconstructions of the Pechora Basin for particular time "slices" critical to the evolution of sedimentation in the Late Permian.

The study was based on core and log data from more than 100 wells and eight outcrop sections, and incorporated paleontological evidence (Grunt *et al.* (eds), 1998; Entzova *et al.*, 1969; Kanev & Koloda, 1997; Koloda & Kanev, 1994; Koloda *et al.*, 1992; Konovalova, 1991; Chuvashov, 1997; Chuvashov *et al.*, 1990) and analytical data on the chemistry and mineralogy of the rocks.

CONTINENTAL FACIES

The recognition of facies within the most representative sections of the Upper Permian both in cores and outcrops revealed a variety of depositional environments including

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offshore shelf, lower and upper shoreface, tidal flat, coastal and alluvial plains, and lacustrine (Malysheva, 1997). Coals, alluvial and lacustrine deposits, paleosols and calcretes have been recognised in the Permian continental succession. Many publications have been devoted to the problems of coal-bearing formations in the Pechora Basin (Makedonov, 1965; Dedeev, 1990). Coals are referred to as paralic and limnic types that correspond to coastal and alluvial plain swamps.

Alluvial channel bodies are recognised by significant lateral heterogeneity, lenticular forms, thinning upward sections, sharp to erosional contacts with subjacent layers, planar to trough cross-bedding and some other criteria including the shape of gamma and electric logs. Channel and flood plain deposits have been distinguished within alluvial units. Flood plain accumulation dominated and was commonly accompanied by pedogenic processes. The number and thickness of channels increases up the Permian section and eastward. The thickness of the channel fill within the synclise does not exceed 20 m, while within the Pre-Ural foredeep it reaches 100 m. Moreover, coarse sandy-conglomeratic beds are most frequent within the foredeep, while medium sandstones with thin conglomeratic interlayers are typical of the synclise. Morphology and composition of the channel beds also differ between the northern humid and southern semi-arid zones.

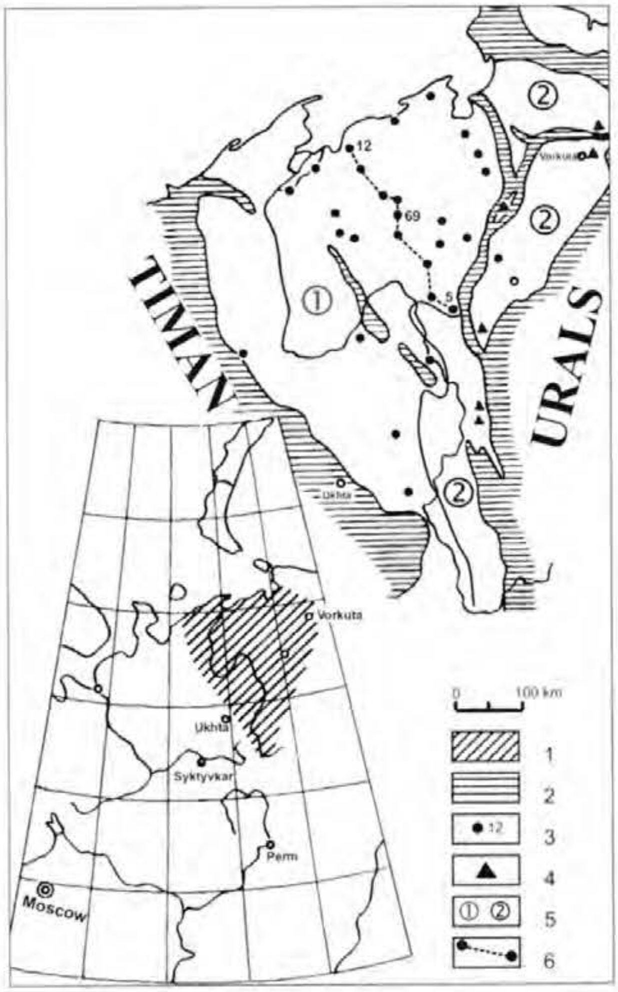


Fig. 1 – Location map.

1. considered area; 2. absence of the Upper Permian; 3. location of the boreholes; 4. location of the outcrops; 5. major structural zones: *1*. Pechora Synclise, 2. pre-Ural foredeep; 6. location of facies cross-section.

Lacustrine deposits are very common but they are regarded as proved only in association with subtidal grey shales with horizontal to lenticular bedding and clayey carbonates with non-marine bivalves and ostracods. Representatives of such genera as *Palaeumutella, Antraconauta, Synjaella,* and *Abiella* preferred a muddy substratum in the subtidal zone of the lacustrine parts of the basins (Koloda & Kanev, 1994).

Fossil soils were primarily proved and comprehensively studied in one of the sections of the Pre-Ural foredeep (Chalyshev, 1974). The major features of the identified mature soil profiles could be summarised as destratification, rootlets and horizonation (formation of soil horizons) with obvious alternations in colour, mechanical and chemical compositions, and content of organic matter from parent rocks upwards in the soil profile. Our studies of the area of the Pechora Synclise revealed abundant intervals in flood plain sections overprinted by pedogenic processes and few paleosols with more or less expressed horizonation. In general, they are represented by mottled, green or red clayey destratified rocks with peds, root relics or dessication fractures, and to a varying degree differ from the parent rocks in clay mineralogy and chemical composition. Immature fossil soils dominate.

Calcretes, in most cases interpreted as calcic paleosols, are widespread in the southern semi-arid zone of the Pechora Basin and mark periods of aridisation, even in the northern areas. Calcretes have been recognised using the criteria suggested by V.P. Wright (1989), M. Esteban & C.F. Klappa (1991) and others. Scattered nodules, globular to massive and brecciated calcretes have been distinguished. Typical microstructural features include rounded peloids and grains, circumgranular fractures and crystallaria, sitting in a micritic groundmass. The most mature profiles contain those calcretes, and are characterised by a gradual transition from weakly calcareous forms with rare carbonate nodules to impermeable massive or brecciated carbonate horizons. The number and thickness of individual calcrete horizons increase up the profile.

EVOLUTION OF SEDIMENTATION

A sequence stratigraphy approach (Weimer & Posamentier, 1994; Van Wagoner *et al.*, 1990) was applied to the

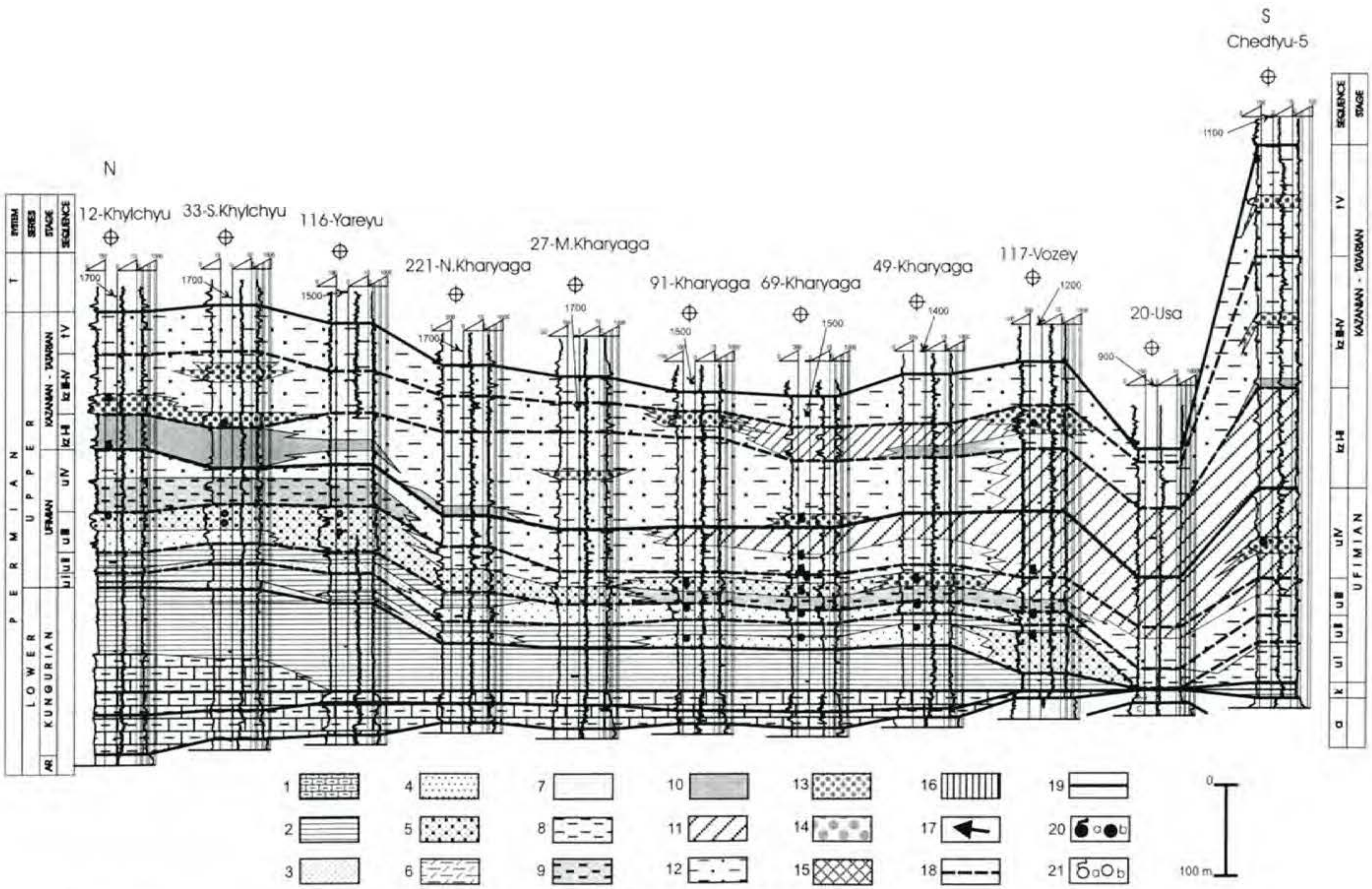


Fig. 2 – Facies cross-section.

1. offshore shelf with mixed carbonate and clastic deposits; 2. offshore shelf dominated by clastics; 3. distal bars (finegrained sandstones); 4. lower shoreface; 5. upper shoreface; 6. partly isolatated shelf or lagoon with carbonates; 7. tidal flat (intertidal clastics and carbonates predominate); 8. coastal plain with red beds; 9. coastal plain with peat accumulation; 10. alluvial-lacustrine plain with peat accumulation; 11. continental environments (in general) dominated by red beds; 12. continental environments (in general), dominated by grey beds; 13. alluvial and distributary channels; 14. alluvial fans (conglomerates and gravelites); 15. absence of Upper Permian deposits; 16. absence of Lower Ufimian deposits; 17. influx of coarse clastics; 18. sequence boundaries; 19. stage boundaries; 20. oil productive reservoir: *a.* in the well, *b.* in the field; 21. gas and condensate productive reservoir.

correlation of the sections and identification of the intervals favourable for paleogeographical reconstruction. So-called reference sections, both lithologically and paleontologically representative, were used as the basis for sedimentological interpretation and identification of possible sequence boundaries (Malysheva *et al*., in press). The latter was based on such criteria as evidence of erosional truncation, basinward shifts in facies and changes in parasequence stacking patterns. Vertical and lateral associations of depositional environments within the available biostratigraphic framework provided identification of sequences in the Upper Permian succession. One of the cross-sections displayed in Figure 2 shows facies relationships and possible sequence boundaries, sometimes coinciding with stage boundaries that were traced along the Kolva swell. Lowstand and transgressive systems tracts are considered to be the most favourable for paleogeographical maps.

The boundary between the Kungurian and the Ufimian in some sections, the Kozhim River being the best (Grunt *et al.* (eds), 1998), is defined by several groups of fossils: bivalves, brachiopods, bryozoans, as well as microflora. The latter are of greatest importance in the age definitions of the Upper Permian. In the northeast of the Pechora Syncline this boundary is marked by a basinward shift in facies, producing a change in the stacking pattern of parasequences and is regarded as the sequence boundary. Progradation of a bar-deltaic complex forms a well-documented lowstand systems tract, dominated by lower and upper shoreface sandstones (Fig. 3-A). An intertidal flat with oolitic shoals, coquinas and small tidal channels and coastal plain with peat accumulation, channels, first nonmarine bivalves and interbeds with lingulas and marine bivalves developed in the Pre-Ural foredeep landward of bar-deltaic zone. An offshore marine shelf draining basinwards is characterised by dark bioturbated shales, siltstones and interbedded, very finegrained sandstones, sometimes with abundant marine fossils.

In the southwestern areas of the Pechora Basin the Kungurian-Ufimian boundary is also marked by a basinward shift in facies, but the lowstand systems tract of the first Ufimian sequence is dominated here by sediments of a semi-restricted shelf or lagoon (with mixed clastic and carbonate accumulation, poor in fossils), intertidal flats and coastal plains with red beds. Alluvial fans, composed of conglomerates and gravelites, have been reported by Muravyev (1972) from the south of the pre-Ural foredeep.

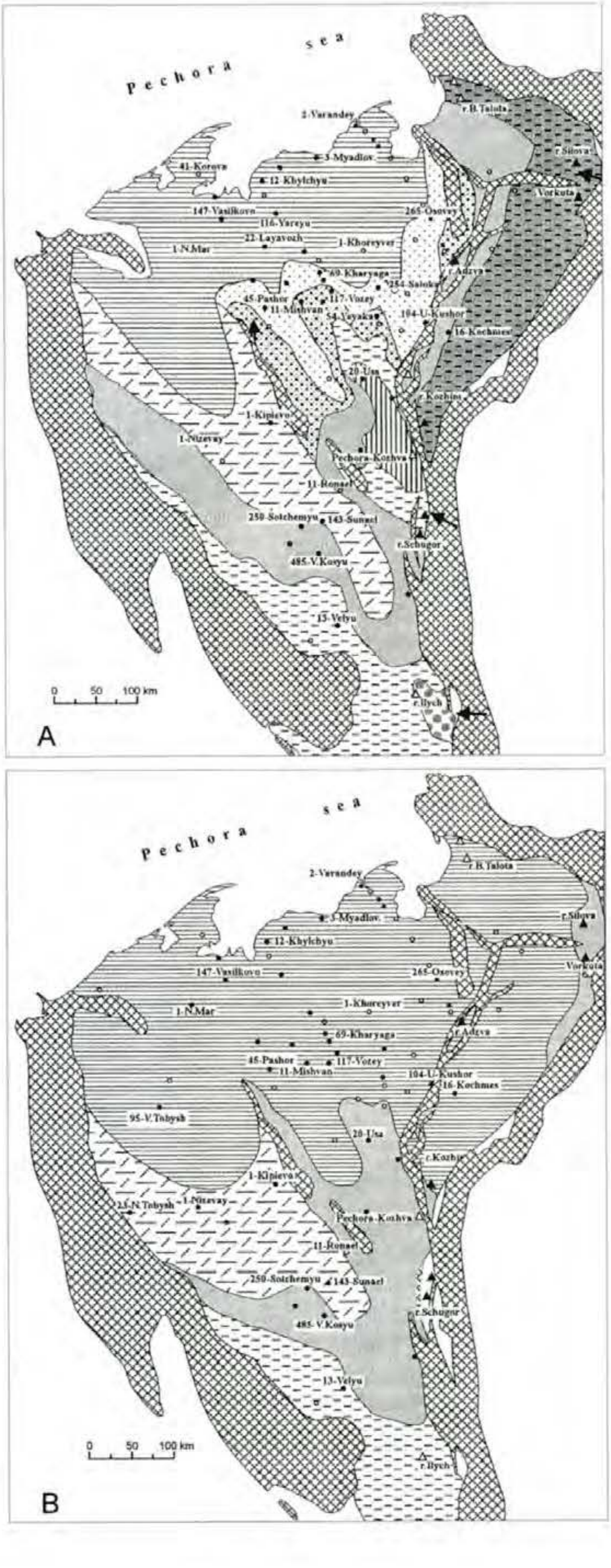
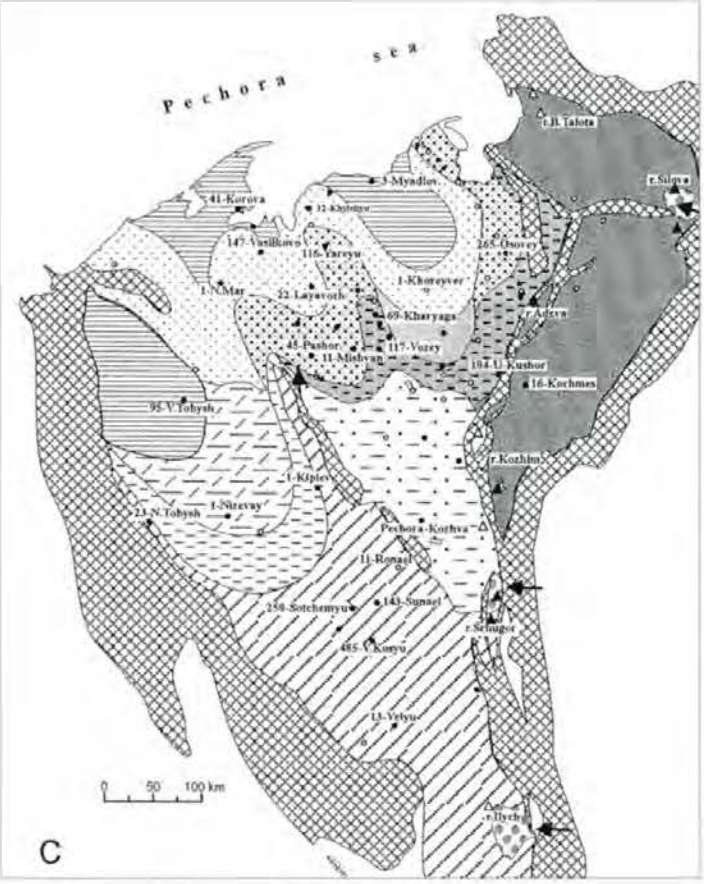
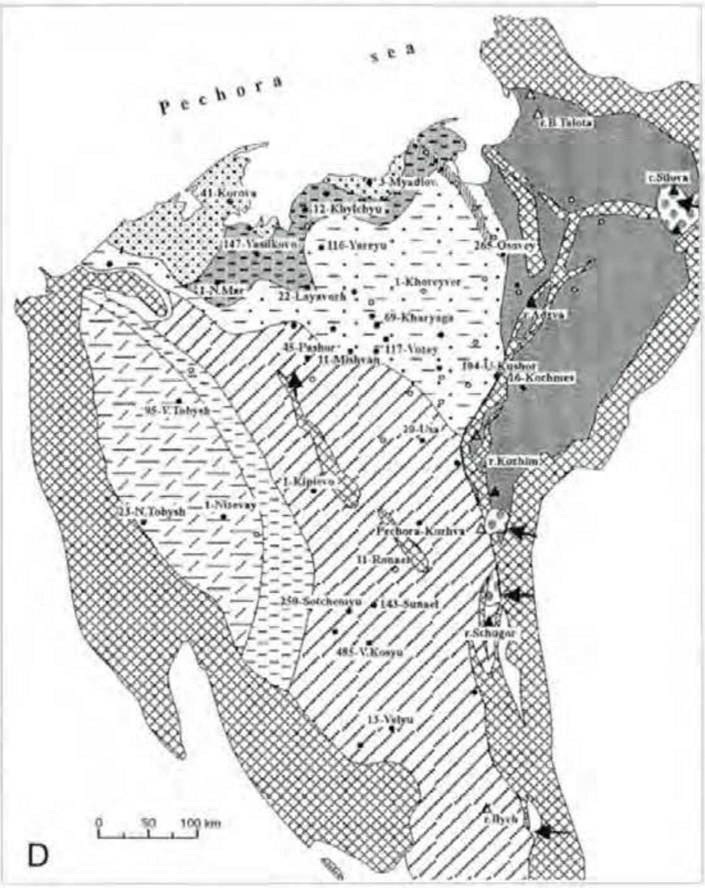


Fig. 3 – Paleogeographical maps:

A. lowstand system tract of the I Ufimian sequence; B. transgressive system tract of the I Ufimian sequence; C. lowstand system tract of the III Ufimian sequence; D. lowstand to transgressive system tract of the I Kazanian sequence. (See Fig. 2 for legend).





Facies and thickness distributions as well as the petrography of sandstones and conglomerates, strongly suggest, that the paleo-Urals mountains were the major source of polymictic clastics. However it is assumed that in the Upper Permian the area of the Timan Ridge represented the lowland plain which could also serve as a transition zone for the Uralian material. A series of islands and peninsulas might have existed on the area of the Pechora-Kozhva swell, restricting and providing specific sedimentation to the southwestern part of the Pechora Basin.

The maximum flooding surface of the first Ufimian sequence is well expressed over the entire area of the Pechora Basin. Maximum transgression occurred in the north. The map of transgressive systems tract is dominated by offshore marine facies in the northwest and semi-restricted facies in the southeast (Fig. 3-B).

Each following Ufimian sequence marks a basinward facies shift, with progradation of lowstand deltaic-nearshore facies to the north and northwest. The third Ufimian sequence is characterised by considerable sand influx which resulted in the development of a widespread bar-deltaic complex over the area of the Pechora Synclise (Fig. 3-C). A coastal plain (lowstand) with peat accumulation shifted westwards from the pre-Ural foredeep, and a deltaic complex with distributaries and mouth bars (highstand) is documented on the Kharyaga field. By the end of Ufimian times, continental deposition dominated over most of the considered area and was strongly controlled by climatic variations: coals became very common in humid climates (northern areas), while red beds with calcretes developed in the semi-arid areas (south). Very often the latter beds mark sequence boundaries. The most mature and thick calcrete horizons are confined to the tops of the Ufimian and the Lower (?) Kazanian.

The boundary between Ufimian and Kazanian stages is defined by spores and pollen, floral complexes, bivalves and ostracods. However, it appeared to be less well grounded than the Kungurian-Ufimian boundary. Non-marine facies dominate (Fig. 3-D). Marine (shoreface) environments and coastal plains with peat accumulation and some interbeds with marine fossils were preserved only in the northwestern part of the area. In the west, semi-isolated environments rich in marls accumulated. Correlation of sequences and identification of system tracts become more complicated in the higher part of the section because of continental facies with alluvial channels. Only some sequence boundaries, marked by calcrete horizons in the southern and some northern areas, could be more or less correlated throughout the basin. Transgressive and highstand systems tracts become most expressed. Transgressive deposits in continental environments are marked by the development (even within the red beds) of grey lacustrine facies with abundant non-marine bivalves and ostracods.

The boundary between the Kazanian and the Tatarian is the least proved over the most part of the considered area. Only in the outcrops and well sections with sufficient coring can they be distinguished by microflora, bivalves and ostracods. The composition of the deposits is similar to the Kazanian.

CONCLUSIONS

During the Upper Permian, continental environments completely replaced marine deposition in northeastern Europe. Vertical and lateral variations of facies patterns caused by steady regression of the sea basin, interrupted by short transgressions, suggest that facies mapping can be most valuable for relatively short time intervals. The constructed maps, illustrating the evolution of sedimentation, should be regarded as the first approach. Cyclic regressive development of the Pechora Basin in the Upper Permian together with climatic variations provide a good opportunity for correlation of nonmarine and marine deposits and can be applied to chronostratigraphical analysis using sequence stratigraphy as a tool.

Acknowledgements – I wish to thank my colleagues Dr G.P. Kanev and Dr N.A. Koloda for consultations on biostratigraphy, Prof. G.Baum for an introduction to sequence stratigraphy, Dr V.I. Bogatsky for permission to work with well data (cores and logs), and Dr S.V. Lyurov for technical assistance with drawings. I gratefully acknowledge the Organising Committee of the Permian Conference in Brescia and personally Prof. Giuseppe Cassinis, and the Russian company "Nobel Oil" for this opportunity and the financial support of my participation in the Conference.

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2. NON-EUROPEAN TERRITORIES AND GLOBAL MATTERS

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INVERTEBRATE FAUNAS AND PRELIMINARY PALYNOLOGY, CARBONIFEROUS-PERMIAN BOUNDARY STRATOTYPE, AIDARALASH CREEK, KAZAKHSTAN

MICHAEL T. DUNN[1], CLAUDE SPINOSA[2] and BRUCE R. WARDLAW[3]

Key words – Ammonoids; Carboniferous; Conodonts; Fusulinaceans; Palynology; Permian; Stratotype; Ural Mountains.

Abstract – The global stratotype section and point (GSSP) for the base of the Permian System and therefore the Permian-Carboniferous boundary and the base of the Asselian Stage has been formally established in the southern Ural Mountains along Aidaralash Creek, Kazakhstan. The definition is based on the First Appearance Datum (FAD) of the conodont *Streptognathodus isolatus*. A previously suggested ammonoid boundary occurs 26.8 meters above, at the base of bed 20. A "traditional" fusulinacean boundary occurs 6.3 m above the conodont boundary. The ammonoid, fusulinacean, and conodont faunas from the GSSP are well studied and provide a basis for correlation with other marine sections within the Urals and internationally. However, the Permian System includes extensive non-marine strata that are not easily correlated with their marine counterparts. Correlation of non-marine strata to marine stratotype requires study of fossil biota that bridge the two. Recent examination of the palynology of the Carboniferous-Permian boundary strata (24.2 m below to 26 m above) from Aidaralash confirms the occurrence of a miospore assemblage similar to the *L. monstruosus-V. costabilis* Assemblage Zone of Utting in stratigraphic association with abundant conodonts, ammonoids and fusulinaceans.

Parole chiave – Ammoniti; Carbonifero; Conodonti; Fusulinidi; palinologia; Permiano; stratotipo; Monti Urali.

Riassunto – Il punto e la sezione dello stratotipo globale (GSSP) per la base del Permiano, e pertanto il limite Permiano-Carbonifero e la base dell'Asseliano sono stati formalmente stabiliti negli Urali meridionali lungo il torrente Aidaralash, in Kazakhstan. La definizione di questo limite è basata sulla prima comparsa (FAD) del conodonte *Steptognathodus isolatus*. Un limite ad ammoniti, precedentemente proposto, è presente 28 m al di sopra, e cioè alla base dello strato 20. Un limite "tradizionale" a fusulinidi figura 6.3 m sopra il limite a conodonti. Le faune a ammoniti, fusulinidi e conodonti del GSSP sono ben studiate e forniscono una base per correlazioni con altre sezioni marine entro gli Urali e internazionalmente. Tuttavia, il Permiano include estesi strati non-marini che non sono facilmente correlabili con i loro sostituti marini. La correlazione di strati non-marini con stratotipi marini richiede lo studio di faune che facciano da ponte tra i due. Recenti esami palinologici degli strati al limite tra il Carbonifero e il Permiano (da 24.2 m sotto a 26 m sopra) nella sezione di Aidaralash conferma l'evento di un'associazione a miospore simile alla Zona di Associazione *L. monstruosus - V. costabilis* di Utting, unita stratigraficamente ad abbondanti conodonti, ammoniti e fusulinidi.

INTRODUCTION

The global stratotype section and point (GSSP) for the base of the Permian has been officially defined (Davydov *et al.*, 1998) in strata at Aidaralash Creek, Aqtöbe (formerly Aktyubinsk) region, in the southern Ural Mountains of northern Kazakhstan. The base of the Permian System occurs at the first appearance of the conodont *Streptognathodus isolatus*. Establishment of the GSSP for the base of the Permian in the Ural Mountains represents the culmination of a long series of studies dating back to the original founding of the Permian System by Murchison (1841). Subsequent to its establishment, the lower boundary of the Permian has been repeatedly lowered in the Urals and various other regions, however, a GSSP for the base of the Permian had not been established until recently. Lacking a formal world standard, the lower boundary of many Permian successions outside of the Urals was drawn at locally convenient arbitrary levels without reference to the Ural sections; this practice was particularly flagrant in China and Australia.

Following the initial work by R.I. Murchison (1841), A.P. Karpinsky (1874), D.M. Rauser-Chernosova (1940), V.E. Ruzhencev (1936, 1945, 1950, 1951, 1952, 1954),

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I.V. Khvorova (1961) and S.E. Rosovskaya (1962), among others, conducted classic studies of Urals stratigraphy. More recently, M.F. Bogoslovskaya *et al.* (1995), V.I. Davydov *et al.* (1998), B.I. Chuvashov *et al.* (1993), V.V. Chernykh & S.M. Ritter (1994, 1997), V.V. Chernykh *et al.* (1997a, 1997b) among others, and the efforts of Permian and Carboniferous workers in preparation for the International Congress of the Permian in Perm, 1991 are particularly noteworthy. The Permian Congress provided the stimulus for renewed emphasis on Permian studies.

Many sections in the classic region of the southern Urals have been studied and in recent years two sections were contenders to serve as the GSSP – the sections at Aidaralash Creek and Usolka (Fig. 1). Strata of the Usolka section were deposited in the Ural sub-basin and the Aidaralash strata in the Aqtöbe sub-basin – both in the Pre-Uralian foredeep. Carboniferous-Permian strata of the Aqtöbe sub-basin were deposited on a marine shelf; those of the Ural sub-basin were deposited in deeper water (Snyder *et al.*, 1994). Strata of the deep marine facies of the Usolka section are exceptionally rich in conodonts, enabling precise correlation with Aidaralash and other sections in the Urals. On this basis, therefore, conodont workers favored Usolka as a potential GSSP. The section at Aidaralash was selected, however, because it meets many of the most important criteria for establishment of GSSPs. Especially significant is the diverse biota: abundant ammonoids, fusulinaceans, and conodonts offer great potential for worldwide correlation with other marine Permian strata. Abundant palynological (Dunn, 1998, 1999) and paleobotanical (Dunn, 1997; Naugoinykh, 1999) remains offer great potential for correlation to continental sections. The co-occurrence of marine and terrestrial biota is particularly important because the Permian contains extensive continental strata. Thus the Aidaralash GSSP may provide a bridge between marine and continental strata.

Fig. 1 – Regional Upper Paleozoic tectonostratigraphic map of the southern Ural Mountains and northern Pre-Caspian basin of Russia and Kazakhstan. Limestone pattern depicts the Russian platform. Black dots represent some of the more important Permian and Carboniferous sections of the region. Aidaralash is located in the southern region and Usolka in the north. Modified after Snyder *et al.*, 1994.

PERMIAN-CARBONIFEROUS BOUNDARY DEFINITIONS

Conodonts

The official boundary definition for the base of the Asselian Stage, and thus the base of the Permian and Carboniferous-Permian boundary, is based on the First Appearance Datum (FAD) of the conodont *Streptognathodus isolatus* that occurs 27 m above the base of bed 19 (Fig. 2).

Fusulinaceans

Previous fusulinacean boundary definitions (Ruzhencev, 1936, 1950) placed the base of the Permian in bed 19, located 6.3 m above the conodont-defined boundary (Fig. 2) and coincident with the base of the *Sphaeroschwagerina vulgaris aktjubensis-S. fusiformis* Zone that overlies the *Ultradaixina bosbytauensis-Schwagerina robusta* Zone. Fusulinaceans are abundant and diverse at Aidaralash and detailed evolutionary lineages are well preserved. However, fusulinacean species from Aidaralash, although widespread regionally, appear to be somewhat provincial and therefore have limited potential for international correlation.

Ammonoids

Ammonoid definitions of the Permo-Carboniferous boundary (Bogoslovskaya *et al.*, 1995) were based on the first appearance of the characteristically Permian families Metalegoceratidae, Paragastrioceratidae and Popanoceratidae. The *Juresanites-Svetlanoceras* genozone was considered the base of the Asselian, which overlies the *Shumardites-Vidrioceras* Genozone. Ammonoids are abundant at Aidaralash (Fig. 3) and the distribution of ammonoid genera is widespread, however, at the species level, similarly to fusulinaceans, ammonoid distribution is somewhat locally restricted.

Palynology

Approximately fifty meters of section (Fig. 4) across the Carboniferous-Permian boundary were sampled for palynomorphs (Dunn, 1998). No significant change was noted in the pollen and spore assemblage within this portion of the Aidaralash section. The palynoflora of the section studied is characterized by abundant and diverse species of *Vittatina* (polyplicate pollen), and a variety of taeniate disaccate pollen genera. As shown in Figure 5 these two suprageneric groups comprise 64% of the palynomorphs in the assem-

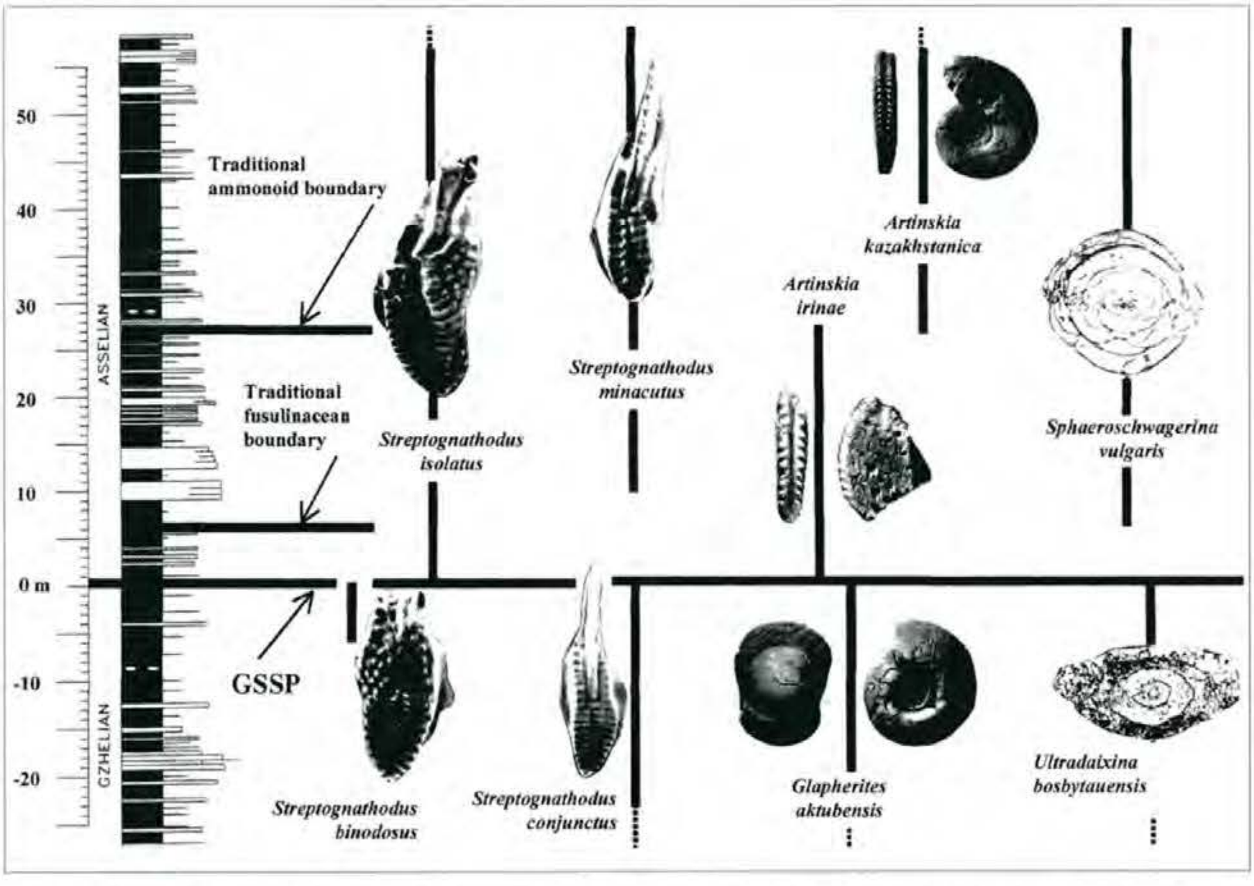

Fig. 2. – Stratigraphic column and ranges of selected representatives of significant invertebrate fossil groups in the GSSP for the base of the Permian System, Aidaralash Creek, Aktöbe (formerly Aktyubinsk) region, Northern Kazakhstan. Shown are the traditional boundaries based on ammonoids, fusulinaceans and the GSSP definition based on conodonts.

blage. Monosaccate and non-taeniate pollen comprise 8% and 7% of the population respectively. In situ trilete spores account for 13% and reworked Devonian and Lower Carboniferous trilete spores total more than 7%. The co-occurrence of *Limitisporites monstruosus* and *Vittatina costabilis* in conjunction with the abundance and diversity of taeniate disaccate and polyplicate pollen suggests that the palynological assemblage at Aidaralash Creek may be correlatable with the *Limitisporites monstruosus - Vittatina costabilis* Assemblage Zone of Utting (1989, 1994).

Important taxa include *Vittatina costabilis* Wilson, *Vittatina vittifera* (Lyuber) Samoilovich ex Hart, *Vittatina simplex* Jansonius, *Vittatina saccifer* Jansonius, *Vittatina subsaccata* Samoilovich, *Hamiapollenites bullaeformis* (Samoilovich) Jansonius, *Hamiapollenites tractiferinus* Samoilovich, the *Protohaploxypinus latissimus-Protohaploxypinus perfectus* complex, *Striatoabieites* sp., *Limitisporites monstruosus* Lyuber & Val'ts, *Illinites unicus* Kosanke, the *Lueckisporites-Scutasporites* complex, *Potonieisporites* spp., *Florinites luberae* Samoilovich, and *Cordaitina uralensis* Lyuber & Val'ts (Fig. 6). The most common trilete spores are generally not biostratigraphically useful, such as *Punctatisporites*, *Calamospora* and *Leiotriletes*, or are reworked such as *Densosporites* and *Apiculatisporis*.

Dyupina (1975) recognized that an increase in the quantity of acritarchs and a reduction in the diversity and quality of preservation of miospores correlate with an onset of a transgressive phase. At Aidaralash, acritarchs (*Inderites*) do not increase across the Permian-Carboniferous boundary, thus Dyupina's hypothesis is in agreement with the physical evidence (Snyder *et al.*, 1994) that no discernable transgressive cycle occurs in strata within 50 meters of the GSSP at Aidaralash.

The abundance of disaccate pollen and the polyplicate *Vittatina* with the relative paucity of spores and monosaccate pollen suggests that the macroflora of the Carboniferous-Permian boundary at Aidaralash Creek was dominated by gymnosperms. This gymnosperm dominance suggests that the terrestrial ecosystem of the region was that of an arid dry upland – typically Permian – rather than the coal swamps typical of the Upper Carboniferous. The dominance of gymnosperm pollen indicates that the aridity-tolerant Permian flora had been well established by the beginning of the Permian and that the change had occurred prior to the close of the Carboniferous. These data support the findings of Ziegler (1990) and of Utting & Piasecki (1995) who suggested that the climate of the southern Urals in Early Permian time was that of an arid tropical desert.

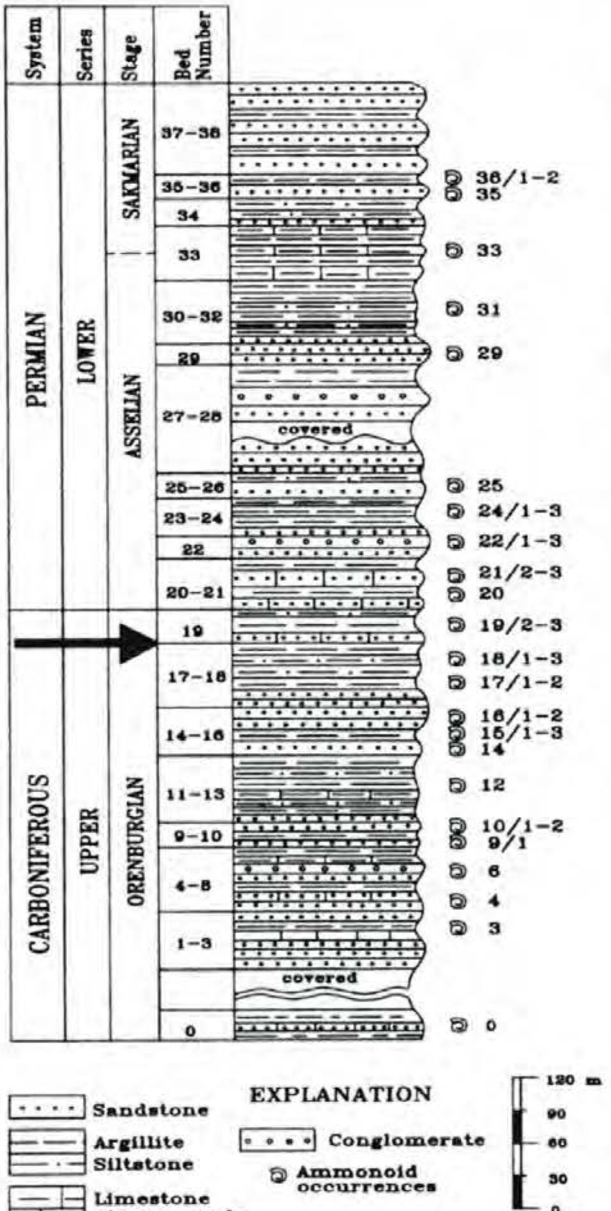

Fig. 3 – Diagrammatic columnar representation of the Aidaralash Creek section with indicated ammonoid occurrences and the Permian-Carboniferous boundary preferred by ammonoid workers. Arrow indicates location of internationally recognized GSSP. Bed numbers represent the terminology used in Russian literature. Adapted from Bogoslovskaya *et al.*, 1995.

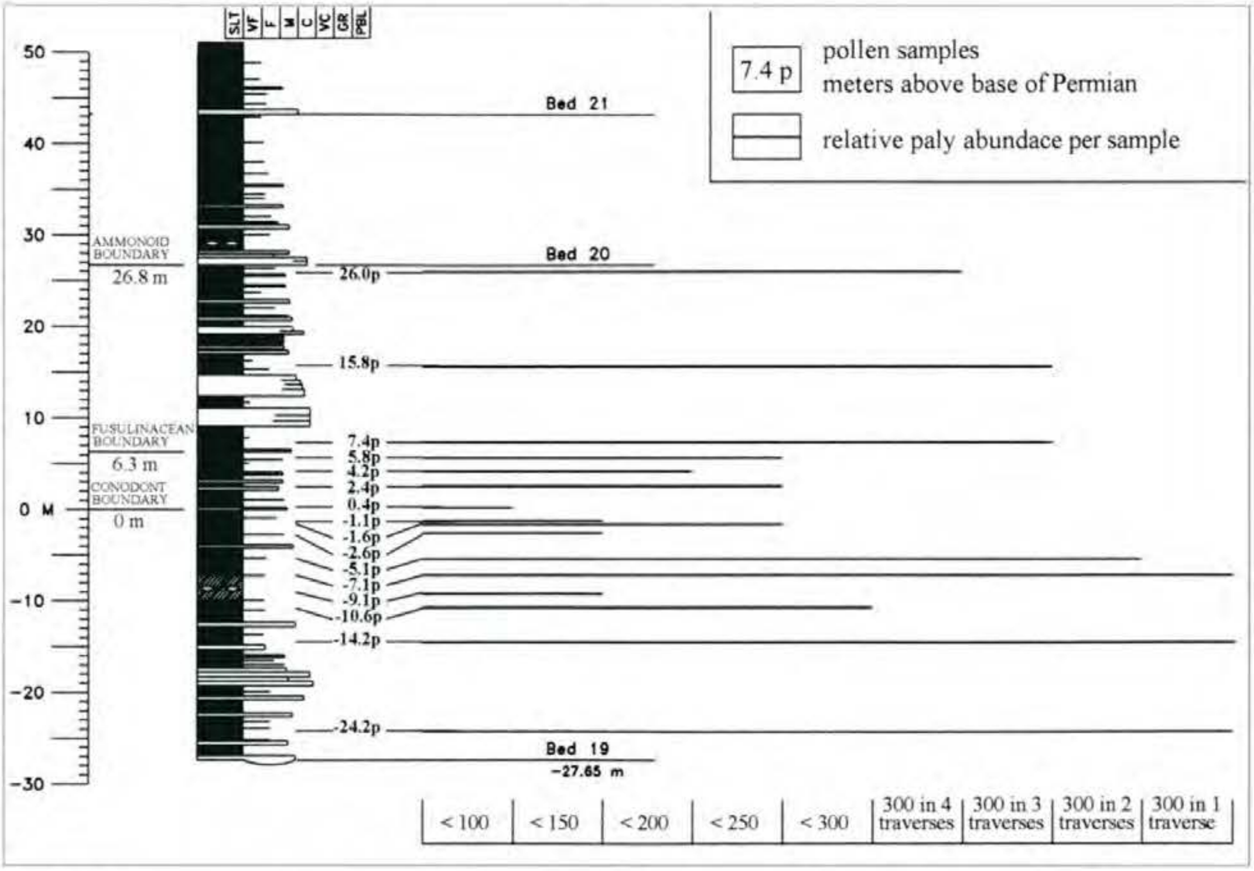

Fig. 4 – Relative abundance and location (meters above base of Permian) of palynomorph samples from a fifty-meter interval of the GSSP section at Aidaralash Creek, Aktöbe (formerly Aktyubinsk) region, Northern Kazakhstan. Adapted from Dunn, 1999.

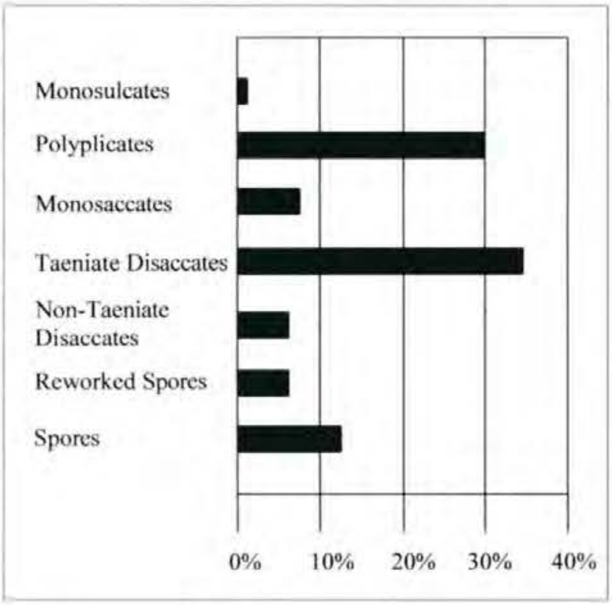

Fig. 5 – Percentage of suprageneric palynomorph groups from Aidaralash Creek, Aktöbe (formerly Aktyubinsk) region, Northern Kazakhstan.

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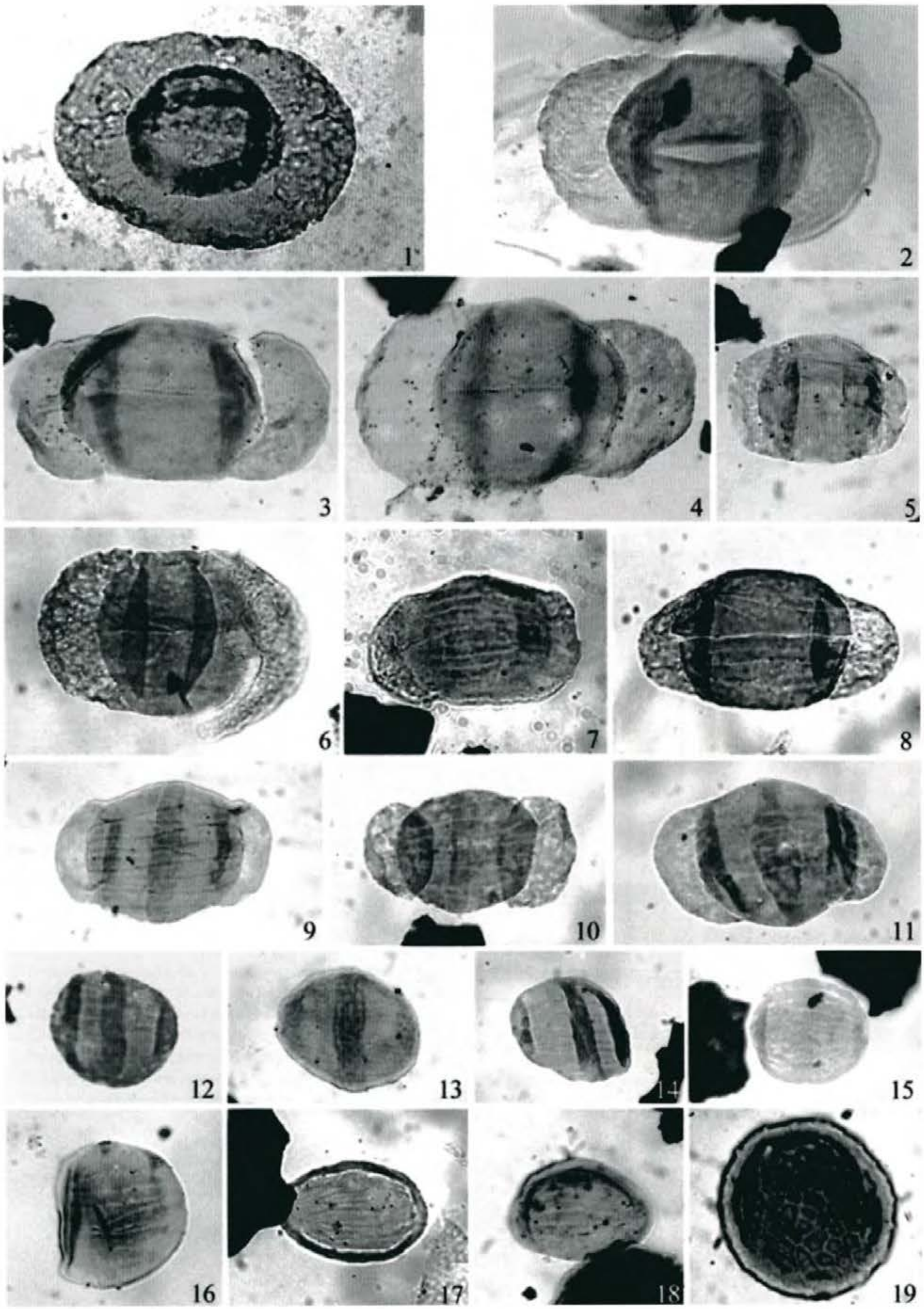
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Fig. 6 – Selected characteristic palynomorphs from the Aidaralash Creek section. Specimens are referenced by name, Geological Survey of Canada processing number, meters above the base of the Permian, and stage coordinates of Olympus Vanox microscope (BSU#31597), respectively. All photomicrographs are at a magnification of 500X.

6.1.	*Potonieisporites novicus* Bharadwaj, 1954;	4201-2, +20; -7.1MAB; 21x104
6.2.	*Limitisporites monstruosus* Lyuber and Val'ts 1941;	4201-2, +20; -7.1MAB; 12x92.
6.3.	*Limitisporites monstruosus* Lyuber and Val'ts 1941;	4202-8, +20; 26.0MAB; 21x86.
6.4.	*Limitisporites monstruosus* Lyuber and Val'ts 1941;	4202-6, +20; 5.8MAB; 20x70.
6.5.	*Protohaploxypinus latissimus-Protohaploxypinus perfectus* complex;	4202-3, +20; -9.1MAB; 13x84.
6.6.	*Protohaploxypinus latissimus-Protohaploxypinus perfectus* complex;	4201-7, +20; 4.2MAB; 11x87.
6.7.	*Protohaploxypinus latissimus-Protohaploxypinus perfectus* complex;	4202-8, +20; 26.0MAB; 18x73.
6.8.	*Striatoabieites spA*;	4204202-1, +20; -24.2MAB; 15x98.
6.9.	*Hamiapollenites bullaeformis* (Samoilovich) Jansonius 1962;	4202-1, +20; -24.2MAB; 19x74.
6.10.	*Hamiapollenites bullaeformis* (Samoilovich) Jansonius 1962;	4201-1, +20; -24.2MAB; 6x87.
6.11.	*Hamiapollenites bullaeformis* (Samoilovich) Jansonius 1962;	4201-1, +20; -10.6MAB; 21x79.
6.12.	*Vittatina costabilis* Wilson 1962;	4201-8, +20; 7.4MAB; 9x99.
6.13.	*Vittatina costabilis* Wilson 1962;	4202-7, +20; 15.82MAB; 18x81.
6.14.	*Vittatina costabilis* Wilson 1962;	4202-8, +20; 26.0MAB; 10x100.
6.15.	*Vittatina subsaccata* Samoilovich 1953;	4201-1, +20; -10.6MAB; 19x76.
6.16.	*Vittatina simplex* Jansonius 1962;	4202-3, +20; -9.1MAB; 10x98.
6.17.	*Vittatina vittifera* (Lyuber) Samoilovich ex Hart 1965;	4202-1, +20; -24.2MAB; 15x94.
6.18.	*Vittatina vittifera* (Lyuber) Samoilovich ex Hart 1965;	4202-7, +20; 15.82MAB; 13x88.
6.19.	*Inderites* sp. (Abromova and Marchenko) Dyupina, 1970;	4202-6, +20; 5.8MAB; 2.5x81.

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PERMIAN AND EARLY TRIASSIC PALYNOMORPH ASSEMBLAGES FROM CANADIAN ARCTIC ARCHIPELAGO, ALASKA, GREENLAND, AND ARCTIC EUROPE

JOHN UTTING[1]

Key words – Palynomorphs; Permian; Early Triassic; Arctic Canada; Alaska; Greenland; Arctic Europe.

Abstract – In the Sverdrup Basin of the Canadian Arctic Archipelago two pollen and spore zones have been established in Kungurian? to Wordian rocks at the basin margin. A further zone occurs in unconformably overlying beds which, based on ammonoids, have been assigned traditionally to the lower Griesbachian (lower Triassic), although recently some workers have suggested that the lowest of these beds may be uppermost Permian (Changhsingian), based on conodont data.

The palynomorph assemblages in the zones of Kungurian to Roadian, Wordian and Griesbachian age resemble those of approximately similar age on the North Slope of Alaska, northern and eastern Greenland, Spitsbergen, Svalis Dome, Finnmark, and Kolguyev Island, thereby enabling relatively precise age determinations, in terms of North American stages, to be made throughout the circum-polar area.

Many workers correlate the Ufimian stratotype in the Volga-Urals region of Russia with the Roadian of Texas, and the Kazanian stratotype of Russia with the Wordian and Capitanian of Texas. However, precise correlation between Texan and Russian stratotypes is hampered by the fact that, whereas the former contain a rich marine fauna, the Russian stratotypes contain only sparse brachiopods, ammonoids, corals and conodonts and a non-marine fauna of bivalves, ostracodes and conchostracans. Palynological comparisons cannot yet be made with assemblages from the Texan stratotypes because published data are unavailable, largely because the abundant carbonates lack palynomorphs.

However, palynomorphs are abundant in Kungurian? to Wordian rocks of the Canadian Arctic that also contain marine faunas, and in the Russian Ufimian and Kazanian stratotype areas, thus allowing comparisons to be made. These indicate that there are major differences in the composition of pollen and spore taxa of the two areas.

If the age correlations are valid, then the palynological differences may be the result of differences in floral province, paleoclimate, paleolatitude, facies and relative geographic location on Pangea.

Parole chiave – Palinomorfi; Permiano; Triassico inferiore; Artico canadese; Alaska; Groenlandia; Artico europeo.

Riassunto – Nel Bacino di Sverdrup, situato nell'Arcipelago Artico canadese, sono state stabilite due zone a pollini e spore in rocce kunguriane-wordiane poste al margine del bacino. Un'ulteriore zona è presente nei sovrastanti strati discordanti che, in base alla presenza di ammoniti, è stata tradizionalmente assegnata al Griesbachiano inferiore (Triassico inferiore), sebbene recentemente alcuni ricercatori abbiano proposto, sulla base di dati a conodonti, che il più basso di questi strati possa corrispondere al Permiano più alto (Changhsingiano). Le associazioni a palinomorfi nelle zone che vanno dal Kunguriano al Roadiano, Wordiano e Griesbachiano rassomigliano a quelle di età approssimativamente simili presenti sullo *slope* settentrionale dell'Alaska, in Groenlandia settentrionale e orientale, nelle Spitzbergen, nel "Duomo di Svalis", in Finnmark e nell'isola di Kolguyev, consentendo pertanto che determinazioni di età relativamente precise, in termini di piani nord-americani, siano compiute attraverso l'area circum-polare.

Molti ricercatori correlano lo stratotipo relativo all'Ufimiano nella regione Volga-Urali della Russia con il Rodiano del Texas, e lo stratotipo relativo al Kazaniano russo con il Wordiano e il Capitaniano del Texas. Tuttavia, una precisa correlazione tra gli stratotipi texani e russi è ostacolata dal fatto che, mentre i primi contengono una ricca fauna marina, gli stratotipi russi includono solo rari brachiopodi, ammoniti, coralli e conodonti ed una fauna non-marina a bivalvi, ostracodi e concostraci. Confronti palinologici non possono ancora essere fatti con associazioni provenienti dagli stratotipi texani in quanto i dati pubblicati sono inutilizzabili, in gran misura perché gli abbondanti carbonati sono privi di palinomorfi. Tuttavia, i palinomorfi sono diffusi nelle rocce kunguriane?-wordiane dell'Artico canadese, che pure contengono faune marine, e nelle aree a stratotipi dell'Ufimiano e del Kazaniano russi, consentendo pertanto che si possa procedere a confronti. Questi indicano che vi sono maggiori differenze nella composizione di taxa a pollini e spore delle due aree. Se le correlazioni cronologiche sono valide, le differenze palinologiche possono allora rappresentare il risultato di differenze legate alla provincia floristica, al paleoclima, alla paleolatitudine, alle facies ed alla relativa posizione geografica nell'ambito della Pangea.

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INTRODUCTION

Early to Middle Permian rock units in the marginal facies of the Sverdrup Basin include the Sabine Bay, Assistance and Trold Fiord formations (Figs 1 and 2). The Sabine Bay Formation (Tozer & Thorsteinsson, 1964) was probably deposited relatively rapidly in response to the Melvillian disturbance (Beauchamp *et al.*, 1989 b); it is dominated by sandstone, with intercalations of shale, and with rare coaly and carbonaceous shale intercalations (Fig. 2). The overlying Assistance Formation (Harker & Thorsteinsson, 1960; Fortier *et al.*, 1963; Thorsteinsson, 1974; Nassichuk, 1975) is mainly marine, fossiliferous, calcareous, glauconitic sandstone. It is overlain by the Trold Fiord Formation (Tozer & Thorsteinsson, 1964; Nassichuk, 1975; Beauchamp *et al.*, 1989 a, b), which consists of glauconitic, fossiliferous, calcareous sandstone, with some thin cherty intercalations. There is a hiatus between the Trold Fiord and the overlying lower Triassic Blind Fiord Formation (Tozer, in Fortier *et al.*, 1963); the latter is composed of green and grey shale and siltstone, considered to have been deposited on an offshore shelf (Embry, 1988, 1991).

The Permian formations have been dated with marine faunas of conodonts, brachiopods, and ammonoids (Fig. 2). These data suggest a Kungurian to Roadian age for the Sabine Bay Formation (Waterhouse, 1969; Nassichuk, 1995; Henderson, 1988; Beauchamp *et al.*, 1989 b; Beauchamp *et al.*, in press), a Roadian age for the Assistance Formation (Waterhouse, 1969; Nassichuk, 1995) a Wordian age for the Trold Fiord Formation (Waterhouse, 1969; Waterhouse in Thorsteinsson, 1974; Nassichuk, 1995). A review of the macrofaunal data has recently been provided by Fedorowski and Bamber (in press) for the Trold Fiord and Degerböls . The lower part of the unconformably overlying Blind Fiord Formation was dated as Early Triassic (early Griesbachian) on the presence of *Otoceras concavum* (Tozer, 1967). Conodonts are sparse in the basal beds, but Henderson & Baud (1997) suggested the former correlate with the uppermost Changhsingian of Meishan (China). This conclusion is based on the presence in the lowest 14-18 m of the Otto Fiord South Section, Ellesmere Island, of *Neogondolella* sp. cf. *subcarinata*, *N.* sp. aff. *changxingensis*, *N. meishanensis*, and questionable *N. deflectus*. However, Orchard & Tozer (1997, 1999) questioned this interpretation and recommended a detailed study of conodonts from the beds containing *Otoceras*. Until that is carried out an Early Triassic Griesbachian age is assumed in this paper for the lower part of the Blind Fiord Formation.

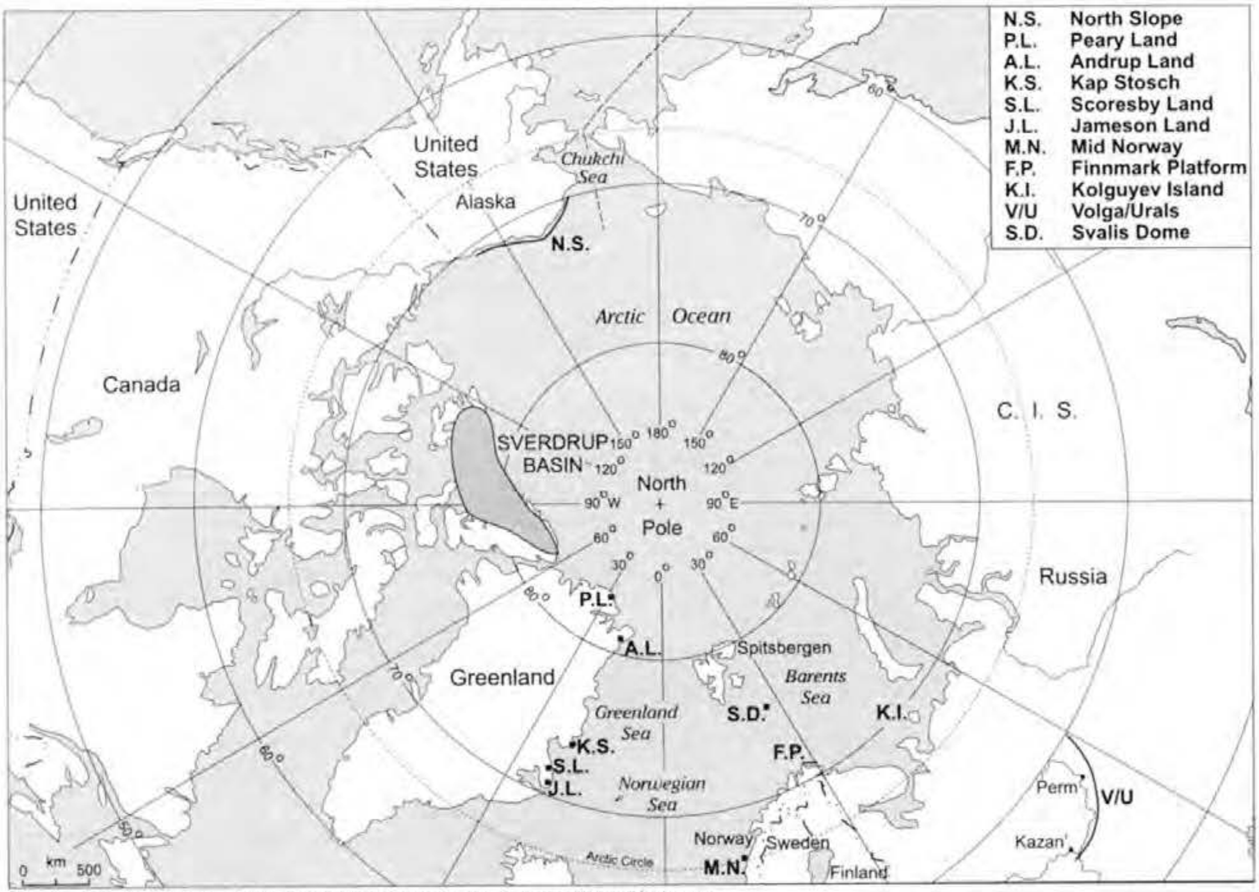
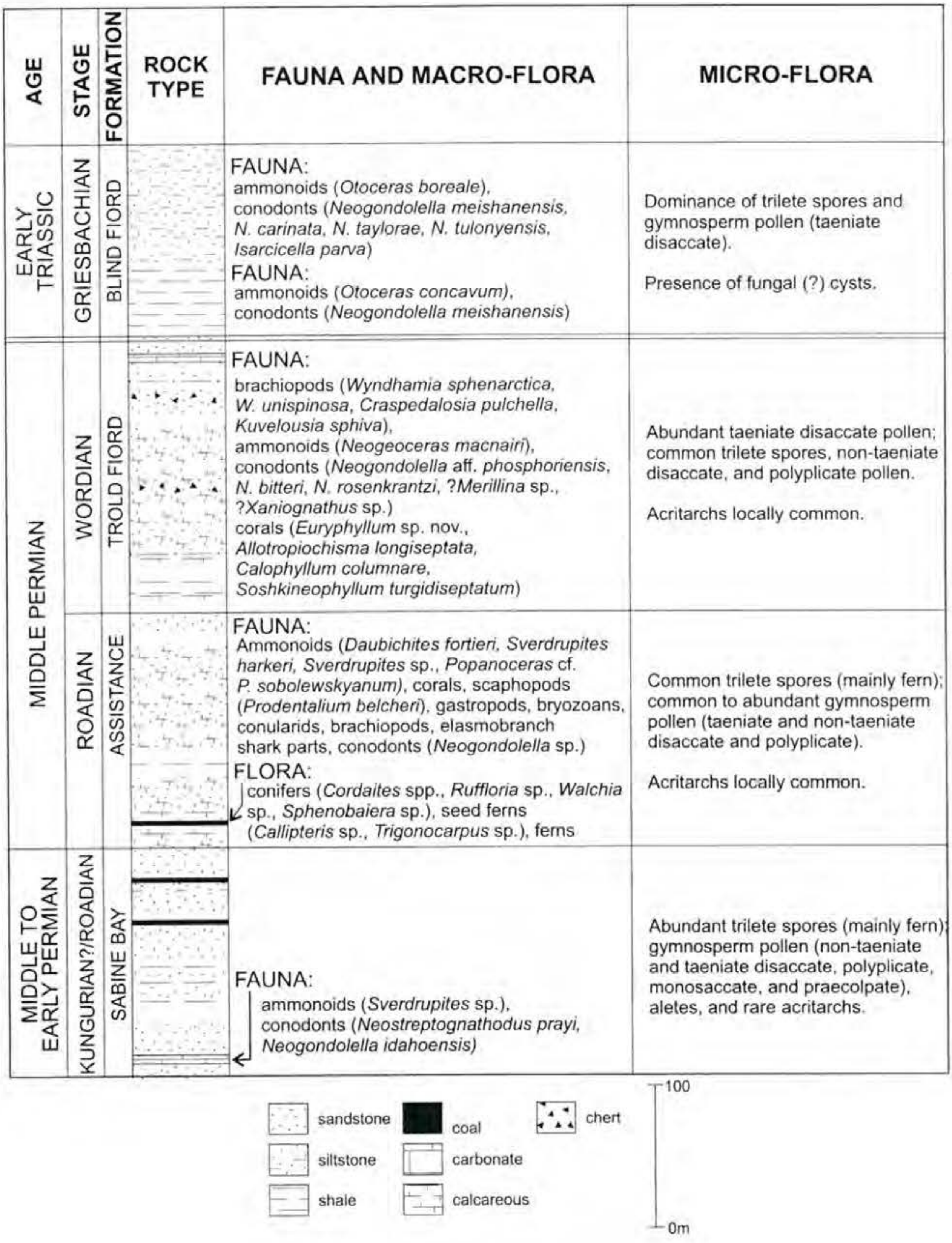


Fig. 1 – Location of areas studied in circum-polar area and in the Volga/Urals area.



AGE	STAGE	FORMATION	ROCK TYPE	FAUNA AND MACRO-FLORA	MICRO-FLORA
EARLY TRIASSIC	GRIESBACHIAN	BLIND FIORD		FAUNA: ammonoids (*Otoceras boreale*), conodonts (*Neogondolella meishanensis, N. carinata, N. taylorae, N. tulonyensis, Isarcicella parva*) FAUNA: ammonoids (*Otoceras concavum*), conodonts (*Neogondolella meishanensis*)	Dominance of trilete spores and gymnosperm pollen (taeniate disaccate). Presence of fungal (?) cysts.
MIDDLE PERMIAN	WORDIAN	TROLD FIORD		FAUNA: brachiopods (*Wyndhamia sphenarctica, W. unispinosa, Craspedalosia pulchella, Kuvelousia sphiva*), ammonoids (*Neogeoceras macnairi*), conodonts (*Neogondolella* aff. *phosphoriensis, N. bitteri, N. rosenkrantzi, ?Merillina* sp., *?Xaniognathus* sp.) corals (*Euryphyllum* sp. nov., *Allotropiochisma longiseptata, Calophyllum columnare, Soshkineophyllum turgidiseptatum*)	Abundant taeniate disaccate pollen; common trilete spores, non-taeniate disaccate, and polyplicate pollen. Acritarchs locally common.
	ROADIAN	ASSISTANCE		FAUNA: Ammonoids (*Daubichites fortieri, Sverdrupites harkeri, Sverdrupites* sp., *Popanoceras* cf. *P. sobolewskyanum*), corals, scaphopods (*Prodentalium belcheri*), gastropods, bryozoans, conularids, brachiopods, elasmobranch shark parts, conodonts (*Neogondolella* sp.) FLORA: conifers (*Cordaites* spp., *Ruffloria* sp., *Walchia* sp., *Sphenobaiera* sp.), seed ferns (*Callipteris* sp., *Trigonocarpus* sp.), ferns	Common trilete spores (mainly fern); common to abundant gymnosperm pollen (taeniate and non-taeniate disaccate and polyplicate). Acritarchs locally common.
MIDDLE TO EARLY PERMIAN	KUNGURIAN?/ROADIAN	SABINE BAY		FAUNA: ammonoids (*Sverdrupites* sp.), conodonts (*Neostreptognathodus prayi, Neogondolella idahoensis*)	Abundant trilete spores (mainly fern); gymnosperm pollen (non-taeniate and taeniate disaccate, polyplicate, monosaccate, and praecolpate), aletes, and rare acritarchs.

Fig. 2 – Age, formation, rock type, fauna, macro-flora, and micro-flora of rock units in Sverdrup Basin.

FLORAL PROVINCE

Macro-floras are rare in the Permian of the circum-polar study area, and interpretations of floral province are speculative. Mamay & Reed (1984) reported an Angaran flora from the central Alaska Range no younger than Early Permian. Wagner *et al.* (1982) and Wagner *et al.* (in press) described Late Permian (Kazanian) floras from northern Greenland that have Angaran and rare Cathaysian affinities. Recently in the Sverdrup Basin, study of macroflora in bioclastic limestone approximately equivalent to the Assistance Formation near the Svartevaeg Cliffs of northern Axel Heiberg has indicated elements in common with Angaran, European and Euramerian provinces (LePage, pers. comm. 2000). Also present are taxa unknown or rare in the Angaran floras and those that are more typical of the Upper Permian and Lower Triassic. The flora is dominated by cordaites (*Cordaites, Ruffloria, Vojnovskaya* and *Zamiopteris*), but abundant remains of *Utrechtia* indicate that this conifer co-dominated the regional vegetation throughout the extrabasinal regions (LePage, pers. comm. 2000). The flora is characterised by a diverse assemblage of pteridosperms. It contains medullosan seed ferns not normally associated with Angara. Also present are peltasperms, which are the dominant elements of the Upper Permian of Russia. The microflora in associated beds has been assigned to the upper part of the *Alisporites plicatus - Jugasporites compactus* Concurrent Range Zone of Roadian age (Fig. 2). The Sverdrup Basin was assigned to Sub-Angara using palynological criteria (Utting & Piasecki, 1995).

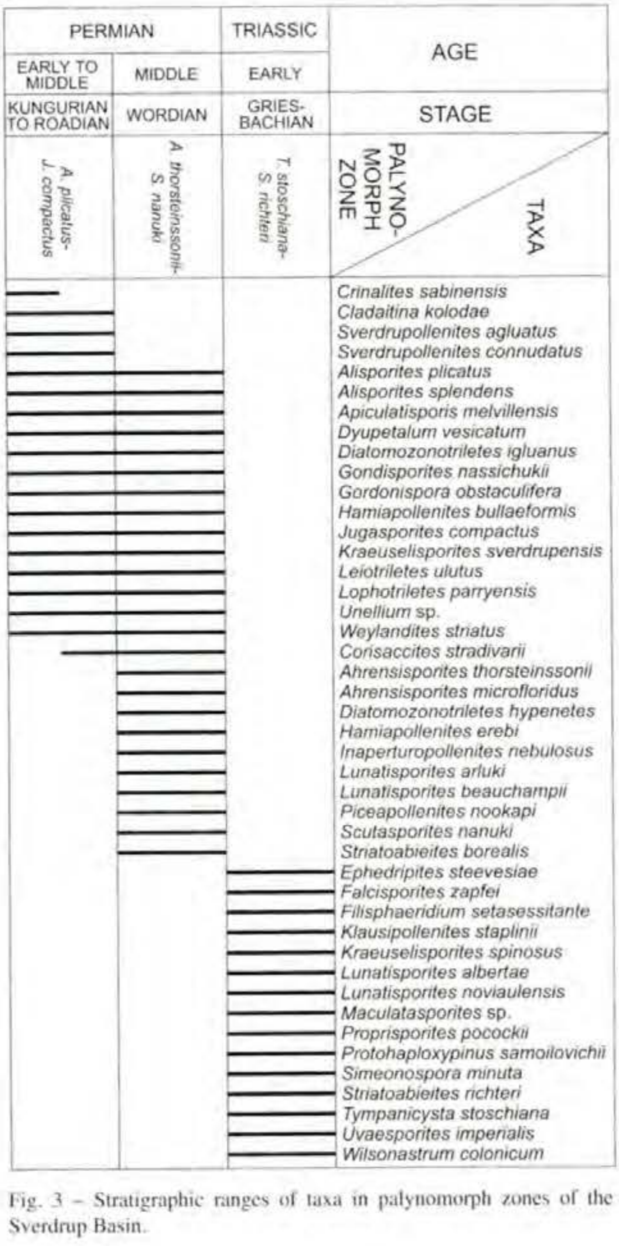


Fig. 3 – Stratigraphic ranges of taxa in palynomorph zones of the Sverdrup Basin.

PALYNOMORPH ZONES OF CANADIAN ARCTIC ARCHIPELAGO (SVERDRUP BASIN) AND COMPARISON WITH SELECTED CIRCUM-POLAR LOCALITIES

In the following sections Kungurian? to Wordian and Griesbachian assemblages of the Sverdrup Basin are compared with those of other circum-polar areas. This does not necessarily imply that the microfloras are restricted to that geographical area. For example, in Canada assemblages similar to the Griesbachian assemblages of the Sverdrup Basin occur some 1800 km to the south in northern Alberta (Jansonius, 1962).

SVERDRUP BASIN

The *Alisporites plicatus - Jugasporites compactus* (Kungurian? to Roadian) and the *Ahrensisporites thorsteinssonii - Scutasporites nanuki* (Wordian) Concurrent Range Zones (Utting, 1994a) are based on the lowest occurrence of a number of diagnostic taxa (Fig. 3). The palynomorph assemblages contain different proportions of trilete spores and gymnosperm pollen (Fig. 2), but fern spores are commonly represented, as are gymnosperm pollen including taeniate and non-taeniate disaccates, polyplicates and monosaccates. Acritarchs are rare to common. The ages of the Sverdrup zones (Figs 4, 5^{1-3} and 6^{1}) were derived from marine faunal ages summarised above, and are subject to change as more information becomes available concerning the latter.

The diversity of the palynoflora and the abundance of fern spores in the Sabine Bay and Assistance assem-

AGE		NORTHERN URALS-RUSSIAN PLATFORM	U.S.A. TEXAS		CANADA SVERDRUP BASIN	PALYNOMORPH ZONES OF THE SVERDRUP BASIN	FORMATION
TRIASSIC	EARLY	Induan	No data (Ochoan)		Griesbachian	*Tympanicysta stoschiana-Striatoabieites richteri*	Blind Fiord
PERMIAN	LATE	Tatarian			No data	No data Hiatus at basin margin	
	MIDDLE	Kazanian	Guadalupian	Capitanian	? Capitanian ?	-?-	?
				Wordian	Wordian	*Ahrensisporites thorsteinssonii-Scutasporites nanuki*	Trold Fiord
		Ufimian		Roadian	Roadian	*Alisporites plicatus-Jugasporites compactus*	Assistance Sabine Bay
	EARLY (PART)	Kungurian	Leonardian (part)		Kungurian	Not studied in detail	

Fig. 4 – Correlation of stages in Northern Urals-Russian Platform, Texas, U.S.A. and Sverdrup Basin with ages of palynomorph zones and formations.

AGE			STAGE	SELECTED PALYNOMORPH ZONES OF CIRCUM-POLAR AREA	MARINE ZONE FOSSILS
TRIASSIC	EARLY		GRIESBACHIAN (PART)	[5]*Tympanicysta stoschiana - Striatoabieites richteri*	Ammonoids and Conodonts
PERMIAN	LATE	LOPINGIAN	CHANGHSINGIAN	? ? [4]*Tympanicysta stoschiana*	None, Age Uncertain
			WUCHIAPINGIAN		Ammonoids
	MIDDLE	GUADALUPIAN	CAPITANIAN	[3]*Vittatina*	Conodonts
			WORDIAN	? ? [2]*Ahrensisporites thorsteinssonii - Scutasporites nanuki*	Brachiopods, Ammonoids and Conodonts
			ROADIAN	[1]*Alisporites plicatus - Jugasporites compactus*	Ammonoids and Conodonts
	EARLY (PART)	CISURALIAN	KUNGURIAN	?	
			ARTINSKIAN		

Fig. 5 – Composite stages of the Permian of the world proposed by Jin *et al.*, 1999, and composite palynological zones in circum-polar area with associated marine zonal fossils. [5] *Tympanicysta stoschiana - Striatoabieites richteri* Assemblage Zone Utting 1994 (Sverdrup Basin and most circum-polar localities); [4] Lowest occurrence of *Tympanicysta stoschiana* in E. Greenland (Utting and Piasecki, 1995); [3] *Vittatina* Association Balme 1980a (E. Greenland); [2] *Ahrensisporites thorsteinssonii - Scutasporites nanuki* Concurrent Range Zone Utting 1994 (Sverdrup Basin and most circum-polar localities); [1] *Alisporites plicatus - Jugasporites compactus* Concurrent Range Zone Utting 1994 (Sverdrup Basin and most circum-polar localities).

blages suggest a diverse vegetation growing in a humid climate - an interpretation supported by the presence of thin coal seams and carbonaceous shales in the Sabine Bay Formation. On Axel Heiberg Island, possible equivalents of the Assistance Formation include carbonaceous shale associated with bioclastic limestone, which contain the macroflora described above as well as a microflora dominated by fern spores (Utting, 1994b). A relative decrease of fern spores in samples from the overlying Wordian Trold Fiord Formation suggests an increase in aridity, which is supported by lack of coal seams and the appearance of red beds. Beauchamp (1994) came to similar conclusions based on sedimentological and marine faunal criteria, although he also suggested that the climate in the Wordian was cold. This contrasts with the warm temperate climate proposed by Rees *et al.* (1999), who determined paleoclimates from floral and lithological data globally.

Unconformably overlying early Griesbachian (Early Triassic) beds contain the *Tympanicysta stoschiana - Striatoabieites richteri* Assemblage Zone (Utting, 1994a). Although the top has yet to be defined, the zone is known to locally extend 100 m above the base of the formation. The zone is characterised by trilete spores, abundant taeniate disaccate and rare non-taeniate disaccate and polyplicate pollen. Acritarchs are rare to common. Also present are entities of uncertain affinity (Kalgutkar & Jansonius, 2000), which Elsik (1999) attributed to *Fungi incertae sedis*. These have been described under various names, including *Tympanicysta stoschiana* Balme, 1980a; *Chordecystia chalasta* Foster, 1979 and *Reduviasporonites stoschianus*, Elsik, 1999. Another characteristic of the zone is the common occurrence of well preserved reworked Late Devonian spores.

There are significant differences between the Wordian *Ahrensisporites thorsteinssonii - Scutasporites nanuki* Concurrent Range Zone and the Griesbachian *Tympanicysta stoschiana - Striatoabieites richteri* Assemblage Zone. They have many genera, but virtually no species in common (Fig. 3). At some localities the basal part of the *Tympanicysta stoschiana - Striatoabieites richteri* Assemblage Zone is dominated by the trilete spore *Uvaesporites imperialis* (Jansonius) Utting, which suggests arid conditions. Visscher *et al.* (1996) pointed out that microspores of herbaceous and subarborescent lycopodiophytes were commonly abundant after the extinction event at the Permian/Triassic boundary. If the suggestion by Henderson & Baud (1997) that Changhsingian rocks are present in the lower part of the Blind Fiord Formation is correct then one might anticipate some changes in the palynomorph assemblages, but other than the abovementioned dominance of *Uvaesporites imperialis,* this does not occur in the sections investigated, including the Otto Fiord South section, Ellesmere Island studied by Henderson & Baud (1997).

With the exception of the basal samples, most contain assemblages with abundant taeniate disaccate pollen known to be well adapted to arid conditions (Foster, 1979) . This is consistent with the presence of red shale and siltstone of overbank origin (Embry, 1991), and small carbonate nodules suggesting poorly developed caliches (Devaney, 1991) that indicate a seasonally dry, hot, subtropical savanna-type climate. *Tympanicysta stoschiana*, although present in many Blind Fiord samples, is generally rare, and there is no marked peak in abundance as occurs in some localities of the Italian Southern Alps, such as the Butterloch and Tesero sections (*e.g.* Conti *et al.*, 1986; Massari *et al.*, 1988, 1996, 1999) and the Badia Valley (Cirilli *et al.*, 1998). Recent work in other localities in northern Italy by Cirilli (pers. comm., 2000) indicates that abundance of *T. stoschiana* is not a single peak occurrence near the Permian/Triassic boundary, but may correspond to the upper parts of shallowing upwards sequences. This is not inconsistent with the gradual carbon-isotope shift at the boundary (Magaritz *et al.*, 1988). The suggestion was made by Visscher *et al.* (1996) that world-wide proliferation of *Tympanicysta stoschiana* in terrestrial and marine facies at the Permian-Triassic boundary implies an excessive heterotrophic presence, and reflects terrestrial ecosystem destabilization and collapse.

ALASKA (NORTH SLOPE)

The Sadlerochit Group in the Prudhoe Bay, North Slope area includes beds that have been assigned to the Permian and the Triassic (Moore *et al.*, 1994). In the lower part of the group is the Echooka Formation, which includes the lower part of the Joe Creek Member, consisting of calcareous mudstone, radiolarian chert and bioclastic, glauconitic limestone, overlain by the Ikiapauruk Member, consisting of glauconitic quartzose sandstone and siltstone (Moore *et al.*, 1994; Jones & Speers, 1976). These rock types resemble those of the Roadian (Assistance Formation) and Wordian (Trold Fiord Formation) of the Sverdrup Basin. The Joe Creek Member has been dated by a brachiopod fauna as Sakmarian to Kazanian, and the Ikiapauruk Member as Kazanian or late Guadalupian (Detterman *et al.*, 1975), or as Ufimian (late Leonardian) to Wordian (Dutro & Silberling, 1988). The Echooka Formation has been dated by ammonoids as Roadian or Wordian (Nassichuk, 1995). There is little published palynological data from this unit, although a mid-Permian age has been suggested based on the common occurrence of *Vittatina* and taeniate disaccate pollen and the lack of *Lueckisporites virkiae* Potonié and Klaus (Jones & Speers, 1976).

A core sample of the Echooka(?) Formation from Kaparuk State Mobil #1 (17612 - 17621 ft. = 5370.88 - 5374.54 m), loaned to the present writer by Dr. B. Balme, University of Western Australia, yielded an assemblage with abundant gymnosperm pollen (53%), abundant trilete spores (35%), and common acanthomorph acritarchs (12%) consisting mainly of *Micrhystridium* spp. and rare *Veryhachium* spp. (Fig. 6[2]).

The assemblage comprises the following taxa:

Gymnosperm pollen:

Taeniate disaccates (18%): *Corisaccites stradivarius* Utting, *Protohaploxypinus latissimus* (Luber) Samoilovich, *P. perfectus* (Naumova) Samoilovich, *Protohaploxypinus* sp., *Striatoabieites striatus* (Luber & Waltz) Hart

Non-taeniate disaccates (18%): *Alisporites plicatus* Jizba, *A. splendens*(Leschik) Foster, *Vitreisporites pallidus* (Reissinger) Nilsson

Polyplicates (15%): *Weylandites cincinnatus* (Luber ex. Varyukhina) Utting, *W. striatus* (Luber) Utting

SELECTED TAXA	SVERDRUP BASIN [1]			ALASKA NORTH SLOPE [2-4]			NORTH GREENLAND				EAST GREENLAND				SPITSBERGEN [10-15]			SVALIS DOME [16,17]			FINNMARK PLATFORM [18]			KOLGUYEV ISLAND [19]		MID-NORWAY [20]	VOLGA/URALS [21]	
							AMDRUP LAND [5]	SLETTEN [5,6] PEARY LAND			KAP STOSCH, JAMESON LAND AND SCORESBY LAND [7-9]																	
	K/U	Ka	G	U	"G"	G	Ka	K/U	Ka	G	Ka	KW	W	G	K/U	Ka	G	K/U	Ka	G	K/U	Ka	G	U	Ka	G	U	Ka
Aratrisporites tenuispinosus																	X						X					
Proprisporites pocockii			X		X	X						X		X			X			X			X					
Klausipollenites schaubergeri					A	X					X						X											
Tympanicysta stoschiana			X			X						X	X	X			X						X					
Striatoabieites richteri			C		A	A						X		A			X						X					
Ephedripites steevesiae			X			A				X				A			X						X					
Klausipollenites staplinii			X											X		X					X	X	X					
Lunatisporites noviaulensis			A		X	A				X	X	X		A		X	X		X	X		X	X			X		
Protohaploxypinus samoilovichii			C		A	X					X	X		X		X	X		X									
Uvaesporites imperialis			A			A											X						X					
Densoisporites nejburgii														X		X	X			X			X					
Densoisporites playfordii														X			X						X			X		
Maculatasporites spp.			X													X	X			X			X					
Lundbladispora obsoleta														X			X						X			X		
Cycadopites spp.	X		X			A			X	X				X		X	X		X	X			X					
Lueckisporites virkkiae					"A"	"X"					X	X		"X"		X	"X"		X		X	X	"X"					X
Ahrensisporites thorsteinssonii		X							X													X	X		X			
Ahrensiporites multifloridus		X							X										X						X			
Lunatisporites beauchampii		X					X												X									
Piceapollenites nookapii		X					X		X																			
Scutasporites nanuki		X					X		X			X	X						X			X			X			
Striatoabieites borealis		C					X		X																			
Hamiapollenites erebi		X					X		X																X			X
Crinalites sabinensis	X	X																										
Cladaitina kolodae	X	X					X	X							X	X			X		X	X						
Sverdrupollenites agluatus	X	X																										
Sverdrupollenites connudatus	X	X					X																					
Alisporites plicatus	X	X		X			X		X																		X	X
Dyupetalum vesicatum	X	X					X														X			X	X			
Hamiapollenites bullaeformis	X	X					X												X								X	X
Jugasporites compactus	X	X																										
Diatomozonotriletes igluanus	X	X		X											X	X											X	
Corisaccites stradivarii	X	X		X			X																					
Weylandites striatus	C	X		X			X	X			X	A			C	C		X	X					X			X	X
Weylandites cincinnatus	X	X		X			X																					
Vittatina spp.	C	X	"X"				X	C	X		A	A	X	"X"	C	C	"X"	X	X	"X"	X	X	"X"	X			X	X
Leiotriletes ulutus	X	X		X			X									X		X				X		X	X			
Protohaploxypinus perfectus	X	X		X			X	C							X	X			X		X	X		X	X		X	X
Hamiapollenites tractiferinus	X	X																									X	X
Kraeuselisporites sverdrupensis	X	X		X				X	X						X	X		X	X					X	X			
Scutasporites unicus									X																			
Inaperturopollenites nebulosus		X						X			C	A				X	X		X			X	X					
Unellium spp.	X	C					X		X						A	A	X		X		X	X						
Micrhystridium spp.	X	C		X			X		C	C		C		A	A	A	D	X	X	X	X	X	X					
Veryhachium spp.	X	C		X					X	X		C		A	A	A	X		X	X	X	X	X					
Baltisphaeridium spp.								X						A														
Tasmanites spp.								X				A		A			X				X		X					

Fig. 6 - Selected taxa present in circum-polar localities.

K/U = Kungurian? to Ufimian (Roadian); Ka = Kazanian (Wordian and Capitanian); KW = Kazanian to early Wuchiapingian; W = Wuchiapingian; **"G" = Griesbachian with abundant Late Permian reworking; G = Griesbachian**

Monosaccates (1%): *Florinites luberae* Samoilovich
Monosulcates (1%): *Cycadopites* sp.

Trilete spores:
Apiculatisporis melvillensis Utting, *A.* sp.,
Densosporites sp., *Gordonispora obstaculifera* Utting,
Kraeuselisporites sverdrupensis Utting, *Leiotriletes ulutus* Utting, *Lophotriletes parryensis* Utting,
Neoraistrickia sp., *Raistrickia* sp., *Waltzispora* sp.

Some palynomorphs are fairly well preserved in spite of a moderate Thermal Alteration Index of at least TAI 3 suggesting that the organic matter is in the dry gas generation zone (Utting *et al.*, 1989). Although many specimens have mild to severe damage caused by the growth of sulphide pseudomorphs on the exines, sufficient taxa can be identified to tentatively propose a correlation with the *Alisporites plicatus - Jugasporites compactus* Concurrent Range Zone (Kungurian? to Roadian) of the Sverdrup Basin (Figs 3, 4 and 6). No taxa diagnostic of the Wordian *Ahrensisporites thorsteinssonii - Scutasporites nanuki* Concurrent Range Zone were seen, but such an age cannot be completely ruled out in view of the limited amount of material studied and the fact that some specimens are too poorly preserved for identification.

The unconformably overlying Ivishak Formation consists of fine to coarse grained clastic rocks deposited in marine and non-marine environments (Moore *et al.*, 1994). The Kavik Member, abruptly overlying the Echooka Formation, consists of dark-coloured, laminated to thin bedded, silty shale and siltstone, lithologically resembling the Blind Fiord Formation of the Sverdrup Basin. Ivishak rocks represent pro-delta deposits that grade upwards into massive deltaic sandstone and conglomerate of the Ledge Sandstone Member, similar sedimentologically to the Bjorne Formation of the Sverdrup Basin.

In outcrop the Kavik Member has been dated as Griesbachian by ammonoids (*Otoceras* and *Ophiceras*) and pelecypods (*Claraia*) (Detterman *et al.*, 1975; Jones & Speers, 1976), but in the subsurface, rocks of the same member have been dated by palynology as late Permian (Jones & Speers, 1976; Balme, 1980 b and pers. comm. 2000). The palynological assemblages (Fig. $6^{3,4}$) are very different in content from the Roadian? Echooka Formation, indicating a significant hiatus below the Kavik Member. Core samples from one locality (BP 9-11-13) contain abundant *Lueckisporites virrkiae* (up to 25%), but in most boreholes there is a variety and abundance of gymnosperm pollen, and rare trilete spores. Reworked Late Devonian spores are abundant (Jones & Speers, 1976; Balme, 1980 b and pers. comm. 2000).

Kavik taxa include *Striatoabieites richteri* (Klaus) Hart, *Lueckisporites virrkiae* (variants A, B and C of Clarke, 1965; Norms Aa to AC of Visscher, 1971), *Klausipollenites schaubergeri* (Potonié and Klaus) Jansonius and *Protohaploxypinus samoilovichii* (Jansonius) Hart. The assemblage was dated as Upper Permian (Tatarian) largely on the basis of abundant *Lueckisporites virrkiae*, *Klausipollenites schaubergeri* and *Striatoabieites richteri* and comparisons were made with the Upper Permian Zechstein microflora of Europe (Balme, 1980b). However, the fact that rare, but stratigraphically significant taxa, such as broadly taeniate *Lunatisporites* spp. ("*Taeniaesporites*"), *Proprisporites pocockii* Jansonius, *Ephedripites steevesiae*, *Uvaesporites imperialis* and *Tympanicysta stoschiana* (Balme, pers. comm. 2000) occur sporadically in core samples, suggests that another interpretation is possible and that all the Kavik Member assemblages are Griesbachian rather than Late Permian. With the exception of *L. virrkiae* and *K. schaubergeri*, all of the taxa listed above occur in the *Tympanicysta stoschiana - Striatoabieites richteri* Assemblage Zone of the Sverdrup Basin. Dating these subsurface assemblages as Griesbachian would eliminate the age discrepancy between the sub-surface and outcrop localities of the Kavik Member. However, if this interpretation proves correct then it would raise the important question of the age, provenance and significance of the abundant specimens of *Lueckisporites virrkiae*, normally characteristic of Upper Permian Zechstein assemblages of western Europe (*e.g.* Visscher, 1971).

The overlying Ledge Sandstone Member, which is partly a lateral facies equivalent of the Kavik Member, is virtually devoid of macrofauna or microfauna, but in the subsurface, samples from the Ledge Sandstone Member and the upper Kavik Member, contain rich palynomorph assemblages (Fig. 6^{4}) with the following taxa (Balme 1980 b, pers. comm. 2000):

Gymnosperm pollen:
Taeniate disaccates: abundant *Striatoabieites richteri* (Klaus) Hart, *Lunatisporites* spp. (*Taeniaesporites* spp.), *Protohaploxypinus* spp, *Striatopodocarpites* spp., rare *Lueckisporites virrkiae* Potonié and Klaus
Non-taeniate disaccates: *Alisporites* spp.
Monosulcates: common (in some samples)
Ephedripites steevesiae (Jansonius) de Jersey and Hamilton, *Cycadopites* sp.

Trilete spores:
Uvaesporites imperialis (Jansonius) Utting,
Proprisporites pocockii Jansonius

***Incertae sedis*:**
Tympanicysta stoschiana Balme

Reworking:
common Late Devonian; Late Permian

The assemblage is comparable with those in rocks dated as Griesbachian by marine fauna from Kap Stosch, East Greenland (Balme,1980 b), and is similar to those recorded from the Griesbachian *Tympanicysta stoschiana - Striatoabieites richteri* Assemblage Zone. Thus a Griesbachian age is indicated, although a tentative Late Permian to Early Triassic age was proposed by Jones & Speers (1976).

The fact that reworking of Upper Devonian spores was prevalent in northern Alaska throughout deposition of the Ivishak Formation indicates that erosion of the Upper Devonian persisted through the early Griesbachian as the marine transgression took place. This is not surprising as the existence of Upper Devonian rocks in northern Alaska and the Sverdrup Basin is well documented (Ziegler, 1988). If the postulated Griesbachian age for the subsurface Kavik Member is correct, then there is presently no biostratigraphic evidence for Upper Permian rocks in this area. The nearest known Upper Permian locality with "Zechstein" affinities within the study area is East Greenland, where shallow marine carbonate and gypsum of the Karstryggen Formation contain many species (including *L. virrkiae*) in common with the Zechstein beds of Europe (see East Greenland below). However, in view of the Late Permian hiatus commonly present at the basin margin where most of the studied localities occur, it is possible that Upper Permian Zechstein soft evaporitic and argillaceous rock types, with an abundant micro-flora including abundant *L. virrkiae*, may have been deposited in many localities, but later relatively easily eroded during the Griesbachian transgression. Thus abundance of *L. virrkiae* in the lower Kavik Member may correspond to the active erosional phase, the numbers being dramatically reduced in the upper part of the member and in the Ledge Sandstone Member as the advancing transgression buried, or completely removed the Upper Permian rocks.

This problem of reworking versus *in situ* Griesbachian occurrence of species such as *L. virrkiae* was discussed in some detail by Ouyang & Utting (1990) for the Permian/Triassic boundary at Meishan in China. They postulated that *L. virrkiae* may have survived in refuges into the Griesbachian. It is of course possible for *L. virrkiae* to be reworked from the Upper Permian, and also for its stratigraphic range to extend into the Griesbachian. Thus, with such a scenario all rare and sporadic occurrences of *L. virrkiae* in rocks dated by marine fauna as Griesbachian, such as those in the *Protohaploxypinus* Association of East Greenland (Balme,1980 a), may be either reworked or *in situ*.

Overlying the Griesbachian is an assemblage with *Aratrisporites tenuispinosus* Playford; a Smithian (pers. comm. Balme 2000) age is supported by the presence of the ammonoid *Euflemingites* (Silberling, 1971).

NORTH GREENLAND (WANDEL SEA BASIN)

At Ingolf Fiord (lat. 80° 30'N; long. 18° W) in Amdrup Land (Fig. 1) an un-named unit, approximately 65 m thick, consisting of sandstone and siltstone, contains taxa diagnostic of the *Ahrensisporites thorsteinssonii - Scutasporites nanuki* Concurrent Range Zone (personal observation); these include *Lunatisporites beauchampii* Utting, *Scutasporites nanuki* Utting and *Hamiapollenites erebi* Utting (Figs 4 and 6[illegible]).

At Sletten (lat. 82°40' N, long. 22° W) in Peary Land (Fig. 1), the Kim Fjelde Formation consists of well-bedded chert-rich, biogenic limestone, dated by foraminifers and conodonts as Artinskian to Kungurian (Stemmerik *et al.*, 1996). The Sletten palynomorph assemblage is relatively poor but contains *Cladaitina kolodae* Utting (*Maculatasporites* sp.), common *Vittatina* spp., *Weylandites striatus* (Luber) Utting, *Protohaploxypinus perfectus* (Naumova) Samoilovich, *Kraeuselisporites sverdrupensis* Utting, *Inaperturopollenites nebulosus* Balme, and rare spinose acritarchs (Stemmerik *et al.*, 1996; this paper; Fig. 6[illegible]). The assemblage is correlated with the *Alisporites plicatus - Jugasporites compactus* Concurrent Range Zone (Kungurian? to Roadian).

The Kim Fjelde Formation is overlain by the Midnatfjeld Formation, which consists of shale and carbonate in eastern Kim Fjelde and shale and sandstone in northern Kim Fjelde, dated from small foraminifers as late Kungurian to Kazanian (Stemmerik *et al.*, 1996). It contains assemblages that are similar to the *Ahrensisporites thorsteinssonii - Scutasporites nanuki* Concurrent Range Zone of the Sverdrup Basin. Diagnostic taxa include *Ahrensisporites thorsteinssonii* Utting, *A. multifloridus* Utting, *Hamiapollenites erebi, Piceapollenites nookapii* Utting, *Striatoabieites borealis* Utting, *Scutasporites nanuki*, and *Scutasporites unicus* Klaus. Acritarchs of the genus *Micrhystridium* are common, and *Veryhachium* spp. and *Unellium* spp. are present (Stemmerik *et al.*, 1996; this paper; Fig. 6[illegible]). The assemblage contains relatively few pollen and spores, and it is not possible to determine whether the climate was humid or dry. However, the macro-flora from a nearby locality suggests a warm temperate humid climate (Wagner *et al.*, 1982; Wagner *et al.*, in press). This contrasts with the dry, cold climate proposed by Beauchamp (1994) for rocks of similar age in the Sverdrup basin. However, it is possible that the adjacent sea water was cooled by circulation of ocean currents, whereas the land was warm.

A few productive samples investigated in the present study from the fine to coarse grained sandstone of the overlying Parish Bjerg Formation, contain mainly taeniate disaccate pollen and monosulcate pollen. Species include *Ephedripites steevesiae* and *Lunatisporites novi-*

aulensis (Leschik) Foster, suggesting correlation with the Griesbachian *Tympanicysta stoschiana - Striatoabieites richteri* Assemblage Zone (Figs 4 and 6^{5}).

EAST GREENLAND

Assemblages in the Karstryggen Formation (marine carbonate and gypsum) are similar to those of the Zechstein (Utting & Piasecki, 1995). They contain *Klausipollenites schaubergeri*, early forms of *Lueckisporites virrkiae*, *L. tatooensis* Jansonius, *Jugasporites delasaucei* (Potonié and Klaus) Clarke, *J. paradelasaucei* Klaus, *J. lueckoides* Klaus, *Lunatisporites noviaulensis*, *Perisaccus granulosus* (Leschik) Clarke, *Protohaploxypinus samoilovichii*, *Vittatina costabilis* Wilson and *Weylandites striatus* (Fig. 6^{7}). Unlike the Zechstein they contain common and diverse *Vittatina* spp. The abundance of taeniate and polyplicate grains in rocks containing evaporite deposits suggests a hot dry climate for the Karstryggen.

The overlying Wegener Halvø and the Ravnefjeld formations contain the *Vittatina* Assemblage (Fig. 5^{3}) of Balme (1980a) and Piasecki (1983). It is the upper Ravnefjeld Formation where the conodont *Neogondolella rosenkrantzi* has been recorded. This suggests an age from Wordian to early Wuchiapingian according to Kozur & Mostler (1995). Present are *Striatoabieites richteri*, *Lunatisporites noviaulensis*, *Protohaploxypinus samoilovichii*, *Lueckisporites virrkiae*, Scutasporites *nanuki* (= *Scutasporites* sp. cf. *S. unicus*) and *Weylandites* sp. Abundant is *Inaperturopollenites nebulosus* (Fig. $6^{8,9}$). *Scutasporites nanuki* has its earliest occurrence in the *Ahrensisporites thorsteinssonii - Scutasporites nanuki* Concurrent Range Zone, but the assemblage also resembles the *Tympanicysta stoschiana - Striatoabieites richteri* Assemblage Zone in that it contains *Striatoabieites richteri*, *Lunatisporites noviaulensis* and *Protohaploxypinus samoilovichii*. The presence of rare *Lueckisporites virrkiae* indicates some similarities with the Zechstein of western Europe (Visscher, 1971).

In the overlying Oksedal Member (Fig. 5^{4}) of the Schuchert Dal Formation of Jameson Land the ammonoid *Paramexicoceras* occurs approximately 4 m below the lowest fish horizon of the Lower Triassic Wordie Creek Formation (Perch-Nielsen *et al.*, 1972; Nassichuk, 1995; and pers. comm. 2000). In the Kap Stosch region, stratigraphic relationship between ammonoids recorded from the traditional lithological unit, the "Martinia Limestone", and the units Oksedal member and the Ravnefjeld Formation is not clear. All units are dark mudstone and locally there is a potential for stratigraphic errors due to poor exposure and significant faulting (Piasecki pers. comm. 2000). However, it appears that *Paramexicoceras* is associated with the Dzhulfian (Wuchiapingian) *Cyclolobus* (Nassichuk, 1995). In the Oksedal Member (Fig. 5^{4}) there is an abundance of taeniate and non-taeniate disaccates and *Vittatina* is less common than in underlying beds (Utting & Piasecki, 1995). *Tympanicysta stoschiana* and acritarchs are rare. Trilete spores are rare, but become increasingly common in the uppermost few metres of the member (Fig. 6^{7}).

Overlying beds of the Wordie Creek Formation contain *Otoceras woodwardi boreale* and thus are of Griesbachian age. They contain the *Protohaploxypinus* Zone of Balme (1980a) which resembles the *Tympanicysta stoschiana - Striatoabieites richteri* - Assemblage Zone (Fig. 6^{8}). Diagnostic taxa include *Proprisporites pocockii*, *Tympanicysta stoschiana*, *Striatoabieites richteri*, *Ephedripites steevesiae*, *Protohaploxypinus samoilovichii*, and *Densoisporites playfordii* (Balme) Dettmann. *L. virrkiae* occurs rarely. Overlying this zone is the *Taeniaesporites* Association also of Griesbachian age (Balme, 1980a) containing *Lundbladispora obsoleta* Balme, *Cycadopites follicularis* Wilson and Webster, *Ephedripites* spp., *Klausipollenites staplinii*, *Tympanicysta stoschiana*, *Lunatisporites noviaulensis*, *Densoisporites nejburgii* (Schultz) Balme, and *Endosporites* spp. (Fig. 6^{8}).

SPITSBERGEN

Mangerud & Konieczny (1991, 1993) described palynomorph assemblages from a number of formations including the Kapp Starostin Formation (Fig. $6^{10,11}$). The lower to middle parts of the formation consist of shale, sandstone, carbonate with cherty intercalations, and the upper part shale with chert nodules and carbonate intercalations. The formation contains conodonts, brachiopods and corals (Nakamura *et al.*, 1992, and Fedorowkski & Bamber, in press). Nakamura *et al.*, (1992) suggested a Roadian to early Dzhulfian age based on brachiopods, although Fedorowski & Bamber (in press) pointed out that there were no biostratigraphic data to indicate an age younger than early Capitanian. The lower to middle parts of the formation contain the *Kraeuselisporites* assemblage, but the upper part lacks identifiable palynomorphs. The lower part of the *Kraeuselisporites* assemblage was correlated by Mangerud & Konieczny (1991,1993) with the *Alisporites insignis - Triadispora* sp. Assemblage Zone of Utting (1989), which is equivalent to the *Alisporites plicatus - Jugasporites compactus* Concurrent Range Zone of Utting (1994a), and the upper part of the *Kraeuselisporites* assemblage was correlated with the

Taeniaesporites sp. Assemblage Zone of Utting (1989), which is equivalent to the *Ahrensisporites thorsteinssonii - Scutasporites nanuki* Concurrent Range Zone of Utting (1994a). Significant is the presence of *Lueckisporites virrkiae* (Fig. 6) in the upper part of the *Kraeuselisporites* assemblage zone suggesting a Kazanian or younger age based on the Volga/Urals stratotype area (Utting *et al.*, 1997).

The overlying Deltadalen Member (greenish grey silty shale and minor sandstone) of the Vardebukta Formation contains the *Densoisporites nejburgii* Zone of Griesbachian age. Significant taxa include *Proprisporites pocockii. Striatoabieites richteri Ephedripites steevesiae, Lunatisporites noviaulensis, Protohaploxypinus samoilovichii, Uvaesporites imperialis, Densoisporites nejburgii. Maculatasporites* sp. and *Tympanicysta stoschiana* (Hochuli *et al.*, 1989; Mørk *et al.*, 1990, 1992, 1999). This assemblage (Fig. 6^{12-15}) closely resembles the *Tympanicysta stoschiana - Striatoabieites richteri* Assemblage Zone of the Sverdrup Basin, the top of which has yet to be defined. However, in Spitsbergen the equivalent zone, Assemblage P (?Early Griesbachian), is defined by the range and common occurrence of *T. stoschiana* (= *C. chalasta*). In other respects it is difficult to differentiate from Assemblage O (Dienerian) (Hochuli *et al.*, 1989; Mørk *et al.*, 1992).

SVALIS DOME AND FINNMARK PLATFORM

Mangerud (1994) and Nilsson *et al.* (1996) correlated subsurface rock units of the Svalis Dome and Finnmark with those of the Svalbard Archipelago. In the lower Tempelfjorden Group of Svalis Dome they recognised the *Kraeuselisporites* Assemblage and in the upper part of the group the *Scutasporites* sp. cf. *S. unicus - Lunatisporites* spp. Assemblage Zone (Fig. 6^{16}). In the Havert Formation, which consists of laminated and slightly bioturbated greenish grey shale, they recorded the *Pechorosporites* assemblage, which on the basis of a high percentage of *Aratrisporites* spp. pollen appears to be slightly younger than the *Tympanicysta stoschiana - Striatoabieites richteri* Assemblage Zone (Fig. 6^{17}). A late Griesbachian age is indicated from the marine fauna (Vigran *et al.*, 1998).

In Finnmark Mangerud (1994) recognised three zones (Fig. 6^{18}) and correlated them with those established for the Sverdrup Basin (Utting, 1994a). These were:

i) *Dyupetalum* sp. (*Dyupetulam vesicatum* Utting, 1994 a) - *Hamiapollenites bullaeformis* Assemblage Zone (Kungurian? - Ufimian), equivalent to the *Alisporites plicatus - Jugasporites compactus* Concurrent Range Zone (Utting, 1994 a).

ii) *Scutasporites* sp. (*Scutasporites nanuki* Utting 1994 a) - *Lunatisporites* spp. Assemblage Zone (Kazanian - Tatarian?) equivalent to the *Ahrensisporites thorsteinssonii - Scutasporites nanuki* Concurrent Range Zone (Utting, 1994 a).

iii) *Lundbladispora obsoleta - Tympanicysta stoschiana* Assemblage Zone (early Griesbachian) equivalent to the *Tympanicysta stoschiana - Striatoabieites richteri* Assemblage Zone.

The *Dyupetalum* sp. - *Hamiapollenites bullaeformis* Assemblage Zone was defined by the earliest occurrence of *Dyupetalum* sp. (= *D. vesicatum* of Utting, 1994 a), and the latest occurrence of *Hamiapollenites bullaeformis* (Samoilovich) Jansonius. In the Sverdrup Basin *D. vesicatum* has its earliest occurrence in the *Alisporites plicatus - Jugasporites compactus* Concurrent Range Zone, but *H. bullaeformis* extends into the *Ahrensisporites thorsteinssonii - Scutasporites nanuki* Concurrent Range Zone (Fig. 3). The base of the *Scutasporites* sp. cf. *S. unicus - Lunatisporites* sp. Assemblage Zone was defined at the earliest occurrence of *Scutasporites* sp. cf. *S. unicus* (= *Scutasporites nanuki*) of Wordian age, and the *Lundbladispora obsoleta - Tympanicysta stoschiana* Assemblage Zone is defined by the presence of the *Tympanicysta stoschiana, Striatoabieites richteri, Proprisporites pocockii*, and the *Uvaesporites imperialis* morphon. There is a similar abundance of *Uvaesporites imperialis* in the lower part of the Havert Formation to that found in the basal Blind Fiord assemblages. Interesting is the presence in the early Griesbachian of poorly preserved specimens of *Vittatina* and well preserved specimens of *Lueckisporites virrkiae*. Mangerud (1994) considered the former to be reworked but the latter, which are rare to common, to be *in situ*. As discussed above in the section concerning Alaska, it is difficult to resolve this problem of *in situ* versus reworked taxa. In view of the hiatus present between the Wordian and Griesbachian in Finnmark, *L. virrkiae* could have been derived from post-Wordian rocks that have susequently been eroded, on the other hand its rare, but consistent presence in circum-polar Griesbachian rocks could indicate that the parent plant was not extinct.

KOLGUYEV ISLAND

Ufimian and Kazanian assemblages from Kolguyev Island and the Kungurian? to Roadian and Wordian of the Sverdrup Basin have many stratigraphically diagnostic taxa in common and correlation of the spore zones was proposed by Grigoriev & Utting (1998). For example the Kazanian (Wordian) Assemblage II of Kolguyev includes *Ahrensisporites thorsteinssonii, A. multifloridus, Scutasporites nanuki*, and *Hamiapollenites* *erebi* (Fig. 6^{19}). Nevertheless there are differences: *Lueckisporites* sp. (a small representative of the *L. virrkiae* morphon) is present on Kolguyev, but absent in the Sverdrup Basin. Also present on Kolguyev, but absent from the Sverdrup basin in rocks of Kungurian? to Wordian age, are taxa such as *Limitisporites monstruosus* (Luber and Waltz) Hart and *Crucisaccites ornatus* (Samoilovich) Dibner. In addition Kolguyev assemblages differ in that they are dominated by pteridophyte spores and this suggests that the climate may well have been more humid than that of the Sverdrup Basin. Griesbachian rocks are probably absent from the island (Hochuli *et al.*, 1989; Mørk *et al.*, 1992).

MID-NORWAY

In this area data concerning the Kungurian? to Wordian microfloras are sparse (Fig. 6^{20}), but more details are available concerning the overlying late Griesbachian to Smithian rocks (Vigran & Mangerud, 1991). The latter are dominated by trilete cavate spores including *Uvaesporites imperialis*. The fact that *Aratrisporites* spp. were common was taken to indicate an age younger than early Griesbachian.

VOLGA/URALS REGION

When comparisons are made between the Roadian and Wordian assemblages of the Sverdrup Basin with those from the Ufimian and Kazanian stratotype areas of the Volga-Urals region, Russia, it is evident that there are major differences in composition (Utting *et al.*, 1997; and Fig. 6^{21}). For example the Sverdrup basin contains abundant trilete spores in the Roadian and Wordian, but although these are common in the type Ufimian, they are rare in the Kazanian. Many taxa found in the Wordian of the Canadian Arctic are absent from the Kazanian (Utting *et al.*, 1997). For example taxa that are present in the Wordian, but lacking in the Kazanian of Russia, include stratigraphically diagnostic taxa such as *Ahrensisporites multifloridus*, *A. thorsteinssonii*, *Lunatisporites beauchampii*, *Piceapollenites nookapii* Utting, *Scutasporites nanuki*, *Striatoabieites borealis* Utting, *Diatomozonotriletes hypenetes* Utting, *Lunatisporites arluki* Utting, *Grandispora jansonii* Utting and *Inaperturopollenites nebulosus*. The only taxon present in both the Wordian and Kazanian assemblages is *Hamiapollenites erebi*. Taxa restricted to the Ufimian and Kazanian are *Hamiapollenites tractiferinus*, *Limitisporites monstruosus*, *Crucisaccites ornatus*, *Cordaitina subrotata* var. *isopolaris* (Varyukhina) Varyukhina, *Cordaitina uralensis* (Luber) Samoilovich, *Kraeuselisporites papulatus* Virbitskas and, *Entylissa caperata* (Luber) Varyukhina. Those restricted to the Kazanian, and absent from the Wordian, are *Lueckisporites virrkiae* and *Discernisporites* sp.

If, as suggested by the marine faunas the Wordian and Kazanian are correlative (see summary by Fedorowski & Bamber, in press), then the fundamental differences in the palynomorph assemblages between the Volga/Urals area, and the Sverdrup Basin and other circum-polar areas may have been caused by a variety of factors independent of time including paleoclimate, facies, latitude, topography, and relative position on Pangea. For example, the climate was probably hot and arid in the Volga/Urals region from the Ufimian to the Tatarian (Utting *et al.*, 1997), whereas in the Sverdrup Basin it was humid and cool in the Kungurian? to Roadian, and cool and dry in the Wordian (Beauchamp, 1994; Utting, 1994a).

CONCLUSIONS

1. Assemblages of Kungurian? to Wordian, and Griesbachian age are similar throughout the circum-polar area studied.
2. With the exception of East Greenland, there are no palynological data available from the Wuchiapingian and Lopingian stages.
3. Middle Permian assemblages on Kolguyev Island have many features in common with other circum-polar localities, but there are also some taxa in common with the Volga/Urals region.
4. The circum-polar assemblages of Kungurian? to Roadian and Wordian age differ markedly from the Ufimian and Kazanian assemblages of the Russian stratotype areas in the Volga /Urals region, probably reflecting differences in a number of factors including climate, facies, latitude, elevation and location in Pangea.

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FORMATION AND EVOLUTION OF THE PERMIAN STRATA OF THE EASTERN TIANSHAN MOUNTAIN IN XINJIANG, CHINA

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Key words – Xinjiang; eastern Tianshan Mountain; Permian; molasse facies; homologous flysch facies; uniform intracontinental lake basin.

Abstract – Owing to the inhomogeneity of orogeny with the compression force chiefly from the southern flank, the uplift folding (orogeny) formed since the Late Carboniferous at the southern and northern margins of the eastern Tianshan Mountain in Xinjiang, China is asymmetrical. In the early to Middle Permian, a set of piedmont molasse facies sedimentary associations were developed at the southern margin of the eastern Tianshan Mountain, near the core of the orogeny; at the northern margin there existed a set of assemblages of homologous flysch facies formed in a foreland basin. By the end of the Middle Permian, the difference between the basement topographies of the southern and northern margins disappeared gradually, and the eastern Tianshan Mountain and its periphery area thus became a broad, uniform, intracontinental lake basin. The depositionally continuous terrestrial sediments of the Permian to Triassic boundary are found broadly in these areas.

Parole chiave – Xinjiang; Tianshan orientale; Permiano; facies molassica; facies flyshoidi omologhe; uniforme bacino lacustre intracontinentale.

Riassunto – A causa della disomogeneità dell'orogenesi derivante dalla forza di compressione esercitata principalmente dal fianco meridionale, il sollevamento per pieghe determinatosi a partire dal Carbonifero superiore sui margini meridionale e settentrionale del Tianshan orientale in Xinjiang, Cina, è asimmetrico. Durante il Permiano inferiore e medio, un gruppo di associazioni sedimentarie caratterizzate da facies molassiche pedemontane si sviluppò lungo il margine meridionale del Tianshan orientale, vicino al nucleo dell'orogenesi; sul margine settentrionale esisteva un gruppo di associazioni di facies omologhe di flysch formatesi in un bacino di avampaese. Entro la fine del Permiano medio, le differenze topografiche relative al basamento dei margini meridionale e settentrionale scomparvero gradualmente, e il Tianshan orientale e la sua periferia divennero pertanto un esteso, uniforme, bacino lacustre intracontinentale. I sedimenti terrestri deposizionalmente continui al limite P/T sono ampiamente presenti in queste aree.

INTRODUCTION

Xinjiang Uygur Autonomous Region (1.6 million km^2 in area) is the largest provincial region in China. The Tianshan mountain range lies across the central part of Xinjiang. Habitually, taking the highway from Urumqi City, the provincial capital of Xinjiang, to Toksun county as a boundary, to the west of this boundary is called the western Tianshan Mountain, and to the east is the eastern Tianshan Mountain which chiefly comprises Mount Bogda and Mount Karlik. On the southern margin of the eastern Tianshan Mountain is the Turpan-Hami Basin and on the northern margin is the southeastern part of the Junggar Basin.

Permian rocks are widespread throughout Xinjiang, especially in the north of Xinjiang where they are best developed. The sedimentation types are varied and fossils are abundant in the Early, Middle and Late Permian strata of the eastern Tianshan Mountain studied in this paper. There are many complete and continuous stratigraphic sections (Fig. 1) in this region, which has gradually become the "hot spot" for studies of the continental Permian strata and the continental Permian- Triassic boundary beds in recent years in China (Cheng Zhengwu *et al.*, 1997; Zhou Tongshun *et al.*, 1997; Sheng Jinzhang & Jin Yugan, 1994).

TECTONIC SETTING OF THE FORMATION OF THE EARLY AND MIDDLE PERMIAN STRATA OF EASTERN TIANSHAN MOUNTAIN

The middle and late Hercynian Orogeny, and the two plate suture belts which between them pinned the eastern Tianshan Mountain, were the chiefly controlling factors affecting the formation, development, and distribution of the

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Lower and Middle Permian Series. The Karamaili suture belt on the northeastern side of eastern Tianshan Mountain was the convergent margin between the Siberian plate and the Kazakhstan - Junggar plate, and finally closed in the Middle-Late Devonian (Li Jinyi *et al.*, 1989, 1990), but did not result in strong compressive folding and metamorphism. It resulted only in formation and uplift of transitional crust (Xiao Xuchang *et al.*, 1992) over a vast area of the southeastern part of the Junggar Basin and the continuous shrink of the residual Carboniferous sea basin, which changed to give near-shore limnetic facies sediments during the Early Permian. Another suture belf, the Erenhabirga-Kangguer suture belt on the southwestern side of eastern Tianshan Mountain, was the convergent junction of the Tarim plate and the Kazakhstan-Junggar plate. It produced sharp stratigraphic folds and volcanic activity during the Late Carboniferous, with typical piedmont molasse facies at the southern margin of eastern Tianshan Mountain, under the influence of strong and sustained compression from the south during the Early and Middle Permian. At the northern margin of eastern Tianshan Mountain, a paralic transitional facies developed consisting of very thick coarse to fine clastic sediments of foreland basin-type.

THE FORMATION AND GENERAL FEATURES OF THE EARLY AND MIDDLE PERMIAN MOLASSE FACIES AT THE SOUTHERN MARGIN OF EASTERN TIANSHAN MOUNTAIN

During uppermost Late Carboniferous times, with the loss of balance of the originally roughly uniform tectonic-sedimentary framework of the Bogda-Karlik volcanic arc (Li Jiliang, 1989), the nuclear zone of the orogenic belt close by the southern margin of eastern Tianshan Mountain rapidly became folded and uplifted. Seawater withdrew rapidly towards the east and northeast, and the Carboniferous volcanics and pyroclastic rocks as well as carbonate rocks higher than the erosion surface were sharply denuded. In assocation with some Early Permian volcanic eruptive rocks, this debris was rapidly transported from the piedmont belt to the nearshore depression and deposited there along a belt from Ewirgol through Taoxigou and Yiwanquan to Kulai. This sequence of red molasse sediment is characterised by the following:

1. It has a narrow ribbon-shaped distribution in the southern margin area of eastern Tianshan Mountain, about 600 km long and only a few tens of km in width. The parent rocks of this suite of coarse clastic sediments are composed chiefly of the underlying disintegrated Late Carboniferous volcanics and pyroclastic rocks, as well as minor carbonate rocks containing Late Carboniferous fossils. This is a suite of typically continental piedmont molasse (Liao Zhuoting *et al.*, 1999), as a whole dominated by river fan and alluvial fan deposits, with only occasional limnic sediments in the upper part.
2. This suite of continental molasse sediments displays the normal cyclic sequence, coarse below and fine above, which may be looked upon in general as a complete magnacyclothem The interbeds of volcanics only occur in the middle and lower part, indicating the intensity of the Early and Middle Permian tectonic activity and the sedimentation rate changing from strong to weak.

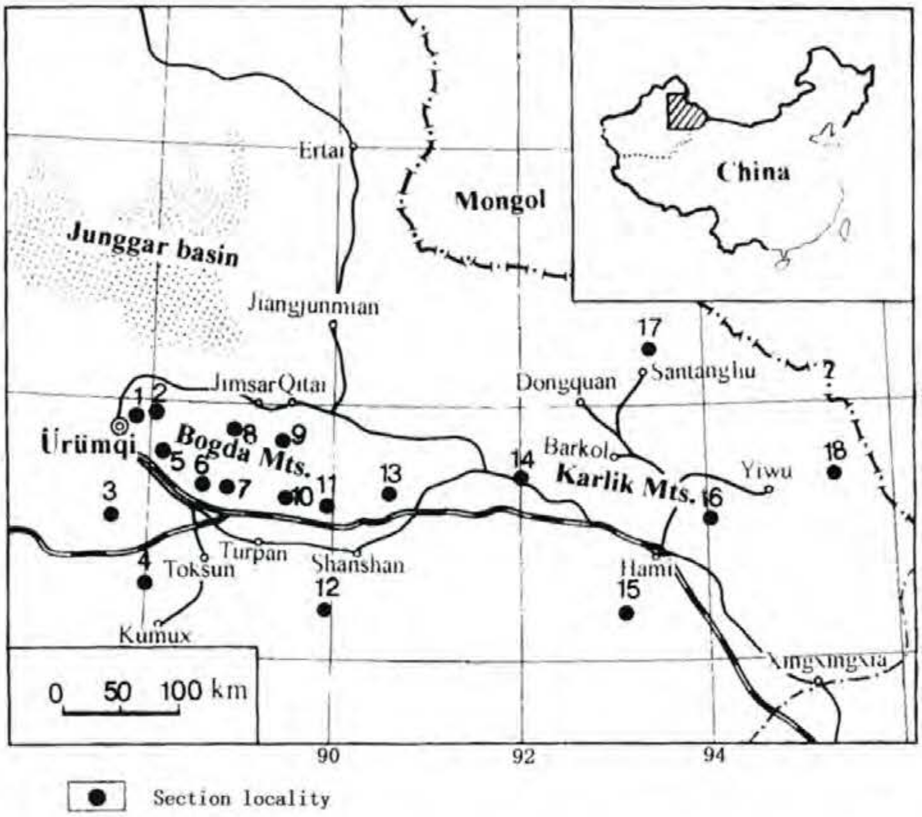

Fig. 1 – Map showing the section localities of Permian strata in eastern Tianshan Mountain and adjacent regions, Xinjiang.

1. Jingjingzigou; 2. Lucaogou; 3. Ewirgol; 4. Mishigou; 5. Guodikeng; 6. Taoxigou; 7. Taotonggou; 8. Dalongkoul; 9. Quanzijie; 10. meiyaogou; 11. Ertanggou; 12. Dikanr; 13. Zhaobishan; 14. Yiwanquan; 15. Dananhu; 16. Kulai; 17. Santanghu; 18. Naomaohu.

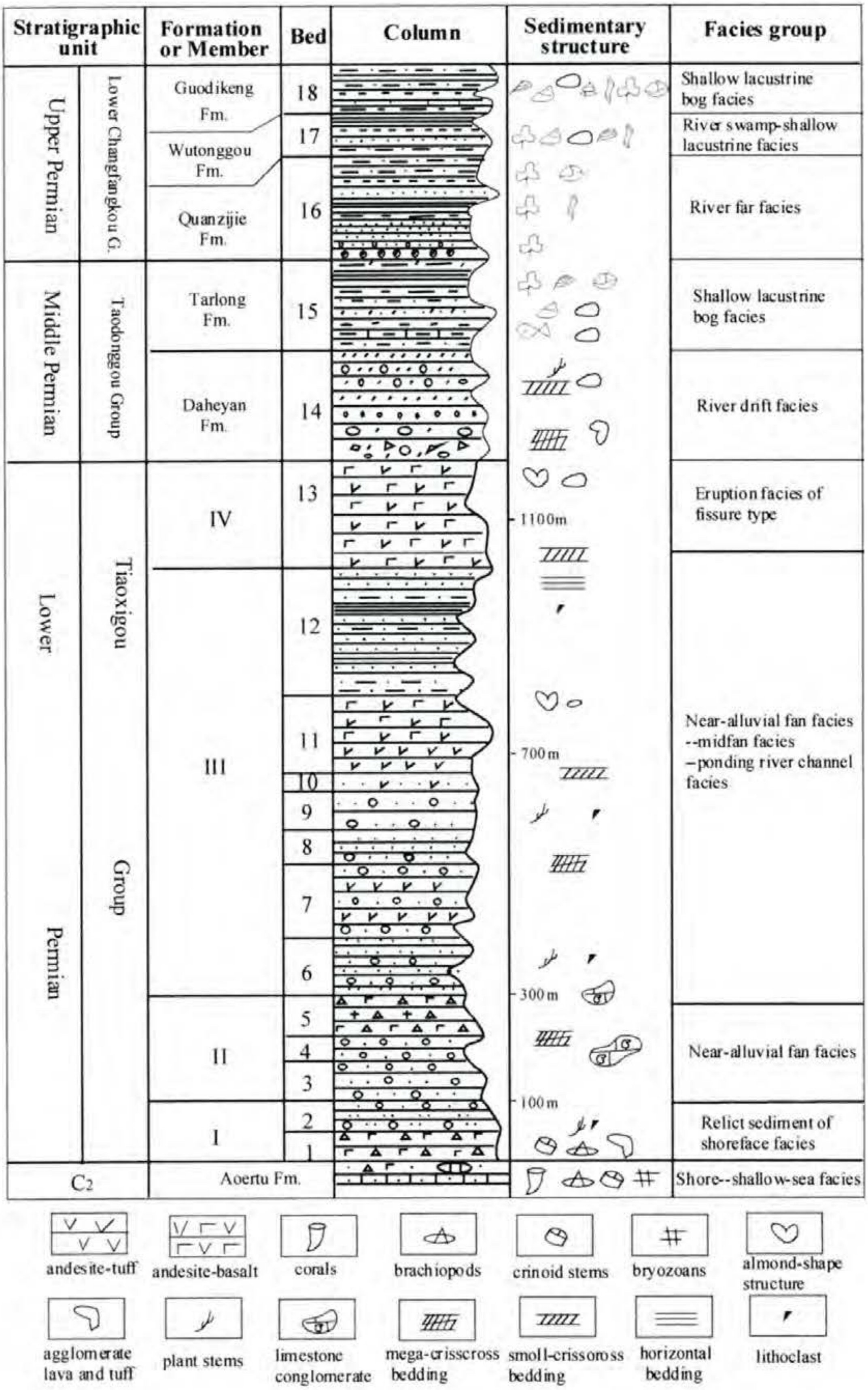

Fig. 2 – Columnar section of the Permian strata on the southern margin of the eastern Tianshan Mountain, Xinjiang, China.

3. There are neither flysch facies sediments below this suite of molasse, nor transitional assemblages intermediate between these two types of sedimentary associations (Li Jiliang, 1978). This occurrence suggests that an abrupt change in the change of the volcanic arc facies from a marginal island arc sedimentary environment into a continental sedimentary environment marks the occurrence of the "bald head" in the orogenic belt of eastern Tianshan

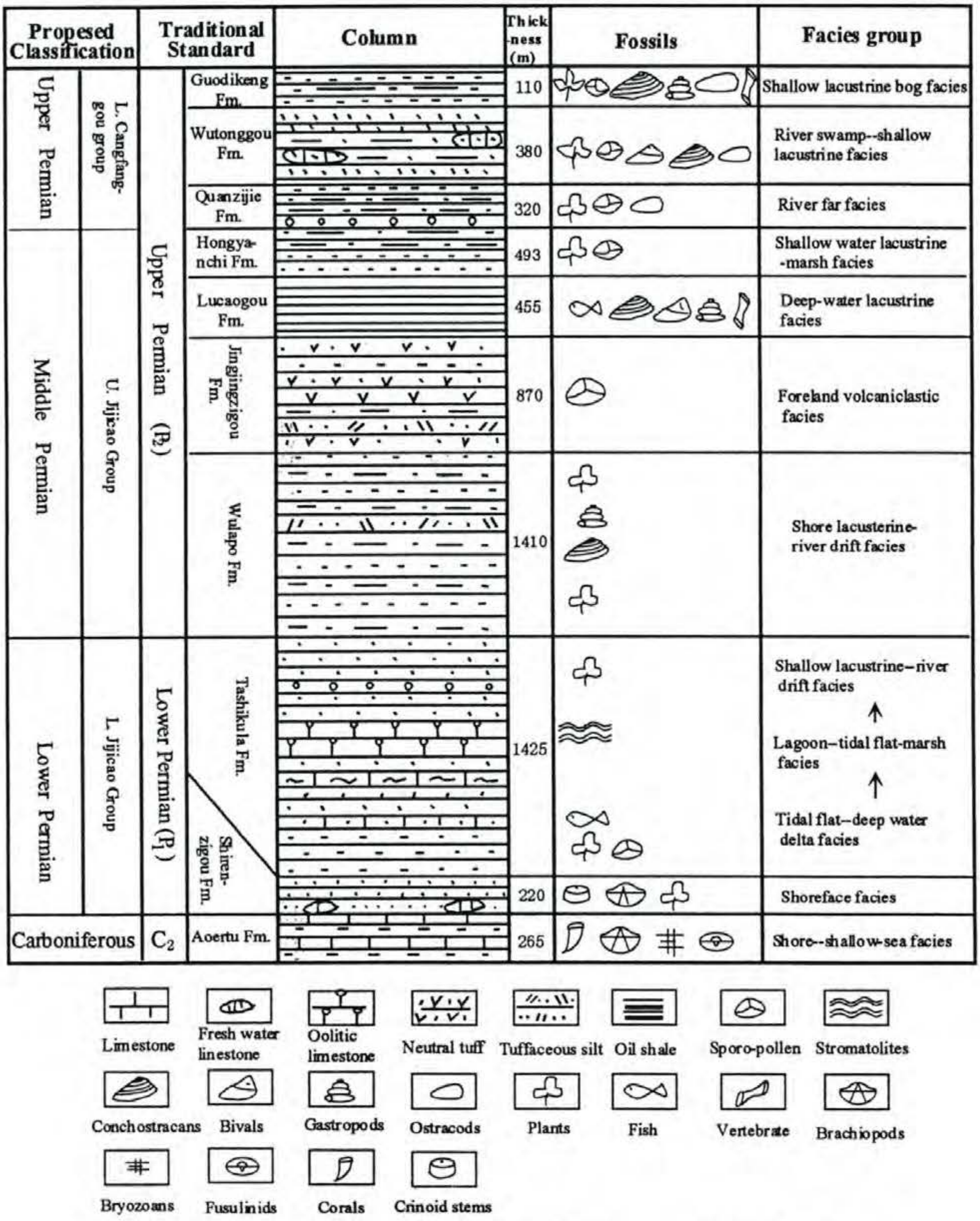

Fig. 3 – Columnar section of the Permian strata on the northern margin of the eastern Tianshan Mountain, Xinjiang, China.

Mountain, and the end of the Hercynian Orogeny. Evidently, the beginning and end orogenic movement is slightly earlier at the southern margin of the eastern Tianshan Mountain than at the northern margin (Fig. 2).

THE FORMATION AND MAIN FEATURES OF THE EARLY AND MIDDLE PERMIAN FORELAND BASIN FACIES AT THE NORTHERN MARGIN OF EASTERN TIANSHAN MOUNTAIN.

Owing to the inhomogeneity of the orogenesis and the influence of compression from the south, the northern margin of eastern Tianshan mountain was resisted by the rigid transitional-type crust at the southeastern part of the Junggar Basin, giving rise to a sharply downwarping and eastward- opening foreland basin. Although the seawater in this region began to withdraw eastward like that in the southern margin during the very beginning of the Early Permian, the rate of its withdrawal to the east was not as rapid as at the southern margin and the period of its complete withdrawal was also not as short, exhibiting a slow and continuous process. Therefore a flysch facies suite consisting chiefly of sandy and argillaceous sediments, in the basal part of which are intercalated slumps composed of shallow-water marine carbonate rocks (Liao Zhuoting *et al.*, 1987). Upwards there are transitional sandstone beds containing large numbers of plant fossils, ooid-bearing dolomite, and interbeds of stromatolites, and upwards again there are medium-and fine-grained clastic rooks containing coal streaks and thin coal seams. The top part is similar to the Middle Permian of the southern margin, in the dominance of limnetic oil shales, dolomite, argillaceous limestone and mudstone. In this Middle and Lower Permian Series, the sediment was not found to be derived from the underlying, reworked, Upper Carboniferous fossil-bearing carbonate rocks like those in the southern margin, and the volcanics and interbedded volcanic sedimentary rocks are not so well-developed as those in the southern margin.

The nature of the above-mentioned transitional sedimentary assemblage indicates that the volcanic arc of eastern Tianshan Mountain changed from a strongly subsiding phase to the late stage of orogenic uplift, as the regional tectono-sedimentary environment at the northern margin experienced a continuously changing process from marine through to transitional and continental fasies during the Early and Middle Permian. This suite of foreland basin transitional sediments is quite different from the contemporary piedmont molasse facies of sedimentary association at the southern margin, in terms of its genesis, lithologies, sedimentation type and spatial extent (Fig. 3).

FORMATION OF THE LATE PERMIAN UNIFORM INTERIOR BASIN FACIES IN EASTERN TIANSHAN MOUNTAIN

Above paragraph, we have expounded the changes in the Early and Middle Permian tectono-sedimentary environment, and the features of stratigraphic development at the southern and northern margins. As a whole, during the Early Permian, the two regions were distinctly different, until the Middle Permian when the differences between them reduced, and the sedimentary succession and texture gradually came to be identical, especially in the uppermost horizons where the extrusive volcanics and volcaniclastic rocks that occur are restricted to the Upper Jijicao Group, indicating that the regional volcanic activity ended in the Middle Permian (Liao Zhuoting & Wu Guogan, 1998). The overlying Cangfanggou Group is a suite of time-transitional (from Late Permian to Early Triassic), depositionally continuous, widespread continental clastic rocks. The regional unconformity between them and the underlying Upper Jijicao Group represents the end of the Hercynian Orogeny and the beginning of the non-orogenic, within-plate developmental stage. From then on, the difference between the southern and northern margins of the eastern Tianshan Mountain orogenic belt, in structure, landform, relief, biological assemblage, and entire sedimentary environmental differences resulting from the originally inhomogeneous orogeny, began to diappear, and a vast inland lake basin occupied the whole eastern Tianshan Mountain (Zhou Tongshun *et al.*, 1997). This new and uniform tectonic paleogeographical framework lasted from the Late Permian to the Early Triassic. Thus, judging from the history of tectonic development and the sedimentary features, it is reasonable to divide the eastern Tianshan Permian into three series: the Lower, Middle and Upper Series.

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EARLY PERMIAN TETRAPOD TRACKS - PRESERVATION, TAXONOMY, AND EURAMERICAN DISTRIBUTION

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Key words – Tetrapod footprints; Lower Permian; red beds; taxonomy; stratigraphy.

Abstract – After the first comparative studies, most of the material known from the European Permian red beds corresponds to the track fauna of the Abo Formation of Wolfcampian age in North America. All differing stratigraphic interpretations of European track sites in red bed facies come under question. The spectrum of ichnotaxa in red beds of Lower Permian age is restricted to *Batrachichnus*, *Limnopus*, *Amphisauropus*, *Hyloidichnus*, *Ichniotherium*, *Dromopus* (*D. lacertoides* = *D. agilis* = *D. didactylus*), *Tambachichnium*, *Dimetropus* and *Gilmoreichnus*. These ichnotaxa can be correlated with temnospondyls, seymouriamorphs, diadectids, araeoscelids, and pelycosaurs, taxa characteristic of the Lower Permian. The vast majority of occurrences of tetrapod tracks in red bed facies of the Permian show no significant differences when examined using the taxonomic criteria accepted by the authors. The ichnofauna of the Abo, and related formations of Wolfcampian age, are consequently, a potential standard for both ichnofaunal and stratigraphic purposes. The distribution in time of most Euramerican Permian red beds with tetrapod tracks, inclusive of the so-called Upper Rotliegend, is confined to the lowermost Permian, correlating to the Asselian, Sakmarian, and Artinskian.

Parole chiave – Impronte di tetrapodi; Permiano inferiore; *red beds*; tassonomia; stratigrafia.

Riassunto – Dopo i primi studi comparativi, la maggior parte del materiale conosciuto nei *red beds* del Permiano europeo corrisponde alla fauna ad impronte della Formazione di Abo del Wolfcampiano nord-americano. Tutte le varie interpretazioni stratigrafiche di siti di impronte europee in facies di *red beds* sono poste in discussione. Lo spettro di icnotaxa nei *red beds* del Permiano inferiore è ristretto a *Batrachichnus*, *Limnopus*, *Amphisauropus*, *Hyloidichnus*, *Ichniotherium*, *Dromopus* (*D. lacertoides* = *D. agilis* = *D. didactylus*), *Tambachichnium*, *Dimetropus* and *Gilmoreichnus*. Questi icnotaxa possono essere correlati con temnospondili, seymuriamorfi, diadectidi, areoscelidi e pelicosauri, taxa caratteristici del Permiano inferiore. L'ampia maggioranza di eventi di tracce di tetrapodi nei *red beds* permiani non mostra tra esse alcuna significativa differenza allorché sono prese in esame usando i criteri tassonomici accettati dagli autori. L'icnofauna dell'Abo, e le connesse formazioni di età wolfcampiana, sono conseguentemente un potenziale standard per scopi icnofaunistici e stratigrafici. La distribuzione cronologica della maggior parte di *red beds* permiani euroamericani con tracce di tetrapodi, comprensive del così chiamato Rotliegende superiore, è confinata al Permiano più basso, correlabile all'Asseliano, Sakmariano e Artinskiano.

INTRODUCTION

About 140 ichnogenera related to Permian tetrapods have hitherto been named in the literature. This high number of taxa could be understood as evidence of 1) high faunal diversity , and 2) a possible basis for refined stratigraphical subdivision of the track-bearing formations. However, most such results are derived from regional studies and relatively few local samples. The trigger for a critical revision was the discovery by J. P. MacDonald of extensive tracksites in the "Abo Tongue of the Hueco Formation" (Robledo Mountains Formation of Hueco Group) of southern New Mexico in the late 1980s. From a large sample size at a Lower Permian megatrack-site, many preservational variations along trackways can be demonstrated. Isolated segments of these trackways were formerly often understood as different ichnotaxa worthy of species- and genus-level recognition. The traditional interpretation of a high diversity in tetrapod ichnofauna is opposed by a low-diversity interpretation, both documented in the volume edited by Lucas & Heckert (1995). The characteristic tetrapod ichnogenera of the low-diversity interpretation of the Lower Permian Wolfcampian red beds in North America are *Batrachichnus*, *Limnopus*, *Hylodichnus*, *Dromopus*, *Gilmoreichnus*, and *Dimetropus* (Haubold *et al.*, 1995

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a). In the continuation of this study, an attempt was made at a reorganisation of the taxonomy, classification and stratigraphical value of the tetrapod tracks of the Permian (Haubold, 1996). As one result, the cosmopolitan character of tetrapod ichnofaunas of Early Permian age became evident (Hunt & Lucas, 1998). These results and analyses were continued through 1998 and 1999 by further fieldwork in North America and Europe, with additional collections at track sites of red bed facies.

TRACKBEARING FORMATIONS OF WOLFCAMPIAN AGE

The collections from the Abo and Sangre de Cristo Formations of central and northern New Mexico were extended in 1999, in addition to the occurrences in coastal plain environments of the Robledo Mountains Formation of the Hueco Group (Lucas *et al*., 1998) in southern New Mexico (Fig. 1). Track sites with large number of samples have been excavated and provide most of the obligate ichnotaxa in the broad scale of muddy to sandy red-bed facies. After comparative studies of Permian tetrapod ichnofaunas from Europe, most of the trackbearing Permian formations of red-bed facies correspond in age to those of the Hueco, Abo, and Sangre de Cristo Formations of Wolfcampian age in New Mexico. Note that the Wolfcampian Stage-Age is a provincial dating term used in North America to refer to much of Early Permian time; it is approximately equivalent to the Asselian, Sakhmarian and part of the Artinskian using the standard global chronostratigraphic scale.

Over the last 100 years, Permian ichnofaunas and their geological occurrences have been described by several authors. However, the determinations and many of the names listed by some authors are relatively incompatible taxonomically with each other. For a principal revision, all known track-bearing formations and the majority of specimens have been investigated and re-examined, particularly during the last decade. Hitherto published results of reinvestigations, revisions and new collections, concern tracks from the Hermit Shale (Haubold *et al*., 1995 a), the Standenbühl/Nierstein Formation (Haubold & Stapf, 1998) and the Tambach Formation (Haubold, 1998).

In summary, the following trackbearing units correlate to the Wolfcampian tetrapod track faunas in the Hueco (Robledo Mountains), Abo and Sangre de Cristo Formations in New Mexico:

- USA – Arizona, and Colorado: Hermit Shale, and Cutler Formation
- Northern Italy – Collio Formation of the Southern Alps
- Southern France – Permian sequence of the Lodève Basin up to the Rabejac Formation; Permian sequences of the Luc, Bas Argens and Estérel Basins up to the Mitan and Gonfaron Formations; Permian sequence of the St. Affrique Basin up to the pelites of St. Pierre.
- Germany – Rotliegend sequence of the Saar-Nahe Basin up to the Nierstein/Standenbühl Formation of the Wadern Group; Hornburg Formation of the eastern Harz Foreland Basin; Rot-

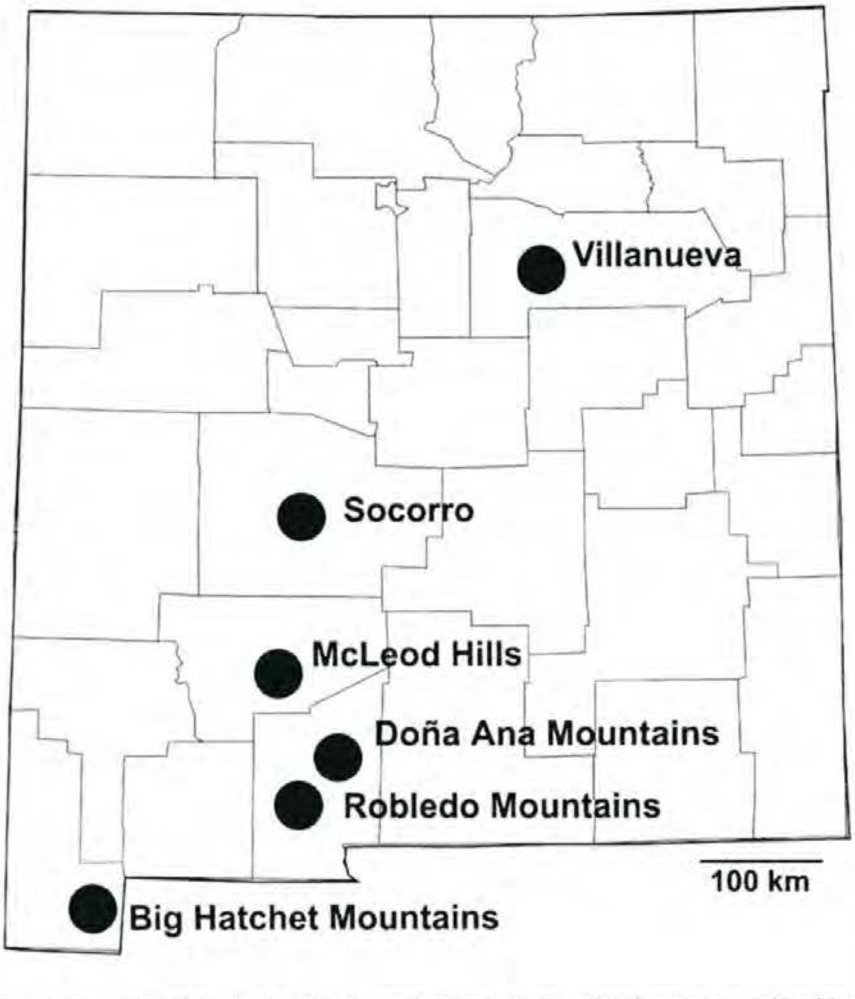

Fig. 1 – Geographical distribution of the Lower Permian track-sites of Wolfcampian age in New Mexico. The occurrences belong to, from south to north, the Robledo Mountain, the Abo and Sangre de Cristo formations.

liegend sequence of the Thüringer Wald up to the Tambach Formation.

Other track sites of Permian red beds with the same ichnofaunal elements are known in southern Poland, nothern Bohemia (Czechien), England, northern Spain, Nova Scotia, Argentina, and southern Russia.

Of separate age are the tetrapod ichnofaunas of the Val Gardena Sandstone in northern Italy, the Salagou Formation (site La Lieude) of the Lodève Basin in southern France, and the Choza Formation in Texas.

Different in facies and somewhat different in age are the principally aeolian track occurrences, the so-called *Chelichnus* ichnofacies (*Laoporus* ichnofacies of Lockley *et al.*, 1994) of the Supai Formation, Coconino Sandstone, DeChelly Sandstone, Corncockle and Locharbriggs Sandstones, Hopeman Sandstone, and Cornberger Sandstein (Haubold *et al.*, 1995 b; Lockley *et al.*, 1995; McKeever & Haubold, 1996; Morales & Haubold, 1995).

As a result, the Wolfcampian track fauna can be characterised by five to six basic track types, of about nine ichnogenera. This morphological subdivision is in agreement with the range of presumed perpetrators of the tracks, the osteologically-recorded Lower Permian temnospondyls, seymouriamorphs, diadectids, araeoscelids, captorhinomorphs, and pelycosaurs (Fig. 2). As currently understood, the record of tracks of captorhinomorphs and pelycosaurs is comparatively more diverse. Tracks of temnospondyls, araeoscelids, and seymouriamorphs are most frequent, whereas the record of diadectid tracks – *Ichniotherium* – appears restricted.

FORMER ATTEMPTS AT PERMIAN TETRAPOD ICHNOSTRATIGRAPHY

All former stratigraphic subdivisions using tetrapod tracks come into question as a result of the new data. Indeed, not one of the taxa used for the tetrapod track zonation by Boy & Fichter (1988) and Kozur (1989), such as *Saurichnites*, *Telichnus*, *Varanopus*, *Hardakichnium*, *Palmichnus*, *Anhomoiichnium* and *Actibates*, can be accepted as valid. In other words, the age of the formations in red bed (Rotliegend) facies – as reflected in the zonations proposed by these authors, as well as the associations I to III of Gand (1987), Gand & Haubold (1988), and the so-called Saxonian distinguished by tetrapod footprints by Haubold & Katzung (1972, 1975) – is restricted to the Wolfcampian.

These results – which conflict with several former opinions – are related to two basic tenets of biostratigraphy. Firstly, similar biological forms found as fossils are potential evidence of a similar age for related formations. Secondly, differences in recorded/observed biological forms are evidence of different ages.

If one uses these premises positivistically, just a handful of divergences may lead to a wide range of subjective interpretations. Every ichnological form of tetrapod track that looks different may be new and may be

Ichnotaxon	**anatomical interpretation**
***Batrachichnus* Woodworth, 1900** *B. salamandroides* (Geinitz, 1861) *B. delicatulus* (Lull, 1918) ***Limnopus* Marsh, 1894** *L. cutlerensis* Baird, 1965 *L. zeilleri* (Delage, 1912)	Temnospondyli
***Amphisauropus* Haubold, 1970** *A. latus* Haubold, 1970 *A. imminutus* Haubold, 1970	Seymouriamorpha
***Ichniotherium* Pohlig, 1895** *I. cottae* (Pohlig, 1885)	Diadectidae
***Dromopus* Marsh, 1894** *D. lacertoides* (Geinitz, 1861) ***Tambachichnium* Müller, 1954** *T. schmidti* Müller, 1954	Araeoscelida
***Hyloidichnus* Gilmore, 1927** *H. microdactylus* (Pabst, 1897) *H. bifurcatus* Gilmore, 1927 *H. major* (Hey. &. Less., 1963) ***Gilmoreichnus* Haubold, 1970** *G. hermitensis* (Gilmore, 1927) ***Dimetropus* Romer & Price, 1941** *D. nicolasi* Gand & Haubold, 1984	Captorhinomorpha /Pelycosauria

Fig. 2 – The Lower Permian – Wolfcampian – principal tetrapod ichnotaxa of Euramerican distribution, and their interpretation.

Acibates Acrodactylichnium Acutipes Agostopus Akropus Allopus Amblyopus Amphisauroides Amphisauropus Anhomoiichnium Anthichnium Anthracopus Attenosaurus Auxipes "Antianhomopus" "Archaeotheriopus" "Arktopus" "Asteipodiscus"
Baropezia Baropus Barypodus Batrichnis Batrachichnus Brontopus
*Camunipes Cardiodactylum Chelaspodus Chelichnus *Chirotherium Cincosaurus Collettosaurus Crenipes Cursipes "Caseipus" "Cyclopus"*
*Devipes *Dicynodontipus Dimetropus Diversipes Dolichopodus Dromillopus Dromopus "Dromicopezus"*
Erpetopus Eumekichnium "Edaphopus" "Eobatrachidopus" "Eobarachipodiscus" "Eocercopithecopus" "Eocynodontipus" "Eodicynodontipus" "Eomacrochlichnus" "Eootokosaurus" "Eotheriopodiscus" "Eulaoporoides" "Eulaoporus" "Exopodiscus"
Fichterichnus Foliipes
Gampsodactylum Gargalonipes Gilmoreichnus Gonfaronipes Gracilichnium "Gnamptonycopus"
Hardakichnium Harpagichnus Herpetichnus Hyloidichnus Hylopus
Ichniotherium Ichnium "Isolaoporus"
Jacobiichnus Janusichnium
Korynichnium "Keraunopus"
Labyrinthodon Laoporus Limnopus Luneapes Loxodactylus
"Laodromus" "Laopezus" "Laoporoides" "Leptotheriopodiscus"
Margennipes Merifontichnus Microsauropus Moodieichnus
"Macrochelichnus" "Megalaoporus" "Micropodiscus" "Moschopopus"
Nanopus Nanipes Notalacerta
Oklahomaichnus Onychichnium Opistopus "Okypus"
Pachypes Palaeopus Palmichnus Parabaropus Paradoxichnium Permomegatherium Phalangichnus Planipes Prochirotherium Procolophonichnium Protritonichnites Pseudobradypus Pseudosynaptichnium "Paranodontipus" "Plagionycopus" "Praefoliipes" "Pseudoanthropopus" "Pseudopithecopus" "Psililaoporus"
Quadropedia
**Rhynchosauroides*
*Salichnium Saurichnis Saurichnites Serripes Sphaerodactylichnium Stenichnus Strictipes *Synaptichnium "Sphenacopus"*
Tambachichnium Telichnus Testudo Tetrapodichnus Thecodontichnus Tridactylichnium "Therocephalopus" "Theriobematistes" "Theriopezus" "Theriopodiscus"
Varanopus

Fig. 3 – Ichnogeneric names related to tetrapod tracks of Permian formations, as an alphabetical overview of about 140 names. In "quotation marks" are undefined names listed by ELLENBERGER (1983, 1984) from the Permian formations of the Lodève Basin. *Taxa that were originally related to tracks from Triassic beds.

separated taxonomically. This common position has produced about 140 ichnogenera, or ichnogeneric names used or introduced for tetrapod tracks of Permian age (Fig. 3), and thereby it has been the basis for several biostratigraphical subdivisions of continental Permian sequences.

During earlier investigations, up to the early 1980s, one of the authors (HH) was influenced by some of these aspects, especially by the potentially attractive idea of detailed biostratigraphical subdivision of red beds using tetrapod tracks. However, in the face of increasingly divergent and contradictory opinions published by some colleagues, a more skeptical and critical position was established. This position has been justified by the extensive studies of tetrapod tracks in collections and in the field since 1990 in Germany, northern Italy, southern France, northern Spain, and particularly in 1994 and 1999 in New Mexico. The discovery of the Robledo tracksites in southern New Mexico was a test case for the Permian tetrapod ichnotaxonomy and ichnostratigraphy. After the initial analyses it seemed to be the most diverse Permian ichnofauna, with about 30 different taxa (Hunt *et al.*, 1995). However, after the transfer of the huge amount of material collected by J. P. MacDonald to the collection of the New Mexico Musem of Natural History, followed by detailed study, this position was fundamentally modified by the joint investigations of the authors.

In short, in our present state of knowledge the main question is not which 140 generic names and published binominal ichnospecies may be valid, but whether it is the case that only six and no more than 10 different morphotypes are real? All these morphotypes are comparable to and principally represented in the ichnofauna known from the Abo Formation and its equivalents. This interpretation will not be accepted without protest by some other students of the same topic. This might become obvious in several lists of names (ichnotaxa) used in local or regional related descriptions previously. However, the only possible conclusion is that these very different names and interpretations are based only on the same few basic morphotypes and their variations.

One of the most extended examples of ichnotaxonomic oversplitting may be *Batrachichnus* (Fig. 4). It is one of the most common track types of the Permian and Permocarboniferous red beds. The perpetrators of *Batrachichnus* can be interpreted as juvenile temnospondyls. Their locomotory abilities together with their small size are the reasons for the large range of variability in track preservation. Like *Batrachichnus*, the other basic morphotypes *Amphisauropus*, *Dromopus* and *Dimetropus*, are discussed by Haubold (1996). *Tambachichnium* is closely related to *Dromopus* (Haubold, 1998), while for *Ichniotherium* see Voigt (this volume). *Hyloidichnus* and *Gilmoreichnus* have yet to be discussed in their taxonomic context together with an objective documentation of their variation.

POSSIBILITY OF A CONSENSUS

The difficulities in reaching a consensus on the outlined basic morphotypes might be due to

- subjective positions,
- ignorance of the phenomenon of extramorphology in track preservation,
- the use of less representative type specimens (phantom taxa), and
- principally, differences in ichnotaxonomic procedures.

These aspects seem to be the background of some formalistic, less constructive discussions, which have as their only aim the conservation of some personal, subjective results in faunal analyses related to problematic ichnotaxa and derived biostratigraphic subdivisions. We may summarise the experience of two positions in the understanding of Permian tetrapod track faunas from the red beds:

The concentration of individual discoveries and local separation reflects increasing degrees of difference.

The larger the sample sizes and the broader the range of comparison, the smaller the differences in taxonomy and stratigraphy.

At the present time, we see problems in making the second position understandable, if not acceptable.

- Ichnofaunas hitherto separate in time and taxonomy are much more uniform,
- so the age of these faunas and the trackbearing formations may be more or less restricted to Wolfcampian age, and
- our position is in conflict with many traditional and personal opinions.

However, if tetrapods and tetrapod footprints are a key element of Permocarboniferous stratigraphy, then it should be accepted consequently as one possible stratigraphic model. The current increasingly extensive record of tetrapod tracks in the Abo Formation of New Mexico is evidence of the Wolfcampian age of most tetrapod track faunas known in Europe.

Some seemingly problematic exceptions concern the Permian trackbeds in southern France, particularly eastern Provence. Visscher (1968) determined the flora of sites at Agay (Pradineaux Formation, in the Estérel Basin) and le Muy (Muy Formation, in the Bas-Argens Basin) as Upper Permian. He concluded that the basin of Estérel, an important centre of volcanic activity, was of Thuringian, Upper Permian, age. In their analyses of the ichnofaunas, Demathieu & Gand (in Demathieu *et al.*, 1991) argued for a lower Kazanian or Kungurian age for the Pradineaux Formation. Gand *et al.* (1995) described from the site St. Se-

Krkonoshe Basin, Czech Rep. Kalna-Formation	Geinitz, 1861 Fritsch, 1895, 1901	*Saurichnites salamandroides* *? Saurichnites caudifer* *? S. comaeformis*
	Pabst 1908	Ichn. rhopalodactylum kalnanum
Thüringer Wald, central Germany Goldlauter and Oberhof Formations	Pabst, 1908	*Ichn. anakolodactylum* I. brachydactylum kabarzense
	Haubold, 1970, 1973 etc.	*Anthichnium salamandroides* *Gracilichnium jacobii* *Gilmoreichus brachydactylus* *Gilmoreichnus minimus* *Jacobiichnus caudifer*
Southern Alps, Collio Formation	Dozy, 1935 Ceoloni *et al.*, 1988	*Anhomoiichnium orobicum* *Gracilichnium berrutii*
Lodève and St. Affrique Basins, France Formation of Tulières to Rabejac and Pelites of St.Rome to St.Pierre	Heyler & Lessertisseur, 1963	*Diversipes proclivis* *Foliipes abscisus* *Devipes caudatus* *Crenipes abrectus* *Crenipes abscurvus* *Acutipes decessus* *Strictipes regularis* *Nanipes minutus* *Serripes pectinatus* *Anthichnium salamandroides*
	Gand, 1987, 1993, Gand & Haubold, 1984	*Limnopus regularis* *Salichnium pectinatus* *Salichnium decessus*
Saar-Nahe Basin, SW Germany Altenglan Formation to Nahe-Group	Fichter, 1983 a, b, 1984 Boy & Fichter, 1988	*Saurichnites slamandroides* *S. intermedius* *S. incuvatus* *Amphisauroides sp.* *Foliipes abscissus* *Gilmoreichnus minimus* *G. kablikae (brachydactylus)* *Hyloidichnus arnhardti* *Jacobiichnus caudifer* *Limnopus palatinus*
Hermit Shale, Arizona	Lull, 1918 Gilmore, 1927	*Exocampe delicatula* *Batrachichnus delicatulus* *Batrachichnus obscurus* *Dromillopus parvus*
Hueco Formation, Robledo Mountains Member, New Mexico	Schult, 1995	*Anthracopus ellangowensis* *Batrachichnus plainvillensis* *Chelichnus bucklandi* *Cursipes dawsoni* *Dromillopus quadrifidus* *Foliipes caudatus* *Hyloidichnus bifurcatus* *Limnopus regularis* *Laoporus cf. L. nobeli* *Nanopus caudatus* *Quadropedia prima* *Salichnium becki*
	Haubold *et al.*, 1995 a	*Batrachichnus delicatulus*

Fig. 4 – *Batrachichnus salamandroides*, an extended example of ichnotaxonomic oversplitting. Overview of the presumed synonyms and phantom taxa, separated by formations and authors.

bastien (in Saint Raphael of the Estérel Basin) tracks from an extended surface with both traditional and several new names. The determinations, as well as the stratigraphic interpretation, raise some questions. Our own investigations of the ichnofauna of St. Sebastien show exceptional extramorphological preservation on a rhyolitic tuff surface. It is, in contrast to Gand *et al.*, a member of the Mitan Formation, which is intercalated between the Pradineaux and Muy formations. The stratigraphic position and the track assemblage of St. Sebastien, as well as all track faunas of the Pradineaux, Mitan, and Muy formations, can be interpreted as Lower Permian, or Wolfcampian.

More compatible with a Wolfcampian interpretation appears to be the correlation of the track formations from the Saint Affrique and Lodève basins (except La Lieude) as Asselian, Sakmarian and ?Artinskian, after Gand (1993). Only a few names listed by Gand (1993) differ from the above-suggested basic morphotypes, such as *Anthichnium*, *Salichnium*, and *Varanopus*. In our interpretation they are synonyms of *Batrachichnus* and *Hyloidichnus*.

As a result, we can present evidence of only one Early Permian Euramerican terrestrial tetrapod fauna, and in consequence a restriction in time for most related red bed sequences in Europe to approximately Wolfcampian age. This conclusion seems compatible with the trend derived from other observations, as well as from biostratigraphy and radiometric data, which point more and more to a restriction of most European Permocarboniferous red bed sequences to the lowermost Permian. We hope to have presented our results with care and acceptance of divergent opinions. Our result may be understood as the initiation of a forthcoming constructive discussion.

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A PERMIAN TIME SCALE 2000 AND CORRELATION OF MARINE AND CONTINENTAL SEQUENCES USING THE ILLAWARRA REVERSAL (265 MA)

MANFRED MENNING[1]

Key words – Permian; time scale; geochronology; isotopic ages; magnetostratigraphy; global correlation.

Abstract – Synthesis of an increased number of reliable U-Pb, Ar-Ar, and Rb-Sr ages, and field indicators of the duration of Permian stages provide a time scale that differs significantly from those of Harland *et al.* (1982, 1990), Odin (1982, 1994), and Gradstein & Ogg (1996). The duration of the Lower Permian Series (Cisuralian: Asselian, Sakmarian, Artinskian, Kungurian) is comparable with the duration of the Middle Permian Series (Guadalupian: Roadian, Wordian, Capitanian) plus the Upper Permian Series (Lopingian: Wuchiapingian, Changhsingian).

U-Pb zircon SHRIMP ages from the southern Ural Mountains indicate 292 Ma for the Carboniferous-Permian (Gzhelian-Asselian) boundary. In contrast, Ar-Ar sanidine ages from Central Europe provide about 296 Ma for that boundary. Using available data, the best estimate for the Permian-Triassic boundary is 251 ±1 Ma.

The 265 Ma Middle Permian Illawarra Reversal (IR) of the Earth´s magnetic field (Irving & Parry, 1963) is not positioned consistently with traditional Permian correlations. Referred to regional mapping units the Illawarra Reversal is within the Lower Permian of Central Europe (Rotliegend, continental) and South China (Maokou, marine) but in the Upper Permian of East Europe (Tatar, continental), North America (Guadalupe, marine), and North China (Upper Shihhotse Formation, continental). Thus, the duration of deposition of sequences mapped as "Upper Permian" ranges from about 7 Ma (Zechstein) to 23 to 20 Ma (Ufa+Kazan+Tatar ~ Guadalupe+Ochoa).

A preliminary estimation of the duration of lithostratigraphic units for the described stratigraphic profiles, together with SE Australia, is provided.

Parole chiave – Permiano; geocronologia; età isotopiche; scala cronologica; magnetostratigrafia; correlazione globale.

Riassunto – La sintesi di un crescente numero di attendibili età U-Pb, Ar-Ar e Rb-Sr, nonché le indicazioni di età e durata dei piani permiani forniscono una scala cronologica che differisce sensibilmente da quelle di Harland *et al.* (1882, 1990), Odin (1982, 1994) e di Gradstein & Ogg (1996). La durata del Permiano inferiore (Cisuraliano: Asseliano, Sakmariano, Artinskiano, Kunguriano) è confrontabile con la durata complessiva del Permiano medio (Guadalupiano: Rodiano, Wordiano, Capitaniano) e del Permiano superiore (Lopingiano: Wuchiapingiano, Changhsingiano).

Le età U-Pb ottenute mediante microsonda SHRIMP da zirconi presenti negli Urali meridionali indicano 292 Ma per il limite Carbonifero-Permiano (Gzheliano-Asseliano). Al contrario, le età Ar-Ar inerenti a cristalli di sanidino provenienti dall'Europa centrale forniscono all'incirca 296 Ma per questo limite.

L'inversione medio-permiana "Illawarra" (IR) di 265 Ma del campo magnetico terrestre (Irving & Parry, 1963) non è posizionata in modo consistente con le tradizionali correlazioni permiane. La cartografia regionale pone l'"Illawarra Reversal" entro il Permiano inferiore dell'Europa centrale (Rotliegende, continentale) e della Cina meridionale (Maokou, marino), ma entro il Permiano superiore dell'Europa orientale (Tatar, continentale), del Nord America (Guadalupa, marino) e della Cina settentrionale (Formazione di Shihhotse Superiore, continentale). Conseguentemente, il tempo di deposizione di successioni cartografate come "Permiano superiore" va da circa 7 Ma (Zechstein) a circa 23-20 Ma (Ufa+Kazan+Tatar ~ Guadalupe+Ochoae). È data una stima preliminare delle unità litostratigrafiche per i descritti profili stratigrafici, annettendo anche l'Australia sud-orientale.

INTEGRATIVE TIME SCALE CALIBRATION

Refinement of the geologic time scale has proceeded by steps. In an integrative calibration, all available time proxies of different types and sources should be used. The most reliable isotopic data must be compared with one another and with field indicators such as the weighted number of biozones, weighted average thicknesses, and sequences of comparable duration located elsewhere.

Using Ar-Ar sanidine and Rb-Sr biotite ages from Central Europe (Lippolt *et al.*, 1984; Lippolt & Hess, 1989) the Gzhelian-Asselian boundary is at about 296 (297) Ma (Menning, 1995) whereas the boundary age is at about 292 Ma according to Pb-U SHRIPM data from zircon from easternmost Europe (Chuvashov *et al.*, 1996; Jin *et al.*, 1997:13; Menning *et al.*, 2000: Fig. 7). For the Kasimovian to Asselian time span the U-Pb zircon ages seem to be systematically younger than stratigraphically corre-

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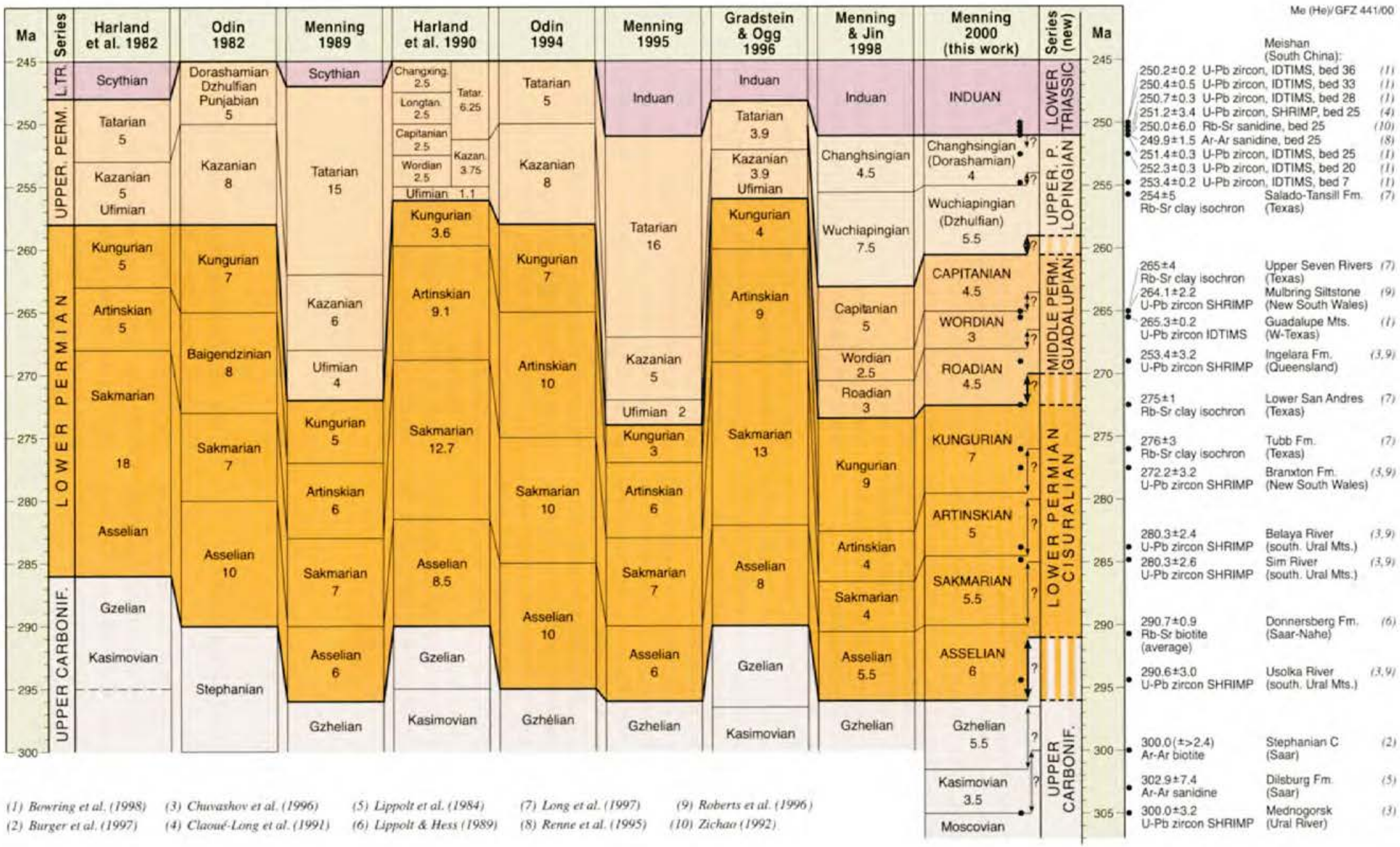

(1) Bowring et al. (1998) *(3) Chuvashov et al. (1996)* *(5) Lippolt et al. (1984)* *(7) Long et al. (1997)* *(9) Roberts et al. (1996)*
(2) Burger et al. (1997) *(4) Claoué-Long et al. (1991)* *(6) Lippolt & Hess (1989)* *(8) Renne et al. (1995)* *(10) Zichao (1992)*

Fig. 1 – Permian time scales. The ages of Harland *et al.* (1982, 1990), Odin (1982, 1994), and Gradstein & Ogg (1996) are significantly younger in part compared with the integrative estimated ages of Menning (1989, 1995) and Menning & Jin (1998). The isotopic ages are shown according to their stratigraphic position. Permian standard stages (Jin *et al.* 1997) accepted by the Subcommission on Permian Stratigraphy of the IUGS are in CAPITAL letters.

sponding Ar-Ar sanidine and Rb-Sr biotite ages (Fig. 1). These age differences correspond to those in the pre-Kasimovian Carboniferous (Menning *et al.*, 2000: Fig. 6, Time Scales A and B). Thus, in the lower part of our Permian time scale 2000 (Fig. 1) the ages, based on Ar-Ar and Rb-Sr data in combination with field-based time indicators, are about 5 Ma older than a calibration using U-Pb SHRIMP ages (Fig. 1, upward arrows).

The 264.1 ± 2.2 Ma age from the Mulbring Siltstone (New South Wales) fits with the time scale if it is allocated to the Wordian-Capitanian boundary (Fig. 1) using the magnetostratigraphic results of Théveniaut *et al.* (1994). But the age of 253.4 ±3.2 Ma from the Ingelara Formation (Queensland) does not fit if a Kazanian stratigraphic position (Chuvashov *et al.*,1996; Roberts *et al.*, 1996) is used (Fig. 1).

Claoué-Long *et al.* (1991) used ^{238}U/^{206}Pb SHRIMP data on zircon to obtain 251.2 ±3.4 Ma for the Permian-Triassic boundary. This age is further supported by sanidine dating by the Rb-Sr (Zhang, 1992) and Ar-Ar (Renne *et al.*, 1995) methods, and by U-Pb dating of zircon by ID-TIMS (Bowring *et al.*, 1998). A combination of all of these data available provides 251 ±1 Ma as the best estimate for the Permian-Triassic boundary (Fig. 1) whereas an age of ~253 Ma is favoured by Mundil *et al.* (2000).

According to the number of conodont, ammonoid and fusulinid zones the duration of the Lower Permian Series (Cisuralian: Asselian, Sakmarian, Artinskian, Kungurian) is comparable to that of the Middle Permian Series (Guadalupian: Roadian, Wordian, Capitanian) plus the Upper Permian Series (Lopingian: Wuchiapingian, Changhsingian). If we assign 296 Ma to the Carboniferous-Permian boundary (Menning, 1995) and 251 Ma to the Permian-Triassic boundary (Claoué-Long *et al.*, 1991), this results in a Kungurian-Ufimian boundary age about halfway between: *i.e.* 275 Ma to 270 Ma (Menning, 1995).

According to a duration of the Permian of about 45 Ma and to weighted average thicknesses of 11 stratigraphic sections from five continents the Middle Permian (Guadalupian) Illawarra Reversal is 10 ±4 Ma older than the Permian-Triassic boundary (Menning, 1986). Consideration of the number of fusulinid, ammonoid, and conodont zones suggests that the reversal is 14 Ma older than the Permian-Triassic boundary, which, according to Menning (1995), is 265 Ma (Illawarra Reversal).

The Kungurian could be the longest Permian stage if its base is defined with the first occurrence of the conodont *Neostreptognathodus pnevi* and the base of the Roadian coincides with the first occurrence of *Mesogondolella nankingensis* (Kozur, 1995, 1997). Such a definition of the Kungurian would include the uppermost part of the original Artinskian and the lower part of the Ufimian (Kotlyar, 2000) (Figs 1, 3).

In summary, recently obtained isotopic ages (Chuvashov *et al.*, 1996; Roberts *et al.*, 1996; Long *et al.*, 1997; Burger *et al.*, 1997; Bowring *et al.*, 1998) from samples that can be positioned within the new Permian stratigraphic standard scale confirm the ages estimated by Menning (1989, 1995) on geological grounds. Discrepancies, which are no more than 5 Ma, fit mostly within the ±2σ errors of the isotopic ages. These ages differ significantly from the time scales of Harland *et al.* (1982, 1990), Odin (1982, 1994), and Gradstein & Ogg (1996) (Fig. 1), but only moderately from the fusulinid-related time scale of Davydov *et al.* (1999) and the conodont-related time scale of Wardlaw & Schiappa (this volume). More data of diverse sorts (U-Pb, Ar-Ar, palaeontological, sequence-stratigraphic) are necessary to provide more reliable estimates of the duration of deposition of Permian stratigraphic units.

BIOSTRATIGRAPHIC CORRELATION

Extremly strong provincialism is a characteristic of all Permian fossil groups. Conodonts, fusulinids and ammonoids serve as index fossils for global correlation of marine sequences. Tetrapod body and trace fossils, shark teeth, macroplants, arthropod tracks, insect wings, and palynomorphs are used to correlate continental sequences.

Only few stratigraphic sections contain an interfingering of continental and marine beds, making intercalibration possible. Palynomorphs are the most usable fossil in this regard, but they are not found in red beds unless gray intercalations are also present – a situation that is rare in Pangaea. Moreover, Permian floral realms were distinctive and for this reason interregional palynological correlation is limited.

GEOLOGICAL MAPPING UNITS

Mapping units are defined for each geographic area on a practical basis, by observable lithologic properties. A mapped succession of rocks is assigned roughly to a unit of the global stratigraphic reference scale (Fig. 2). For instance, the Rotliegend of Central Europe was assigned to "Lower Permian" and the Zechstein to "Upper Permian" (Fig. 2). However, according to recent biostratigraphic, magnetostratigraphic and isotopic age evidence, the base of the Rotliegend lies in the Upper Carboniferous Gzhel and its top lies in the Tatar of Upper Permian age (Fig. 2). The Chihsia and Maokou limestones in South China were mapped as "Lower Permian" and Longtan and Changhsing rocks as "Upper Permian" (Fig. 2). However, the time span represented by the "Lower Permian" Rotliegend

Group is more than 300 Ma to 260 Ma, whereas the accumulation of "Lower Permian" Chihsia and Maokou Formations was between about 280 Ma to 260 Ma, a much shorter duration (Fig. 3).

Correlation of mapping units that are ostensibly "Lower Permian" (Fig. 2) but which accumulated over different time spans (cf. Fig. 3) can create confusion. For instance, consider the information from early Permian palaeomagnetic poles. A more reliable palaeogeographic reconstruction results if we combine palaeomagnetic poles from South China (Chuanshan = "Upper Carboniferous" + Chihsia = "lower Lower Permian") with "Lower Permian" poles from East Europe and North America (Figs 2, 3).

Fig. 2 presents stratigraphic units of five areas assigned in regional geological maps respectively to the "Lower Permian" and "Upper Permian". The inconsistent position of the Illawarra Reversal (IR) (Irving & Parry, 1963) argues that the correlation of most of those Permian mapping units used in several correlation charts must be incorrect (Fig. 2).

Durations of deposition of "Upper Permian" sequences (Fig. 2) vary from about 7 Ma (Zechstein), to about 9 Ma (Longtan+Changhsing), to about 16 Ma (Upper Shihhotse+Shihchienfeng), to about 23 to 20 Ma (Ufa+Kazan+Tatar ~ Guadalupe+Ochoa) (Fig. 3).

Ar-Ar and Rb-Sr ages (Lippolt *et al.*, 1984; Lippolt & Hess, 1989) and our integrative time analysis assign a maximum duration of 10 Ma (301-291 Ma) for deposition of the Lower Rotliegend of the Saar-Nahe Basin (Kusel+Lebach+Tholey). For the Upper Rotliegend of Central Europe the duration increases to about 34 Ma which is several times longer than previously thought (Fig. 3). In Rotliegend basins the boundary between "Lower" and "Upper" Rotliegend deposits seems to be significantly time transgressive. This is indicated in Fig. 3 by a diagonal dashed line.

MAGNETOSTRATIGRAPHIC CORRELATION

The IR is the best magnetic time marker within Palaeozoic

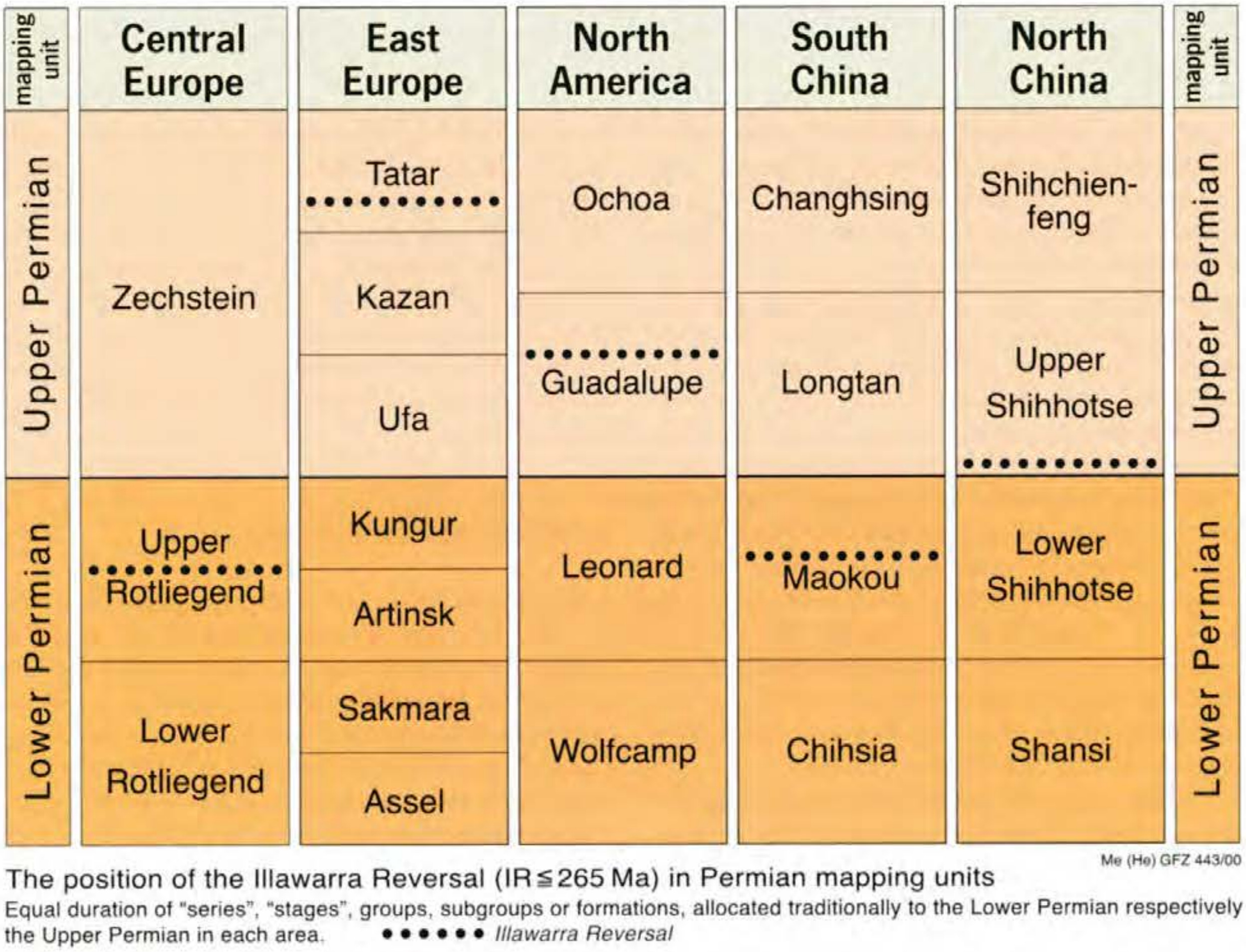

Fig. 2 – Stratigraphic scheme showing Lower Permian and Upper Permian mapping units of five areas. The Illawarra Reversal (dotted lines) is within the Upper Permian (Tatar, Guadalupe, Upper Shihhotse) but also in the Lower Permian (Upper Rotliegend, Maokou). It is detected within marine (Guadalupe, Maokou) and continental (Tatar, Rotliegend, Shihhotse) units. Equal duration of "series", "stages", groups, subgroups or formations.

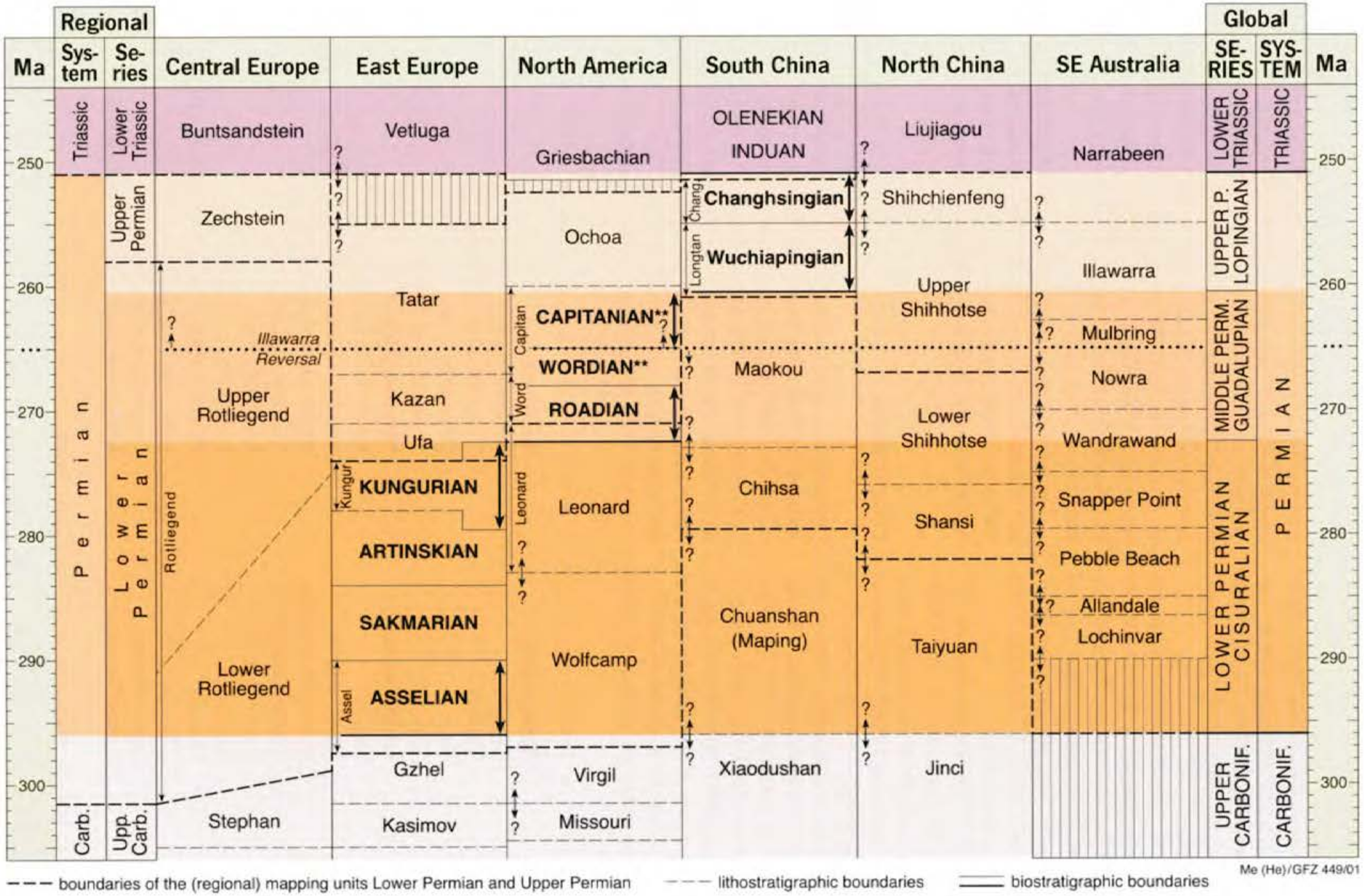

Fig. 3 – Revised stratigraphic scheme using an integrative time scale calibration, particularly magnetostratigraphic information. Preliminary estimation of age and duration of important Permian stratigraphic units. Permian standard stages (Jin *et al.*, 1997) are shown in bold. Standard stages accepted by the Subcommission on Permian Stratigraphy of the IUGS are in CAPITAL letters.

*The (increased) KUNGURIAN is defined by the first occurrence of *Neostreptognathodus pnevi* at the base and the first occurrence of *Mesogondolella nankingensis* at the base of the Roadian (Kozur, 1995, 1997).

**The chronostratigraphic units WORDIAN, CAPITANIAN, ASSELIAN, KUNGURIAN, ARTINSKIAN, WUCHIAPINGIAN, and CHANGHSINGIAN (Jin *et al.*, 1997) differ from the lithostratigraphic units Word, Capitan, Assel, Kungur, Artinsk, Longtan, and Changhsing as used earlier (*e.g.* Dunbar *et al.*, 1960).

rocks. It marks the boundary between the Carboniferous-Permian Reversed Megazone (CPRM = Kiaman Magnetic Division of Irving & Parry, 1963) and the Permo-Triassic Mixed Megazone (PTMM = Illawara (RN) Hyperzone of Molostovsky *et al.*, 1976). CPRM and PTMM refer to rock, and the corresponding time terms are Permo-Carboniferous Reversed Superchron (PCRS = Kiaman Magnetic Interval of Irving & Parry, 1963) and Permo-Triassic Mixed Superchron (PTMS).

The number of magnetic zones within the CPRM and PTMM is unknown, and consequently many global correlations are speculative. In the pre-Illawarra Permian System (ca 31 Ma) there could be as many as four zones of short-duration normal polarity. The post-Illawarra Permian (ca 14 Ma) may contain about 15 magnetic zones (Menning, 1995; Embleton *et al.*, 1996).

The very existence of the CPRM is under discussion although nearly all uppermost Carboniferous and Lower Permian sequences are reversely magnetized. Have some normally polarized rocks been overlooked or ignored as they were interpreted as the result of remagnetization?

Among all Permian magnetostratigraphic markers the IR can be best used for intercontinental correlation. Its numerical age is about 265 Ma (Menning, 1995; Menning, 1992 (pers. comm.) in Opdyke, 1995:42), which is significantly older than estimated earlier. The numerical age of the IR and its stratigraphic position according to the East European reference section changed as shown in Tab. 1.

The IR has been found within the continental lower Tatarian (Upper Permian) of East Europe (Khramov, 1963 ff.; Gialanella *et al.*, 1997) whereas its age has been interpreted to be Ufimian (Théveniaut *et al.*, 1994; Klootwijk *et al.*, 1994; Opdyke, 1995; Embleton *et al.*, 1996) or Kungurian (Ogg, 1995) (Tab. 1). Menning (2001) summarizes details of the arguments. Moreover, the IR is said to be positioned in the continental Lower Permian (Upper Rotliegend) of Central Europe (Dachroth, 1976), the back-reef Upper Permian (Guadalupe) of North America (Peterson & Nairn, 1971), the marine Lower Permian (Maokou) of South China (Heller *et al.*, 1995), and the continental Upper Permian (Upper Shihhotse) of North China (Embleton *et al.*, 1996) (Figs 2, 3).

Guadalupian marine sequences in SW North America and in South China are correlated using conodonts (Kozur, 1997). It is important to discover the accurate position of the IR to confirm their biostratigraphic correlation.

CONCLUSIONS

Our integrative time analysis (Fig. 1), the inconsistent position of the IR in units mapped as "Lower Permian" and "Upper Permian" (Fig. 2), and the revision of the age of the IR to an older value (Tab. 1) have important consequences for a Permian global stratigraphic correlation, particularly for the Upper Permian, and for estimates of the duration of important Permian stratigraphic units (Fig. 3).

In the future, all regional Permian stratigraphic units

Age [Ma]	Stratigraphy	Reference
—	Tatarian	Khramov (1963)
235	Tatarian	Khramov *et al.* (1974, 1982)
---	Tatar	Dachroth (1976)
250	Tatarian	Harland *et al.* (1982)
255*/257*/259**	Lower Tatarian	Menning (1986, 1991, 1992)
261	Tatarian	Haag & Heller (1991)
—	Lower Tatarian	Solodukho *et al.* (1993)
—	Ufimian/Kungurian	Théveniaut *et al.* (1994)
>267	Ufimian/Kungurian	Klootwijk *et al.* (1994)
≤265***	Lower Tatarian	Menning (1995)
261	Kungurian	Ogg (1995)
262	Ufimian	Opdyke (1995), Opdyke & Channel (1996)
—	Ufimian	Embleton *et al.* (1996)
—	Lower Tatarian	Gialanella *et al.* (1997)
265***	Lower Tatar(ian)	Menning & Jin (1998), Menning (this work)

*10 ± 4 Ma older than the Permian Triassic boundary (Menning, 1986)
**10 + 2 Ma older than the Permian Triassic boundary
***10 + 4 Ma older than the Permian Triassic boundary

Tab. 1 – Numerical age and stratigraphical position of the Illawarra Reversal according to the East European reference section.

should be referred (if possible) to the revised global Permian chronostratigraphic reference scale (Jin *et al.*, 1997) which is subdivided into a Lower Permian Series (Cisuralian), a Middle Permian Series (Guadalupian), and an Upper Permian Series (Lopingian) (Figs 1, 3). Until the significant disagreement of Permian time scales (Fig. 1) is resolved, one should quote the reference and the stratigraphic source of each numerical age.

In stratigraphic figures and tables, the global chronostratigraphic and geochronologic terms that are recommended by the International Stratigraphic Commission should be written in CAPITAL letters to support the scientific communication (Figs 1, 3).

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TOWARD A REFINED PERMIAN CHRONOSTRATIGRAPHY

BRUCE R. WARDLAW[1] and TAMRA A. SCHIAPPA[2]

Key words – Permian scale; conodont zonation; numerical ages.

Abstract – The generalized standard marine conodont zonation for the Permian of 24 zones is placed within a framework utilizing the presently available reliable radiometric as well as estimated numerical ages. The base of the Permian is taken to be 291.6 Ma and the top to be 251.4 Ma.

Parole chiave – Scala del Permiano; zonazione a conodonti; età numeriche.

Riassunto – La generalizzata zonazione standard a conodonti marini relativa al Permiano di 24 zone è inserita in uno quadro strutturato che utilizza le attendibili età radiometriche e le stimate età numeriche attualmente disponibili. Il limite inferiore del Permiano è correntemente riferito a 291.6 Ma e il limite superiore a 251.4 Ma.

INTRODUCTION

This is a working document to: 1) encourage more rigorous studies on radiometric age dating within biostratigraphically well constrained sections; 2) further discussions of the 'standard' Permian scale; and 3) to better correlate the marine to continental sections. The premise was to use recent age-dates thought reliable (Chuvashov *et al.*, 1996; Menning, 1995; Bowring *et al.*, 1998) and fit them into the evolving generalized standard marine conodont zonation as currently recognized by the authors. Each conodont zone represents time, and therefore, radiometric ages that suggested no time elapsed for a zone were extended to their maximum error range to reflect an elapsed time.

CONODONT ZONATION

The Lower Permian (Cisuralian Series) conodont zonation is from a variety of published and unpublished sources. The Asselian and Sakmarian zonation, based on the succession of *Streptognathodus* species is from Chernykh *et al.* (1997), Boardman *et al.* (1998), and Wardlaw *et al.* (1999). This succession is well represented in Kansas and the southern Ural Mountains of Russia.

The Artinskian zonation is based on species of *Sweetognathus*, *Streptognathodus*, and *Neostreptognathodus* and reflects the major changeover in the forms dominating shelf faunas during this interval. It is largely based on unpublished material from the southern Urals, Russia and Kazhastan and the Great Basin, USA.

The Kungurian zonation is based on the succession of *Neostreptognathodus* species modified from Wardlaw & Grant (1987) from West Texas, USA.

The Middle Permian (Guadalupian Series) conodont zonation is from Wardlaw & Lambert (1999) except that the rapid succession of upper Guadalupian *Jinogondolella* (*altudaensis*, *prexuanhanensis*, *xuanhanensis*, and *crofti*) are all overlapped by *J. altudaensis* and considered as subzone indicators of that zone. This succession is well represented in West Texas and South China.

The Upper Permian (Lopingian Series) conodont zonation is from Mei *et al.* (1994, 1998) as modified by Wardlaw & Mei (1998) and reflecting the change of selecting the first appearance *Clarkina dukouensis* in an evolutionary cline from *C. postbitteri* as a more appropriate base of the Wuchiapingian. This succession is well represented in both South China and the Dzhulfa area of Iran and Transcaucasia.

In all these generalized zones, more local zones (or subzones) are recognized. In particular, the Asselian and Sakmarian Stages of Kansas (based on many more species of *Streptognathodus*), the Kungurian Stage of West Texas (based on the concurrent succession of *Mesogondolella* species with the *Neostreptognathodus* species), and the Lopingian Series of China (based on more species of *Clarkina*).

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Informal names such as "*exsculptus*", *postwhitei*, *florensis*, and *trimilus* are those proposed in various taxonomic works involving one or both of the authors currently in various stages in the publication process.

IMPORTANT RADIOMETRIC AGES

Chuvashov *et al.* (1996) report one very well biostratigraphically constrained SHRIMP (Super High Resolution Ion Microprobe) analysis date for the base of the *constrictus* (and corresponding local fusulinid zone) of 290.6 ± 3.0 Ma which we feel is very close to on-the-mark. By projection we suggest that the *isolatus* zone is no more than 1 million years in duration and that 291.6 probably provides a very good age for the base of the Permian. Chuvashov *et al.* (1996) also report less well constrained ages for the uppermost Sakmarian (280.3 ± 2.4) and the lowermost Artinskian (280.3 ± 2.6). We project an age of 283 Ma for the boundary as defined by conodonts, which falls close to the margin of error for both dates. The dates utilized by Chuvashov *et al.* (1996) from Australia, although important, are not well enough constrained to be used in building the standard time scale.

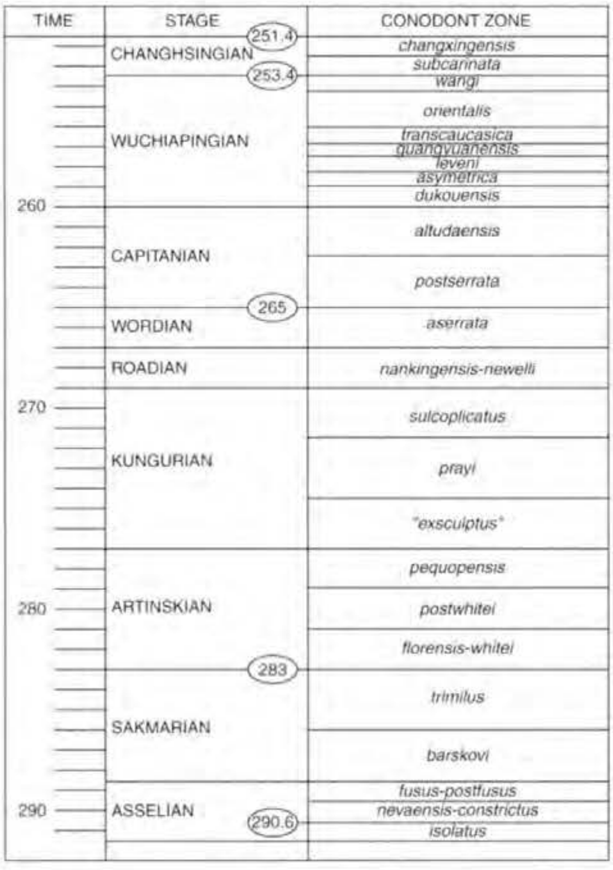

Fig. 1 - Chronostratigraphic chart with age in million years before present, Permian stages, and generalized marine conodont zonation. Ages thought to be reliable are highlighted in ellipses.

Bowring *et al.* (1998) discuss several important ID-TIMS (Isotope Dilution Thermal Ionization Mass Spectrometry) dates, of which a few are very well constrained within the proposed stratotypes for the Middle and Late Permian. In particular, an age of 265.3 ± 0.2 Ma from just below the recently approved GSSP for the base of the Capitanian coincides with the estimated age of 265 Ma by Menning (1995) for the Illawarra Reversal. Menning (in Glenister *et al.*, 1999) places the Illawarra Reversal within this important section between the horizon isotopically dated and the conodont defined base of the Capitanian.

Bowring *et al.* (1998) report several dates from the Meishan section in China, the proposed GSSP for both the Changhsingian and the Permian-Triassic boundary. A date of 253.4 ± 0.2 Ma is derived from bed 7, immediately below the first occurrence of *Clarkina subcarinata (sensu strictu)*, which is the proposed definition of the base of the Changhsingian Stage. Also, from immediately below the proposed conodont-defined base of the Triassic, the first occurrence of *Hindeodus parvus*, they report an age of 251.4 ± 0.3 Ma.

CONCLUSIONS

Permian conodont zones appear to range in age from 0.7 to 3.0 million years. This initial study suggests that the stages as now defined represent the following span in years:

Changshingian	2.0 million years
Wuchiapingian	6.6 million years
Capitanian	5.0 million years
Wordian	2.0 million years
Roadian	2.0 million years
Kungurian	8.0 million years
Artinskian	6.0 million years
Sakmarian	5.6 million years
Asselian	3.0 million years

The base of the Permian is taken to be 291.6 Ma at the base of the *isolatus* conodont zone. The base of the Triassic (and therefore, the top of the Permian) is taken to be 251.4 Ma at the base of the *parvus* conodont zone.

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MEETING REPORT

GIUSEPPE CASSINIS[1]

GENERAL

The international Congress on "The continental Permian of the Southern Alps and Sardinia (Italy). Regional reports and general correlations" was held in Italy from 15-25th September 1999. It followed another meeting, in July 1986, which was set up by a team of Italian researchers involved in the IGCP project No. 203 ("Permo-Triassic events of East Tethys region and their intercontinental correlation"), who have been working for years in the Southern Alps. Brescia, in eastern Lombardy, was the official centre of both the initiatives.

The last meeting was inspired by a number of scientific activities. In particular, the wish of the IUGS Subcommission on Permian Stratigraphy (SPS) to create a "Continental Permian Group", and the consequent decision of its Officers to give impetus to this research, was a determining factor in organising the Brescia Field Conference. The meeting has also greatly benefited by funds from the Ministry of University and Scientific and Technological Research (MURST), and the National Research Council (CNR), for a new study programme on the Alpine and Apennine Late Paleozoic evolution, compared with the contemporaneous framework of Sardinia and other western Mediterranean areas. Further, the Brescia Museum of Natural Sciences generously gave financial support for the publication of these proceedings.

Due to the participation of foreign experts in Carboniferous to Triassic continental successions, and the large number of oral and poster contributions outside the selected areas of the meeting (Southern Alps and Sardinia), the subject of these Proceedings has been changed accordingly. The new title "Permian continental deposits of Europe and other areas. Regional reports and correlations" corresponds better to the contents of this volume.

The Congress consisted of a scientific Conference held in the Civic Museum of Natural Sciences in Brescia, and two field trips carried out in Sardinia and in the central-eastern Southern Alps, respectively. Over 100 participants came generally from Europe, and some from North American and Asiatic countries.

THE PRELIMINARY EXCURSION IN SARDINIA (15-18 SEPTEMBER)

The visit to some major Late Paleozoic continental basins on the island was the aim of this trip, of which the itinerary and stops are indicated in Fig 1. The participants met in the maritime station of Porto Torres, in northwestern Sardinia.

15 September (Speakers: Barca, Del Rio, Pittau)

The first day was dedicated to the examination of the Carboniferous to Permian continental deposits of the small San Giorgio (Iglesiente) and Guardia Pisano (Sulcis) basins. However, due to the long distances involved, the or-

Fig. 1 - Excursion itinerary (15-18 September) and main stops on some Late Paleozoic continental basins of Sardinia.

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ganisers made a preliminary stop near Barrumini village, to visit the famous archaeological site of "Su Nuraxi". The participants appreciated very much the opportunity to explore this fortress ("Nuraghe"), which is dated to 1500-1300 BC.

The San Giorgio Basin essentially consists of a detrital succession, about 30 m thick, which unconformably overlies a Cambrian basement. Polymict conglomerates pass upwards to dolostones alternating with sandstones and conglomerates, pelites, shales and coals rich in fossil plants; coarse- to fine siliciclastic sediments, again bearing floristic remains, follow above. The macro- and microflora are generally related to "Stephanian" times.

The Guardia Pisano Basin is made up of both fluvial-to-lacustrine clastic sediments and volcanic products (Fig. 2). This succession, about 100 m thick, consists of grey shales more or less carbonaceous and rare lenticular sandstone with plants and palynomorphs; volcanic breccias of rhyolitic-rhyodacitic lavas (295±5 Ma) alternating with coal-shales, sandy dolostone and tuffs rich in conifer fragments; coarse- to fine siliciclastics; and reddish shales with intercalations of silty sandstone-to-conglomerate, locally with cross-bedding structures and burrows. On the top, Eocene limestones crop out unconformably. The palynological data may correlate with the "Stephanian-Autunian" of Western Europe, the Wolfcampian of the North America Midcontinent and the Ghzelian-Asselian of the Donetz and Urals basins.

Later, after a long trip, the group reached the Sant'Elmo Beach Hotel (Costa Rey), on the southeastern coast of the island.

16 September (Speakers: Broutin, Cortesogno, Gaggero, Pittau, Ronchi)

The second day was spent visiting the Escalaplano (Gerrei) and Perdasdefogu (Ogliastra) volcanic and sedimentary basins. In the former, the investigated S. Salvatore section, about 170 m thick, can be subdivided into two sequences. The lower one (80 m), which unconformably rests on the Variscan crystalline basement, generally consists of, in ascending order: a basal conglomerate (reddish breccia); varicoloured sandstones-pelites alternating with tuffs; rhyolitic cinerites, more or less silicified, with interbedded limestones, and including near the top a black chert layer; and massive rhyolitic ignimbrites. The upper sequence (about 80-90 m) is made up of a breccia body, with metamorphic and volcanic rock-fragments; a volcaniclastic deposit (interpreted as a lahar), dacitic to andesitic in composition; reddish conglomerate, bearing only the rock-elements of the underlying presumed lahar; brownish and dark red volcaniclastic pelites with carbonate-siderite nodules and, at the top, silicified cinerites and limestone with chert layers (hyaloclastites); and an andesitic lava and a massive breccia body. Algae and fossil plants (rare) suggest an Autunian age.


Fig. 2 – Observing the Guardia Pisano Permian outcrops, Sulcis, SW Sardinia.

The second stop in the Escalaplano Basin was at its southeastern edge, along the road going up to the village. Here, Buntsandstein-type red clastic deposits, with chalky and marly-clayey intercalations, unconformably overlie the Variscan metamorphic basement. On the basis of palynomorphs, these deposits generally relate to Anisian times.

The Perdasdefogu Basin, north of this village, crops out over an area of about 25 km^2, with deposits which show marked thickness changes, and lateral sedimentary and volcanic variations. The succession of the Punta Gardiola area can be subdivided into two parts. The lower one, over 100 m thick, initially consists of dark-grey, sandy-shaly clastic sediments, associated with thin conglomerates and a number of calcalkaline, intermediate to acidic volcaniclastic breccias and lavic products. Lacustrine limestones and dolostones (from 30-70 m), affected by diffuse silicification and with black chert of volcanic origin, in places including conglomerates and rare coal layers, follow above. A huge dacite lava flow (Bruncu Santoru, ca. 180 m thick) occurs on the top; elsewhere, this manifestation is associated with, or followed by, rhyolitic volcaniclastic deposits, mostly in the form of tuffs and ignimbrites; dacite and rhyolite dykes, cross-cutting the Variscan basement and the overlying units, also crop out. Middle Jurassic carbonate rocks rest unconformably on the Permian succession.

The above-mentioned finer laminated and carbonate sediments yield a fossil macro- and microflora, amphibians, algal stromatolites, ostracods and fish teeth, which have been related to the Early Permian ("Autunian").

On returning to the Hotel S. Elmo, the participants enjoyed a performance of traditional Sardinian dances and songs.

17 September (Speakers: Broutin, Cassinis, Cortesogno, Gaggero, Sarria)

The Seui Basin, in central Sardinia (Barbagia di Seulo), was the topic of the third day. At the first stop, a panoramic view from a site (the small church of San Sebastiano), located in the southern sector, led the participants to examine the bulk of this trough, which can be considered the most example on the island when studying and refining the local sedimentary and volcanic systems, and the geological evolution.

Sedimentation in the basin again began with an alluvial "Basal Conglomerate". Rhyolite pyroclastic layers suggest early volcanic activity. Upwardly, fine fluvio-lacustrine-to-palustrine clastic and coal sediments generally follow. They are cut by and intercalated with andesitic bodies ("Porfiriti" *Auct.*), in the form of plugs and lavas. The succession is topped by rhyolitic ignimbrites, probably originating in the north of the basin, where they attain more than 500 m in thickness at Mount Perdedu. Meanwhile, along the northern boundary of this small basin, large calcalkaline diorite dykes fed dacitic and rhyolitic domes, which intruded at shallow levels and inflated the Variscan crystalline basement and/or the overlying sediments. Due to dome intrusions, slices of metamorphic basement were emplaced locally over the Lower Permian, volcanic and sedimentary deposits.

A large part of the fossil macroflora ascribes the Seui sediments to the Autunian. However, the chronostratigraphy of the overlying volcanic rocks, due to the irregular radiometric dates and the need for more careful correlation with other volcanic sections of Sardinia, deserves additional study.

The second stop in the basin was preceded by a rustic but substantial lunch in the field (with "porchetta" and other Sardinian foods, accompanied by local red wine, myrtle liqueur and "Filu Ferru" brandy), kindly prepared by the native Calzia family (Fig. 3). This surprise lunch allowed the participants to appreciate greatly some of the typical and famous produce of the island.

Stop 2, on the northern side of the Seui Basin, allowed the group to collect from fine clastic sediments a large number of plant-bearing samples, related by the accompanying paleobotany specialists to a presumed "Autunian interval".

Later, after a long trip, the group reached Alghero, on the northwestern coast.

18 September (Speakers: Cortesogno, Gaggero, Fontana, Neri, Oggiano)

The Permian-Triassic succession of Cala Viola-Porto Ferro was the main topic. However, an intense downpour forced the organisers to make the first presentation on the local sections in a bar. Once the sun returned, the Torre del Porticciolo (Stop 1) and the Cala Viola (Stop 2) successions were examined in the field (Fig. 4). They are generally represented by red clastics. In particular, two units are recognisable. The lower one is made up of sandstones and subordinate pelites, both rich in well defined sedimentary structures (trough cross-bedding, fluvial channels, bioturbation, etc.). The onset of the overlying unit is marked by a disconformity. The lowermost part consists of a well-sorted quartz conglomerate, 5-7 m thick, passing upwards to more sandstones and minor pelites. Plant remains, ascribed to *Equisetum mougeotii*, occur locally. At Cala Viola, the upper boundary of this unit, which resembles the typical Buntsandstein of Western Europe, is in tectonic contact with Keuper deposits.

Stop 3 was at Torre Nera, on the rocks which, to the north, surround the large beach of Porto Ferro. Reddish coarse sandstones and polygenic conglomerates, along with subordinate finer lithotypes, crop out. Trough cross-bedded sandy or gravel bodies appear mainly amalgamated and thick (> 1 m) bars with step foreset occur. The sedimentary facies indicate an overall braided-river setting.

Fig. 3 – Enjoying a "light" Sardinian lunch near the village of Seui, Barbagia, central Sardinia.

Fig. 4 – Taking a break in front of the Porticciolo hillock, Nurra, NW Sardinia.

This tract of section (about 50 m thick) lies below the previous Torre del Porticciolo and Cala Viola successions, but the age is as yet unknown. However, as these red beds developed later then the Autunian plant-bearing P.ta Lu Caparoni Fm., which crops out in this sector, their general attribution to late Early Permian and/or slightly younger times may be suggested. Therefore, the described interval corresponds, at least in part, to the "Saxono-Thuringian" of the French authors.

Later, outside the programme and the topic of the meeting, an additional stop was made, in order to illustrate the structural setting of the Monte Santa Giusta area, on the way to the last stop.

Stop 4 highlighted the Permo-Triassic sequence, probably found in other parts of northwestern Sardinia, near Porto Torres. The investigated section led to the recognition of basal rhyolitic volcanic products (ignimbrites and tuffs), heavily weathered and tectonised. Reddish clastic sediments crop out above but, although their alluvial environment is obvious, detailed facies analysis is prevented by poor exposure. On the top, a quartz-conglomerate bank (ca. 2 m thick) occurs (Fig. 4). It is regarded, at least so far, as the lateral equivalent of that confined in the basal Buntsandstein between the Torre del Porticciolo and the Cala Viola successions. The conglomerate bank is overlain by a thin silty-sandy succession and by, a few metres above, the Middle Triassic Muschelkalk. The thickness (about 100 m) of these local red beds records a slightly reduced subsidence rate. According to some authors, it is also noteworthy that the volcanic products are alkaline in nature, and consequently demonstrate the presence of a second anarogenic magmatic cycle in Nurra, as in Corsica, southern France and the Pyrenees.

Later, the participants reached Porto Torres, in order to embark for Genova.

19 September

Following an early morning arrival in Genova, the participants were transported to Brescia for the Conference.

THE CONFERENCE IN BRESCIA (20-22 SEPTEMBER)

20 September

According to the programme, the opening ceremony began at 10.00h. First, speeches were given by the Mayor of Brescia, Prof. Paolo Corsini, and Prof. Mario Vanossi, as Director of the Earth Science Department and Head of the "Alps Group" in Pavia, from where the meeting initiative started. They are reported at the beginning of this volume.

Later, after a welcoming reception, Prof. Peter A. Ziegler from the University of Basel opened the Conference with a general lecture on the "Late Palaeozoic-Early Mesozoic Plate Boundary Reorganization: Collapse of the Variscan Orogen and Opening of Neotethys". This extensive and updated geological framework, from the Late Carboniferous to Middle-Late Triassic times, was greatly appreciated by the participants. Later, there was a guided tour of the Science Museum by its curator Dr. Paolo Schirolli.

In the afternoon, the oral sessions began. The first one was devoted to paleontological, stratigraphical, sedimentological and paleogeographical contributions. It consist-

Fig. 5 – Participants' group photograph outside the Natural Sciences Museum of Brescia.

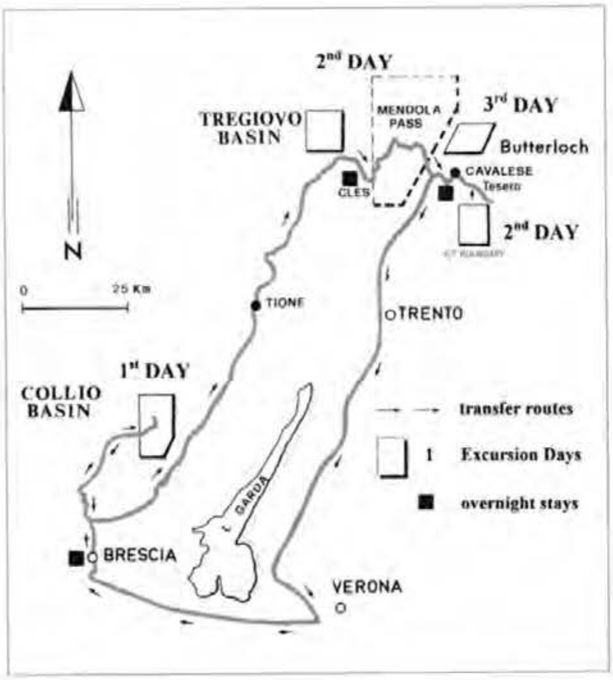

Fig. 6 – Excursion itinerary (23-25 September) and stops on the Permian of the central-eastern Southern Alps.

ed, in this first day, of six oral presentations (H. Kerp, P. Pittau, J. Utting, C. Spinosa, S. Voigt and U. Nicosia). A poster session was drawn up. Independent meetings on differing Permian subjects were also promoted early in the evening.

After dinner, the participants enjoyed an organ concert by Mrs. Eva Frick Galliera in the church of S. Gaetano, in Brescia.

21 September

The previous session (1) continued, and another one (2), on the Permian-Triassic boundary in central to eastern European areas, followed. Both the sessions included 13 oral presentations (H. Haubold, R. Wernenburg, D. Sciunnach, A. Schaefer, J.P. Deroin, C. Virgili, J. Schneider, A. Vozarova, M. Popa, A. Del Bono, E. Malysheva, Z. Liao and S. Radrizzani). A poster session followed. As on the first day, independent meetings on various subjects were held.

A conference dinner, in the picturesque "Porta Bruciata" restaurant, was enjoyed by a part of the group.

22 September

Session 2 and three others, on the Late Carboniferous to Permian volcanism and tectonics of some European and external regions, as well as on the subdivision and discussion of some time-scales, represented the aim of this last day. Nine presentations were given by C. Neri, V. Lozovsky, N. Capuzzo, P. Brack, C. Breitkreuz, J. Feijth, N. Esaulova, M. Menning and B.R. Wardlaw, respectively. A poster session was again drawn up.

The Conference ended with some general reflections on the topics highlighted by three-days of speeches and debates on the continental Permian, thanks to the involvement of the participants (Fig. 5).

A guided tour of the Museum of S. Giulia, in Brescia, concluded the programme.

THE FINAL EXCURSION IN THE CENTRAL-EASTERN SOUTHERN ALPS (23-25 SEPTEMBER)

The itinerary and general stops are indicated in Fig. 6.

23 September (Speakers: Brack, Breitkreuz, Cassinis, Cortesogno, Gaggero, Nicosia)

The day was devoted to examining the continental, sedimentary and volcanic Permian of the Brescian Pre-Alps. The visited outcrops occur between the Upper Trompia Valley and the Giogo della Bala, along the Maniva-Croce Domini road, south of the Tertiary intrusive Adamello massif. The lithostratigraphical succession is among the most notable in the Southern Alps, thanks to the numerous stratigraphical, sedimentological, paleontological and petrographical studies.

The first stop was a panoramic view of the Permian succession from the mountain crest beyond the Refuge Bonardi. The observed section reaches, in the upper Val Dasdana, up to 1500 m in thickness. From the base, the following units generally stand out: rhyolitic ignimbrites, unconformably overlying the Variscan crystalline basement; tuffs interbedded with some alluvial-fan clastic deposits; fluvial to lacustrine variegated and laminated sandy-shaly sediments (lower Collio Fm.); the M. Dasdana volcaniclastic mass-flow deposit, about 15 m thick; turbiditic, fluvial to lacustrine green-brownish coarse to fine clastic sediments (upper Collio Fm.); varicoloured conglomerates and sandstones intercalated with finer sediments which pass laterally into the Collio Fm. (lower Dosso dei Galli Conglomerate); stratified and bioturbated red-brown sandstones and siltstones ("Pietra Simona" Member of the Dosso dei Galli Conglomerate); coarse-grained reddish conglomerates, including metamorphic basement and volcanic rock-fragments, which upwards and laterally, towards the boundaries of the basin, progressively substitute part of the underlying Permian units; and massive rhyolitic-rhyodacitic ignimbrites ("Auccia Volcanics"). The lower volcanic and sedimentary succession (first Cycle or Cycle 1) is unconformably covered by the fluvial red beds of the Verrucano Lombardo Fm., which marks the beginning of Cycle 2.

Stop 2 allowed the participants to see in detail, along the Maniva-Croce Domini road, the boundary between the Variscan metamorphic substrate and the basal volcaniclastic unit (over 50 m thick) of the Permian succession. This boundary spans a gap of as-yet-unknown duration, which however, from local radiometric dates (339±8 Ma, Del Moro, pers. comm. and 283±1, Shaltegger & Brack, 1999, respectively), could be evaluated as about 60 Ma. The contact between the weathered basement and the overlying unconformable volcanics is locally affected by a slight Alpine dislocation. Furthermore, well-bedded varicoloured pyroclastic products (about 30-90 m thick), which include some alluvial bodies, come into tectonic contact with the underlying prominent ignimbrites. A brick-red bed with accretionary lapilli occurs at the top of this section. Immediately above, a conglomerate band (10-13 m), interpreted as a distal fan, marks the beginning of the Collio Basin. The subsequent, typical Collio beds (*Auct.*) are made up of laminated sandstones and shales, up to about 200 m thick, progressively green, reddish and black in colour. Researchers from Genova University gave explanations related to the aforementioned basal volcanics.

Generally, these Collio sediments mark a cycle (from distal alluvial fan to sandflat, mudflat and lacustrine environments) towards deeper water conditions. However, the presence of ripple-marks, mud-cracks, raindrops, and so on, as well as of tetrapod footprints indicate that the basin was never very deep and was often exposed. Carbonate lenses and nodules also occur, especially concentrated in the lower and middle parts of the section.

Stop 3 was along the watershed between the Trompia and Caffaro Valleys, at the sharp Maniva-C. Domini road-bend (2100 m a.l.m). The panoramic view enabled the group to examine in detail some units also seen from Stop 1, in particular the upper dark band of the lower Collio Fm., the M. Dasdana volcaniclastic beds, and the lower member of the Dosso dei Galli Conglomerate.

Fig. 7 – Taking shelter in the Val Trompia Basin, Mt. Dasdana, Brescian Prealps.

Specialists from Rome University presented a poster, showing the stratigraphic position and the names of the tetrapod footprints found in the Val Trompia-Val Caffaro area, from the lowermost Collio up to the first levels of the "Pietra Simona" Member of the Dosso dei Galli Conglomerate.

The stop also allowed the participants to note the local dark shales, traditionally rich in fossil plants and ichnofaunas, cropping out on the side of the road (Fig. 7). The included layers and nodules, which show yellow-orange in colour due to weathering, consist of spherulitic danburite, ankeritic carbonates with minor dravite and trace gold. These mineralisations are interpreted as precipitation from hydrothermal activity associated with the emplacement of the overlying volcaniclastic mass-flow deposits ("Dasdana Beds").

These deposits were the topic of nearby Stop 4. Recent investigations carried out by German geologists, in partial collaboration with Italian researchers, led to the interpretation of this and other subsequent key-beds as the result of a dome activity in the eastern Collio Basin. At Mount Dasdana, they consist of (1) a lower crystal-rich gravelly greyish sub-unit and (2) well-bedded, green, sandy-to-pelitic turbidites. In the former, black pelites (lacustrine Collio rip-up clasts), and various volcanic and metamorphic porphyritic SiO_2-rich lava fragments are included. According to the above authors, a presumed sublacustrine/subaerial eruption column formed as a consequence of the lava dome fragmentation, from which, in the first instance, dense crystal-rich mass flows originated. Much of the foamy lava fragments remained in the column and sedimented later in a second phase from dilute turbidity currents together with sandy-pelitic deposits, and from fall-out.

Stop 5 was at the upper Dosso dei Galli Conglomerate, on the western side of the type-locality. The unit, which is characterised by the inclusion of large Variscan metamorphic rock fragments and Permian volcanics, can be interpreted as a result of debris flows, in alluvial fan deposits.

Stop 6 was located at the topmost part of this "Conglomerate", near the boundary (not exposed along the road) with the overlying Auccia volcanics, reaching a maximum thickness of 130-140 m.

Stop 7 allowed the participants to examine the transition from the aforementioned volcanics to the Verrucano Lombardo, *i.e.* the contact between Cycles 1 and 2 of the Permian. The Auccia volcanics, which consist of massive violet rhyolitic/rhyodacitic ignimbrites, calcalkaline in composition, are subjected at the top to intense weathering and erosion processes. Therefore, a paleosol originated locally.

The Verrucano fluvial red clastics, which initially correspond to sandy braided-stream deposits, unconformably cover the Collio Basin area, and step down outside on to the Variscan crystalline basement. On the whole, the unit ranges from approximately 200 m to 500 m in thickness, and could be related to the onset of a new geodynamic regime.

Logistical and time problems forced the organisers to stop at the Giogo della Bala. A long trip, through the Trompia-Sabbia-Rendena-Meledrio-Sole valleys, led the participants to reach Cles in Val di Non (Trento region), late in the evening.

24 September (Speakers: Bargossi, Neri, Nicora, Radrizzani)

The Tregiovo Basin area was the aim of the early part of this geological excursion. Some researchers from Bologna University, the CARG project and the Geological Office of the autonomous province of Bolzano, who are involved in publication of the new local map at a scale of 1:50.000, illustrated the stratigraphy and petrography of some volcanic bodies underlying the lacustrine Tregiovo Fm., within the so-called Monte Luco stratigraphic sequence. After some brief stops, another followed near the base of the aforementioned sedimentary unit. The outcrops on the side of the road to Lauregno allowed the participants to collect a number of plant-bearing samples from the local fine blackish pelites.

The importance of the Tregiovo Fm. is due to the fossiliferous content, and consequently some knowledge of the presumed age. Investigations on the macroflora, microflora and tetrapod footprints have recently led researchers to relate the unit to the late Early Permian (Kungurian) and early Late Permian (Ufimian, perhaps up to Kazanian) times. However, this attribution deserves further paleontological and radiometric research, and correlation, for a general agreement. As the Tregiovo Fm. is overlain by the last volcanic products ("upper rhyolitic ignimbrites"), the age may approximate to the end of the volcanic activity in this sector of the Southern Alps; moreover, the chronostratigraphical classification would lead us to refine the boundary between the Permian Cycles 1 and 2, and indirectly to evaluate the time gap better.

The subsequent stop was near the Mendola Pass. The participants appreciated a panoramic view of the Athesian volcanics and, towards the east, the magnificent Dolomite Alps. A small guide for this stop was distributed.

The final stop of the day was on the well-exposed Tesero section, in Val di Fiemme (Western Dolomites), which crops out along a road near the village (Fig. 8). During the second half of the last century, this section became famous worldwide after the discovery of Permian-type, unworked brachiopods and foraminifers (= "mixed fauna") located about 1.5-2.0 m above the marine Bellerophon-Werfen lithostrati-

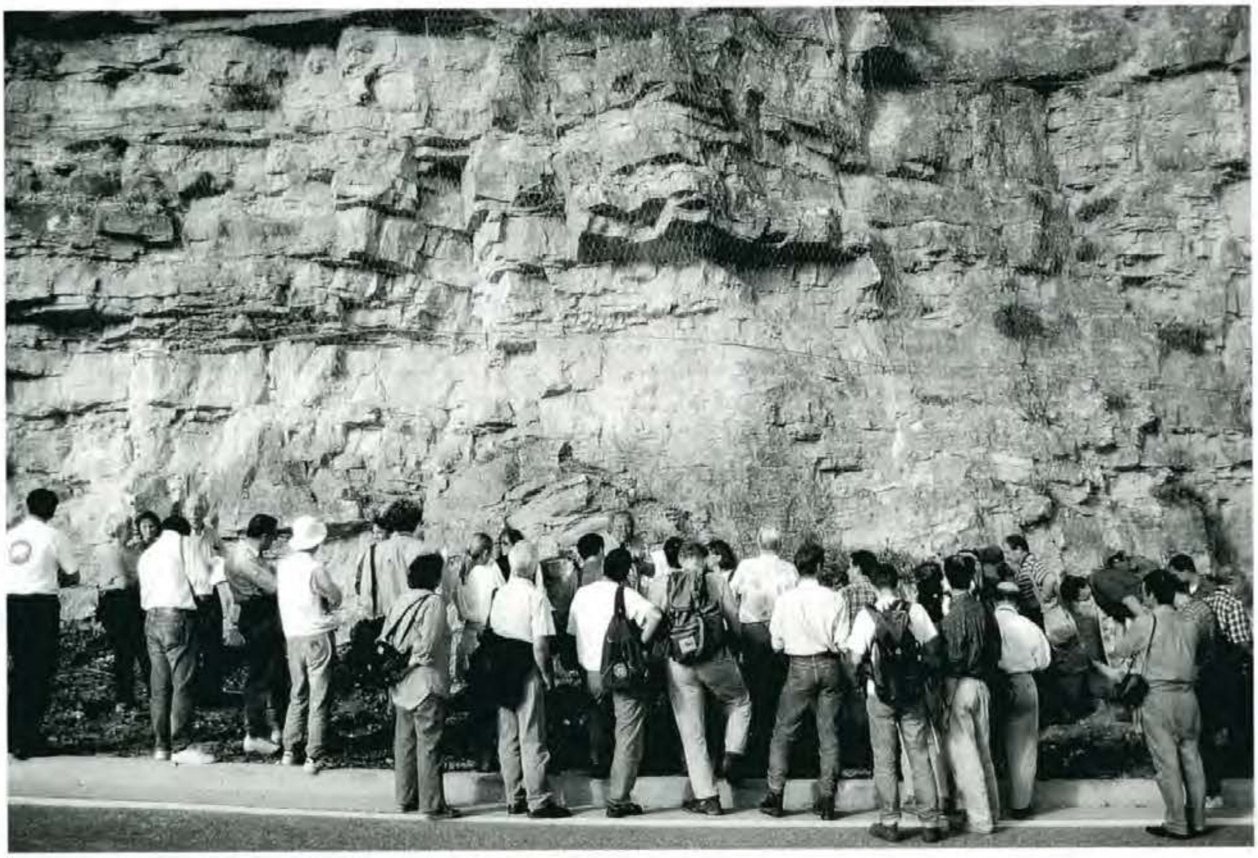

Fig. 8 - Participants observing the P/T boundary along the famous Tesero section, western Dolomites.

Fig. 9 – At the Bletterbach-Butterbloch waterfall, western Dolomites.

graphic boundary. This finding allowed a re-consideration of the position of the P/T boundary, traditionally placed at the base of the Tesero Member of the Werfen Fm. Paleontological, sedimentological and geochemical studies were intensively performed by Italian and foreign researchers. Recently, the discovery of conodont faunas led to a refinement of the debated chronological marker. The co-occurrence (35-40 cm above the onset of the Tesero Member) of *Hindeodus praeparvus* (Morphotypes M1 and M2), *Hi.* sp. *A* and a few ramiforms indicates the *praeparvus* Zone, considered the base of the Triassic by Orchard & Krystyn (1998). Upward (about 1.3 m above), *Hi. changxingiensis* also occurs along with *Hi. praeparvus*. The next conodont fauna is found in the lower Mazzin Member, 11 m above the base of the Werfen Fm.; it is characterised by *Hindeodus parvus parvus* associated with *Hi. praeparvus* M1. The former species represents the first conodont biozone of the Induan. In the Tesero section the FO of such a fossil is at least 8 m above the disappearance of the Permian-like components of the already recorded "mixed fauna".

Later, in the evening, the participants reached Cavalese, in Val di Fiemme.

25 September (Fontana, Massari, Kerp, Nicosia, Pittau)

The last day of this post-Congress excursion was once again dedicated to visiting the Bletterbach Gorge near Redagno (Radein), in Bolzano province. The local section has long been known for its spectacular outcrops and abundance of plant remains and tetrapod footprints, repeatedly highlighted in a very large number of old and current studies. The Upper Permian succession, which was the focus of attention, displays an overall transgressive trend, and may be divided into a number of depositional sequences (the first five and the lower part of a sixth sequence have been identified). It is made up of two sedimentary units represented, from base to top, by the continental fluvial red beds of the Val Gardena Sandstone, and by the evaporites to marine sediments of the Bellerophon Fm. Upwards the succession is followed by the Lower Triassic Werfen Fm., which initially includes the so-called "Tesero Horizon" *Auct.*

Four stops were made climbing the Bletterbach Gorge. They generally included, at different heights, stratigraphical, sedimentological, paleontological (on the fossil macroflora, microflora and the tetrapod footprints) and petrographical explanations. The first stop was at the famous Bletterbach waterfall (Fig. 9), the second one slightly upstream, the third at the most important ichnological site of the section, and the last stop at the head of the valley, where the upper part of the Permian succession and the overlying Lower Triassic and Anisian units are spectacularly exposed.

The excursion closed in Redagno, with a short visit to the new, small Natural Science Museum, which includes some geological drawings and samples of this area of the South-Alpine Permian, along with a number of fossils, mainly represented by tetrapod footprints and vegetal remains. Later, on behalf of the local community, Mr. Sepp Perwanger welcomed the participants. He also stressed that the geology of the investigated Bletterbach area has always attracted the interest of many Italian and foreign researchers. The organisers of the meeting thanked Mr. Perwanger and the other representatives for their warm hospitality. Finally, after eleven eventful days of enlightening debate and wonderful scenery, in a very friendly atmosphere, a hearty toast concluded the Congress.

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