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PHANEROZOIC PALEOENVIRONMENT AND PALEOLITHOFACIES MAPS. LATE PALEOZOIC

Mapy paleośrodowiska i paleolitofacji fanerozoiku. Późny paleozoik

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Abstract: The paper presents the detailed plate tectonic, paleogeographic, paleoenvironment and paleolithofacies maps for eight Late Paleozoic time intervals. These maps are dealing with the Devonian, Carboniferous and Permian time slices. The relationship of the continental configuration, lithofacies, tectonics and climate from the disassembly of Oldredia to the assembly of Pangea is clearly depicted on this series of reconstructions. The distribution of lithofacies shows climatic change associated with continental disassembly and assembly. The breakup of continents and origin of oceans generated basins related to rifting and passive margin development. The assembly of continents contributed to the formation of foreland basins. The subduction zones are related to the back-arc basins. The biological extinction events were perhaps related to the plate reorganization and mantle plume activity.

Key words: Devonian, Carboniferous, Permian, plate tectonics, paleogeography, mass extinction

Treść: Artykuł przedstawia szczegółowe mapy obrazujące tektonikę płyt, paleogeografię, paleośrodowisko i paleolitofacje ośmiu przedziałów czasowych późnego paleozoiku. Mapy dotyczą szeregu przedziałów czasowych w obrębie dewonu, karbonu i permu. Wzajemne stosunki pomiędzy konfiguracją kontynentów, litofacjami, tektoniką płyt i klimatem, jakie panowały w okresie od rozpadu superkontynentu Oldredia aż po powstanie nowego superkontynentu Pangen, są wyraźnie zaznaczone na poszczególnych mapach tworzących spójną serię rekonstrukcji palinspastycznych. Rozkład litofacji jest wyraźnie związany z rozpadem i łączeniem się kontynentów, a także ze zmianami klimatu wywołanymi tektoniką płyt. Rozpad kontynentów i tworzenie się oceanów wpłynęło na powstanie basenów związanych z ryftingiem i rozwojem krawędzi pasywnych. Łączenie się kontynentów przyczyniło się do tworzenia basenów przedgórskich. Strefy subdukcji związane są z basenami załukowymi. Zmiany klimatu i wymieranie są związane z reorganizacją płyt i aktywnością pióropuszy płaszcza.

Słowa kluczowe: dewon, karbon, perm, tektonika płyt litosfery, paleogeografia, masowe wymieranie

INTRODUCTION

The aim of this paper is the presentation of Late Paleozoic paleographic maps of the world, containing paleoenvironment and paleolithofacies details. The whole set of Phanerozoic maps will be published in four chapters. In the previous papers (Golonka *et al*. 1994, Golonka 2000, 2002, Golonka & Bocharova 2000, Golonka & Ford 2000) the author presented global paleogeographic maps or details of selected regions (Golonka 2000, 2002, Ford & Golonka 2003, Golonka *et al*., 2003a, b, 2006a, b, c). Similar maps were presented before (Golonka 2007), but they covered only Late Triassic and Early Jurassic time slices. Now, the author attempts to cover the entire Phanerozoic in four papers. This paper is dealing with the Devonian (three time slices), Carboniferous (three time slices) and Permian (two time slices). The papers covering Early Paleozoic and Cenozoic will follow soon. The maps were constructed using a plate tectonic model, which describes the relative motions between approximately 300 plates and terranes. The detailed reconstruction methodology was described previously in Golonka *et al*.'s (2003b) paper. The rotation file was presented in Golonka's (2007) paper (the appendix, online version only). The facies were assembled according to rules established during the production of Phanerozoic reefs map (Kiessling *et al*. 1999, 2003), and also presented by Golonka *et al*. (2006a, b, c) and Golonka (2007).

MAP DISCUSSION

Early Devonian

One enigmatic large supercontinent Oldredia existed during Early Devonian times (Figs 1–4). Its southern part, Gondwana (Figs 1, 2, 5) existed previously, during Early Paleozoic times (Scotese & McKerrow 1990, Golonka 2000, 2002). South America, Africa, Madagascar, India, Antarctica and Australia formed main part of Gondwana (or Gondwanaland, see Veevers 2004). Yucatan, Florida, central European (Cadomian) terranes between the Armorica and Bohemian Massif, Moesia, Iberia, Apulia, and smaller, southern European terranes, central Asian terranes (Karakum and others), China (several separate blocks) and the Cimmerian terranes of Turkey, Iran, Afghanistan, Tibet and Southeast Asia were adjacent to Gondwana during Early Devonian. Laurussia was assembled during Caledonian orogeny. North America, Baltica, Avalonia and Chukotka-Slope plates form the Laurussia continent (P.A. Ziegler 1982, 1988, 1989, 1990). Its central part was occupied by the large mountain belt (Figs 2–5). A late stage of thrust-related deformation occurred in northern Scandinavia (Soper *et al*. 1992). According to Milnes *et al*. (1997), eclogites formed about 410 Ma in Norway, in an over-deepened root of Baltica, which had developed in the ductile lower crust, as a response to extreme crustal shortening (Golonka 2002). Late Caledonian deformation was also noted in Polish and German Caledonides (Fig. 5) (Pożaryski *et al*. 1982, P.A. Ziegler 1982, Golonka 2002, Golonka *et al*. 2006b). In North America (Fig. 2 on the interleaf) the Caledonian collisional event, known as the Acadian orogeny, also went into its late stage, involving western Avalonia and Laurentia (McKerrow *et al*. 1991, Rast & Skehan 1993, Golonka 2002). At the same time extension began in the Caledonides (Milnes *et al*. 1997, Rey *et al*. 1997) and the Rhenohercynian Basin was established on the former Avalon terrane, along the South Laurussian margin (P.A. Ziegler 1989, Franke 1992, Franke *et al*. 1995).

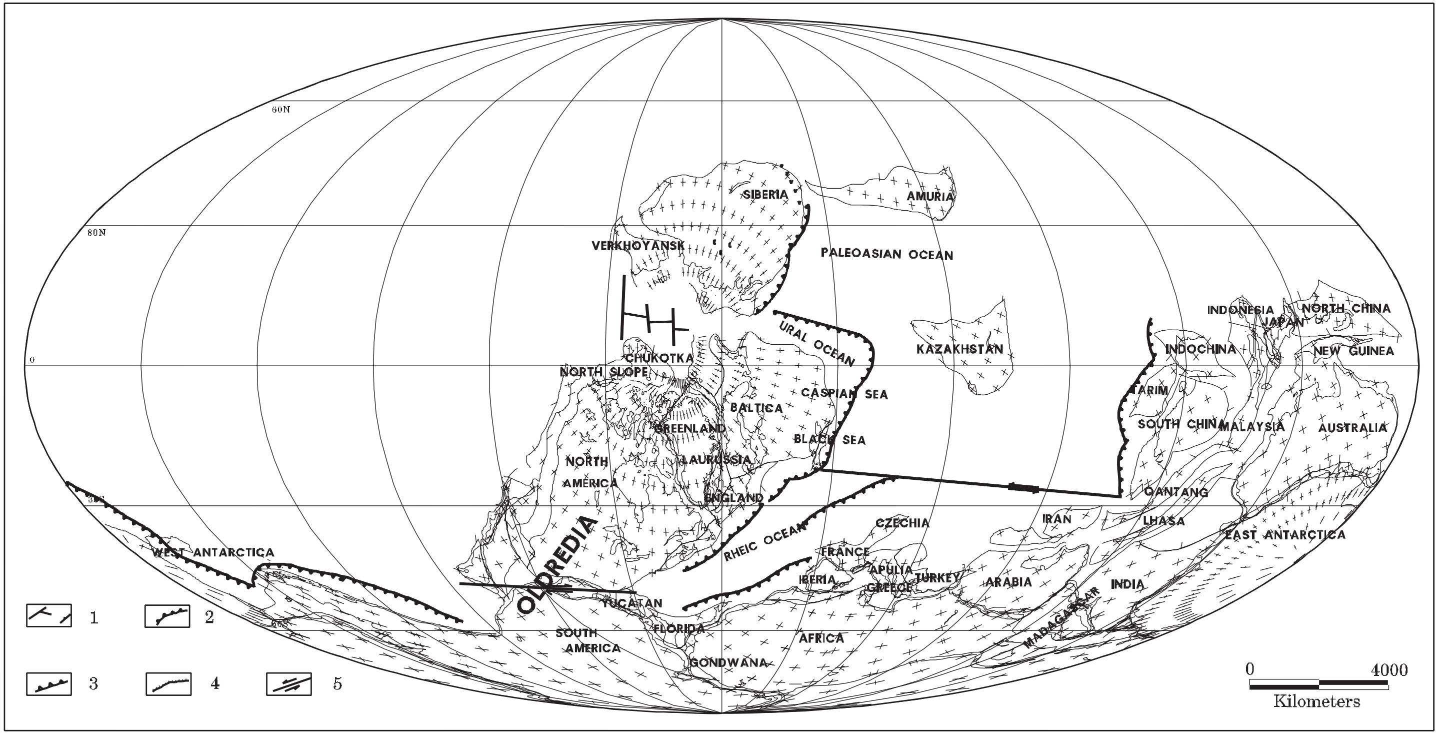

Fig. 1. Plate tectonic map of Early Devonian (plates position as of 401 Ma). Modified from Golonka (2002): 1 – oceanic spreading center and transform faults, 2 – subduction zone, 3 – thrust fault, 4 – normal fault, 5 – transform fault

Fig. 1. Mapa tektoniki płyt wczesnego dewonu (pozycja płyt 401 milionów lat temu). Zmieniona wg Golonki (2002): 1 – centrum spredingu oceanicznego i uskok transformujący, 2 – strefa subdukcji, 3 – nasunięcie, 4 – uskok normalny, 5 – uskok przesuwczy

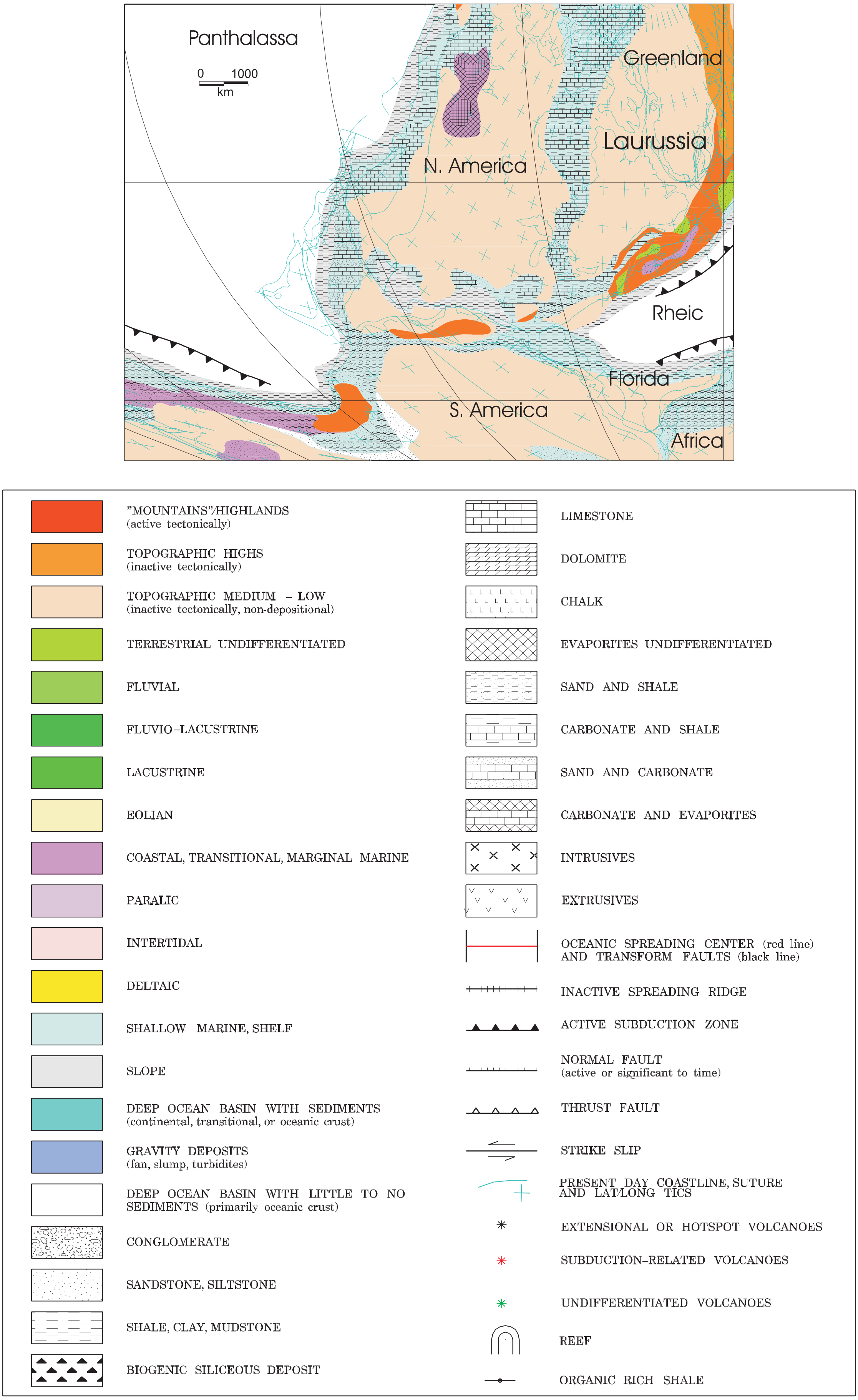

Fig. 2. Plate tectonic, paleoenvironment and lithofacies map of western Laurussia, adjacent Gondwana and Rheic Ocean during Early Devonian time. Explanations to figures 2–5, 7–10, 12–15, 17–20, 22–25, 27–30, 32–35, 37–40. Qualifiers: B – bauxites/laterites, C – coals, E – evaporites, F – flysch, Fe – iron, G – glauconite, M – marls, O – oolites, P – phosphates, R – red beds, Si – silica, T – tillites, V – volcanics

Fig. 2. Mapa tektoniki płyt, paleośrodowiska i litofacji zachodniej Laurosji oraz przyległych obszarów Gondwany i oceanu Rheic we wczesnym dewonie. Objaśnienia do figur 2–5, 7–10, 12–15, 17–20, 22–25, 27–30, 32–35, 37–40. Oznaczenia literowe: B – boksyty/lateryty, C – węgle, E – ewaporyty, F – flisz, Fe – żelazo, G – glaukonit, M – margle, O – oolity, P – fosfaty, R – utwory czerwone, Si – krzemionka, T – tillity, V – utwory wulkaniczne

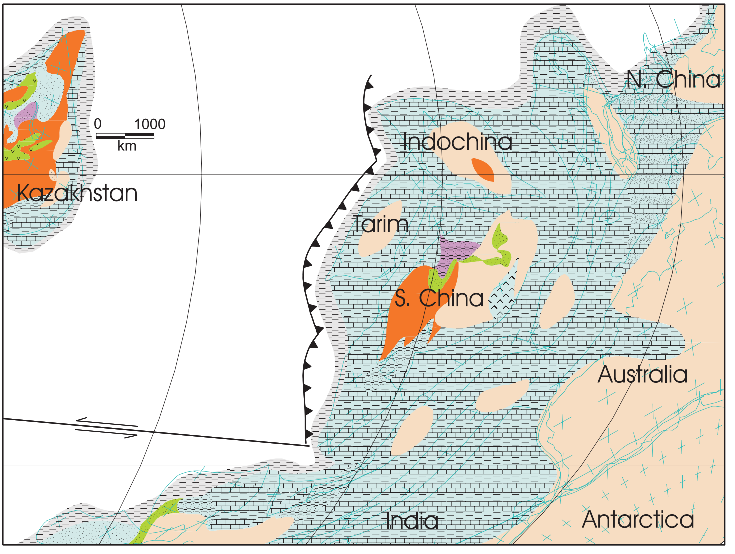

Fig. 3. Plate tectonic, paleoenvironment and lithofacies map of China, Indochina and adjacent areas during Early Devonian time

Fig. 3. Mapa tektoniki płyt, paleośrodowiska i litofacji Chin, Indochin oraz obszarów sąsiednich we wczesnym dewonie

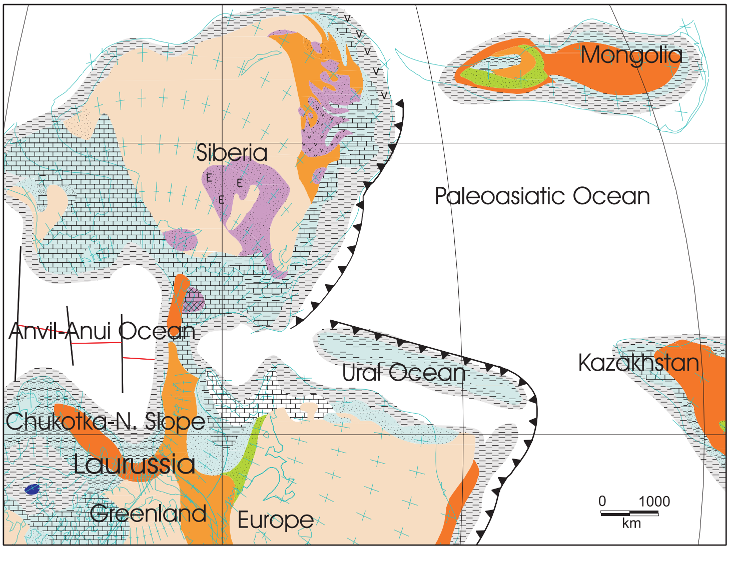

Fig. 4. Plate tectonic, paleoenvironment and lithofacies map of Siberia, northern Laurussia, Paleoasiatic Ocean and adjacent areas during Early Devonian time

Fig. 4. Mapa tektoniki płyt, paleośrodowiska i litofacji Syberii, północnej Laurosji, Oceanu Paleoazjatyckiego oraz obszarów sąsiednich we wczesnym dewonie

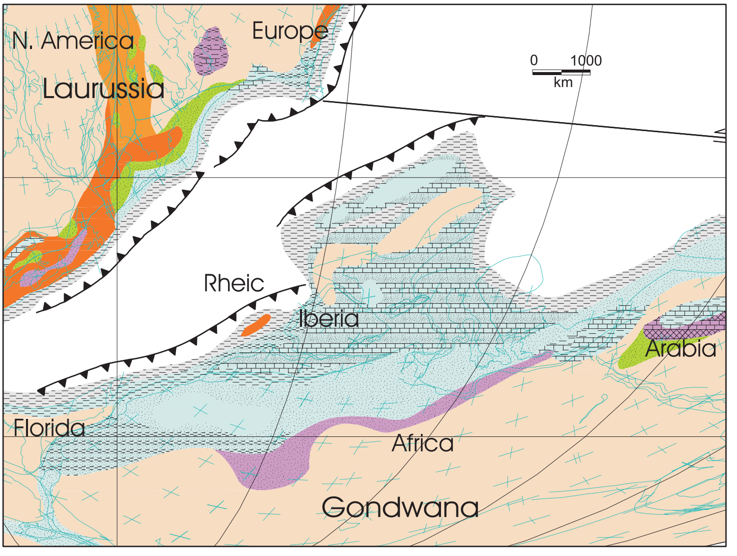

Fig. 5. Plate tectonic, paleoenvironment and lithofacies map of northern Africa, Peri-Gondwanian Europe, southeastern Laurussia, Rheic Ocean and adjacent areas during Early Devonian time

Fig. 5. Mapa tektoniki płyt, paleośrodowiska i litofacji północnej Afryki, perygondwańskiej Europy, południowo-wschodniej Laurosji, oceanu Rheic oraz obszarów sąsiednich we wczesnym dewonie

Transgression occurred in the north-western part of the Laurussia continent (Fig. 2), as the result large West Canadian basin appeared, the size of which increased in the Early Devonian times (Cook & Bally 1975, Ronov *et al*. 1984, P.A. Ziegler 1988, 1989, Bally 1989, Ford & Golonka 2003, Golonka *et al*. 2003a). Mainly carbonates containing coral--stromatoporoids patch reefs (Copper 2002) were accumulated in the basin, while salt-bearing complex with the thickness of up to 400 m was formed in its southern gulf. The relatively narrow seaway between Northern Canada and the Mid-continent area in North America was covered with mixed carbonate-clastic sediment (Golonka 2000, Kiessling *et al*. 2003). A fraction of terrigeneous rocks in sediments of the relic Michigan and Hudson basins increased. In depressions adjacent to the Appalachian belt, only sandy-argillaceous deposits were accumulated. The wide and long Peri-Cordilleran basin continued to subside, its permanent subsidence was compensated by accumulation of shelf carbonate and terrigeneous rocks, whose thickness gradually increased westwards and was as large as 400–500 m. Mixed carbonate-clastic sedimentation prevailed in the Ouachita area (Golonka *et al*. 2006c).

According to Golonka (2002) there is a possibility of Early Devonian collision between South and North America (see also Keppie 1989, McKerrow *et al*. 1991, Dalziel *et al*. 1994, Keppie *et al*. 1996). It is documented by orogenic events in Venezuela, Columbia, Peru, and northern Argentina (Gallagher & Tauvers 1992, Williams 1995). Paleomagnetic data (Kent & Van der Voo 1990, Van der Voo 1993, Lewandowski 1998, 2003) and paleobiogeography (Young 1990) support the hypothesis about the proximity of South and North America.

The Carolina region (Rast & Skehan 1993) also contains an element of collision and transpression between South and North America (Fig. 2), acting as an indenter, with a dextral strike-slip component. The Western Rheic Ocean was closed at that time and with Siberia in contact with Laurentia (Figs 1, 4), all major continents were together forming the supercontinent Oldredia (Golonka 2000, 2002). In the Peri-Andean zone of South America, the Early Devonian was characterized by a new wave of transgressions and subsidence which occurred also in the Amazon, Maranao and Parana basins (Ronov *et al*. 1984, Williams 1995, Andreis & Archangelsky 1996, Gonzales-Bonorino & Llammbias 1996, Milani & Zalán 1999, Ford & Golonka 2003, Limarino & Spalletti 2006).

The peak of orogenic process occurred during Early Devonian time within Southeast Asia and South China (Fig. 3) (Golonka *et al*. 2006b). In Northern Vietnam deep-water Ordovician and Silurian synorogenic deposits were replaced by continental Early Devonian red beds (General Department 1973, 1978, Tri 1979, Luong & Bao (eds) 1988, Tien P.C. 1989). The important unconformity is visible between Early Paleozoic rocks and Middle--Late Devonian carbonate deposits in Northern Vietnam (Pająk *et al*. 2006). The similar unconformity exists in the adjacent part of China. According to Leloup *et al*. (1995), within Yangtze paraplatform south of Kunming, the lowermost sediments are folded (schistosed Proterozoic shales, carbonates and volcanoclastics). These sediments are covered by Lower Devonian conglomerates and sandstones, followed by Upper Devonian, Carboniferous and Permian shallow-water carbonates. Red beds are also known from Malaysia (Meor & Lee 2005). The mixed carbonate sedimentation containing reefs (Copper 2002) was widespread on Eastern Gondwana, in Indochina, North India and part of South China and Tarim (Fig. 3) (Ronov *et al.* 1984, Hongzen 1985, Gupta & Brookfield 1991, Golonka *et al*. 2006).

Uplifting occurred in Siberia (Fig. 4) (Vinogradov 1968, Ronov *et al*. 1984, Zonenshain *et al*. 1990, Parfenov 1992, 1997, Parfenov *et al*. 1993, Khudoley & Guriev 1994, Vernikovsky 1995, Puchkov 1996, Golonka *et al*. 2003a). The size of the Tunguska basin became even smaller, it was separated into several basins by plain continental zones and developed as shallow half-closed marine basin with an increased water salinity, in some places thick layers of gypsum, sometimes of salt, where deposited together with other sediments. Major part of the deposits is formed there by terrigeneous (both continental and marine facies) and carbonate rocks with the thickness of tens of meters. Basins of the similar type developed in the lower course of Khatanga and in the North Land. Vast Paleoasiatic Ocean connected with Ural Ocean existed between Mongolia, Siberia and Kazakhstan plates (Zonenshain *et al*. 1990, Puchkov 1991, 1996, 1997, Pechersky & Didenko 1995, Golonka 2000, 2002). Siberia began a clockwise rotation gradually closing the Ural-Paleoasiatic Ocean (Smethurst *et al*. 1998). The southern (in present day coordinates) margin of Siberia collided with several microcontinental plates (Zonenshain *et al*. 1990). The clockwise rotation of Siberia caused rifting between the Chukotka-North Slope and the Verkhoyansk terranes, and origin of Anvil-Anui Ocean (Trettin 1989, Parfenov 1997, Golonka *et al*. 2003a).

In the Early Devonian, carbonate sedimentation occurred for the first time in the Phanerozoic, on the Central European part of Gondwana (P.A. Ziegler 1989), due to the movement of these terranes to lower latitudes. Large territories of the Sahara basin underwent regression (Ronov *et al*. 1984, Villeneuve & Dallmeyer 1987, Lécorché *et al*. 1989, P.A. Ziegler 1989, Caby 2003, Ford & Golonka 2003, Villeneuve 2005). An input of coarse-fragmented material increased, it indicates that upwelling in the central parts of the platform became more intensive. Continental facies were widespread in the marginal zones of the Sahara basin. High intensity of tectonic movements resulted in a formation of separate troughs and depressions with more high sedimentation rates. Marine basin in the central part of the Arabia peninsula underwent regression and became smaller, it was a half-closed basin with increased water salinity. Besides sandy-argillaceous deposits, carbonates and gypsum were deposited there.

Middle Devonian

During Middle Devonian times, rifting of continental margins of Oldredia (Fig. 6) led to disassembly of the supercontinent (Golonka 2000, 2002). Strike-slip movements and extension in Caledonides in Scandinavia and Greenland followed transtensional orogenic collapse (Fig. 7) (Soper *et al*. 1992, Golonka 2000, 2002, Ford & Golonka 2003). According to Golonka *et al*. (2006c) the lithostratigraphic sequences in the future Ouachita foldbelt between North and South America support the geodynamic evolution of basin from rift through oceanic passive margin. During the Middle Devonian (Fig. 7), the deep-water oceanic-type basin developed on this area. The deep-water facies consist chiefly of novaculite, a light-colored, extremely fine-grained, homogenous, highly fractured siliceous rock similar to cherts, but characterized by a dominance of quartz rather than chalcedony.

In the cratonic part of North America transgression continued (Golonka 2000, Ford & Golonka 2003). The West Canadian and Illinois basins became larger, transgression took place as well in the Williston basin, and all three of the basins became connected by straights (Fig. 7) (Cook & Bally 1975, Ronov *et al*. 1984, Bally 1989, P.A. Ziegler 1988, 1989, Bally *et al*. 1989, Ford & Golonka 2003, Golonka *et al*. 2003a). The size of the Michigan and the Hudson bays became larger. Restricted conditions together with a warm climate were favorable for water stagnation, increased water salinity and intensive deposition of carbonates and evaporites, such as salt-bearing layers in the West Canadian, Williston and Michigan basins. Barrier reefs were widely developed in the West Canadian basin (Copper 2002). Terrigeneous rocks were not typical for the inner basins; only in the Michigan basin carbonates and evaporites were accumulated.

In South America seas covered relatively small area of the craton (Fig. 7) (Ronov *et al*. 1984, Williams 1995, Andreis & Archangelsky 1996, Gonzales-Bonorino & Llammbias 1996, Milani & Zalán 1999, Ford & Golonka 2003, Limarino & Spalletti 2006). In the Amazon basin transgression developed further to the west and as the result it became connected with the sea of the Andean mobile belt. Numerous uplifts and regressions developed in the zone of the straight which connected the Amazon and the Maranao basins, and broke the connection between them. Sedimentary deposits of the Amazon basin are formed by sandy-argillaceous rocks, some limestones were formed in the east. The sea of the Peri-Andean zone formed a narrow band along the entire Peru-Bolivian segment of the Andes. Terrigeneous deposits were accumulated there.

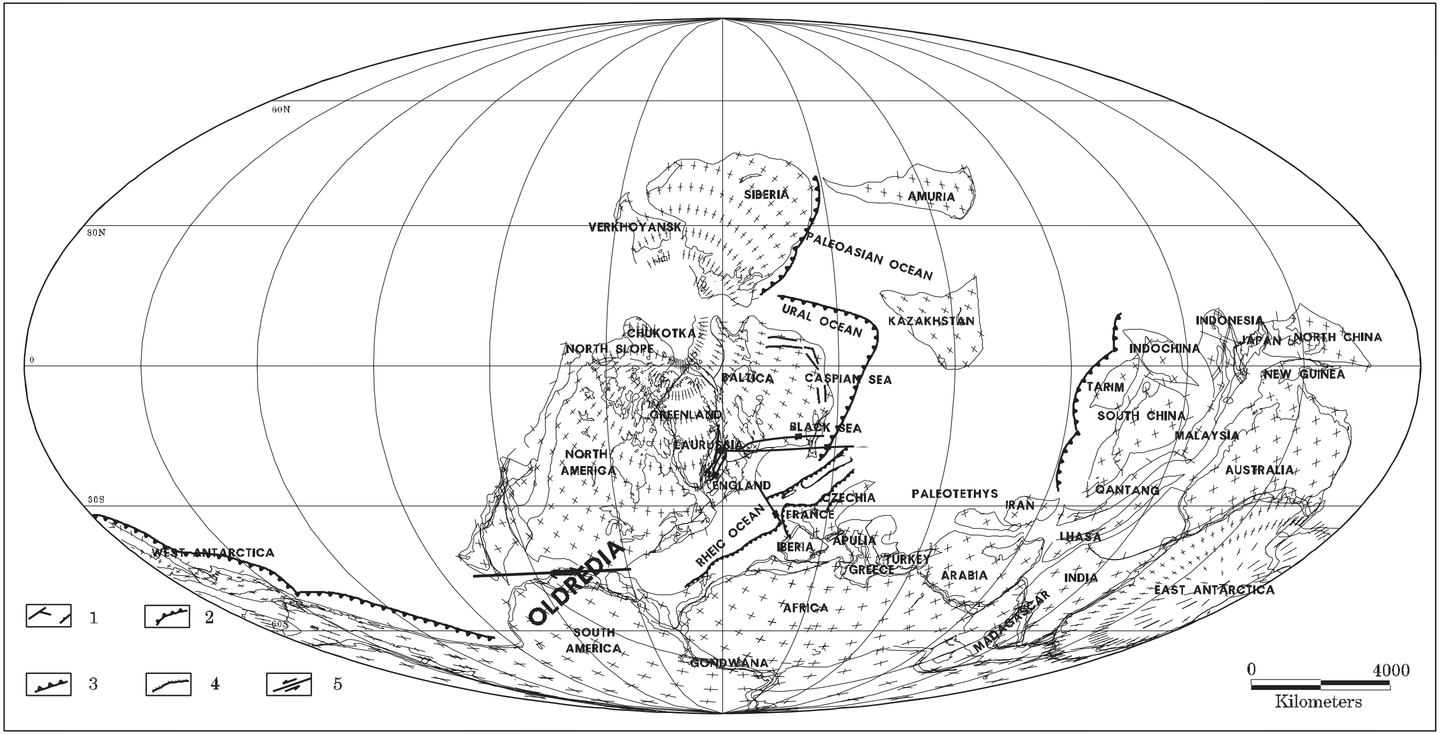

Fig. 6. Plate tectonic map of Middle Devonian (plates position as of 380 Ma). Modified from Golonka (2002, 2006a): 1 – oceanic spreading center and transform faults, 2 – subduction zone, 3 – thrust fault, 4 – normal fault, 5 – transform fault

Fig. 6. Mapa tektoniki płyt środkowego dewonu (pozycja płyt 380 milionów lat temu). Zmieniona wg Golonki (2002, 2006a): 1 – centrum spredingu oceanicznego i uskok transformujący, 2 – strefa subdukcji, 3 – nasunięcie, 4 – uskok normalny, 5 – uskok przesuwczy

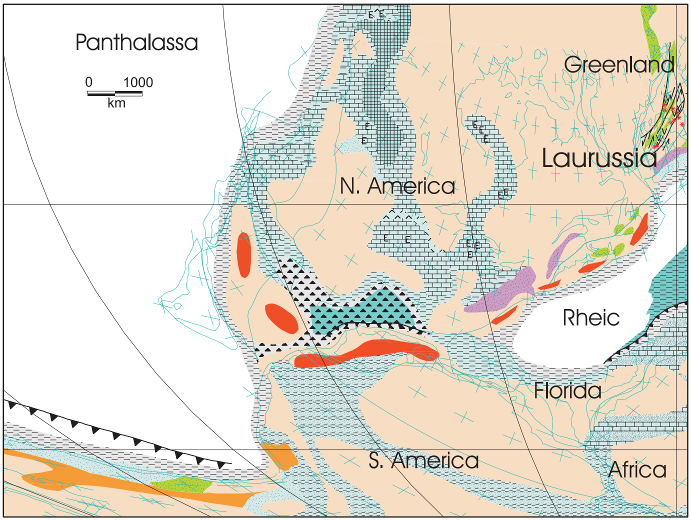

Fig. 7. Plate tectonic, paleoenvironment and lithofacies map of western Laurussia, adjacent Gondwana and Rheic Ocean during Middle Devonian time

Fig. 7. Mapa tektoniki płyt, paleośrodowiska i litofacji zachodniej Laurosji oraz przyległych obszarów Gondwany i oceanu Rheic w środkowym dewonie

The subduction zone was active in Eastern Gondwana (Figs 6, 8) (Golonka 2000, 2002, Golonka *et al*. 2006a). The position of Chinese plates and Tarim, prior to their assembly and suturing with Eurasia during Late Paleozoic – Mesozoic, is quite speculative and controversial (compare Nie *et al.* 1990, Scotese & McKerrow 1990, Zonenshain *et al.* 1990, Golonka *et al.* 1994, Metcalfe 1994, Eide & Torsvik 1996, Şengör & Natalin 1996, Yin & Nie 1996, Golonka, 2000, 2002). In the western part of South China plate (Shouxin & Yongyi 1991) and in Indochina (General Department 1973, 1978, Tri 1979, Luong & Bao (eds) 1988, Tien 1989, Brookfield 1996), the previous synorogenic and postorogenic facies were replaced by shallow water carbonates (Fig. 8). The mixed character of these carbonates is changing upward leading to the deposition of pure limestones and dolomites (Golonka *et al*. 2006a). Sandy-conglomerate, alluvium and coastal marine deposits were formed in marginal parts of basins. Towards the central part of the basin, they changed to carbonate and sandy-argillaceous shelf complexes. A development of a marginal basin continued in the north of Greater India. In the Himalayas and Southern Tibet, the Middle Devonian rocks are formed by carbonate-terrigeneous rocks (Gupta & Brookfield 1991). In the south, in coastal regions, these deposits are sandy.

The Tunguska and Taimyr basins in Siberia became smaller (Fig. 9) (Vinogradov 1968, Ronov *et al*. 1984, Zonenshain *et al*. 1990, Parfenov 1992, 1997, Parfenov *et al.* 1993, Khudoley & Guriev 1994, Vernikovsky 1995, Puchkov 1996, Golonka *et al*. 2003a). Their coastal line was not stable because of numerous regressions and probable connection between the Tunguska and Viluy basins at the end of the epoch. Argillaceous, calciferous and sulphate sediments dominate in the Tunguska basin, while their thickness in the Norilsk basin is up to 700 m. Water was of an increased salinity in the Khatanga basin and in the Northern Land (Severnaya Zemlya).

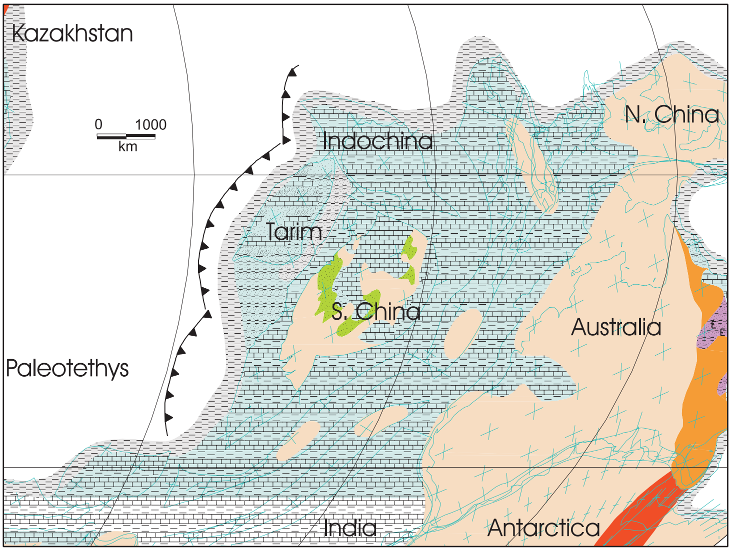

Fig. 8. Plate tectonic, paleoenvironment and lithofacies map of China, Indochina, Australia and adjacent areas during Middle Devonian time

Fig. 8. Mapa tektoniki płyt, paleośrodowiska i litofacji Chin, Indochin, Australii oraz obszarów sąsiednich w środkowym dewonie

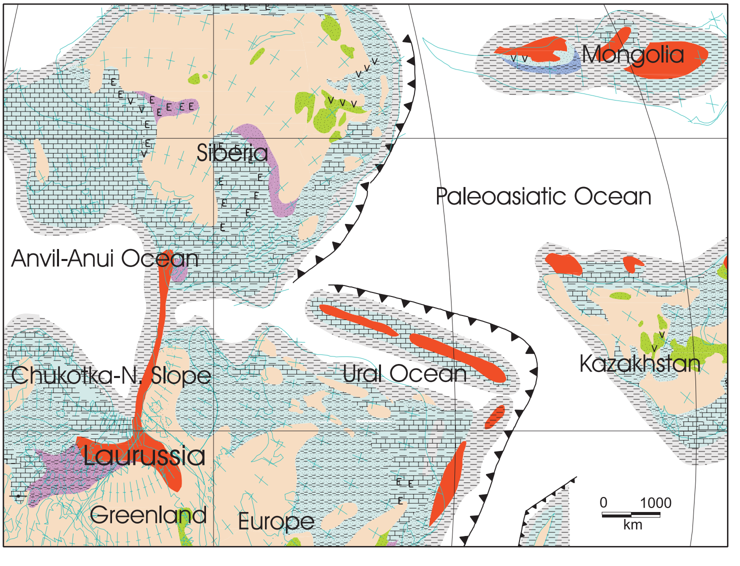

Fig. 9. Plate tectonic, paleoenvironment and lithofacies map of Siberia, northern Laurussia, Paleoasiatic Ocean and adjacent areas during Middle Devonian time

Fig. 9. Mapa tektoniki płyt, paleośrodowiska i litofacji Syberii, północnej Laurosji, Oceanu Paleoazjatyckiego oraz obszarów sąsiednich w środkowym dewonie

The Taimyr basin located between them was an open shallow sea with calciferous-dolomite sediments, with the thickness of up to 500 m. From the beginning of the Middle Devonian, intensive movements along faults resulted in a subsidence of the Viluy trough, where large volumes of plateau-basalts were erupted and continental red-colored and marine argillaceous and carbonate deposits (including sulphate) were formed. Thickness of the Middle Devonian rocks varies in wide limits. Maximal values were found for the Southern Verkhoyansk (up to 1.5 km). The Rybinsk depression was formed in the south-west of Siberia, it was filled with continental coarse-fragmented rocks – products of destruction of the adjacent Sayans orogen.

A large part of the Eastern Europe underwent an intensive transgression which, from the east, reached the central parts of the platform (Fig. 9) (Vinogradov 1968, P.A. Ziegler 1982, 1989, Ronov *et al*. 1984, Zonenshain *et al*. 1990, Nikishin *et al*. 1996, Golonka *et al*. 2003a, Mizens 2004). That transgression was maximal in the Givetian time when more than two thirds of the territory was covered by a sea. The Peri-Caspian basin became well pronounced for the first time in the Middle Devonian when deep-sea sediments (carbonate-argillaceous ooze) were accumulated there. Transgression developed from the east to the west, forming positive structures of the relief with an essential height. The Eifelian in the Saratov region was filled by variegated fluvial and lacustrine deposits. Complex of sedimentary deposits of the Middle Devonian time usually starts with variegated lagoon-continental association, which changed to shallow carbonates by the end of the epoch. In the lagoon of the Moscow basin, dolomites, gypsum and salt were accumulated. These rocks were developed to the south-east of the lower course of Volga. In the north of the craton where humid climate existed at that time, coal-bearing facies developed. Subsidence of the Dnepr-Donets trough started in the Givetian, being accompanied by accumulation of pelitic limestones and marls. Kazakhstan began to converge with Siberia, consuming the Paleoasiatic Ocean floor (Zonenshain *et al*. 1990, Puchkov 1991, 1996, 1997). According to Brown *et al*. (2006) the arc-continent collision with margin of Baltica took place in the Urals in Devonian time. The stable subsidence occurred in the Peri-Urals zone, and transgression developed westwards from it (Vinogradov 1968, Ronov *et al*. 1984, Zonenshain *et al*. 1990, Parfenov 1992, 1997, Parfenov *et al*. 1993, Khudoley & Guriev 1994, Vernikovsky 1995, Puchkov 1996, Golonka *et al*. 2003a). This zone can be traced from the southern part of the New Land (Novaya Zemlya) to the Southern Urals, some large islands remained uplifted there, and in their marginal parts a formation of iron-aluminum crust of weathering and accumulation of bauxites occurred during periods of regression. This marginal zone was a carbonate shelf, where carbonates (including reefogeneous limestones, see Copper 2002) were deposited, only lower parts of the section are formed by sandy rocks.

Subsidence became more intensive in the vast region of the Sahara basin (Fig. 9). Transgression developed southwards and eastwards and involved western parts of Egypt (Ronov *et al*. 1984, Villeneuve & Dallmeyer 1987, Lécorché *et al*. 1989, P.A. Ziegler 1989, Caby 2003, Ford & Golonka 2003, Villeneuve 2005). These large seas in the north and north-west of the craton were shallow; subsidence alternated there with regressions and uplifts, sandy-argillaceous sediments dominated. In the coastal southern zones (Niger, Chad, Sudan), alluvium-delta facies alternated with marine deposits. The Tindouf and Saoura--Ougarta basins were the deepest, and both clays and carbonates, including reefogeneous ones, were accumulated there. The zone of carbonate sedimentation of the Saoura-Ougarta depression became wider to the north, where it was connected with the shelf of the Peri--Atlas zone, which continuously developed as a marine basin. North-west of Sicily is a part of this marginal zone. Carbonate-buildup trends occurred along the north African and central European continental shelves (Ford & Golonka 2003). Many of these carbonate--rimmed shelves provided raised rims for intrashelf basins. The Rheic Ocean was significantly reduced during Middle Devonian times and northward drift of Gondwana resulted in complex tectonics along peri-Gondwanian active margin, with southward-dipping subduction zones (Fig. 10). A development of a semi-closed basin, where carbonates and sandstones were accumulated, continued in the Central Arabia (Ronov *et al*. 1984, Al-Laboun 1986, Alsharhan & Kendall 1986, McGillivray & Husseini 1992, McGillivray 1994). Thickness of the Middle Devonian rocks is as much as 1200 m there and indicates an intensive subsidence. Basins in the east and north-west of Iran became larger. Seas were rather shallow there and argillaceous deposits with the thickness of 200–400 m were accumulated.

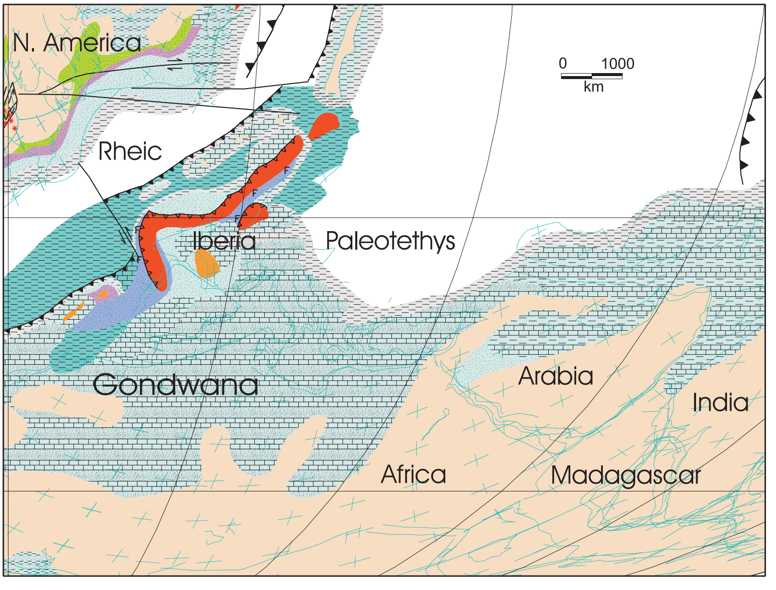

Fig. 10. Plate tectonic, paleoenvironment and lithofacies map of northern Africa, Arabia, Peri-Gondwanian Europe, Rheic Ocean and adjacent areas during Middle Devonian time

Fig. 10. Mapa tektoniki płyt, paleośrodowiska i litofacji północnej Afryki, Arabii, perygondwańskiej Europy, oceanu Rheic oraz obszarów sąsiednich w środkowym dewonie

LATE DEVONIAN

The Late Devonian was the time of disassembly of the Oldredia supercontinent (Figs 11, 12).

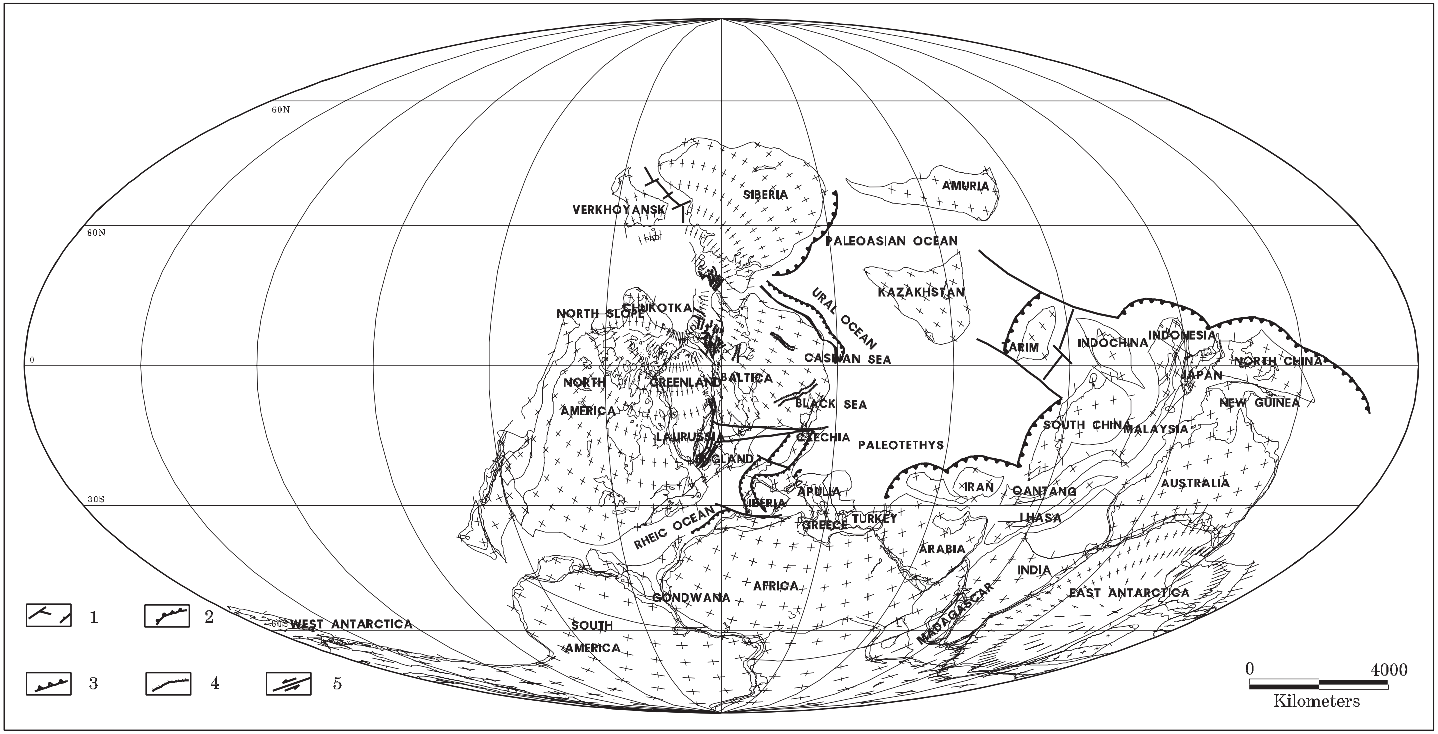

Fig. 11. Plate tectonic map of Late Devonian (plates position as of 370 Ma). Modified from Golonka (2002, 2006a): 1 – oceanic spreading center and transform faults, 2 – subduction zone, 3 – thrust fault, 4 – normal fault, 5 – transform fault

Fig. 11. Mapa tektoniki płyt późnego dewonu (pozycja płyt 370 milionów lat temu). Zmieniona wg Golonki (2002, 2006a): 1 – centrum spredingu oceanicznego i uskok transformujący, 2 – strefa subdukcji, 3 – nasunięcie, 4 – uskok normalny, 5 – uskok przesuwczy

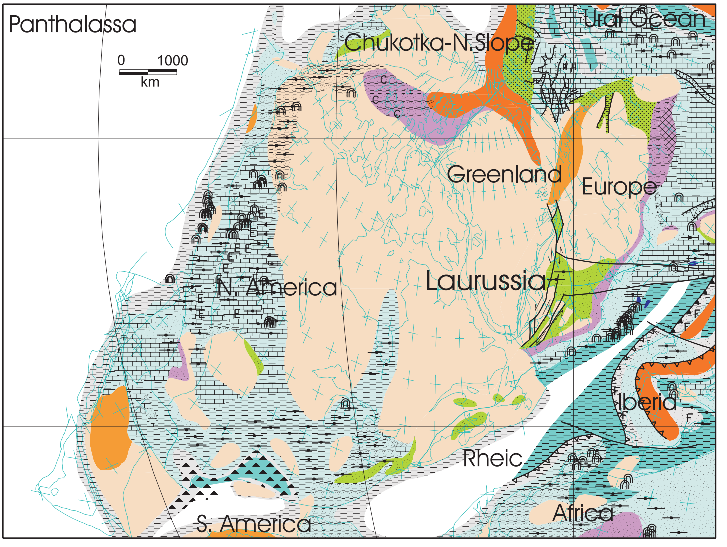

Fig. 12. Plate tectonic, paleoenvironment and lithofacies map of Laurussia, adjacent Gondwana, Rheic Ocean and adjacent areas during Late Devonian time

Fig. 12. Mapa tektoniki płyt, paleośrodowiska i litofacji Laurosji oraz przyległych obszarów Gondwany, oceanu Rheic oraz obszarów sąsiednich w późnym dewonie

South and North America become separated again due to somewhat faster rate of clockwise rotation of Laurussia compared to Gondwana (Scotese & Barret 1990, Scotese & McKerrow 1990,Torsvik *et al*. 1996, Golonka 2002, Ford & Golonka 2003). The gap was not very large, according to the Gondwana position of Scotese & Barret (1990), supported by Scotese & McKerrow (1990), Golonka *et al*. (1994), Williams (1995), Lewandowski (1998, 2003), and Ford & Golonka (2003). With an alternative position of Gondwana (Bachtadse *et al*. 1995), the gap seems much larger, particularly between Africa and Armorica. At the same time, the first contact between Laurussia and the Central European promontory of Gondwana occurred in the Tornquist-Teisseyre zone (Fig. 12), marking the onset of Hercynian orogeny (Golonka 2002, Ford & Golonka 2003). The remnant Rheic Ocean still existed during the Late Devonian, closing gradually with the movements of the Bohemian, Saxoturingian and Małopolska High terranes (Lewandowski 1998, 2003, Golonka 2000, 2002).

The Antler Orogeny occurred in western Laurussia, primarily in Nevada and California, where, during the Late Devonian to Early Carboniferous time, the contents of the Antler basin were deformed and thrust to the east. Sporadic evidence also exists in the rocks of British Columbia, Yukon Territory and Alaska (Oldow *et al*. 1989). This orogeny was perhaps a result of the collision of the eastward advancing island arc with the western margin of North America (Hamilton 1989). After the regression at the boundary between the Middle and Late Devonian, a new rather wide transgression developed in North America (Cook & Bally 1975, Ronov *et al*. 1984, P.A. Ziegler 1988, 1989, Bally 1989, Ford & Golonka 2003, Golonka *et al*. 2003a). The seas covered almost the entire craton, from the Peri-Cordilleran zone in the west to the Peri-Appalachian zone in the south-east.

Some basins had a specific features of facies distribution and thickness of sediments, among them were the Williston basin where accumulation of carbonates and, in the beginning of the epoch, evaporites dominated; and the West-Canadian basin where carbonate rocks with reefogeneous limestones (Webb 2002) formed a large part of deposits and made it different from the Peri-Cordilleran zone adjacent from the west. Argillaceous and sandy rocks dominated in the Peri-Cordilleran zone. Different carbonate rocks were accumulated as well in the south-western part of the craton, though even there, in the Californian part of the Peri-Cordilleran zone, carbonates gradually changed to terrigeneous rocks when moving to the mobile belt. The specific conditions existed in the south-eastern and eastern parts of the craton. There on a vast territory from the north-western Mexico and Arizona to the Hudson Bay. The Upper Devonian rocks are formed by a specific complex of homogeneous black bituminous schists. These Chattanooga schists (and those stratigraphically equivalent to them) include sometimes layers of cherts. Only in the Peri-Appalachian zone they change to "normal" sandy-argillaceous rocks, which reflected the Arcadian orogeny in the Appalachians. Novaculite deposition continued in the Ouachita basin (Golonka *et al*. 2006c).

Drifting of Tarim from South China (Fig. 13), in direction towards Kazakhstan could have occurred at that time (Metcalfe 1994, Golonka *et al*. 2006a). The end of the time slice may be was marked by the onset of drifting of the other Chinese plates. Most of Indochina was closely connected with South China Plate at this time (Fig. 21). Large carbonate platform existed on South China plate. According to Shouxin & Yongyi (1991), the limestones in west-central Guanxi and eastern Yunnan thick-bedded limestones with corals, brachiopods, stromatoporoids, bryozoans, tentaculites, and conodonts developed reaching the thickness over 1400 m.

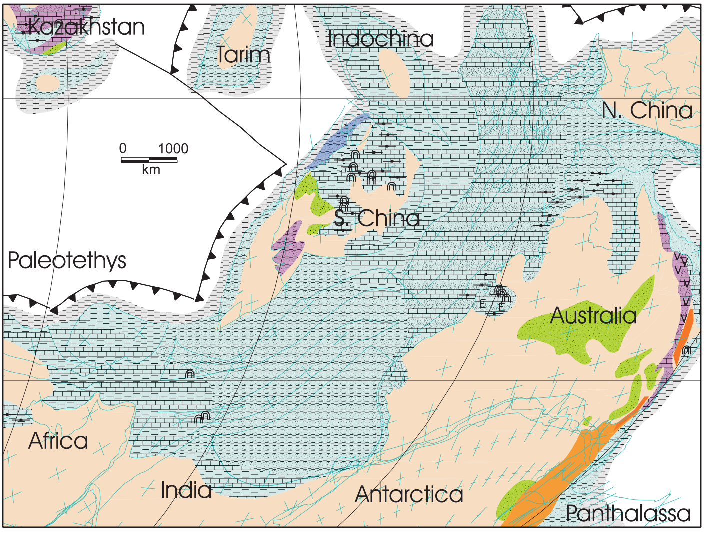

Fig. 13. Plate tectonic, paleoenvironment and lithofacies map of eastern Gondwana, Paleotethys and adjacent areas during Late Devonian time

Fig. 13. Mapa tektoniki płyt, paleośrodowiska i litofacji wschodniej Gondwany, Paleotetydy oraz obszarów sąsiednich w późnym dewonie

The carbonate buildups existed in proximity to the organic rich deposition, during the time of anoxia. This carbonate platform extended to the territory of Vietnam. Massive limestones outcropped in numerous places being subject of karst phenomena. These karst sculptured limestones occurred, among other places in Ha Long Bay area (Krobicki *et al*. 2006) forming beautiful landscape. A formation of shallow marine sandy-argillaceous deposits continued in Greater India, in the marginal basin of the Himalayas and the Southern Tibet (Gupta & Brookfield 1991). Subsidence and transgression occurred in the Carnarvon, Canning, and Bonaparte basins (Ronov *et al*. 1984, Cook 1990, Findlay *et al*. 1991). Their sizes were not large, however, rate of subsidence was rather essential, and thick (1–1.3 km) carbonate-terrigeneous deposits were accumulated there. A large area has again undergone subsidence and sedimentation in the Amadeus basin.

Development of major rift systems took place throughout Baltica and Siberia (Fig. 14). The Dnepr-Donetsk-Pripyat system (Fig. 14) went through the main phase of rifting on Baltica (Vinogradov 1968, P.A. Ziegler 1982, 1989, Ronov *et al*. 1984, Zonenshain *et al*. 1990, Nikishin *et al*. 1996, Golonka *et al*. 2003a, Mizens 2004). In the Dnepr-Donets trough volcanic eruptions were preceded by uplifts, after which a rather intensive subsidence occurred, as a result, a deep trough non-compensated by sedimentation appeared, later it transformed into a lagoon with salt accumulation. Thickness of terrigeneous and carbonate sediments in the coastal part of this trough is as large as 1.5 km. Rifting activity resumed along the eastern margin of Baltica, in the Barents Sea, Kola, Timan, Vyatka and Soligalich areas. All the above rifts were caused by back-arc extension, associated with subduction zone dipping towards the Baltica continent. In the Peri-Urals zone, subsidence was not interrupted by regressions.

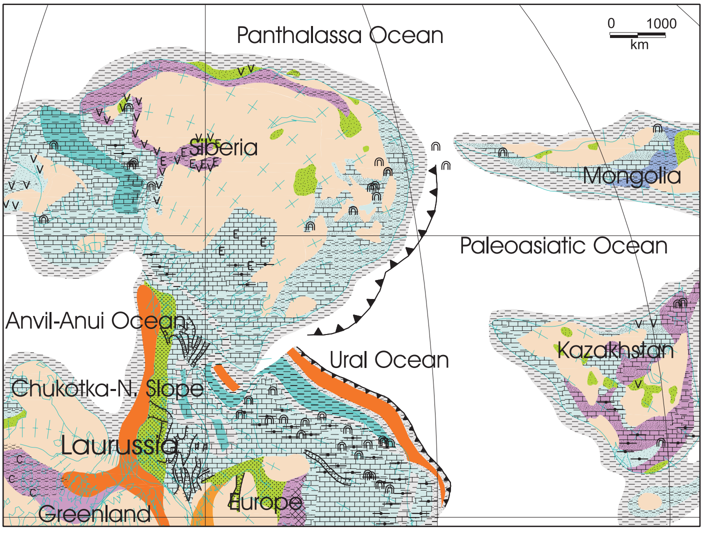

Fig. 14. Plate tectonic, paleoenvironment and lithofacies map of Siberia, northern Laurussia, Paleoasiatic Ocean and adjacent areas during Late Devonian time

Fig. 14. Mapa tektoniki płyt, paleośrodowiska i litofacji Syberii, północnej Laurosji, Oceanu Paleoazjatyckiego oraz obszarów sąsiednich w późnym dewonie

The Upper Devonian is presented there by carbonate and terrigeneous shelf rocks, by bituminiferous clays and pyroschists in the west, and by reefogeneous limestones (Webb 2002) at the outer margin of the craton. It was the major time of the Pechora-Kolva trough development at the Pechora plate. The trough was also bordered by reefs (Webb 2002). Thickness of deposits was 400–600 m there, and more than 1 km at the Pai-Khoi. In general, the East-European craton was characterized by complex conditions and contrasting vertical movements. In many basins marine conditions changed to continental and visa verse, sometimes deep-water troughs, non-compensated by sedimentation, appeared. These conditions resulted in variations of facies composition and thickness of the Upper Devonian deposits, in which carbonates dominated, especially in the east, continental alluvium-lacustrine rock complexes (coal-bearing in the north) formed an essential part of deposits. In the Famennian, some basins became rather shallow, together with a change of climate it resulted in water salinization and limestones changed to dolomites with anhydrite inclusions. In the Frasnian time, non-compensated depressions were formed in Zavolzhie, Volga region, where black bituminiferous argillaceous sediments of so-called Domanic type were accumulated. In the north-east these deposits covered bottoms of four submeridional depressions which were united in the south-east into one relatively deep basin with the width of up to 600 km.

Rifting occurred between the Siberian plate and the Verkhoyansk (Kolyma-Okhotsk) terranes (Khudoley & Guriev 1994, Parfenov 1997). It is possible that the Barents Sea and Verkhoyansk rifts were connected. The Tunguska basin underwent the most intensive subsidence in the Middle Frasnian (Vinogradov 1968, Ronov *et al*. 1984, Zonenshain *et al*. 1990, Parfenov 1992, 1997, Parfenov *et al*. 1993, Khudoley & Guriev 1994, Vernikovsky 1995, Puchkov 1996, Golonka *et al*. 2003a). On the whole, carbonate and evaporite sediments dominated there. The Taimyr basin, which united with the Khatanga basin (and was connected with the Tunguska basin at the time of largest transgressions), has undergone relatively intensive subsidence, it had a large depth and argillaceous-carbonate facies of the Domanic type were deposited in its western part. Limestones, in rare cases dolomites, dominated to the east. A development of the Rybinsk trough, which was filled by marine and continental terrigeneous rocks, continued. The Viluy trough was tectonically active and was not connected with a sea. There wide eruptions of basalts occurred, besides terrigeneous sands and, in the Famennian, gypsum- and salt-bearing complexes were deposited.

In South America (Fig. 15), the Late Devonian is characterized by regressions (Ronov *et al*. 1984, Williams 1995, Andreis & Archangelsky 1996, Gonzales-Bonorino & Llammbias 1996, Milani & Zalán 1999, Ford & Golonka 2003, Limarino & Spalletti 2006). Small seas remained only in the Amazon and Maranao basins. The connection between the Amazon basin and the sea of the Andean belt was distorted; a large input of fragmented material totally compensated small subsidence in the middle course of the Amazon, where terrigeneous rocks were deposited in continental facies. Thickness of the deposits there and to the east, where marine conditions still existed, did not exceed 150 m. Sea did not exist any more in the Amazon basin in the Famennian. Marine conditions existed in the Maranao basin during the entire epoch. Thickness of sandy-argillaceous deposits is as much as 500 m there.

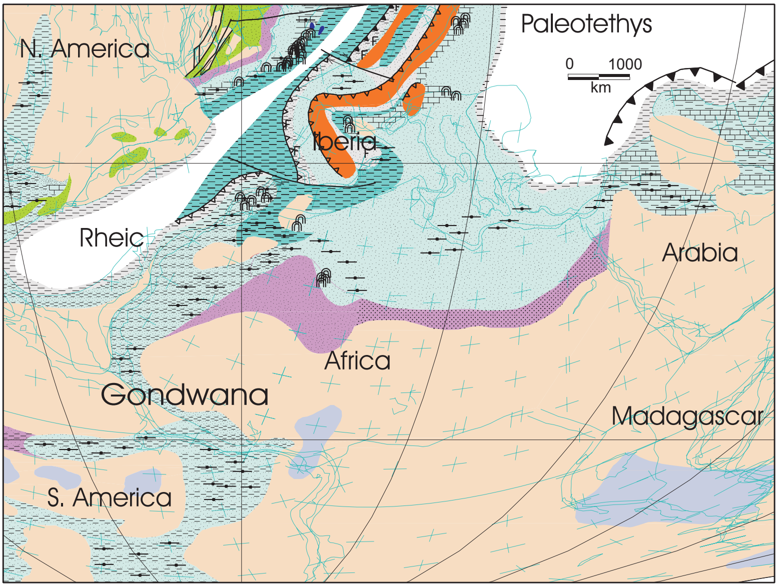

Fig. 15. Plate tectonic, paleoenvironment and lithofacies map of western Gondwana, remnant Rheic Ocean and adjacent areas during Late Devonian time

Fig. 15. Mapa tektoniki płyt, paleośrodowiska i litofacji zachodniej Gondwany, resztkowego oceanu Rheic oraz obszarów sąsiednich w późnym dewonie

In Africa (Fig. 15) (Ronov *et al*. 1984, Villeneuve & Dallmeyer 1987, Lécorché *et al*. 1989, P.A. Ziegler 1989, Caby 2003, Ford & Golonka 2003, Villeneuve 2005), large marine basin in the north and north-west of the craton was shallow. Its size was maximal in the Frasnian time, while since the Famennian regressions started. A fraction of coarse sediments and continental facies in a wide coastal zone increased. The Saoura-Ougarta and the Tindouf depressions quickly subsided, and argillaceous and carbonate rocks dominated in the section. Sandy-argillaceous deposits were accumulated in the basin of the Peri-Atlas zone, while reefogeneous limestones were formed to the north (Webb 2002). At the end of the Late Devonian almost the entire territory of Sahara underwent regression.

The Late Devonian organic-rich marine black shale, potential source rocks, were best developed in large, low-latitude, restricted, intrashelf basins and interior seaways coincident with a global oceanic anoxic event (e.g., Appalachians, Madre de Dios, Parana, Amazon, Chaco, and North Africa). A major extinction event took place around the Frasnian-Famennian boundary (Joachimski & Buggisch 1993, Racki 1998a, b).

Early Carboniferous (Tournaisian-Early Visean)

The Early Carboniferous was the time of ongoing Hercynian convergence in Europe (Figs 16, 17), which emplaced parts of the accretionary complexes and produced large scale dextral and sinistral shortening and overthrusting (Edel & Weber 1995, Golonka 2002, Ford & Golonka 2003). The Rheic Ocean became quite narrow.

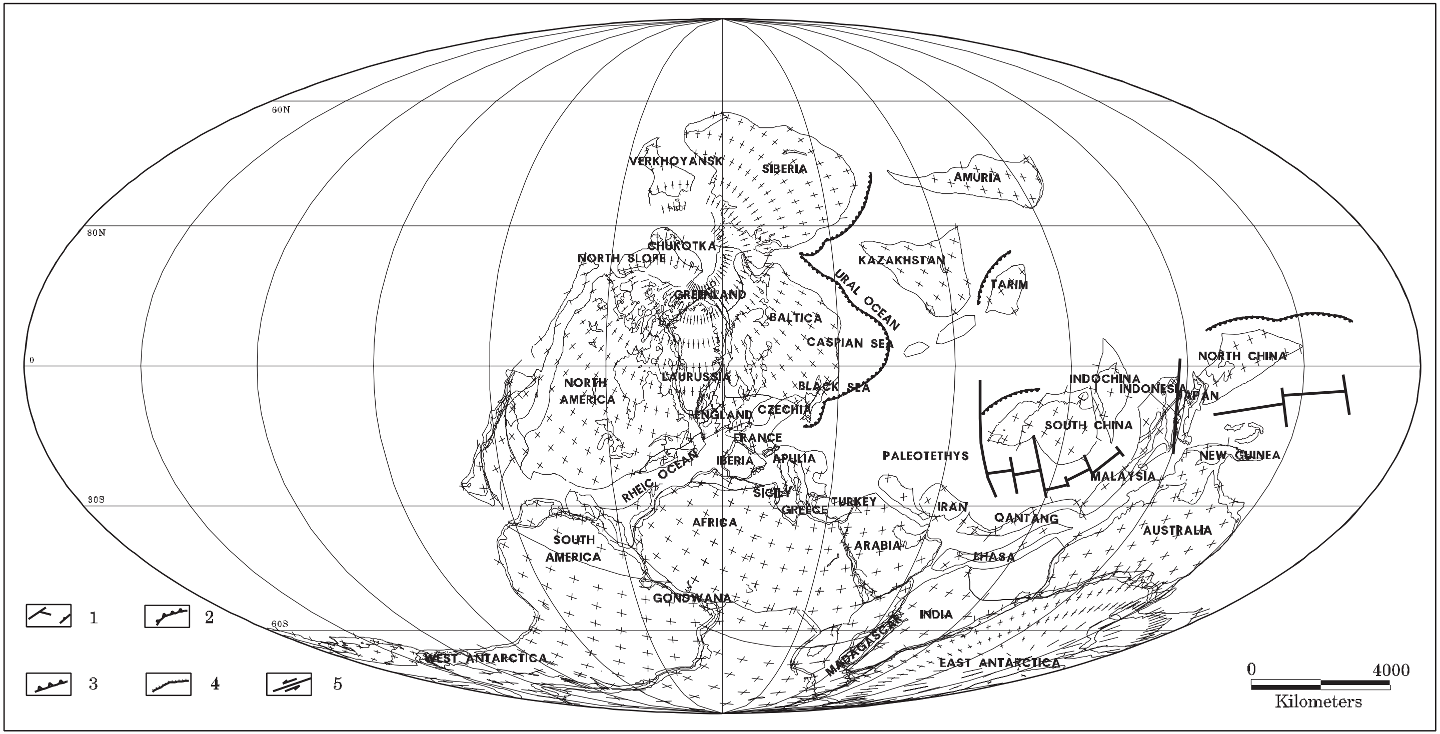

Fig. 16. Plate tectonic map of Early Carboniferous (Tournaisian-Early Visean, plates position as of 348 Ma). Modified from Golonka (2002): 1 – oceanic spreading center and transform faults, 2 – subduction zone, 3 – thrust fault, 4 – normal fault, 5 – transform fault

Fig. 16. Mapa tektoniki płyt wczesnego karbonu (turnej-wczesny wizen, pozycja płyt 348 milionów lat temu). Zmieniona wg Golonki (2002): 1 – centrum spredingu oceanicznego i uskok transformujący, 2 – strefa subdukcji, 3 – nasunięcie, 4 – uskok normalny, 5 – uskok przesuwczy

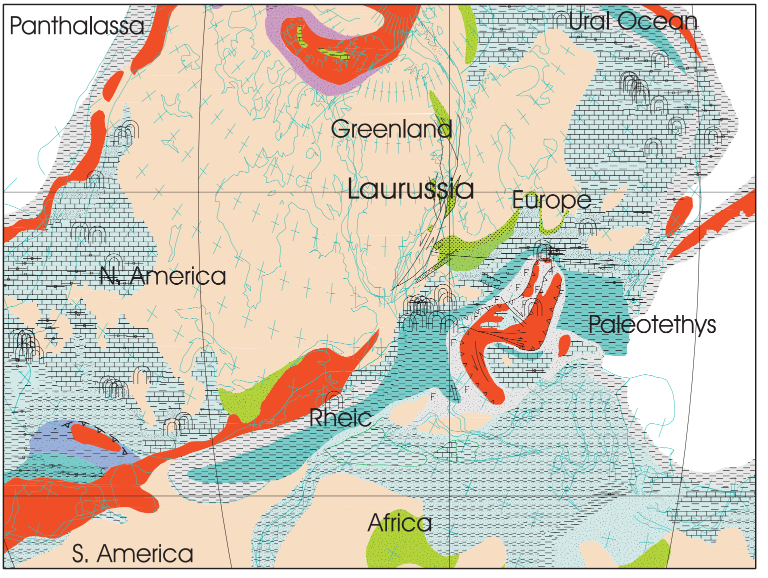

Fig. 17. Plate tectonic, paleoenvironment and lithofacies map of Laurussia, nearby Gondwana, remnant Rheic Ocean and adjacent areas during Early Carboniferous (Tournaisian-Early Visean) time

Fig. 17. Mapa tektoniki płyt, paleośrodowiska i litofacji Laurosji, przyległych obszarów Gondwany, resztkowego oceanu Rheic oraz obszarów sąsiednich we wczesnym karbonie (turnej-wczesny wizen)

The thrusting took place in the Tatra Mts. in the Carpathians (Gawęda *et al*. 1998). The Antler orogeny was concluded in western North America (Hamilton 1989, Oldow *et al*. 1989). The southern part of North America was covered by shallow sea, sometimes with swamped lagoons (Cook & Bally 1975, Ronov *et al*. 1984, P.A. Ziegler 1988, 1989, Bally 1989, Ford & Golonka 2003, Golonka *et al*. 2003a). The carbonate rocks, often with reefs and other carbonate buildups (Webb 2002), sometimes with cherts, were deposited; their thickness being tens of meters, in rare cases 200–300 m. Restricted, low-latitude carbonates exhibit extensive shelf margin with skeletal and oolitic sand bodies. Carbonate buildups (i.e., reef mounds) were mostly composed of muddy, non-framework, algal and skeletal components. The overlying major unconformity and contemporary glacioeustatic sea level fluctuations subjected carbonates of this age to episodes of erosion and karstification (Ford & Golonka 2003). It is likely that a fast subsidence was entirely compensated there by sedimentation. The size of Williston basin gradually decreased. Thickness of the deposits in the central part of this structure is as large as 1 km; carbonates dominate, while gypsum, anhydrites, sometimes salt are also present; continental sandy facies prevail in the upper part of the section. Coal-bearing deposits are known from the West-Canadian Basin. Grabens formed between Greenland and Norway (Stemmerik *et al*. 1991).

The Ouachita basin became a narrowing trough with the flysch basins receiving vast amount of clastics (Cline *et al.* 1959, Briggs & Roeder 1975, Arbenz 1989, Golonka *et al.* 2006c). The subduction probably took place along the southern margin of this narrowing basin, north of the approaching Inner Ouachitas (or of the enigmatic Sabine terrane), and began to consume the Ouachita Ocean. The northern margin supplied the clastic material for flysch deposits. The Lower Carboniferous rocks of predominately flysch character overlie the novaculite chert deposits. These are very thick and most widespread rocks in the Ouachita Mountains region, as well as in the buried Ouachita foldbelt (Cline *et al.* 1959, Flawn *et al.* 1961, Morris 1974, 1989, McBride 1975, Viele & Thomas 1989). Along the southern Ouachitas, sandstones become thicker and more numerous, tuffs and tuffaceous sandstones are prominent at the base, and disturbed bedding, impure cherts, and siliceous shales are rare. Along the Frontal Ouachitas, a thinner section has less turbidites at the base and only a minor tuff interval, but more intervals of impure chert and siliceous shale (Golonka *et al*. 2006c).

Gondwana rotated clockwise and the Chinese plate drifted farther away from Gondwana (Figs 16, 18) (Scotese & McKerrow 1990, Golonka *et al.* 1994, 2006a, Metcalfe 1994, 1996, 1998, 2000, 2002, Golonka 2000, 2002). According to Metcalfe (1998), Carboniferous and younger faunas and flora of South China and Indochina plates show no relationships with those of Gondwana. The paleomagnetic data (Zhao *et al.* 1996) also indicate the detachment of Chinese plates form Gondwana. Following the Devonian rocks, Lower Carboniferous platform deposits are widely distributed in South China and Indochina plate (Fig. 18).

In the Ha Long Bay area, Lower Carboniferous shallow-water marine carbonate deposits with corals and brachiopods conformably cover the Upper Devonian massive limestones (Golonka *et al*. 2006a).

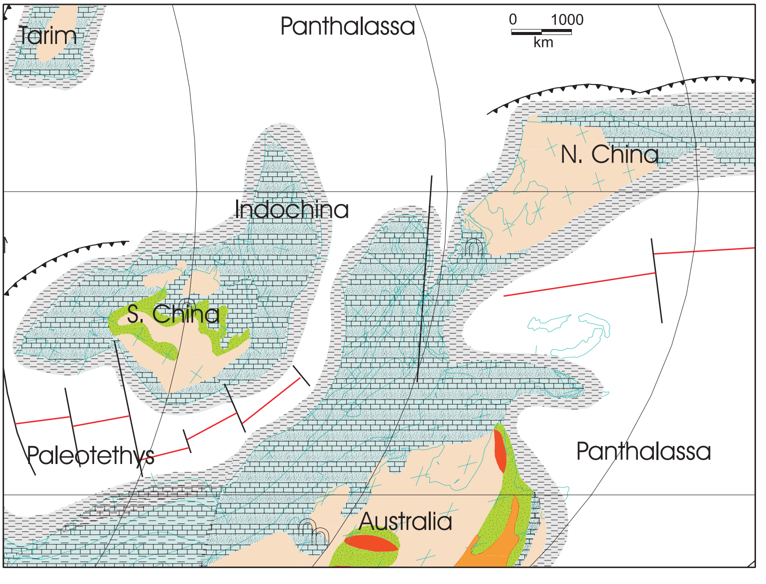

Fig. 18. Plate tectonic, paleoenvironment and lithofacies map of eastern Gondwana, Paleotethys, Chinese plates and adjacent areas during Early Carboniferous (Tournaisian-Early Visean) time

Fig. 18. Mapa tektoniki płyt, paleośrodowiska i litofacji wschodniej Gondwany, Paleotetydy, płyt chińskich oraz obszarów sąsiednich we wczesnym karbonie (turnej-wczesny wizen)

A rather shallow lagoon existed in the Hubei-Guizhou depression and in the lower course of the Yangtze river, organogenic limestones with the thickness of 10–30 m were deposited there. The Jiannan-Guanxi and Jianxi-Guanxi depressions underwent much more intensive subsidence. Continental facies and paralic coal-bearing deposits are widely developed in the coastal zones of these depressions. Coarse continental and marine sandy-pebble layers as well as coal-bearing deposits and, in rare cases (in the deepest areas connected with an open sea), reefogeneous limestones (Webb 2002) were accumulated in North China. The Tarim plate moved farther westwards coming close to Kazakhstan.

Subsidence continued in the Carnarvon, Canning and Bonaparte depressions (Fig. 18) (Ronov *et al*. 1984, Cook 1990, Findlay *et al*. 1991), but sedimentation conditions changed there. Marine conditions were preserved only in the Carnarvon basin where about 800 m of carbonate-terrigeneous deposits were accumulated. In two other basins subsidence was almost entirely compensated by deposition of a fragmented material, which came in excess from the uplifted central parts of the craton. That is why only continental sandy facies were deposited there, with the thickness of up to 1 km. In the Canning basin, sedimentation existed only within the Fitzroy graben. The Alice Springs Orogeny began in central Australia (Cook 1990, Golonka 2000, 2002, Veevers 2004).

Siberia rotated clockwise (Smethurst *et al*. 1998). Kazakhstan continued to converge with Siberia. Only a narrow strait remained from the former Paleoasiatic Ocean (Zonenshain *et al*. 1990, Bush & Filippova 1998). The Verkhoyansk (Kolyma-Okhotsk-Chersky) terranes had broken off Siberia (Zonenshain *et al*. 1990, Khudoley & Guriev 1994). Perhaps Siberia rotated clockwise, drifting towards the Kazakhstan plate (Smethurst *et al*. 1998), while the Verkhoyansk terranes stayed in place. Large fresh-water lakes existed in the central and north-western parts of Siberia (Fig. 19) (Vinogradov 1968, Ronov *et al*. 1984, Zonenshain *et al*. 1990, Parfenov 1992, 1997, Parfenov *et al*. 1993, Khudoley & Guriev 1994, Vernikovsky 1995, Puchkov 1996, Golonka *et al*. 2003a). Sands, aleurolites, clays, sometimes limestones were deposited there. The Viluy trough continued to subside, lagoons, sometimes connected with a sea, existed there. The trough was filled with continental terrigeneous rocks, as well as by limestones, dolomites and sulphates with the total thickness of up to 500 m. Subsidence of the Kan-Taseevo depression continued in the south-west. Its size became larger, and pebbly, sandy and clayey sediments were deposited there, their thickness increasing south-westwards up to 300–500 m.

Shoaly limestones and dolomites dominated in depositions in Eastern Europe (Figs 17, 19), sometimes with argillaceous sediments and alluvium-lacustrine facies in the coastal zones (Ronov *et al*. 1984, Zonenshain *et al*. 1990, Nikishin *et al*. 1996, Golonka 2002, Golonka *et al*. 2003a). The paralic coal-bearing formation was deposited in the Visean time. Besides, some coal deposition occurred in the east and south-west of the continent. An accumulation of dolomites and gypsum occurred in the Peri-Caspian and Pechora depressions. In the marginal basin in the south-west of the continent shelf carbonate deposits, with the thickness of up to 300 m, were formed. To the east, in the Peri-Urals zone, a deposition of limestones, dolomites, in rare cases argillites, continued, it was interrupted by short-time regressions, limestones and clays are sometimes bituminiferous. Hard-coal is known in the Ufa-Solikamsk depression. Gypsum and anhydrites were accumulated sometimes in the Pai-Khoi region.

A wide transgression was developed in the Sahara basin in the first half of the Visean (Fig. 20) (Ronov *et al*. 1984, Villeneuve & Dallmeyer 1987, Lécorché *et al*. 1989, P.A. Ziegler 1989, Caby 2003, Ford & Golonka 2003, Villeneuve 2005).

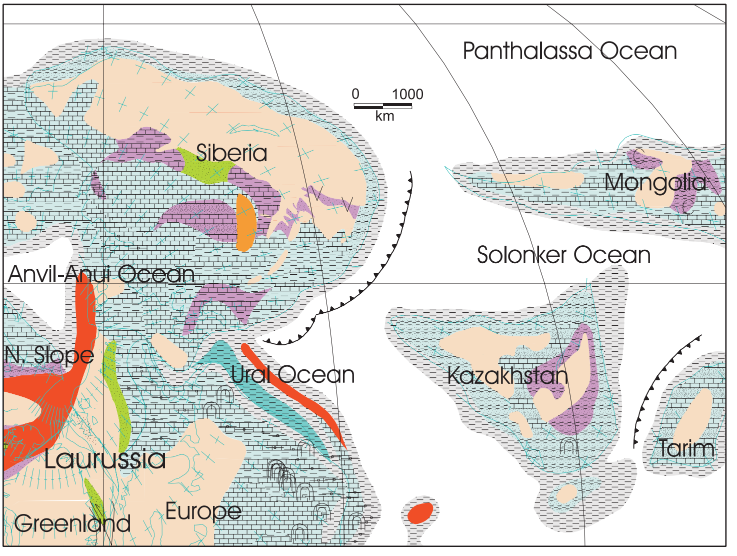

Fig. 19. Plate tectonic, paleoenvironment and lithofacies map of northern Laurussia, Siberia, Ural Ocean and adjacent areas during Early Carboniferous (Tournaisian-Early Visean) time

Fig. 19. Mapa tektoniki płyt, paleośrodowiska i litofacji północnej Laurosji, Syberii, oceanu uralskiego oraz obszarów sąsiednich we wczesnym karbonie (turnej-wczesny wizen)

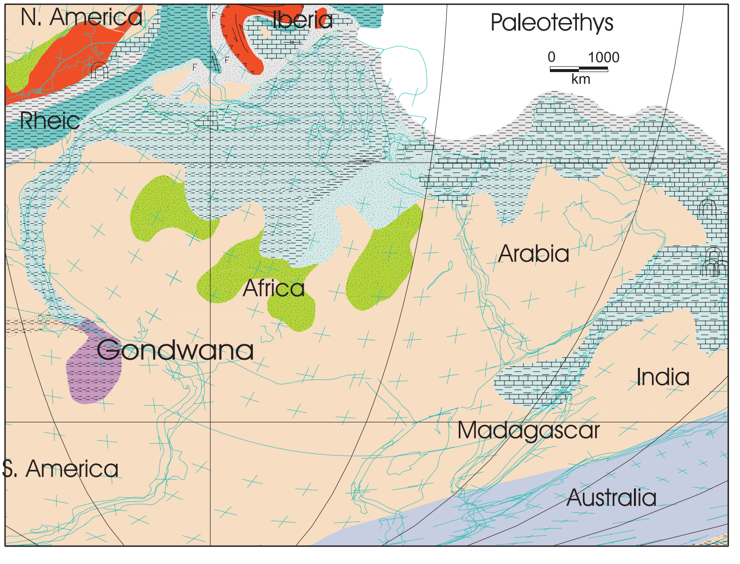

Fig. 20. Plate tectonic, paleoenvironment and lithofacies map of western Gondwana, remnant Rheic Ocean and adjacent areas during Early Carboniferous (Tournaisian-Early Visean) time

Fig. 20. Mapa tektoniki płyt, paleośrodowiska i litofacji zachodniej Gondwany, resztkowego oceanu Rheic oraz obszarów sąsiednich we wczesnym karbonie (turnej-wczesny wizen)

It was not a single basin any more, but wide depressions separated by islands and elongated uplifts. Lagoon sandy-argillaceous, sometimes carbonate sediments were deposited in depressions. Carbonates played an essential role in the Saoura-Ougarta depression and gypsum and salts were deposited there as well. Shelf shallow-marine conditions existed in the region of the Morocco Rif and in the northern Algeria, where carbonate-terrigeneous rocks were deposited. Glaciation developed on the southern part of Gondwana.

Early Carboniferous (Late Visean-Serpukhovian)

The clockwise rotation of Gondwana (Smethurst *et al*. 1998) during the collision with Laurussia closed the southwest remnant of the Rheic Ocean (Figs 21, 22). Western and Central Europe was affected by widespread orogenic deformation. According to Golonka (2000, 2002), the Hercynian orogeny in Europe was a result of collision of several separate blocks with the Laurussia margin (Franke 1989, 1992, Franke *et al*. 1995, Lewandowski 1998, 2003, Matte 2001), followed by the involvement of Gondwana continent. Thrusting and folding occurred in Iberia, Central Massif, and Ligerian, Sardinian-Corsican, Armorican, Harz Mts., Saxoturingian, Bohemian, and Silesia areas (Yilmaz *et al*. 1996, Golonka 2000, 2002). The amount of convergence was modified by large dextral and sinistral transfer faults.

Until the Late Visean-Serpukhovian, crustal shortening was at a maximum in a WNW--ESE direction in the Armorican massif, Massif Central, Vosges, Schwarzwald, and Bohemian Massif. The Rheno-Hercynian basin turned into foredeep, with flysch deposition (Fig. 22). Increased deltaic deposition occurred in orogenic belts and rift grabens. Abundant, deep-water turbiditic/flysch deposition occurred in foreland basins associated with the Hercynian collision (Eastern USA, Morocco, and Europe). The Alleghenian orogeny in North America was a result of the collision of the Gondwanian and Laurussian cratons (Dewey & Burke 1973). This orogenic event was prolonged and polyphase. The thrusting transported remnants of previously deformed rocks to the northwest. In the northern Appalachians, the strongest effects of the Alleghenian orogeny are peripheral to eastern Canadian provinces and American states. In the southern and central Appalachians, the Alleghenian orogeny was widespread and pervasive (Rast 1989).

Carbonate and evaporite sedimentation prevailed in the southern and southwestern parts of North American craton (Cook & Bally 1975, Ronov *et al*. 1984, P.A. Ziegler 1988, 1989, Bally 1989, Ford & Golonka 2003, Golonka *et al*. 2003a). Small semi-closed seas (e.g., the Paradox basin) with an increased water salinity and halite accumulation existed in the western part of the Mid-continent and in the south-east of the Rocky Mountains. Flysch sedimentation continued in the Ouachita basin with gray-black shale and rhythmically interbeded whitish-gray, very fine-grained, quartz-rich turbiditic packets. Olistostrome-type beds dominate in the Frontal Ouachitas of Arkansas, proximal turbidites in the Southern Ouachitas, and thinner-bedded distal turbidites and black siliceous shales in the Ouachitas of Oklahoma.

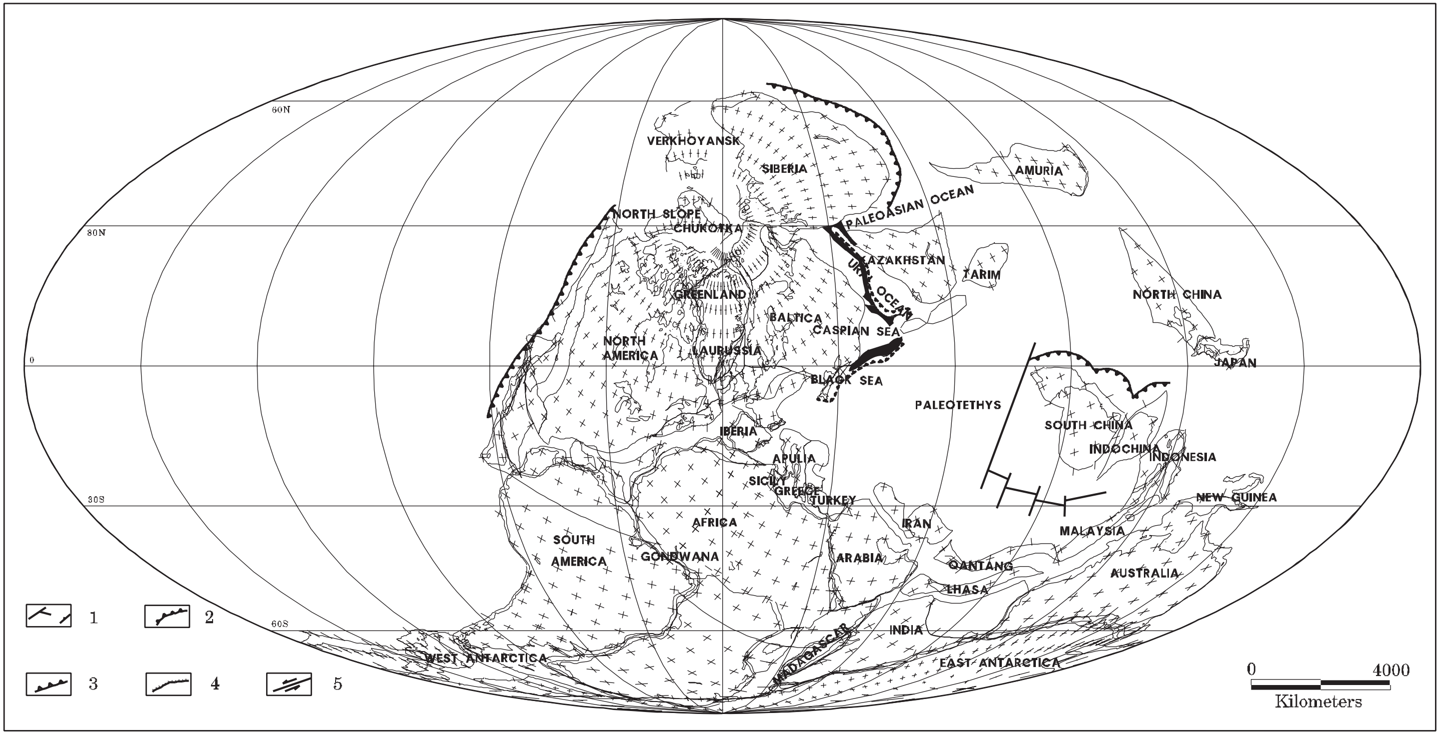

Fig. 21. Plate tectonic map of Early Carboniferous (Late Visean-Serpukhovian, plates position as of 328 Ma). Modified from Golonka (2002): 1 – oceanic spreading center and transform faults, 2 – subduction zone, 3 – thrust fault, 4 – normal fault, 5 – transform fault

Fig. 21. Mapa tektoniki płyt wczesnego karbonu (późny wizen-serpuchow, pozycja płyt 328 milionów lat temu). Zmieniona wg Golonki (2002): 1 – centrum spredingu oceanicznego i uskok transformujący, 2 – strefa subdukcji, 3 – nasunięcie, 4 – uskok normalny, 5 – uskok przesuwczy

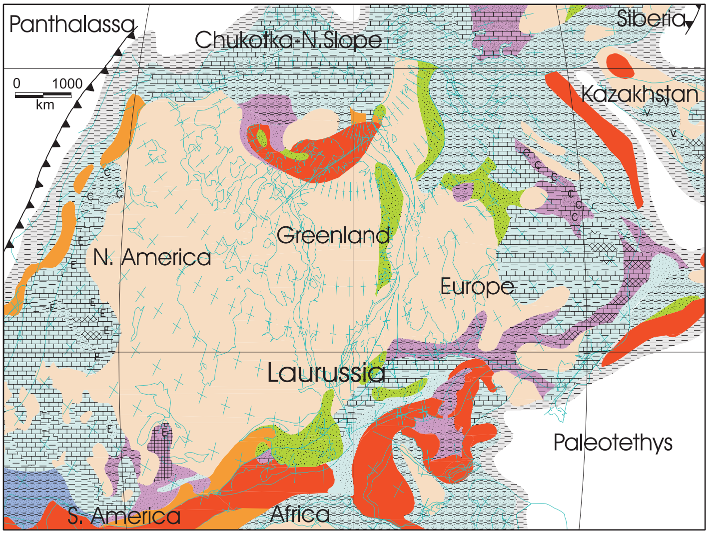

Fig. 22. Plate tectonic, paleoenvironment and lithofacies map of Laurussia and adjacent areas during Early Carboniferous (Late Visean-Serpukhovian) time

Fig. 22. Mapa tektoniki płyt, paleośrodowiska i litofacji Laurosji oraz obszarów sąsiednich we wczesnym karbonie (późny wizen-serpuchow)

The proximal turbidites are massive, ridge-forming, quartz-rich, scour-and-fill units with few or no shale interbeds. Distal turbidites have partial to complete Bouma sequences, better developed sole markings, greater evidence of trace fossils, as well as slope or shock-induced disruptive structures.

According to Nikishin *et al*. (1996), the Hercynian orogen links to the east with the Scythian orogen in the southeastern part of the European craton (Fig. 22). According to Adamia (1991), the collision of the Greater Caucasus terrane with Baltica occurred during the mid-Carboniferous and was associated with the partial closure of the Rheic Ocean in this area and formation of the Scythian platform (Golonka 2000 2002). The mountain ranges were formed on the Laurussian margin. Subsidence gradually developed in the Eastern Laurussia. Sedimentation took place only in the eastern and south-eastern regions and in the Dnepr-Donets trough. In this trough, early post-rift stage was characterized by rapid subsidence (Vinogradov 1968, P.A. Ziegler 1982, 1989, Ronov *et al*. 1984, Zonenshain *et al*. 1990, Nikishin *et al*. 1996, Golonka *et al*. 2003a, Mizens 2004). The East European craton was covered by shallow and marginal seas with mixed carbonate-clastic deposits, locally evaporites. Carbonate facies contained buildups composed of muddy, non-framework, algal and skeletal components. Coals were deposited in the paralic environment in the Moscow basin. Clastics prevailed in the Timan-Peczora basin and in the Peri-Uralian zone. Continental clastics filled the post-Caledonian troughs between Europe and Greenland (Stemmerik *et al*. 1991).

Further drift of the Chinese plates off Gondwana continued (Golonka *et al.* 1994, Metcalfe 1994). North China arrived in the vicinity of Mongolia (Şengör & Natalin 1996). The easternmost remnants of the Rheic Ocean and the newly formed ocean between Gondwana and the South China plates had been called Paleotethys (Şengör 1984, Dercourt *et al.* 1993, Scotese & Lanford 1995, Ricou 1996, Şengör & Natalin 1996, A.M. Ziegler *et al.* 1997, Golonka 2000, 2002). The carbonate and mixed carbonate-clastic shallow-water deposition prevailed in Indochina and adjacent part of South China (Fig. 23). Clastic and coal-bearing sequences were also widespread within South China plate (Shouxin & Yongyi, 1991). According to Metcalfe (1994, 1996, 1998, see also Bunopas & Vella 1978, Fontaine & Workman 1978, Bunopas 1981, Helmcke 1985, Şengör & Natalin 1996, Golonka 2000, 2002) the amalgamation of South China and Indochina occurred at that time, as demonstrated by large scale folding and thrusting along the Song Ma suture in North Vietnam. Findlay (1999) argued with this point of view suggesting that the Song Ma anticlinorium is not an Indosinian subduction zone but an allochthonous terrane, which accreted to the South China plate in Silurian-Devonian. Golonka *et al.* (2006a) observations about Silurian-Devonian boundary orogenic movements seem to support this point of view. The problem requires further research, which is not very easy because if very strong later deformation and metamorphism (e.g. Lepvrier *et al.* 2004). The Carboniferous unconformity perhaps exists, but is not as convincingly defined as Silurian-Devonian one. The Carboniferous deformation was perhaps caused by clockwise rotation of previously amalgamated South China-Indochina block and convergence with peri-Gondwanian margin (Fig. 23).

This peri-Gondwanian margin, including northwestern shelf of Australia was mainly covered by shallow seas with mixed carbonate-clastic deposition (Ronov *et al.* 1984, Cook 1990, Veevers 2004, Meor & Lee 2005, Golonka *et al.* 2006a). The Alice Orogeny continued in Australia.

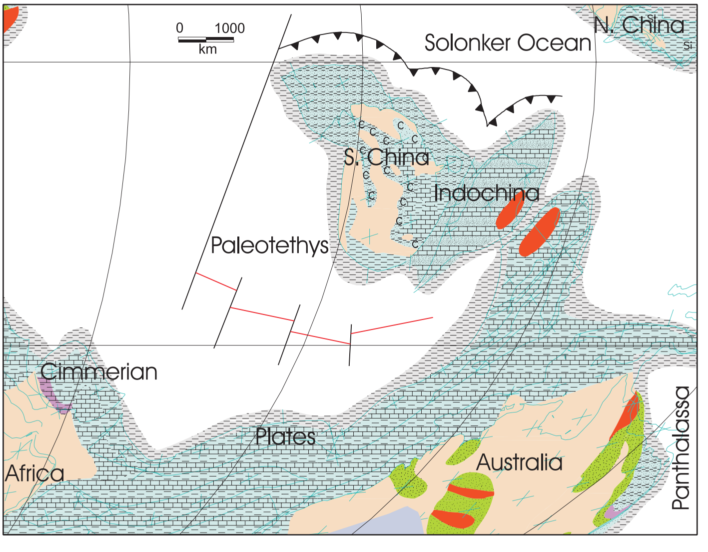

Fig. 23. Plate tectonic, paleoenvironment and lithofacies map of eastern Godwana, Paleotethys, Chinese plates and adjacent areas during Early Carboniferous (Late Visean-Serpukhovian) time

Fig. 23. Mapa tektoniki płyt, paleośrodowiska i litofacji wschodniej Gondwany, płyt chińskich, Paleotetydy oraz obszarów sąsiednich we wczesnym karbonie (późny wizen-serpuchow)

The main collision of Kazakhstan and Siberia began at the end of the Early Carboniferous (Figs 21, 24), as did the collision of Tarim with Kazakhstan (Zonenshain *et al*. 1990, Şengör & Natalin 1996, Golonka 2000, 2002). Mixed carbonate-evaporite sedimentation prevailed in the central part of Kazakhstan plate, while clastics were abundant on its margins (Ronov *et al*. 1984, Bykadorov *et al*. 2003). Coals were also deposited locally.

Laurussia was fully amalgamated with Siberia at that time (Figs 21, 24). The Sverdrup Basin, opened in Northern Canada (Trettin 1989). This basin, as well as adjacent areas on the Chukotka-North Slope plate, was filled with clastic and mixed carbonate-clastic sequences. A passive margin developed along the newly opened basin between Siberia and the Verkhoyansk terranes (Khudoley & Guriev 1994). Thick deposits were accumulated in these areas. Shallow water clastics and mixed carbonate-clastic rocks were deposited on the Siberian margin (Vinogradov 1968, Ronov *et al*. 1984, Zonenshain *et al*. 1990, Parfenov 1992, 1997, Parfenov *et al*. 1993, Khudoley & Guriev 1994, Vernikovsky 1995, Puchkov 1996, Golonka *et al*. 2003a). Marginal marine mixed carbonate-clastic successions and continental clastics prevailed in the center of the continent. Carbonate buildups were composed of muddy, non-framework algal and skeletal components. The glacioeustatic sea-level fluctuations subjected carbonates to episodes of erosion and karstification.

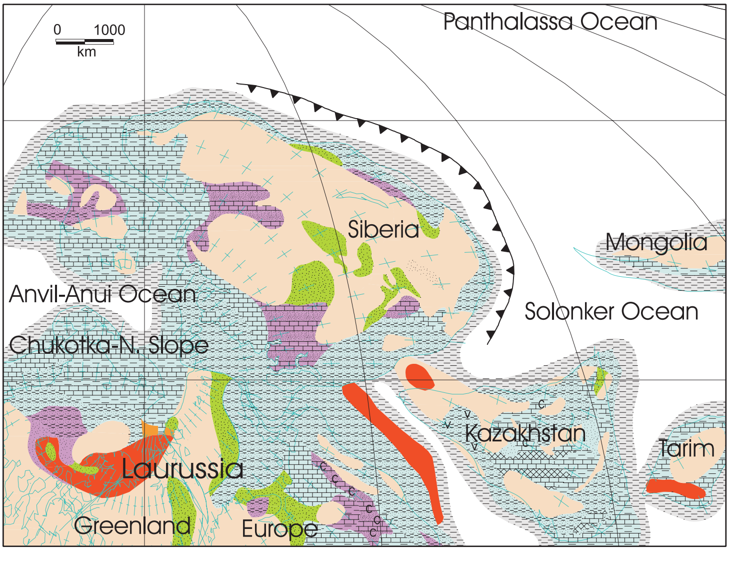

Fig. 24. Plate tectonic, paleoenvironment and lithofacies map of northern Laurussia, Siberia and adjacent areas during Early Carboniferous (Late Visean-Serpukhovian) time

Fig. 24. Mapa tektoniki płyt, paleośrodowiska i litofacji północnej Laurosji, Syberii oraz obszarów sąsiednich we wczesnym karbonie (późny wizen-serpuchow)

In the Late Visean and Serpukhovian, the western regions of the Sahara basin were uplifted and alluvium-lacustrine sands, clays, sometimes coal-bearing deposits were accumulated there at the lacustrine-marsh conditions (Fig. 25) (Ronov *et al*. 1984, Villeneuve &

Dallmeyer 1987, Lécorché *et al*. 1989, P.A. Ziegler 1989, Caby 2003, Ford & Golonka 2003, Villeneuve 2005).

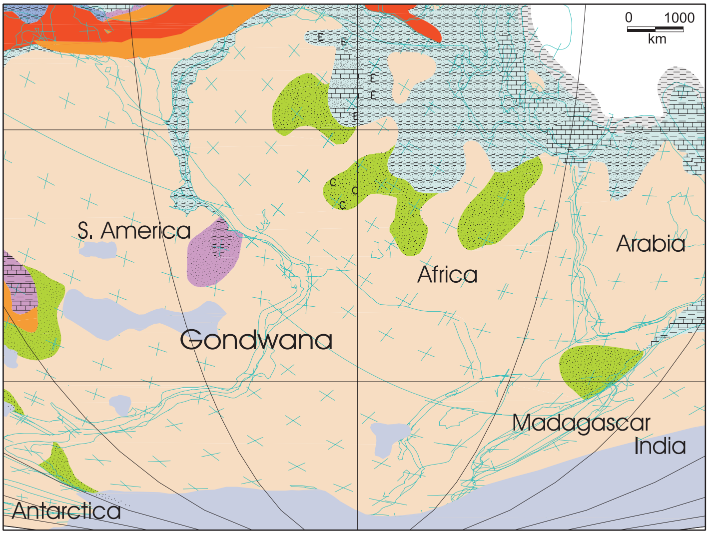

Fig. 25. Plate tectonic, paleoenvironment and lithofacies map of central Gondwana and adjacent areas during Early Carboniferous (Late Visean-Serpukhovian) time

Fig. 25. Mapa tektoniki płyt, paleośrodowiska i litofacji centralnej Gondwany oraz obszarów sąsiednich we wczesnym karbonie (późny wizen-serpuchow)

A new transgression developed in the Northern Sahara and a deposition of marine sediments, mainly of carbonate composition, and thick layers of limestones, in rare cases evaporites, occurred there. Shelf shallow-marine conditions existed in the region of the Morocco and in the northern Algeria where carbonate-terrigeneous rocks were deposited. In the Early Carboniferous a vast territory of the craton located to the south of Sahara was a region of moderate uplifts and plain-hill relief, though in some regions intercontinental depressions, similar to the one presumably distinguished in the east of Ethiopia and Zambia could have existed. An ice cap increased on the southern part of Gondwana. Marine basins existed in the Early Carboniferous in Turkey, north-eastern Syria and Iran, as well as in Afghanistan. Dynamic paleotectonic conditions with contrast vertical movements determined facies variations of deposits and their thickness. Carbonate reef formations (Webb 2002), carbonate-terrigeneous, sandy-argillaceous, continental sandy and sandy-conglomerate layers were deposited there. Subsidence started in the southern South America basins (Limarino & Spalletti 2006). Significant glaciation existed in Gondwana (Golonka 2000, Veevers 2004, Golonka *et al*. 2006a).

Late Carboniferous

This was the time of the initial assembly of the Pangea supercontinent, following the major continental collision of Gondwana and Laurussia (Figs 26, 27).

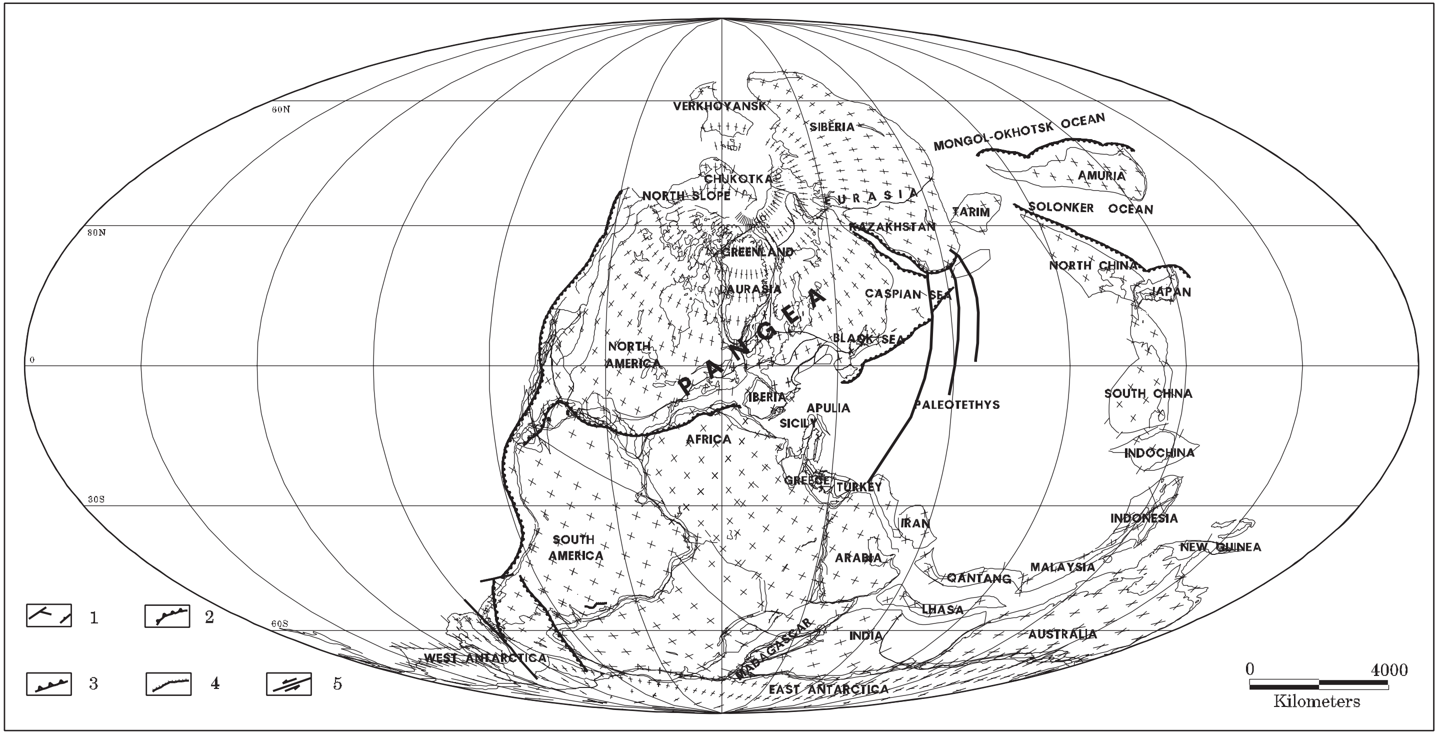

Fig. 26. Plate tectonic map of Late Carboniferous (plates position as of 302 Ma). Modified from Golonka (2002): 1 – oceanic spreading center and transform faults, 2 – subduction zone, 3 – thrust fault, 4 – normal fault, 5 – transform fault

Fig. 26. Mapa tektoniki płyt późnego karbonu (pozycja płyt 302 milionów lat temu). Zmieniona wg Golonki (2002): 1 – centrum spredingu oceanicznego i uskok transformujący, 2 – strefa subdukcji, 3 – nasunięcie, 4 – uskok normalny, 5 – uskok przesuwczy

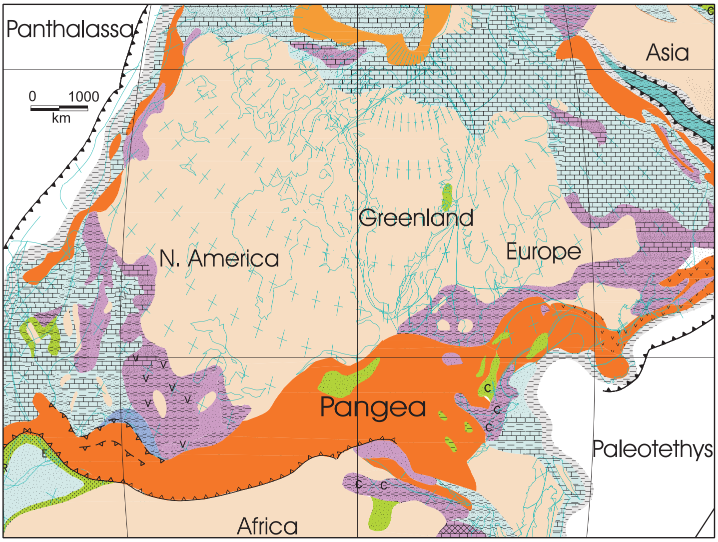

Fig. 27. Plate tectonic, paleoenvironment and lithofacies map of North America, Europe and adjacent areas during Late Carboniferous time

Fig. 27. Mapa tektoniki płyt, paleośrodowiska i litofacji Ameryki Północnej, Europy oraz obszarów sąsiednich w późnym karbonie

The central Pangean mountain range was formed, which extended from Mexico to Poland. The Ouachita foldbelt was formed in Arkansas, Oklahoma, Texas and adjacent part of Mexico (Thomas 1976, Wickham *et al.* 1976, Ross 1979, Thomas & Viele 1983, Arbenz 1989, Viele & Thomas 1989, Golonka *et al*. 2006c). In the circum-Ouachita region, the Inner Ouachitas and Sabine terrane continued their northward movement during Carboniferous time. According to Viele & Thomas (1989), the Sabine composite terrane is a collage of tectonic elements including not only Sabine uplift, but also Yucatan and Coahuila platforms. In this case the Yucatan platform would represent the stable crustal element of Pan-African origin. The Sabine uplift contains volcanics related perhaps to the south dipping subduction. The Sabine terrane collision with the North American plate led to the development of the accretionary wedge of Ouachita Mountains. During the compressional stage, flysch still continued to be deposited. Olistostromes of the Maumelle Chaotic Zone formed during that time. The main collisional activity occurred during the Late Carboniferous-Early Permian. The flysch deposits passed upwards into molasse.

The Alleghenian orogeny in North America also continued (Hatcher *et al*. 1989, Rast 1989, Rast & Skehan 1993). A coastal, plain bordered by the Appalachian mountain system in the east and Ouachita orogen (Fig. 27) in the south, was flooded from time to time by a sea coming from the western regions of the Mid-continent and the region of the Great Plains (Cook & Bally 1975, Ronov *et al*. 1984, P.A. Ziegler 1988, 1989, Bally 1989, Golonka & Ford 2000, Ford & Golonka 2003, Golonka *et al*. 2003a). A typical paralic coal-bearing formation was accumulated under these conditions. Eustatic sea level oscillations, associated with changes in the size of Gondwana glaciation, resulted in a pronounced cyclic structure of the formation, some cycles are well marked on a huge territory from

Kansas to Pennsylvania. The Middle-Late Carboniferous depositions become marine to the west from the Mississippi River. These were mainly carbonates to the west from the Nemaha ridge and in the Williston basin (Ronov *et al*. 1984, Golonka & Ford 2000).

The intercontinental collision affected the northwestern part of Africa (Lécorché *et al*. 1989), forming Mauretinides, Bassarides, and Rokelides orogens. The collision resulted in eastward translation of previously tectonized Mauretinide units over their foreland and emplacement of imbricated nappes (Golonka 2000, 2002). Southwards, the mountain system extended to Morocco (Pique 1989, Simancas *et al*. 2005). The Hercynian orogeny in Europe continued (Franke 1989, P.A. Ziegler 1989). The clockwise rotation of Gondwana resulted in the involvement of this continent in the European deformation. The SW-NE stress direction was added to the northern one. This Gondwanian influence resulted in the convoluted shape of the Hercynian orogen, strike-slip zones (Franke *et al*. 1995), and Hercynian deformation at the eastern end in Poland. The European foreland basin was elevated or changed its sedimentation regime from flysch to molasse. Sea-level changes resulted in paralic sedimentation of clastics in the molasse deposits, often with coals.

Orogenic events were also widespread in the Alps and Carpathians (Vozarová & Vozar 1992, Dallmeyer *et al*. 1996, Gawęda *et al*. 1998, 2003, Von Raumer 1998, Golonka *et al*. 2006b), in the Pannonian area (Kovács *et al*. 2000), the Italian realm (Lustrino 2000), Rhodopes (Yanev 1992), and Greece (Zanchi *et al*. 2003). Most likely, the Pontides terranes were sutured to Eurasia before the Permian (Ustaömer & Robertson 1997). According to Okay *et al*. (1996), the western Pontides Paleozoic sequence was folded and possibly thrust-faulted during the Late Carboniferous-Permian. Paleozoic rocks were strongly deformed and metamorphosed in the North Dobrogea nappes between Moesia and Laurussia. The deformed Paleozoic rocks in the Scythian platform could represent the Hercynian foreland (Golonka *et al*. 2006b). Mountains formed on the northern margin of Paleotethys, as a result of these events, were connected with the Hercynian orogen in Europe. North-dipping subduction developed along the Paleotethys margin (Golonka 2000, 2002). Natalin & Şengör (2005) interpret the deformation within Scythian-Turan domain on the Paleotethys margin as a large transpressional system. The collision between the Kazakhstan plate and Laurussia began in the Late Carboniferous (Puchkov 1991, 1997) in the southern and central Urals, later progressing into the northern parts of Urals. In the area between Ural orogen and uplifted part of Europe (Fig. 27), the shallow Volga-Urals basin was filling with dolomites and limestones deposited almost everywhere, while variegated and red aleurolites and clays (Vinogradov 1968, P.A. Ziegler 1982, 1989, Ronov *et al.* 1984, Zonenshain *et al.* 1990, Nikishin *et al*. 1996, Golonka & Ford 2000, Golonka *et al.* 2003a, Mizens 2004) were accumulated in the peripheral parts. The Dnepr-Donets trough became larger and was transformed into the isometric Ukrainian basin. Terrigeneous rocks, including paralic coal-bearing deposits, dominated there.

The Late Carboniferous Pangea included Australia, India, Antarctica, Africa, Arabia, and the Cimmerian plates, South America, Europe, Kazakhstan, and Siberia (Fig. 26). The subduction zones existed along the western coast of Pangea (present day South and North America). The position of the Chinese plates and Amuria (Mongolia) remains somewhat speculative (Nie *et al.* 1990, Golonka *et al.* 1994, Yin & Nie 1996, Ford & Golonka 2000, Golonka *et al*. 2006a). These plates were located somewhere east of the Paleotethys and were not incorporated into the Pangean supercontinent (Figs 26, 28, 29).

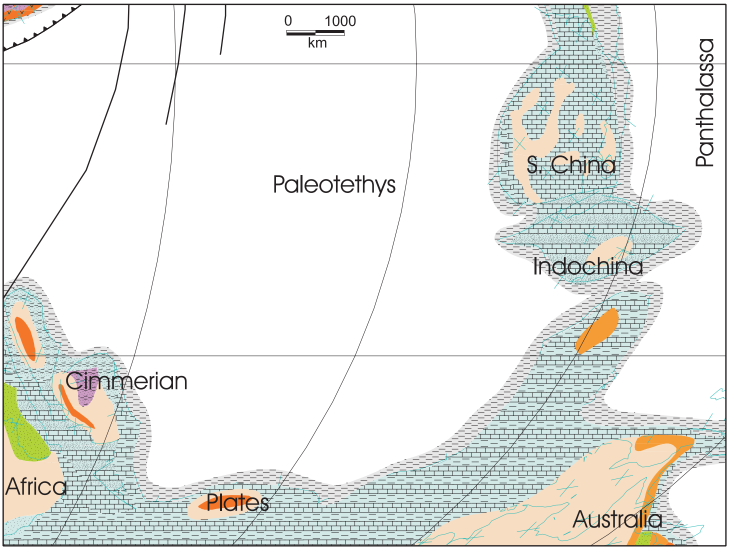

Fig. 28. Plate tectonic, paleoenvironment and lithofacies map of eastern Paleotethys and adjacent areas during Late Carboniferous time

Fig. 28. Mapa tektoniki płyt, paleośrodowiska i litofacji wschodniej Azji oraz obszarów sąsiednich w późnym karbonie

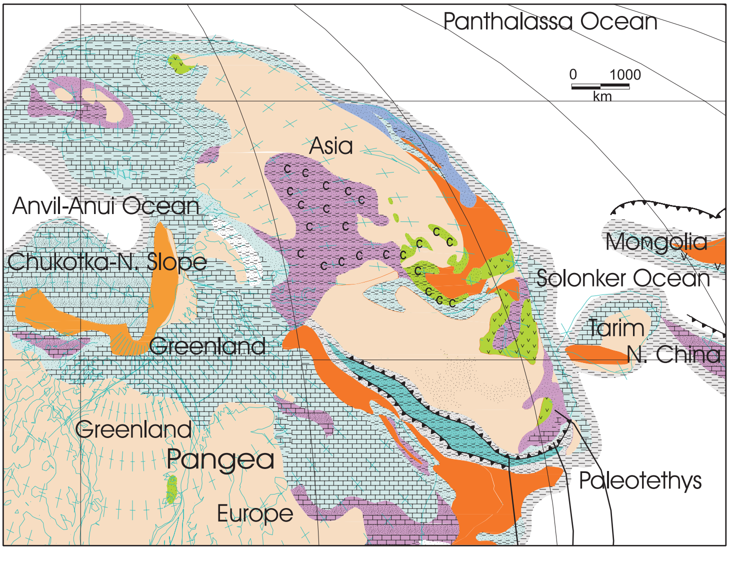

Fig. 29. Plate tectonic, paleoenvironment and lithofacies map of northern North America, northern Europe, Asia and adjacent areas during Late Carboniferous time

Fig. 29. Mapa tektoniki płyt, paleośrodowiska i litofacji północnej części Ameryki, Europy oraz obszarów sąsiednich w późnym karbonie

The Paleotethys Ocean was located between Laurasian and Gondwanian arms of Pangea and Chinese Plates. Carbonates and mixed carbonate/clastic shallow-water facies prevailed on Indochina and South China plates, as well as on the peri-Gondwanian margins (Fig. 28).

The collision of East Siberia and Kazakhstan was nearly completed, forming the Irtysh and Dzungar fold belts (Zonenshain *et al*. 1990). Siberia also began to collide with the Kara Sea plate in the Taimyr area in the Arctic (Vernikovsky 1995, 1997). The central part of Siberia was occupied by marginal marine and lacustrine-alluvial plain where coaly clays, aleurites, sands and sometimes coals were accumulated (Fig. 29) (Vinogradov 1968, Ronov *et al*. 1984, Zonenshain *et al.* 1990, Parfenov 1992, 1997, Parfenov *et al.* 1993, Khudoley & Guriev 1994, Vernikovsky 1995, Puchkov 1996, Golonka *et al.* 2003a). The Tunguska basin was the major region of sedimentation. Thicker Upper Carboniferous marine deposits, represented by clastics and mixed carbonate-clastics facies, were accumulated in the Peri-Verkhoyansk zone (Khudoley & Guriev 1994) and in the vicinity of the Taimyr zone (Vernikovsky 1995).

Icehouse conditions prevailed, with cool temperatures extending to low latitudes. The southern polar ice-cap reached its maximum size (Fig. 30) (Crowell & Frakes 1975, McClure 1978, 1980, Veevers & Powell 1987, Crowley & Baum 1992, Frakes *et al.* 1992, Crowley 1994, Francis 1994, Veevers 1994, 2004, Ford & Golonka 2000, Golonka 2000, 2002). The ice-cap covered Southern Australia, Antarctica, southern India and Arabia, Madagascar, eastern and southern Africa, and southeastern part of South America.

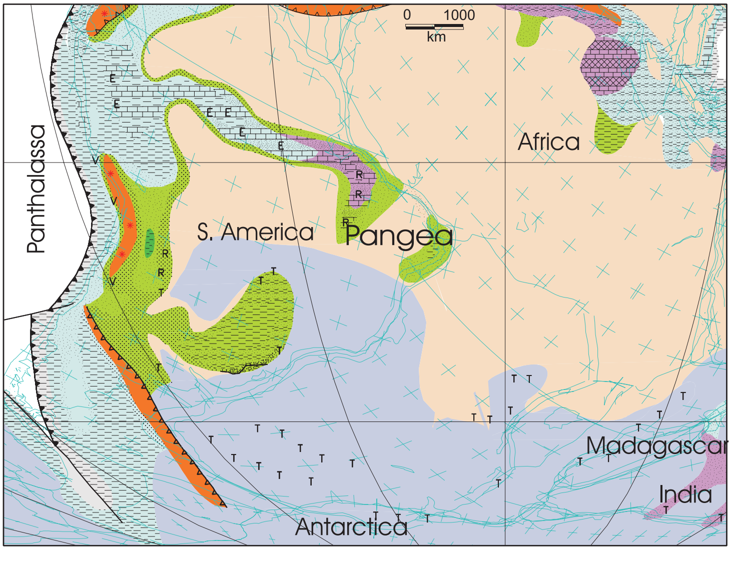

Fig. 30. Plate tectonic, paleoenvironment and lithofacies map of central Gondwana during Late Carboniferous time

Fig. 30. Mapa tektoniki płyt, paleośrodowiska i litofacji centralnej Gondwany oraz obszarów sąsiednich w późnym karbonie

Subsidence was most intensive in the Amazon basin (Ronov *et al*. 1984, Williams 1995, Andreis & Archangelsky 1996, Milani & Zalán 1999, Ford & Golonka 2003, Limarino & Spalletti 2006) in South America, especially in its eastern part. Limestones, argillites and sandstones with interlayers of gypsum, anhydrites, and salt were deposited there. Thickness of the deposits was 300–400 m in marginal zones, 1300–1500 m in the central parts and it was maximal in the east – up to 2000 m. In the east, the basin was connected with the newly-formed Maranao basin, which was also filled with the same rock complex but of a lower thickness – up to 400 m. In the Parana basin subsidence started in the Late Carboniferous, following glaciation (Limarino & Spalletti 2006). Glacial deposits are overlapped by lacustrine-marsh terrigeneous complexes, including coal-bearing. The Cape Fold Belt in southern South Africa (Visser 1987, Veevers 1994, 2004, Veevers *et al*. 1994, Golonka & Ford 2000) was one of the other Circum-Pangean orogenies. It extended into Sierra de la Ventana mountains in South America. The subduction zones existed along the western coast of Pangea (present day South and North America).

Early Permian

Many of the continental collisions, which began in the Carboniferous, were completed in the Permian. The western half of Pangea was assembled (Figs 31, 32), and the new supercontinent, ringed by subduction zones, moved steadily northward. The Ouachita Mountains of Oklahoma record the final phase of deformation in the Early Permian. This major tectonic activity was caused by the collision of the Inner Ouachitas and Sabine terrane with North America, with the accompanying convergence of Laurasia on the north and Gondwana (composed of Africa and South America, including the Yucatan promontory) on the south. To the north of the Ouachitas and partly beneath them was the Northern America platform with its autochthonous cover. As a result of Carboniferous-Permian tectonic movements, Ouachita allochthonous rocks have been thrust over the platform for a distance of 50 to more than 100 km. As a result of Ouachitas overriding the platform, the peripheral foreland Arkoma Basin formed along the moving orogenic front. The Ouachita foldbelt was a part of the central Pangean mountain range, which extended from West Texas to Poland (Keller & Hatcher 1999, Golonka *et al*. 2006c). The environment of deposition in front of the foldbelt seems to have been a relatively shallow fluvial-deltaic to near shore (swamp, marsh with minor marine influence). Some limestone beds occur, but the poorly sorted sandstones and dark gray shales prevail. The facies boundary rocks of the Ouachita Mountains and those of the foreland of the Arkoma Basin and Arbuckle Mountains is sometimes hard to define. A Central Pangean mountain belt created a substantial rain shadow at low and mid latitudes. Orogenic uplift along Pangean margins created internal drainage and stimulated deposition of continental sediments, red beds, evaporites, and eolian sandstones (Ronov *et al*. 1984, P.A. Ziegler 1989). Carbonates occurred at low to mid-latitudes and were dominated by muddy facies and algal/*Palaeoaplysina* buildups (Ronov *et al*. 1984, Flügel 1994, Beauchamp 1995, Kiessling *et al*. 1999). The Western Texas basin, located in the south-western corner of the craton, was open to the ocean in its southern part and had a complicated structure (Walker *et al*. 1995). It was divided by the inner uplift of the Central platform into two subbasins – Delaware and Midland.

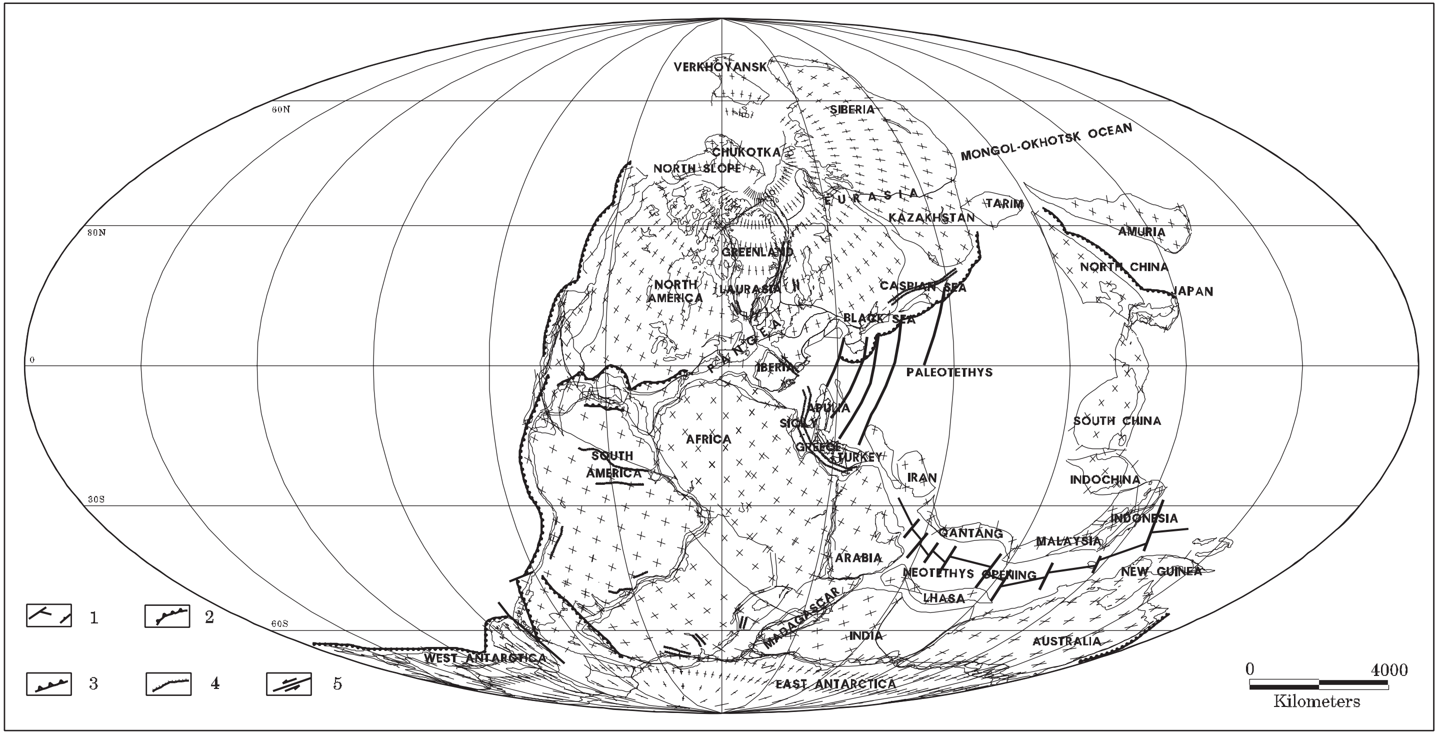

Fig. 31. Plate tectonic map of Early Permian (plates position as of 285 Ma). Modified from Golonka (2002): 1 – oceanic spreading center and transform faults, 2 – subduction zone, 3 – thrust fault, 4 – normal fault, 5 – transform fault

Fig. 31. Mapa tektoniki płyt wczesnego permu (pozycja płyt 285 milionów lat temu). Zmieniona wg Golonki (2002): 1 – centrum spredingu oceanicznego i uskok transformujący, 2 – strefa subdukcji, 3 – nasunięcie, 4 – uskok normalny, 5 – uskok przesuwczy

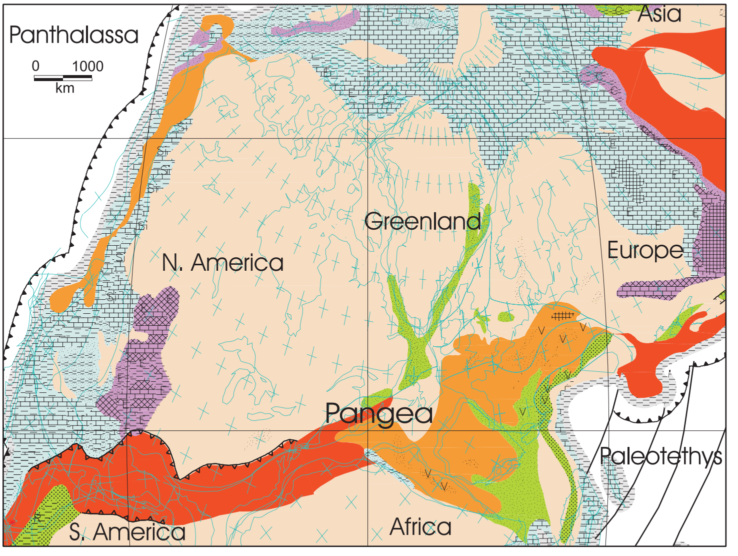

Fig. 32. Plate tectonic, paleoenvironment and lithofacies map of North America, Europe and adjacent areas during Early Permian time

Fig. 32. Mapa tektoniki płyt, paleośrodowiska i litofacji Ameryki Północnej, Europy oraz obszarów sąsiednich we wczesnym permie

In the peripheral parts of the basin and in the Central platform, shelf carbonates were accumulated; in the second half of the Early Permian and in the first half of the Late Permian large barrier reefs (Weidlich 2002) were formed at their margins. At the same time, thick black bituminiferous thin-laminated limestones, aleurolites and schists were deposited in depressions of the subbasins. Marine basins in the southern part of the North American craton became essentially smaller compared to the Late Carboniferous, because of uplifts and regressions in the eastern part of the Midcontinent (Fig. 32) (Cook & Bally 1975, Ronov *et al*. 1984, P.A. Ziegler 1988, 1989, Bally 1989, Bally *et al.* 1989, Golonka & Ford 2000, Ford & Golonka 2003, Golonka *et al*. 2003a). Only a small depression filled with coarse continental sediments remained in the latter zone. Marine basins still existed in the western parts of the Midcontinent with carbonate, clastic and mixed carbonate-clastic deposition. Under the stable tectonic conditions, development of the Sverdrup basin continued in the northern part of the craton. This large depression was filled mainly by carbonates of 1 km thickness, which included evaporites in the southern part of the basin. At the end of the Early Permian almost the entire region underwent a short period of uplift, which led to a gap in sedimentation.

The Hercynian Mountains in the Western and Central Europe became inactive (Fig. 32). Opening of the proto-North Sea was initiated between East Greenland and Baltica (Stemmerik *et al*. 1991). Strike-slip, pull-apart grabens developed in Central Europe (P.A. Ziegler 1988, 1989). Subsidence of a large Volga-Ural basin continued in the eastern apart of Europe (Vinogradov 1968, P.A. Ziegler 1982, Ronov *et al.* 1984, Zonenshain *et al.* 1990, 1989, Nikishin *et al*. 1996, Golonka & Ford 2000, Golonka *et al.* 2003a, Mizens 2004).

It had the largest size in the Asselian time, when the sea almost reached the Moscow region and covered the south-eastern part of the Voronezh uplift. The basin was shallow, with increased water salinity, dolomite oozes and sometimes gypsum and salt were accumulated there. Small amount of terrigeneous material was accumulated in the coastal zones, however, carbonates dominated and thickness of the Lower Permian deposits did not exceed 350 m. Shallow sea was bordered from the east by a rift-forming zone, which included low islands, banks and atolls. Eastwards from the rift belt, the sea abruptly became deeper even in the Urals mobile belt. The Dnepr-Donets basin was connected with the Peri-Caspian basin in the Early Permian, terrigeneous and carbonate deposits were formed there. In the Artinskian time this connection was closed and evaporites were accumulated in an isolated lake.

The Carboniferous-earliest Permian rifting of the Cimmerian Plates (see Dercourt *et al*. 1993, Golonka *et al*. 1994, Şengör & Natalin 1996) from Gondwana turned into drifting during the Permian, marking the inception of the Neotethys Ocean (Fig. 33). The carbonate and mixed carbonate-clastic shallow-water deposition prevailed in Indochina and adjacent part of South China. Marginal marine clastic and coal-bearing sequences were also developed along the marginal areas of sedimentary basins within the South China plate (Shouxin & Yongyi 1991, Enos 1995) and Indochina plate (Brookfield 1996). Volcanics began to develop on the Indochina plate. Carbonates also prevailed on the Cimmerian plates between Paleotethys and Neotethys, and on Neotethys margins (Dercourt *et al.* 1993, Brookfield 1996, Şengör & Natalin 1996).

Formation of Laurasia by collision of Kazakhstan and Siberia with Laurussia was concluded (Fig. 34) (P.A. Ziegler 1989, Zonenshain *et al*. 1990, Nikishin *et al*. 1996).

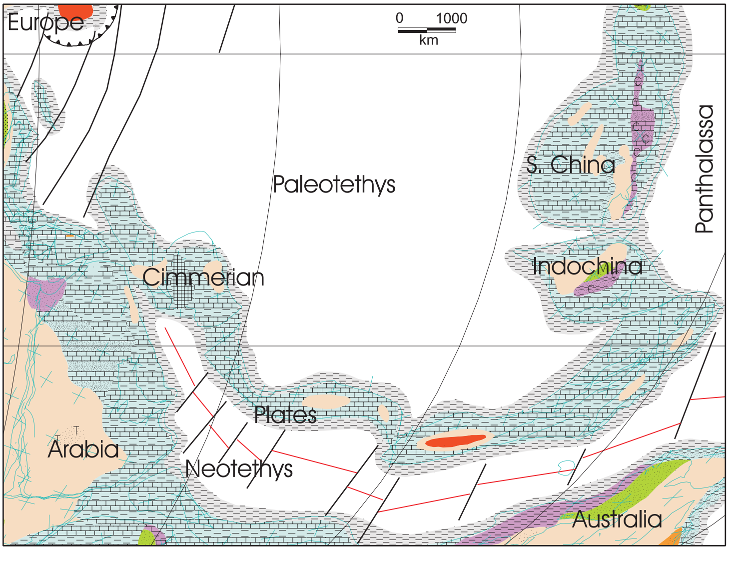

Fig. 33. Plate tectonic, paleoenvironment and lithofacies map of Paleotethys, incipient Neotethys and adjacent areas during Early Permian time

Fig. 33. Mapa tektoniki płyt, paleośrodowiska i litofacji Paleotetydy, inicjalnej Neotetydy oraz obszarów sąsiednich we wczesnym permie

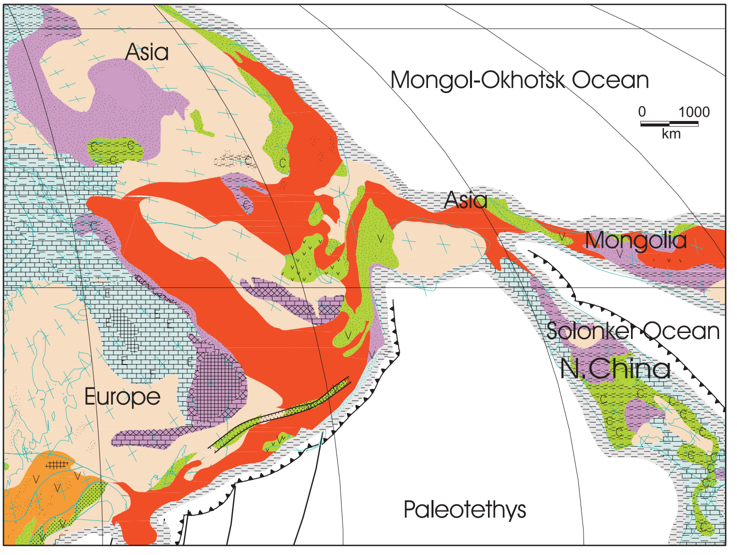

Fig. 34. Plate tectonic, paleoenvironment and lithofacies map of Asia, Eastern Europe and adjacent areas during Early Permian time

Fig. 34. Mapa tektoniki płyt, paleośrodowiska i litofacji Azji, wschodniej Europy oraz obszarów sąsiednich we wczesnym permie

The closing of the Uralian Ocean involved capturing of oceanic crust, which forms the basement for the West Siberian Basin. Uralian Ocean closure also involved foreland basin development and craton margin subsidence (Puchkov 1991, 1997, Nikishin *et al.* 1996). At the beginning of the epoch, the Peri-Caspian basin was connected with the Volga-Ural basin and Paleotethys, and it was characterized by uncompensated subsidence. In the Kungurian, the Peri-Caspian basin was not connected any more with the southern seas of the Paleotethys, because an orogen had developed in the south and the sea-gulf had quickly undergone salinization. In a short time salt filled the vast basin. The Solonker Ocean between North China and Amuria (Mongolia) narrowed (Scotese & Lanford 1995, Şengör & Natalin 1996). Tarim was in collision with the southern margin of Laurasia in the Tyanshan-Dzungar basin area (Nie *et al*. 1990, Yin & Nie 1996). West of Tarim, the Northern Pamir-Gissar terranes docked into Kazakhstan during the Permian time (Puchkov 1991). The alluvium-lacustrine sandy-argillaceous deposits were accumulated on the North China plate. In the southern part of the basin, they included lenses and layers of coals. The lagoonal basin was located in the western part of the Tarim block. The Siberian craton was a vast plain, within which huge marshes and lakes appeared from time to time. In these closed depressions, mainly in the central part of the craton (the Tunguska basin), quartz sands and other terrigeneous rocks (sometimes coal-bearing) were deposited, with the total thickness of no more than few tens of meters. Typical marine basins were developed only in the Peri-Verkhoyansk zone and in the Taimyr peninsula. The system of mountain ridges and intramountain depressions were in the territory of Kazakhstan, the Altay-Sayan region, the Tien Shan, Mongolia and the Inner Mongolia. Formation of molasse complexes, sometimes rather thick, took place from time to time in lakes.

The largest sea-lakes were formed in the Kazakhstan region. Argillaceous-carbonate oozes dominated among the sediments in the Early Permian, thick layers of salt and gypsum were also deposited. The subduction zone along the northern coast of Paleotethys continued its existence (Zonenshain *et al*. 1990, Scotese & Lanford 1995, Şengör & Natalin 1996).

Continental clastic deposition in Gondwana (Fig. 35) is related to the initial rifting and melting of the icecaps (Crowell & Frakes 1975, McClure 1978, 1980, Veevers & Powell 1987, Frakes *et al*. 1992, Francis 1994, Crowell 1995, Veevers 2004). This is a major period of coal formation in high-precipitation areas of Gondwana (South Africa, India, Australia, and South America), (Ronov *et al*. 1984, Veevers & Powell, 1987, Visser 1987, Gupta & Brookfield 1991, Williams 1995, Veevers 2004) and northern China (Enos 1995). By the beginning of the Permian, the Amazon basin in South America underwent regression and both marine and continental terrigeneous sediments with red beds and evaporites were accumulated (Ronov *et al*. 1984, Williams 1995, Andreis & Archangelsky 1996, Gonzales-Bonorino & Llammbias 1996, Milani & Zalán 1999, Ford & Golonka 2003, Limarino & Spalletti 2006). The Maranao basin became smaller, more shallow, and alluvium-lacustrine, lagoon-continental and partly coastal-marine deposits were accumulated there. To the south from these regions, subsidence of the Parana basin continued (Limarino & Spalletti 2006). It consisted of isolated or interconnected post-glacial depressions, where coal was accumulated periodically. Layers of conglomerates indicate that there were short periods of increased tectonic activity.

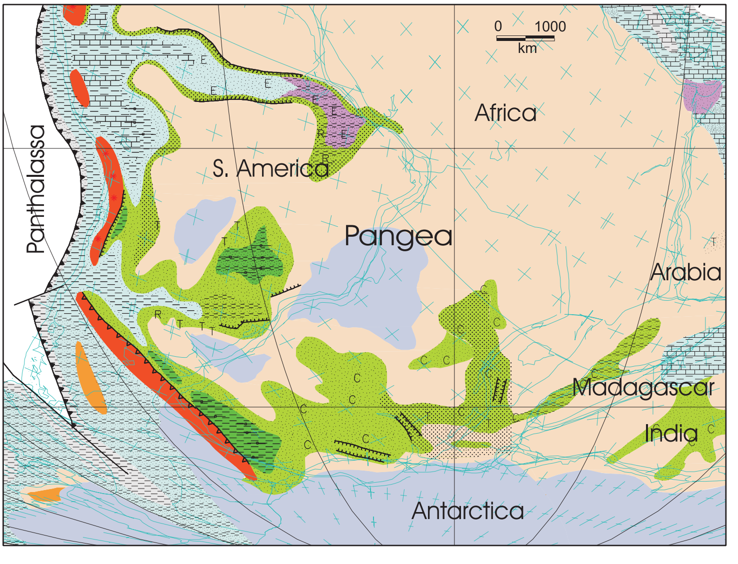

Fig. 35. Plate tectonic, paleoenvironment and lithofacies map of South America, Africa, Antarctica and adjacent areas during Early Permian time

Fig. 35. Mapa tektoniki płyt, paleośrodowiska i litofacji Ameryki Południowej, Afryki, Antarktyki oraz obszarów przyległych we wczesnym permie

From time to time, sea waters flooded this area, however the conditions of a swamped plain dominated. To the south, subsidence of the Central Patagonian basin continued without any interruptions, marine and continental sedimentation conditions replaced each other there. In the northern part of the Peri-Andean marginal zone, carbonate-terrigeneous rocks and sometimes evaporites were deposited in marine basins. Continental marginal depressions in the southern part of the Peri-Andean zone were entirely filled by sediments by the beginning of the Permian. The Cape-Sierra da la Ventana orogen was a major feature in Gondwana (Fig. 35). Karoo rifting began in central Gondwana (Cox 1992, Cadle *et al*. 1993, Veevers 1994, 2004, Veevers *et al.* 1994, Golonka & Ford 2000, Stollhofen *et al*. 2000). Subduction zones existed along the coasts of South America, and Antarctica (Miller 1981, Forsythe 1982, Findlay 1991, Milne & Miller 1992, Golonka & Ford 2000, Golonka 2002).

Late Permian

Supercontinent Pangea existed during Late Permian times (Fig. 36) with the onset of stretching and rifting (Golonka 2000, 2002, Golonka & Ford 2000, Ford & Golonka 2003, Golonka *et al*. 2003a, 2006a). In Eurasia, crustal shortening continued in the northern part of the Ural Mountains, in Pay-Khoy and Novaya Zemlya, while the central and southern part of the Urals had became tectonically inactive (Puchkov 1991, Nikishin *et al*. 1996). The evidence of Permian compression was also found in the Taimyr Peninsula (Vernikovsky 1995). The Asian continent was uplifted with numerous mountain ranges (Fig. 37).

Sedimentary basins in the vast areas of Kazakhstan, Altay-Sayan, Tien Shan, Mongolia, and the Inner Mongolia were formed by intramontane depressions, where molasse-type deposits were accumulated sometimes with evaporites and coal-bearing complexes. Large and shallow lakes periodically appeared in the central part of Siberia where the conditions for the accumulation of terrigeneous and coal-bearing deposits existed (Vinogradov 1968, Ronov *et al*. 1984, Zonenshain *et al.* 1990, Parfenov 1992, 1997, Parfenov *et al.* 1993, Khudoley & Guriev 1994, Vernikovsky 1995, Puchkov 1996, Golonka *et al.* 2003a). Marine basins existed only in the Peri-Verkhoyansk zone and in the eastern part of Taimyr. At the end of the Late Permian intensive trap magmatism was developed in the central, northern and north-eastern regions of Siberia. The episode of very strong, hot spot related, flood basalt eruptions in the Western Siberian basin (Zonenshain *et al*. 1990) occurred within an extremely short period from 255 to 245 Ma (Golonka 2002, Nikishin *et al.* 2002). During 10 million years 1 200 000 km^3 of basalts were extruded. The largest body of the flood basalts covers the Tunguska flood basalt province located on the Siberian craton (Dobretsov 1997, Courtillot & Renne 2003). There are magmatic activities in Siberia and adjacent part of Central Asia connected with the Tunguska superplume: Kuznetsk basalts, age Induan, Verkhoyansk-Viluy region, and Central Kazakhstan (Nikishin *et al.* 2002). The volcanics are present along the entire margin of South America, Antarctica and Australia within the entire Pangean Rim of Fire margin (Ford & Golonka 2000 and references therein). The Uralian orogeny resulted in a rapid subsidence phase and formation of foreland basins filled by clastic sediments mainly of fine-grained molasse type in the eastern part of the Volga-Ural, Timan-Pechora basin on the Eastern European Platform, as well as in the Eastern Barents sea area (Puchkov 1991, Chuvashov 1995, Nikishin *et al*. 1996).

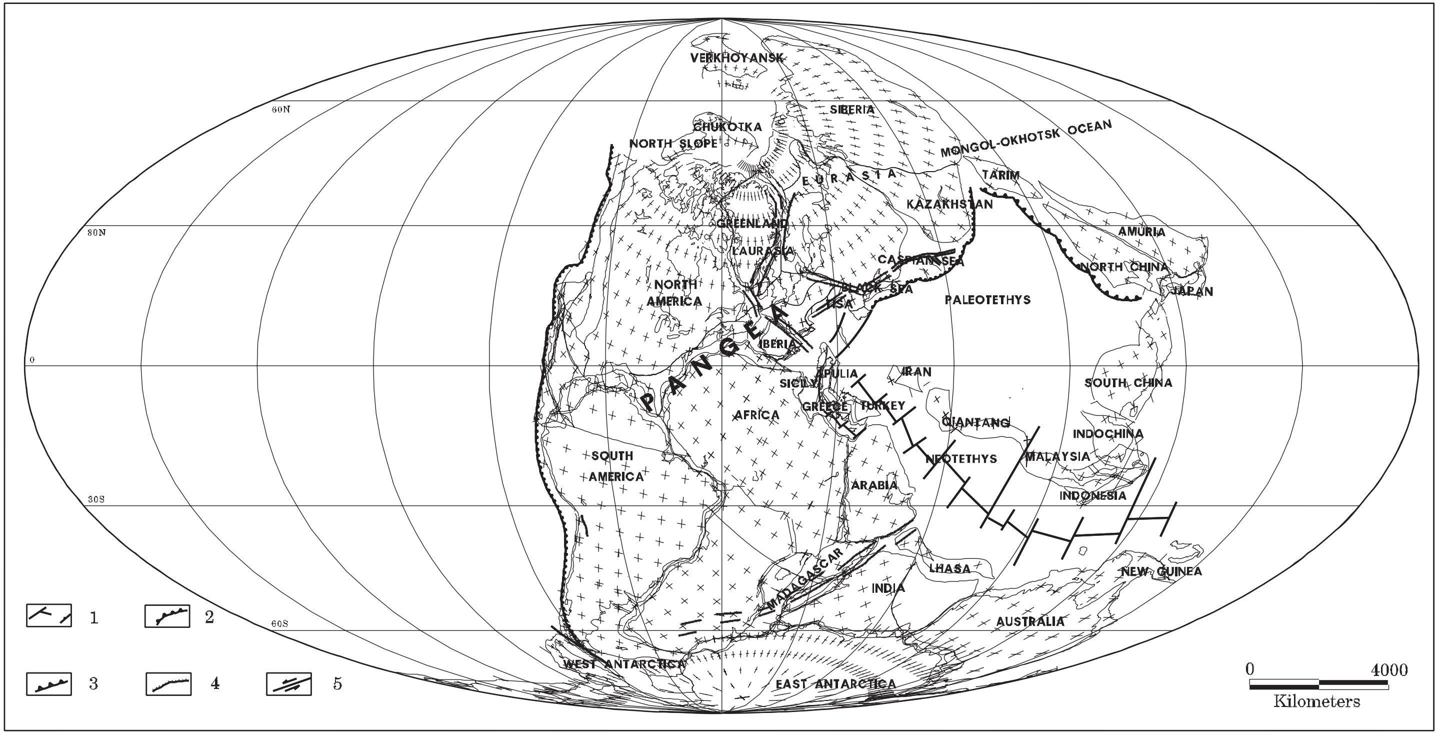

Fig. 36. Plate tectonic map of Late Permian (plates position as of 255 Ma). Modified from Golonka (2002): 1 – oceanic spreading center and transform faults, 2 – subduction zone, 3 – thrust fault, 4 – normal fault, 5 – transform fault

Fig. 36. Mapa tektoniki płyt późngo permu (pozycja płyt 255 milionów lat temu). Zmieniona wg Golonki (2002): 1 – centrum spredingu oceanicznego i uskok transformujący, 2 – strefa subdukcji, 3 – nasunięcie, 4 – uskok normalny, 5 – uskok przesuwczy

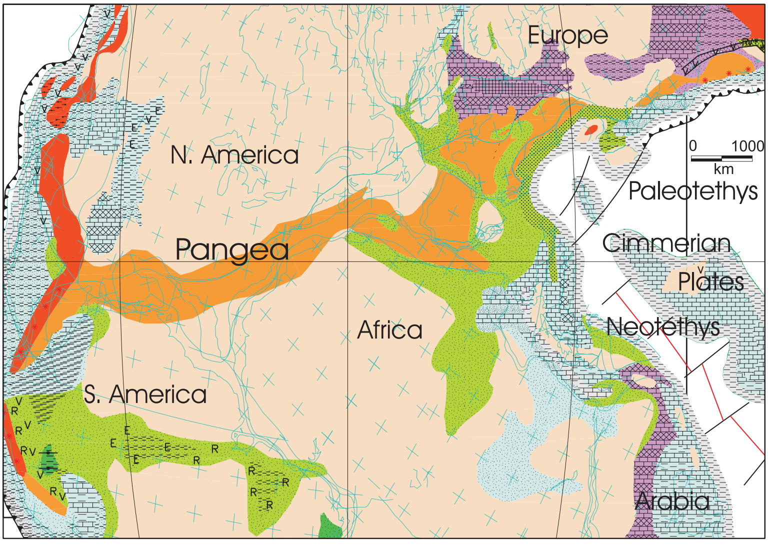

Fig. 37. Plate tectonic, paleoenvironment and lithofacies map of Western Pangea and adjacent areas during Late Permian time

Fig. 37. Mapa tektoniki płyt, paleośrodowiska i litofacji zachodniej Pangei oraz obszarów sąsiednich w późnym permie

The Pechora basin was separated from the Volga-Ural basin by uplifts. An accumulation of coal-bearing terrigeneous deposits took place there under the conditions of fresh lagoons and swamped coasts. Varied and low sea-level caused the formation of restricted and marginal marine basins filled with evaporites, and mixed evaporite-carbonate-clastic facies. Large evaporate pans existed in Central and Western Europe (P.A. Ziegler 1982, 1989, Kiersnowski *et al*. 1995) and on the Eastern European Platform (Ronov *et al*. 1984, Nikishin *et al*. 1996). Restriction was caused by the narrowing of the seaway to the Arctic area (Stemmerik 1995, 2000). Changing sea-level caused the cyclic deposition of the clastic-carbonates-evaporitic sequences. Four of such large cyclothems are distinguished within the European Zechstein sediments. In the western Barents area, carbonates and cyclic spiculitic sediments prevailed (Stemmerik & Worsley 1995, Stemmerik 1997, 2000). Carbonate, mixed carbonate silico-clastics and siliceous deposits dominated in the Arctic area north of Canada (Ronov *et al.* 1984, Beauchamp 1995).

The Neotethys Ocean was already opened and widening (Figs 36, 38, 39) (Dercourt *et al*. 1993, Ricou 1996, Şengör & Natalin 1996). This ocean had Arabia, Greater India and Australia on one side, and Lut-Qiangtang-Southeast Asia on the other. The spreading was driven by trench-pulling forces, related to the north-dipping subduction, as well as the ridge-pushing forces, related to mantle upwelling, expressed by hot spot activity (Golonka & Bocharova 2000). The Northern Chinese plate was sutured, during the Permian time, to the Amurian (Mongolia) terranes (Nie *et al.* 1990, Scotese & Lanford 1995, Yin & Nie 1996). The south dipping subduction, which existed prior to this collision along the North China plate, jumped south forming the north-dipping subduction along the northern coast of the Paleotethys.

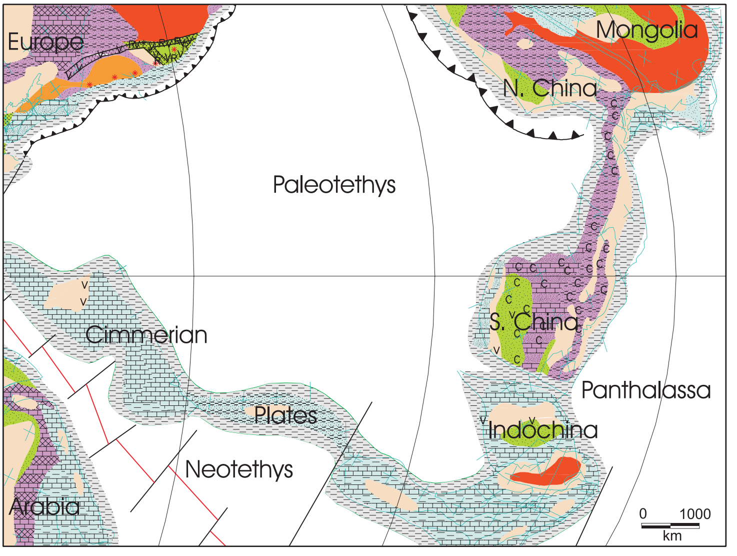

Fig. 38. Plate tectonic, paleoenvironment and lithofacies map of Southeastern Asia, Paleotethys, Neotethys and adjacent areas during of Late Permian time

Fig. 38. Mapa tektoniki płyt, paleośrodowiska i litofacji Azji południowo-wschodniej, Paleotetydy, Neotetydy oraz obszarów sąsiednich w późnym permie

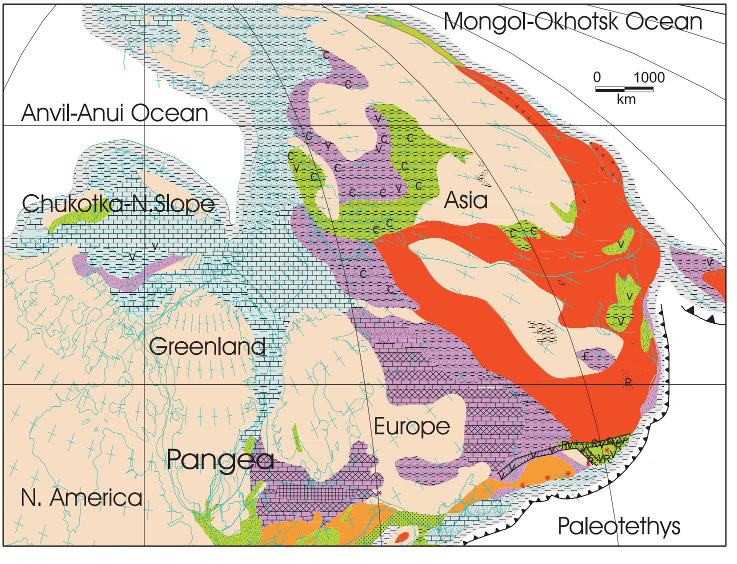

Fig. 39. Plate tectonic, paleoenvironment and lithofacies map of Central Pangea and adjacent areas during Late Permian time

Fig. 39. Mapa tektoniki płyt, paleośrodowiska i litofacji Pangei centralnej oraz obszarów sąsiednich w późnym permie

The Neotethyan passive margin is also marked by the volcanism. The Emeishan basalts in Southwest China (Ali *et al.* 2005) belong to the Late Permian worldwide volcanic episodes. Emeishan large igneous province basalts occupy a rhombic shape wit an area of 0.25 mln square kilometers. According to Ali *et al*. (2005), there are additional part of this province in Red River Fault displaced fragment, southern China and northern Vietnam (Tien 1993, 2000, Xiao *et al.* 2003, Golonka *et al*. 2006a). The South China longitudinal position is quite speculative, so the Emeishan traps fit quite well the present hotspots (Golonka & Bocharova 2000). The question remains: is this mantle plume related to the continental rifting activity and back-arc opening of basin in Indochina and South China? According to Ali *et al*. (2005), geochemical and bio-lithostratigraphic data provide strong evidence in support of an impacting mantle plume. Red-colored fragmented rocks prevailed in sediments which filled large flat depressions in North China. The marine and marginal-marine basins covered large area of the South China plate (Ronov *et al*. 1984, Hongzen 1985, Enos 1995, Golonka & Ford 2000). Carbonates dominated in the sediments in the central part, while to the south-west and south-east, carbonate deposits changed to complex of coal-bearing formation.

Large, shallow carbonate platforms characterized the Guadalupian paleofacies of the Tethyan realm (Dercourt *et al*. 1993, Marcoux & Baud 1996). The carbonates covered the Taurus, Iranian plates, eastern Arabia, and Indonesian plates (Figs 38, 39). The central Pangean belt was no longer active. In particular, the Hercynian Mountains in Europe were subject to erosion, continental deposition, and even locally covered by marine transgression (Fig. 39) (P.A. Ziegler 1982, 1989, Golonka & Ford 2000). To the south, within the future limits of the Alpine belt, the mountain relief existed in the Late Permian and accumulation of sediments of molasse-type occurred in the intramountain depressions. Rifting and oceanic type of basin opening perhaps occurred in the Eastern Mediterranean, being recorded by the deep water sediments of Sicily (Catalano *et al*. 1991, Kozur 1991), Lago Negro (Marsella *et al.* 1993) and Crete (Kozur & Krahl 1987).

The Pangean Rim of Fire represented active Mountain belts and subduction-related arcs spread along the western margin of Pangea in North and South America. Regression developed in North America; the sea remained there as almost closed lagoons in the western United States. Increased water salinity and a hot climate led to an accumulation of not only argillaceous, red-colored sandy and carbonate rocks, but also to a deposition of gypsum and anhydrides. The sedimentological conditions in these deposits changed significantly while the area drifted northward across equator (Walker *et al*. 1995). Carbonate deposits with reefs, evaporites, and phosphorites were dominant (Wardlaw *et al*. 1995, Weidlich 2002).

The continental deposition dominated in South America (Figs 39, 40). Large-scale continental deposits, mainly fluvial and lacustrine with red beds, sometimes with evaporites and coals, occur in Argentina and Brazil (Ronov *et al*. 1984, Williams 1995, Andreis & Archangelsky 1996, Milani & Zalán 1999, Golonka & Ford 2000, Ford & Golonka 2003, Limarino & Spalletti 2006). Subsidence of graben-rifts in the central and southern parts of Africa became slower, and the grabens were filled by lacustrine-alluvium deposits. Quick subsidence occurred only in the Karoo basin (Cox 1992, Cadle *et al*. 1993, Veevers 1994, 2004, Veevers *et al.* 1994, Golonka & Ford 2000, Stollhofen *et al*. 2000). The sedimentation was mainly a continental one. The Upper Permian marginal-marine and continental deposits on the Kenya, Tanzania and Mozambique coasts and in the western part of Madagascar allow assuming the onset of Pangea break-up and formation of future Mozambique Channel. The Gondwanian glaciation waned during the Sakmarian and died out during the Kazanian, about 254–252 Ma (Crowell 1995). The warming which followed the glaciation seems, according to Crowell (1995), to correspond closely with the extinction event at the Permian-Triassic boundary (Sepkoski 1989). The cause of the largest known mass extinction event, at the end of the Permian period, is still a matter of hot debate, with many rapid and catastrophic as well as gradual scenarios having been extensively considered, including impact with an asteroid or comet (see e.g. Holser & Magaritz 1987, Sepkoski 1989, Erwin 1993, Conaghan *et al.* 1994, Wignall & Twichett 1996, 2002, Isozaki 1997, Hallam & Wignall 1999, Metcalfe *et al.* 2001). From the geodynamic point of view, this climatic change and biological extinction were perhaps related to the plate reorganization and mantle plume activity.

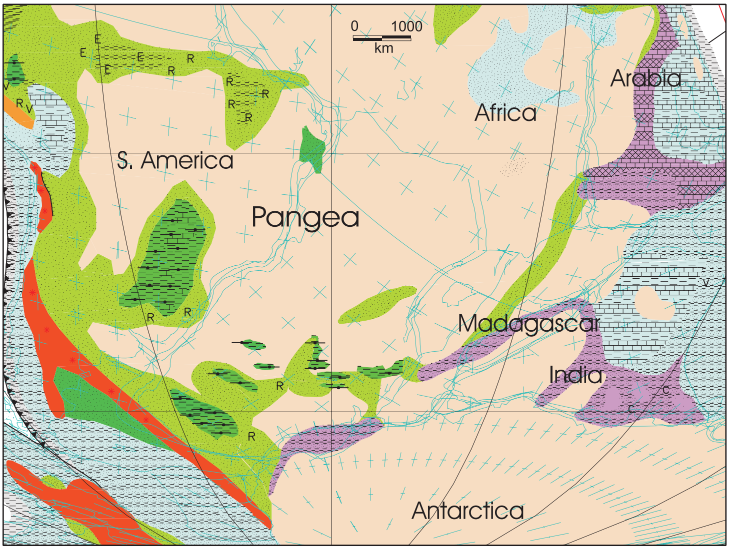

Fig. 40. Plate tectonic, paleoenvironment and lithofacies map of Southern Pangea during Late Permian time

Fig. 40. Mapa tektoniki płyt, paleośrodowiska i litofacji południowej Pangei w późnym permie

The southwestern margin of Gondwana was affected by a major orogenic episode – Gondwanide Orogen, which began during the Moscovian and continued during Permian times (Williams 1995, Golonka & Ford 2000, Veevers 2004, Cawood 2005). Mountains were created in South America (Sierra de la Ventana), South Africa (Cape Fold Belt), Antarctica, and Australia resulting from oceanic-continental plate reactions. In East Gondwana, this orogeny involved a complex interplay of compression and transtension between about 300 and 230 Ma (Cawood 2005).

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Streszczenie

Artykuł przedstawia szczegółowe mapy obrazujące tektonikę płyt, paleogeografię, paleośrodowisko i paleolitofacje ośmiu późnopaleozoicznych przedziałów czasowych. Mapy dotyczą szeregu przedziałów czasowych w obrębie dewonu, karbonu i permu. Wzajemne

stosunki pomiędzy konfiguracją kontynentów, litofacjami, tektoniką płyt i klimatem, jakie panowały w okresie od rozpadu superkontynentu Oldredia aż po powstanie nowego superkontynentu Pangea, są zaznaczone na poszczególnych mapach tworzących spójną serię rekonstrukcji palinspastycznych. Rozkład litofacji jest wyraźnie związany z rozpadem i łączeniem się kontynentów, a także ze zmianami klimatu wywołanymi tektoniką płyt. Rozpad kontynentów i powstawanie oceanów wytworzyło baseny związane z riftingiem i rozwojem krawędzi pasywnych. Łączenie się kontynentów przyczyniło się do tworzenia basenów przedgórskich. Strefy subdukcji związane są z basenami załukowymi. Zmiany klimatu i wymieranie wiążą się z reorganizacją płyt i aktywnością pióropuszy płaszcza.

We wczesnym dewonie po orogenezie kaledońskiej istniał superkontynent Oldredia (Fig. 1–4). Jego częścią była Laurosja obejmująca Amerykę Północną, Bałtykę, Awalonię oraz płytę Czukotki-Alaski północnej. Potężny łańcuch górski zajmował centralną część Laurosji (Fig. 2–5). Łańcuch ten uformował się w czasie orogenezy kaledońskiej, której ostatnie ruchy miały miejsce we wczesnym dewonie. We wczesnym dewonie nastąpiła również transpresjonalna kolizja Ameryki Północnej i Południowej. Również w Azji południowo-wschodniej miały miejsce procesy orogeniczne (Fig. 3). W Wietnamie północnym głębokowodne osady ordowiku i syluru zostały zastąpione przez kontynentalne czerwone osady dolnego dewonu. Syberia była w tym czasie prawdopodobnie połączona z Laurencją (Fig. 4). Kolizje kontynentalne poprzedzały powstanie ryftów na kontynencie Laurosji, a także ekstensyjnych basenów załukowych, takich jak basen renohercyński.

W dewonie środkowym (Fig. 6–10) rozpoczyna się rifting i rozpad Oldredii. Superkontynent ten rozpadł się ostatecznie w późnym dewonie (Fig. 11–15). Ameryka Północna i Południowa rozdzieliły się. W późnym dewonie i wczesnym karbonie ma miejsce orogeneza Antler w zachodniej Laurosji, głównie w Newadzie i Kalifornii. Późny dewon jest również czasem powstania Paleotetydy i dryftu płyt chińskich. W wyniku postępującej dyspersji kontynentów klastyczne osady dewonu dolnego zostały zastąpione przez osady węglanowe środkowo- i górnodewońskie. Dewońskie skały bogate w substancję organiczną, potencjalne skały macierzyste powstawały w ograniczonych basenach na szelfach niskich szerokości geograficznych przesmykach morskich, co wiązało się z globalnym wydarzeniem anoksycznym. Wielkie wymieranie nastąpiło w czasie zbliżonym do granicy franu-famenu.

Oceany Rheic i paleoazjatycki istniały jeszcze w późnym dewonie (Fig. 11, 12) i wczesnym karbonie (Fig. 16–20), ich ostateczne zamknięcie nastąpiło w okresie późniejszym. We wczesnym karbonie nastąpiło całkowite oddzielenie płyt chińskich od Gondwany (Fig. 18), dokumentowane przez wyraźne różnice faunistyczne i florystyczne, jak również przez dane paleomagnetyczne. Nastąpiła też rotacja Syberii w kierunku zgodnym z ruchem wskazówek zegara, a także oddzielenie teranu wierchojańskiego od Syberii.

Superkontynent Pangea powstał w karbonie w wyniku rotacji Gondwany i serii orogenez (hercyńska, alegeheńska), które były wynikiem łączenia się Gondwany i Laurosji.

We wczesnym karbonie (Fig. 21–25) rotacja Gondwany zamknęła resztki oceanu Rheik. Orogeneza hercyńska w Europie była rezultatem kolizji szeregu bloków z krawędzią Laurosji, po czym nastąpiło zaangażowanie się kontynentu Gondwany. Orogeneza alegeheńska i powstanie orogenu Appalachów były wynikiem kontynentalnej kolizji Gondwany i Laurosji. Kolizja ta miała miejsce w późnym karbonie (Fig. 26–30). Wypiętrzył się potężny łańcuch górski ciągnący się od Meksyku po Polskę. W skład niego wchodziły góry Ouachita i Appalachy w Ameryce Północnej, Mauretanidy w Afryce i Hercynidy w Europie. W kierunku południowym pasmo to rozciągało się po Maroko. Późnokarbońskie wydarzenia były również odnotowane na wschód i południe od centralnego pasma, między innymi w Alpach i w Karpatach. We wschodniej Europie nastąpiła kolizja teranu Wielkiego Kaukazu z płytą Bałtyki i utworzenie platformy scytyjskiej. Zachodnią część górotworu centralnego pasma Pangea stanowią góry Ouachita w Arkansas, Oklahomie, Teksasie i przyległej części Meksyku. Zachodnia część oceanu Rheik została zamknięta, wschodnia zamieniała się w Paleotetydę (Fig. 28). W tym samym czasie rozwijał się ryft Zagłębia Doniec-Prypeć.

W późnym karbonie rozpoczęła się również kolizja Kazachstanu i Laurosji (Fig. 29). Utworzenie się superkontynentu, którego część znajdowała się w okolicach bieguna południowego, jak również wypiętrzanie potężnych pasm górskich przyczyniło się do zlodowacenia. Lodowce pokrywały w okresie późnego paleozoiku znaczne połacie Gondwany – południowego ramienia Pangei (Fig. 30). Cykliczne zmiany rozmiaru lądolodu Gondwany oraz topnienie i narastanie powodowały oscylacje poziomu morza, krótkotrwałe transgresje a także powstawanie osadów typu paralicznego. Z osadami tymi, a także z powstaniem rozległych obszarów równin nadmorskich wiąże się powstawanie karbońskich formacji węglonośnych w wielu krajach.

Kontynentalne kolizje, rozpoczęte w karbonie, osiągnęły stadium dojrzałości we wczesnym permie (Fig. 31–35). Główne części Pangei zostały utworzone, a nowo powstały superkontynent, obramowany strefami subdukcji, przesuwał się w kierunku północnym. Północne Alpy Wapienne i Karpaty wewnętrzne tworzyły brzeżną krawędź zachodniej i centralnej Europy. Góry, które utworzyły się wzdłuż północnej krawędzi Paleotetydy jako wynik wydarzeń orogenicznych, były połączone z orogenami hercyńskimi w Europie. Subdukcja o wergencji północnej rozwinęła się wzdłuż krawędzi Paleotetydy. Subdukcja ta była główną siłą napędową, wywołującą późnopaleozoiczny i mezozoiczny ruch płyt na tym obszarze. Kolizja płyty Kazachstanu z Laurosją rozpoczęła się w późnym karbonie i trwała przez cały perm i trias. W wyniku tej kolizji postał górotwór Uralu. Jednocześnie w karbonie i permie trwała kolizja Kazachstanu z Syberią i tworzenie się górotworów Irtyszu i Dżungaru. Na europejskim przedpolu gór Uralu powstało zapadlisko przedgórskie Wołga-Ural wypełnione utworami o charakterze molasy. Na obszarze Afryki i Ameryki Południowej powstał górotwór Gór Przylądkowych i Sierra de la Ventana. Powstały w wyniku karbońskich i permskich kolizji i amalgamacji płyt superkontynent Pangea obejmował Australię, Indie, Antarktykę, Afrykę, Arabię, Południową i Północną Amerykę, Europę, Kazachstan oraz Syberię. Liczne łańcuchy górskie były związane z zapadliskami przedgórskimi i śródgórskimi.

Karbońsko-wczesnopermski rifting płyt kimeryjskich, oddzielający te płyty od Gondwany, przeszedł w permie (Fig. 36–40) w fazę dryftu, zapoczątkowując powstanie oceanu Neotetydy. Ocean ten miał z jednej strony Arabię, Indie i Australię, a z drugiej – płyty Lut, Qiangtang i terany Azji południowo-wschodniej. Ryftowanie i otwieranie basenów typu oceanicznego mogło również wystąpić na obszarze śródziemnomorskim. Wąskie odgałęzienie Neotetydy oddzielało platformę Apulii-Taurusu od kontynentu Afryki. Płyta północnochińska połączyła się w permie z teranem Amurii (Mongolii).

Warunki klimatyczne „icehouse" panowały w późnym paleozoiku. Lodowce osiągnęły swoje maksimum w późnym karbonie, po czym malały, zanikając w permie. Pod koniec permu nastąpiło wielkie wymieranie, którego przyczyny są tematem żywej dyskusji. Z geodynamicznego punktu widzenia zmiana klimatu i wymieranie są związane z reorganizacją płyt i aktywnością pióropuszy płaszcza. Pod konie permu nastąpiły ogromne wylewy law bazaltowych, związane z podnoszeniem astenosfery. Największe wylewy miały miejsce w basenie zachodniej Syberii, gdzie w ciągu 10 milionów lat powstały pokrywy bazaltowe (trapy) o objętości 1 200 000 km^3. Wylewy bazaltowe występowały również w rejonie Emeishan w Chinach i Indochinach na obszarze około 0.25 mln km^2. Działalność wulkaniczna rozwijała się również wokół superkontynentu Pangea, tworząc tak zwany „ognisty pierścień Pangei". Wulkanizm ten wiązał się ze strefami subdukcji, okalającymi superkontynent.