Chapter 10

Plate Tectonic Evolution of the Southern Margin of Laurussia in the Paleozoic

Jan Golonka and Aleksandra Gawęda

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/50009

1. Introduction

The role of an active margin of Eurasia during Mesozoic and Cenozoic times was well defined (Golonka, 2004). The trench-pulling effect of the north dipping subduction, which developed along the new continental margin caused rifting, creating the back-arc basin as well as transfer of plates from Gondwana to Laurasia. The present authors applied this model to the southern margin of Laurussia during Paleozoic times. The preliminary results of their work were presented during the Central European Tectonic Group (CETEG) in 2011 in Czech Republic. The supercontinent of Laurussia, defined by Ziegler (1989), included large parts of Europe and North America. The southern margin of this supercontinent stretched out between Mexico and the Caspian Sea area. The present authors attempted to characterize the entire margin, paying the special attention to Central and Eastern Europe.

2. Methods

The present authors were using a plate tectonic model, which describes the relative motions plates and terranes during Paleozoic times. This model is based on PLATES, GPLATES and PALEOMAP software (see Golonka *et al*. 1994, 2003, 2006a,b, Golonka 2000, 2002, 2007a,b,c, 2009a,b). The plate tectonic reconstruction programs generated palaeocontinental base maps. It takes tectonic features in the form of digitised data files, assembles those features in accordance with user specified rotation criteria (Golonka *et al*. 2006a).

The rigid, outer part of the earth divided into many pieces known as lithospheric plates, comprising both the continental landmasses and oceanic basins These plates are in motion relative to each other and to the earth itself. Assuming the earth is a sphere, the motion of a plate across the earth's surface can be described as motion about the axis of a pole of rotation that goes through the centre of the earth. The intersection of the pole's axis with the earth's surface is referred to by its latitude/longitude coordinates. The distance the plate travels about the pole is an angular distance and is recorded in degrees. A stage pole of rotation describes the distance a plate moved from one time to the next time (i.e. from 20 Ma to 10 Ma). A finite pole of rotation describes the total distance a plate moved from some time in the past to the present day (i.e. from 20 Ma to 0 Ma). A rotation file contains a list of poles of rotation for various plates. The rotation files used by applied software contain finite poles of rotation. Thus for each plate, there are several finite poles of rotation for different times in the past. Plate models that use rotation files that describe the motion of plates relative to other plates are called relative framework models. Among, the data that show the relative motions between plates are fracture zones. Fracture zones are essentially flowlines between plates. For example, in the South Atlantic, the fracture zones show the motion of South America relative to (or away from) Africa. The finite pole of rotation describing this motion is a relative pole. South America is referred to as the moving plate and Africa as the fixed plate (Golonka *et al*. 2006a). The rotation file contains a list of finite rotations between pairs of tectonic elements, at different episodes of time, with brief bibliographic notes or general comments for each individual rotation.

3. Paleozoic major continental plates and ocean related to the Laurussia supercontinent

The break-of the supercontinent Pannotia (Dalziel at al., 1994) during the latest Precambrian times (Golonka, 2000, 2002) lead to the formation of the new continents. Fig 1. depicts the position of these continents at the beginning of the Paleozoic.

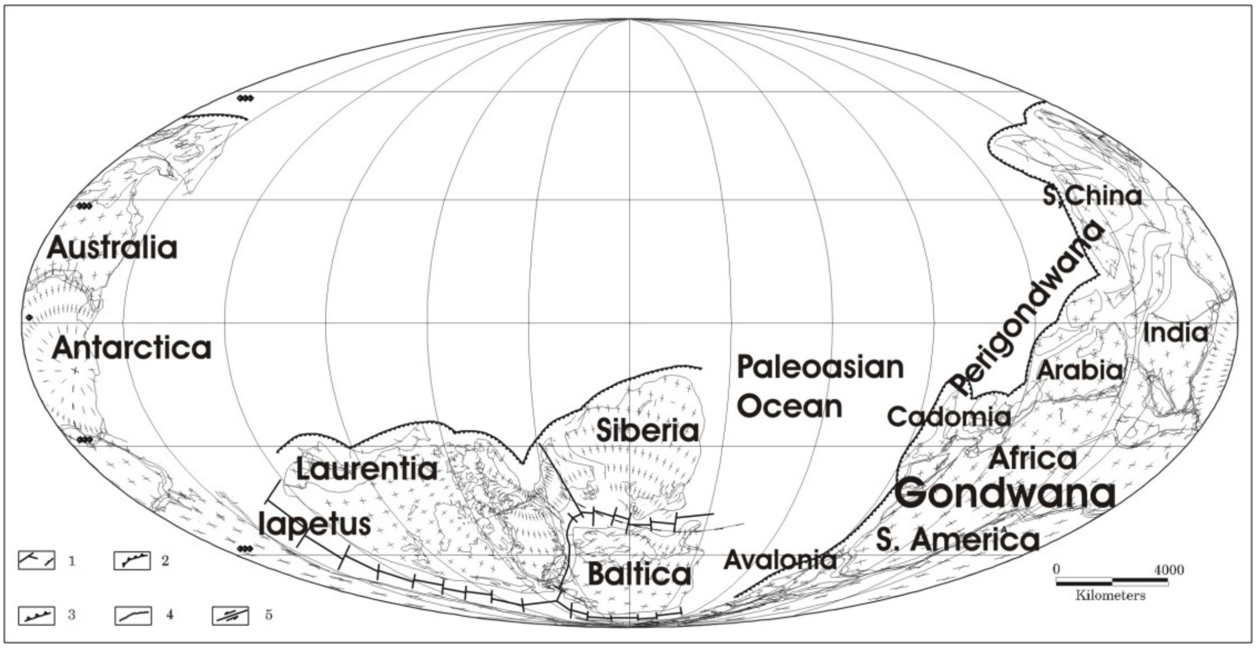

Figure 1. Plate tectonic global map of Early Cambrian (plates position as of 544 Ma). Mollweide projection. Modified from Golonka (2012). 1 - oceanic spreading center and transform faults, 2 - subduction zone, 3 - thrust fault, 4 - normal fault, 5 - transform fault..

3.1. Baltica

The continent Baltica was named after the Baltic Sea. It consisted of a major parts of northern and eastern Europe. It was bounded by the north by the border of the shelf of Norway, southern Barents Sea and Novaya Zemlya, on the east by the Ural suture, and on the southwest by a suture located close, but not quite along the Teisseyre-Tornquist line (Scotese & McKerrow, 1990; Golonka *et al*., 1994). The southern boundary is more controversial. The Ukrainian shield certainly belonged to Baltica (Zonenshain et al, 1990). Perhaps also fragments of the North European platform like the Malopolska block, Bruno-Vistulicum, Moesia and other small blocks located now around the Baltic Sea belonged to Baltica (Kalvoda & Bábek 2010, Żelaźniewicz et al., 2009, Besutiu, 2001). In Central and southwestern Europe the possible boundary of Baltica is marked by the extent of North European plate below the Carpathian and Balkan nappes (Figs. 1-3)

3.2. Gondwana

The supercontinent Gondwana, also known as Gondwanaland (Vevers, 2004) was named after the ancient Indian tribes Gonds; in Sanskrit Gondwana means "the forest of Gonds". The continents forming the core of Gondwana include South America, Africa, Madagascar, India, Antarctica and Australia. The location of numerous smaller continental blocks that bordered Gondwana is less certain. The following were adjacent to Gondwana at some time during the Paleozoic: Yucatan, Florida, Avalonia, central European (Cadomian) terranes between the Armorica and Bohemian Massif, Moesia, Iberia, Apulia and the 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 (Figs, 1, 2).

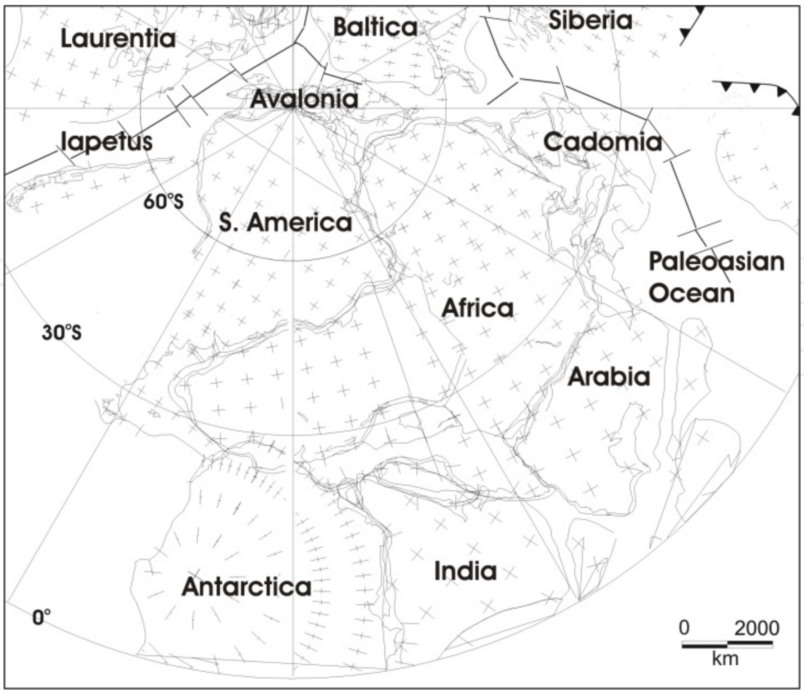

Figure 2. Plate tectonic map of Gondwana. Late Vendian - Early Cambrian (plates position as of 544 Ma). Stereographic polar projection. Modified from Golonka (2012). Legend as in Fig. 1

3.3. Laurentia

The continent Laurentia was named after the Laurentia Shield, in turn after St. Lawrence (Laurentius in Latin) River. North America was a major component of Laurentian plate. This plate also included Greenland, Chukotka peninsula, Svalbard and large part of the Barents Sea (Barentsia) fragment of Alaska (North Slope), northwest Ireland, and Scotland, (Golonka, 2000, 2002, Ford & Golonka, 2003, Golonka *et al.*, 2003). (Figs 1-3). Its southern (present day eastern boundary is located within Appalachians, its northern (present day western) boundary is located within Rocky Mountains. The relationship between Laurentia and Siberia remains speculative (Figs 1-5).

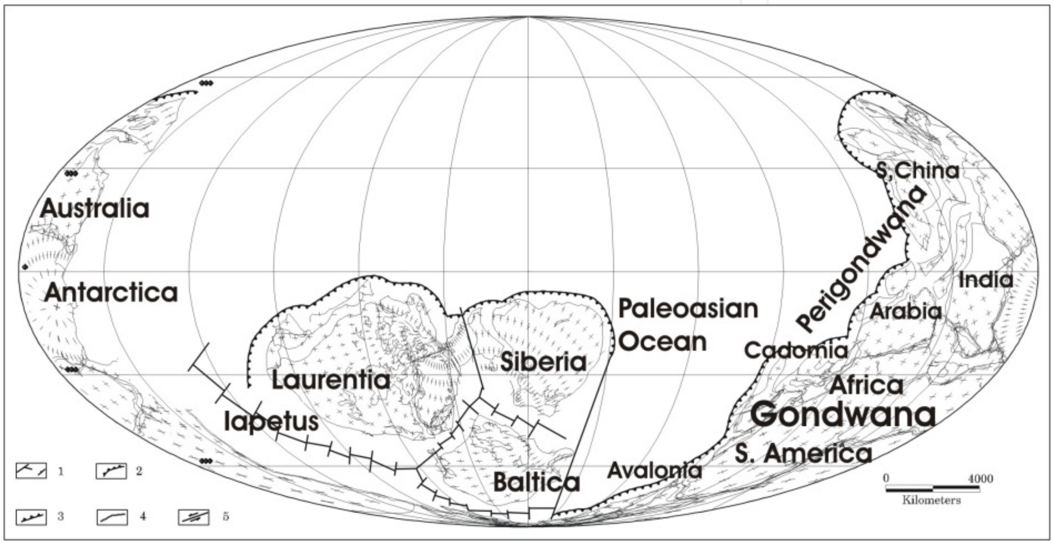

Figure 3. Plate tectonic map of Middle Cambrian (plates position as of 510 Ma). Mollweide projection. Modified from Golonka (2012). 1 - oceanic spreading center and transform faults, 2 - subduction zone, 3 - thrust fault, 4 - normal fault, 5 - transform fault.

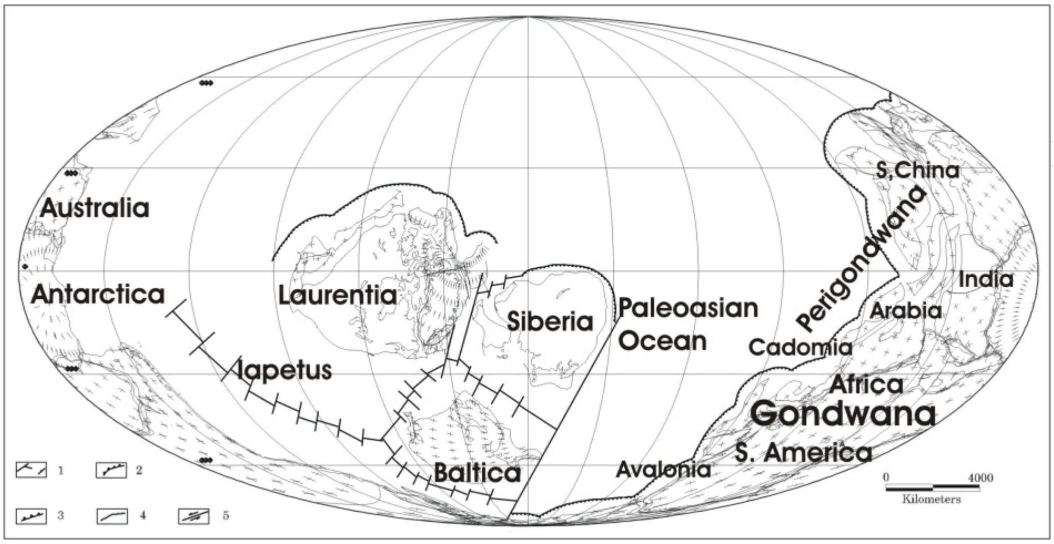

Figure 4. Plate tectonic map of Late Cambrian (plates position as of 498 Ma). Mollweide projection. Modified from Golonka (2012). 1 - oceanic spreading center and transform faults, 2 - subduction zone, 3 - thrust fault, 4 - normal fault, 5 - transform fault.

3.4. Avalonia

The name Avalonia is derived from the Avalon peninsula, Newfoundland, eastern Canada. The names 'Avalon Composite Terrane' (Keppie, 1985), or Superterrane were also used. Western Avalonia included terranes in northern Germany, the Ardennes in Belgium and northern France, England, Wales, southeastern Ireland, eastern Newfoundland, much of Nova Scotia, southern New Brunswick and some coastal parts of New England (Golonka 2009, McKerrow et al. 1991). The inclusion of terranes in the eastern part of Avalonia is more speculative (Fig. 5).

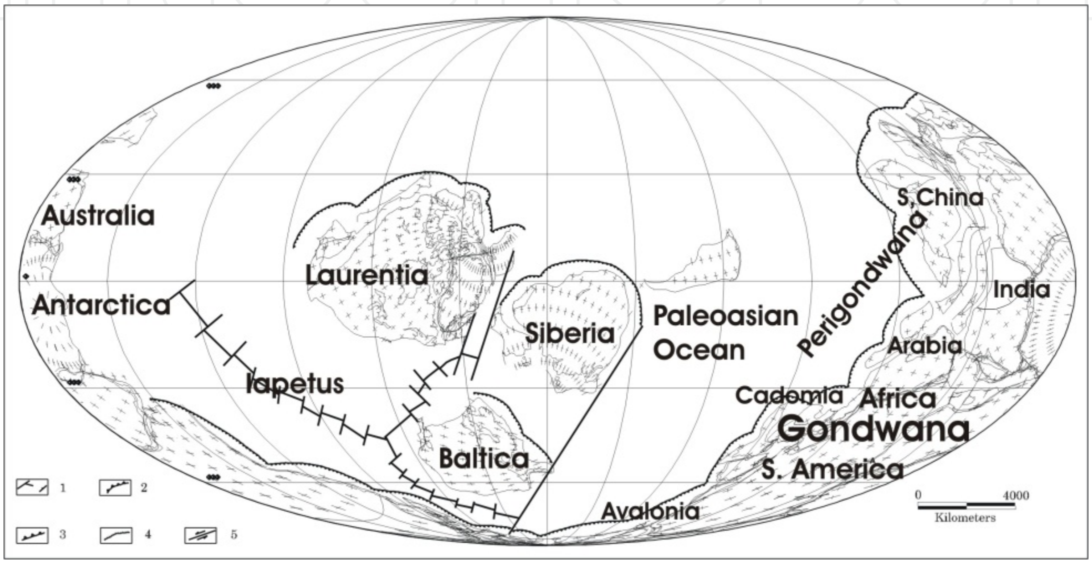

Figure 5. Plate tectonic map of Early Ordovician (plates position as of 485 Ma). Mollweide projection. Modified from Golonka (2012). 1 - oceanic spreading center and transform faults, 2 - subduction zone, 3 - thrust fault, 4 - normal fault, 5 - transform fault.

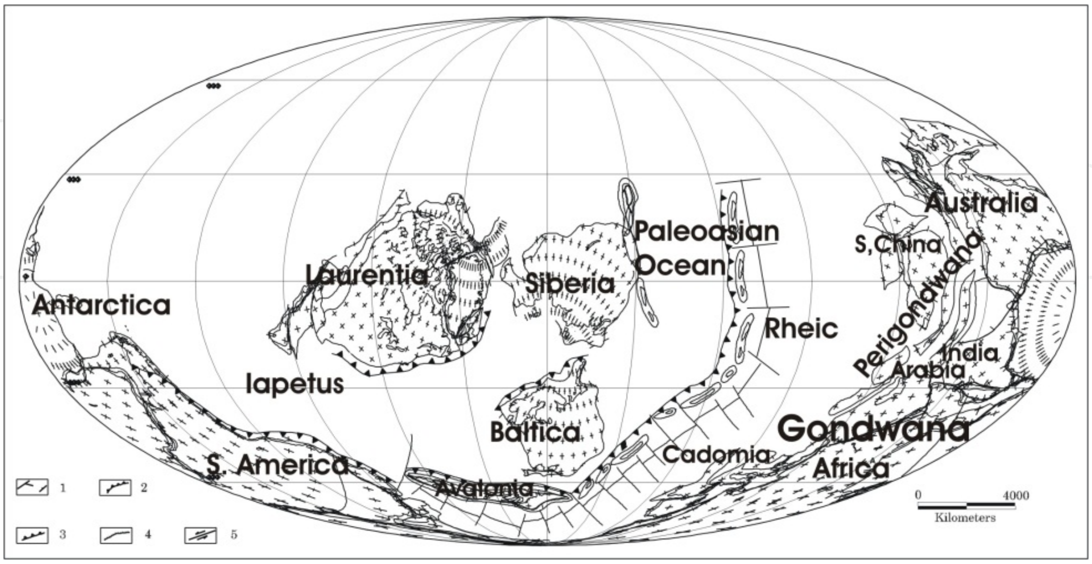

Figure 6. Plate tectonic map of Middle Ordovician (plates position as of 472 Ma). Mollweide projection. Modified from Golonka (2012). 1 - oceanic spreading center and transform faults, 2 - subduction zone, 3 - thrust fault, 4 - normal fault, 5 - transform fault.

Perhaps eastern Avalonia consisted of northwestern Poland fragments now included into Sudety Mountains and Bohemian Massif, terranes accreted in Carpathian-Balkan and Pannonian regions, containing fragments consolidated during Cadomian orogeny, and also Serbo-Macedonian massif, Rhodopes and Pontides in eastern Europe and adjacent part of Asia (Golonka, 2012). Avalonia originated after Gondwana break-up during Early-Middle Ordovician times (Fig.6).

3.5. Cadomia

Cadomia is named after city of Caen, Roman/Latin Cadomia in northern France also known as Armorica or Armorica Group Terrane (e.g. Lewandowski 2003 and references therein) or Gothic terranes (Stampfli, 2001). It consisted of the fragments of western and Central Europe between northwestern France (Brittany) and Czech Republic consolidated during Cadomian orogeny (Figs.1-6). It includes Saxoturingian zone/terrane in Germany and northwestern Czech Republic. Cadomia belonged to Perigondwana during Early Paleozoic times. Perhaps it was detached from Gondwana during Silurian times (Golonka et al. 2006a, Lewandowski 2003), the existence and nature of this detachment as well as extension of Cadomia eastward and westward remain quite speculative.

3.6. Iapetus Ocean

The Iapetus Ocean is named after Titan, son of Uranus, the sky, and Gaia, the Earth, father of Atlas. It preceded Atlantic off the American coast, therefore Atlantic was derived from Atlas and proto-Atlantic was named after Atlas' father. The Iapetus Ocean was located between Gondwana and Laurentia (Figs 1-6), later also between Avalonia and Laurentia (Fig. 6). It started to open as a rift between Laurentia and Rodinia in late Neoproterozoic, about 760-700 Ma, and the maximum obtained at about 600-520 Ma (Kamo et al. 1989; Cawood et al. 2001). Its closure is connected with the rotation and collision of Baltica, Laurentia and the fragment of Gondwana – Avalonia (Hartz & Torsvik 2002). The Iapetus suture was formed Caledonian Orogeny was formed in the time interval 480-440 Ma in the west while the eastern part (in Europe) closed at 440-420 Ma. The eastern extension of Iapetus is not so certain (Golonka, 2002, 2006a, b). Perhaps it was located between Baltica and Gondwana. Part of the Iapetus Ocean is known as Tornquist Sea, the oceanic basin located between the southwest and southern margin of Baltica and Gondwana, and later also Avalonia plate. The name is derived from the Tornquist zone in central Europe, already mentioned border of Baltica. The position of Tornquist Sea is speculative, because Baltica rotated during Early Paleozoic times.

3.7. Rheic Ocean

The Rheic Ocean was named after Rhea, Titaness-Goddess, daughter of Uranos, the sky, and Gaia, the Earth, wife of Cronos and mother of Zeus. Rheic Ocean originated between Gondwana and Avalonia (Fig. 6), later between Gondwana and Laurussia, during Early Paleozoic times (Nance et al. 2010 and references therein). It was opened during Late

Cambrian – Early Ordovician times, around 500 Ma. System of back-arc basins developed along the northern branch of Rheic Ocean after formation of Laurussia during Devonian times (von Raumer & Stampfli, 2008). These basins are considered either as a part of the Rheic Ocean (e.g. Nance et al. 2010, Golonka, 2007b, McKerrow et al., 1991) or as a separate entity known as Rheno-Hercynian or Moldanubian basin in Central Europe (e.g. Golonka et al. 2006b, Golonka 2002, Schulmann et al., 2009). Rheic Ocean narrowed during Devonian and was closed during Carboniferous times as a result of collision of Laurussia with Gondwana.

4. Global Early Paleozoic plate tectonic evolution leading to the assembly of Laurussia

Gondwana supercontinent was located around the South Pole at the beginning of Paleozoic (Figs 1-2). Baltica and Laurentia were located at the high latitude in the southern hemisphere, their southern margins close to the South Pole. They drifted apart from Gondwana during the Late Vendian times (Torsvik et al., 1996, Golonka et al, 2002, 2009b, 2012). Their breakup led to the formation of new oceans, including Iapetus (Figs. 1-2). Continued seafloor spreading occurred in this ocean during Cambrian times (Figs. 2-4). The fragmentation of northern margin of Gondwana was also marked by magmatic activity in the 550-500 Ma (Dörr et al., 1998, Turniak et al., 2000, Tichomirowa, 2002, Burda and Klötzli, 2011). Laurentia drifted rapidly northward and rotated counter-clockwise, reaching low latitudes (Golonka, 2000, 2002). Seafloor spreading also occurred within the Pleionic Ocean between East Siberia and Baltica. The relationship between Laurentia and Siberia remains quite speculative. Latest Cambrian – earliest Ordovician was the time of maximum dispersion of continents during the Paleozoic. Baltica, Laurentia and Siberia drifted further northward (Fig. 5). The subduction along the central margin of Gondwana caused the onset of rifting of the Avalonian terranes (Golonka et al., 1994, Golonka, 2000, 2002). The subduction along the northern margin of Baltica was perhaps related to the Ordovician rotation of this plate (see Golonka et al., 1994, 2006b, Torsvik et al., 1996, McKerrow et al., 1991, Golonka, 2000, 2002, cocks & Torsvik, 2011). The distance between Gondwana and Laurentia, which was situated on equator reached 5000 km (Golonka, 2002, Golonka et al. 2006).

Early-Middle Ordovician were the times of a major plate reorganization (Golonka, 2000, 2002, 2009b, 2012, Golonka et al. 2006b). Avalonia probably started to drift from Gondwana and move northward toward Baltica and Laurentia (Golonka, 2000, 2002, 2009b, 2012). This movement was related to the origin of Rheic Ocean. (Fig. 6). The Iapetus Ocean had begun to narrow.

During Late Ordovician times (Fig. 7 the Rheic Ocean between Gondwana and Avalonia widened significantly (Golonka, 2000, 2002, 2009b, 2012). The position of Cadomia remains uncertain. On the presented reconstruction, the Cadomian blocks are positioned relatively close to Gondwana. This is mainly based on the paleobiogeographical data (Scotese and McKerrow, 1990, Robardet et al., 1993, Golonka, 2002, 2009b, 2012). The alternative

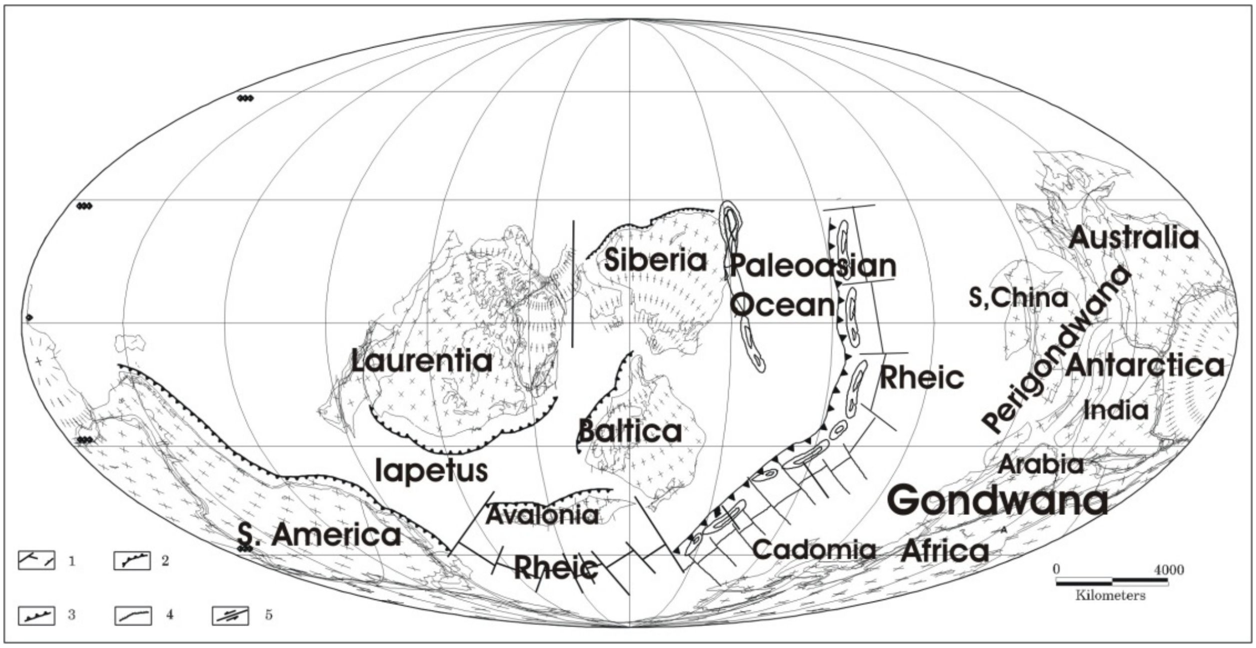

Figure 7. Plate tectonic map of Late Ordovician (plates position as of 452 Ma). Mollweide projection. Modified from Golonka (2012). 1 - oceanic spreading center and transform faults, 2 - subduction zone, 3 - thrust fault, 4 - normal fault, 5 - transform fault.

reconstructions assumed that these terranes were rifted away and formed separate Cadomia plate floating within the Rheic Ocean (Lewandowski, 1993, see also Golonka et al., 2006a). Latest Ordovician- Early Silurian were the times of collision between Avalonia and Baltica (Fig. 8).

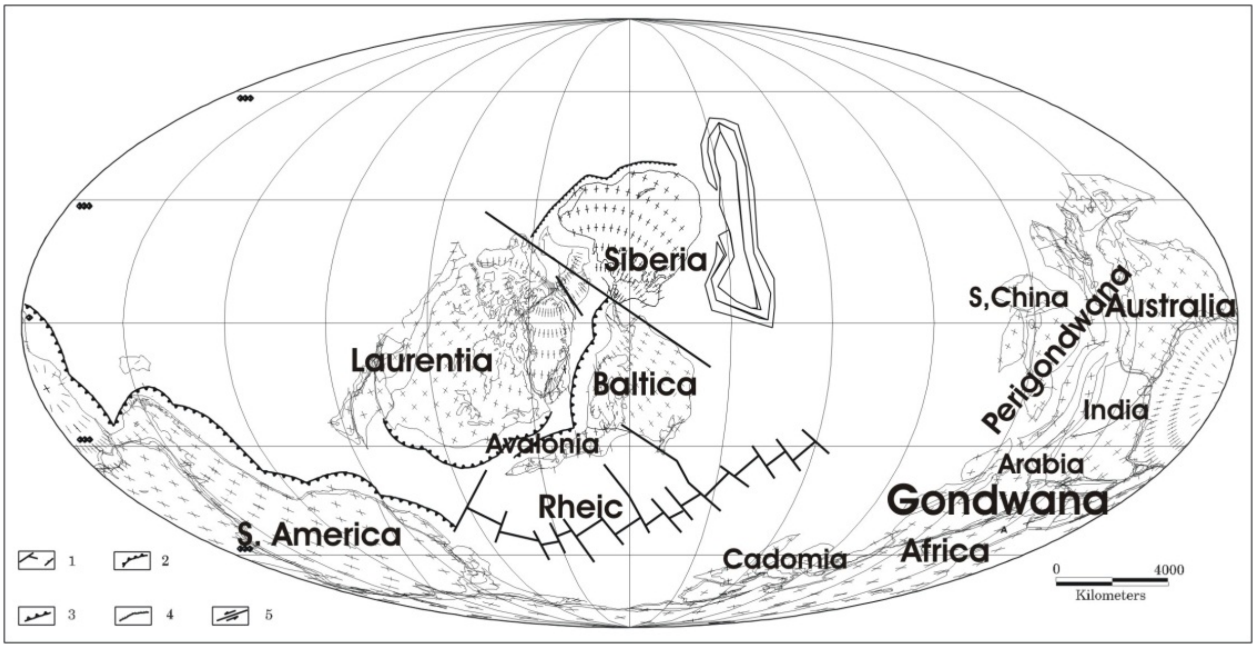

Figure 8. Plate tectonic map of Early Silurian (plates position as of 435 Ma). Mollweide projection. Modified from Golonka (2012). 1 - oceanic spreading center and transform faults, 2 - subduction zone, 3 - thrust fault, 4 - normal fault, 5 - transform fault.

This convergence was dominated by a strike-slip suturing of the two continents, rather than by full-scale continent-continent collision (Golonka, 2000, 2002). Northwestern Poland and adjacent part of Germany was joined with Baltica, along a strike-slip fault zone known as the Tornquist-Teisseyre line forming new continent - Balonia. Perhaps the Brunovistulicum and Malopolska terranes of southern Poland also belonged to Avalonia and joined Baltica (Moczydłowska, 1997, Bełka et al., 2000, Golonka, 2002, 2009b). In the Central Western Carpathians Late Ordovician – Early Silurian tonalitic gneisses of calc-alkaline character, associated with meta-gabbros, revealed the presence of magmatic episodes at 470-435 Ma (Kohut et al. 2008, Janák et al. 2002, Gaab et al. 2003, Gawęda & Golonka, 2011). These rocks and granites present results of docking of Avalonia to Baltica. Also in the East Carpathians in Romania the intrusion of 459-470 Ma granitoids (Munteanu & Tatu, 2003, Pana et al., 2002, Ballintoni et al., 2010) document the collision-related tectono-magmatic effects of docking of eastern prolongation of Avalonia to Baltica. The Scandian Orogeny was the result of the collision between Balonia and Laurentia. the onset of the orogeny occurred during the Early Silurian times and by late Silurian the orogeny was concluded (Golonka et al., 1994, Golonka, 2000, 2002, 2009b). The main phase of the Scandian orogeny is marked by nappes in Norway and Greenland as well as large crustal thickening (Dewey & Burke 1973, Torsvik et al., 1996, Golonka, 2000, 2002, 2009b). During the Mid-Silurian Avalonia collided with Laurentia (Fig. 9). This collision is known as the Caledonian orogeny, named after Roman name of Scotland – Caledonia. This name is also extending into other related orogenic events in Scanidinavia, Greenland and Ventral Europe. After the complete closure of the Iapetus Ocean, the continents of Baltic, Avalonia, and Laurentia formed the continent of Laurussia (Ziegler, 1989).

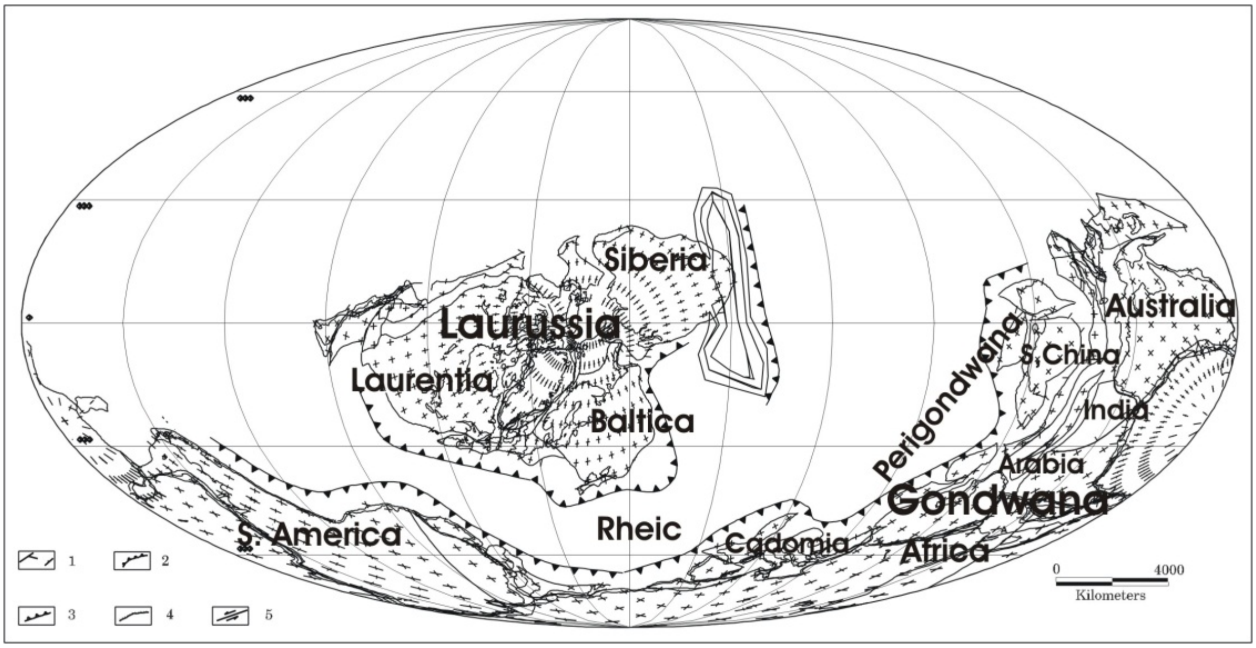

Figure 9. Plate tectonic map of Late Silurian (plates position as of 425 Ma). Mollweide projection. Modified from Golonka (2012). 1 - oceanic spreading center and transform faults, 2 - subduction zone, 3 - thrust fault, 4 - normal fault, 5 - transform fault.

5. Laurussia during Devonian times

Supercontinent Laurussia existed during Late Silurian and Devonian times. Late Silurian Global paleogeography depicted on Fig. 9 id showing separation of Gondwana and Laurussia as well as subduction along the southern margin of Laurussia. Fig 10 depicts the global paleogeography during Early Devonian times. It is showing a possibility of Early Devonian collision between South and North America according to Golonka (2002, 2007b, 2012 see also Keppie 1989, McKerrow *et al*. 1991, Dalziel *et al*. 1994, Keppie *et al*. 1996). This collision was marked 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) also support the hypothesis about the proximity of South and North America (Golonka, 2007, 20012 b). This proximity is also shown by recent maps of Cocks & Torsvik (2010), however without the collision. The Carolina region (Rast & Skehan 1993) also contains an element of collision and transpression between South and North America, acting as an indenter, with a dextral strike-slip component (Golonka, 2012).

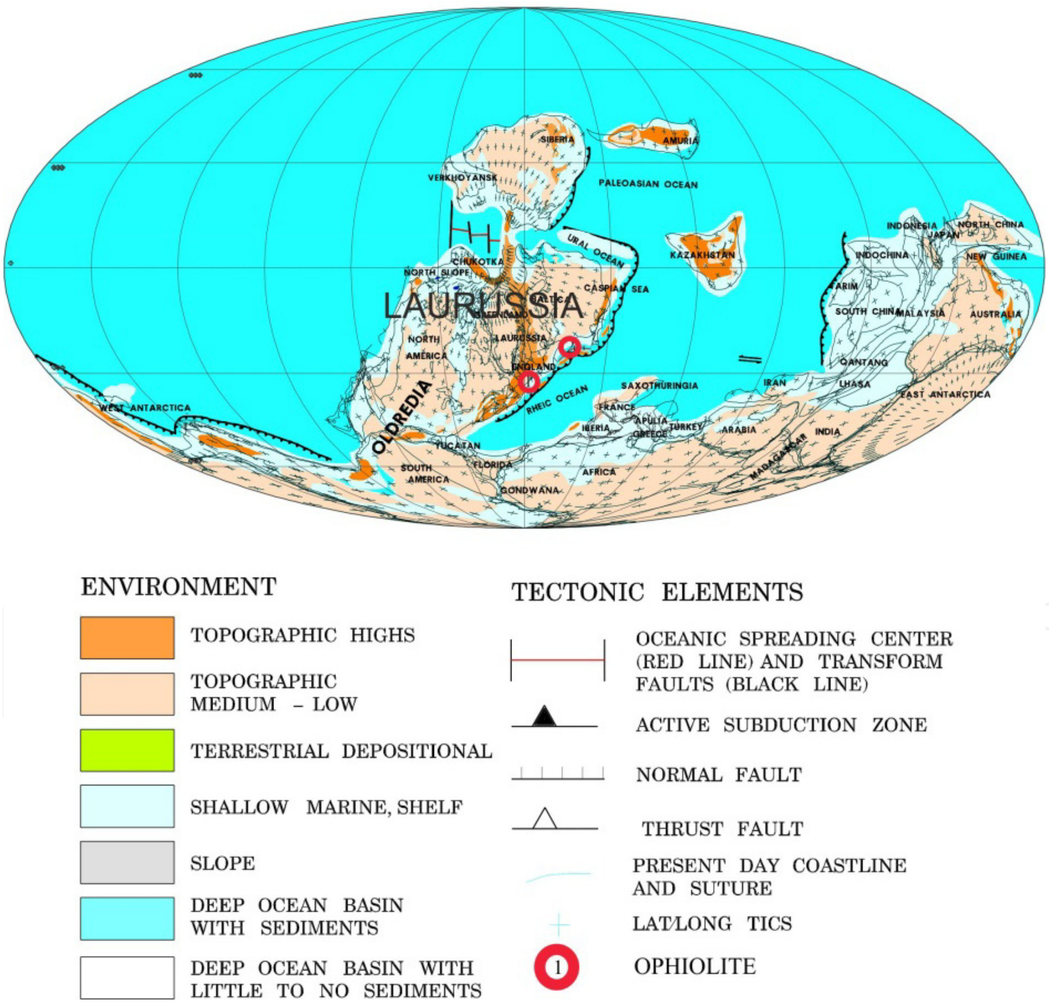

Figure 10. Paleogeographic c map of Early Devonian (plates position as of 401 Ma). Mollweide projection. Modified from Golonka 2007b, 2012) Ophiolites – 1 Lizard ophiolite, 2 – central and eastern European ophiolites (depicted in details on Fig. 11).

The accretion of Avalonia was followed by the development of north dipping subduction, along the new continental margin of Laurussia. That subduction caused rifting and creating the new back-arc basin. That basin was first recognized in central Europe as Rheno-Hercynian zone (Ziegler, 1989, Franke, 1992, Franke et al., 1995, Golonka, 2007b and references therein). Its paleogeography resembled present-day marginal Seas of East Asia. Fragment of Rheno-Hercynian zone, with oceanic crust, was also named Lizard-Giessen Ocean (Zeh & Gerdes, 2010). The name Lizard is derived from the well known Lizard Ophiolitic Complex in Cornwall, United Kingdom (Bromley, 1975, 1976, Kirby, 1976), marked as number 1 on Fig.10. This Devonian complex contain peridotites, serpentinites dolerite dikes as well as amphibolites (Bromley, 1975, 1976, Kirby, 1976, Cook et al., 2002, Clark et al., 2003). Probably El Castillo volcanic rocks from Spain are related to the Lizard ophiolites (Gutiérez- Alonso et al., 2008). They yield Devonian, 394,7±1,4 Ma age of magmatism.

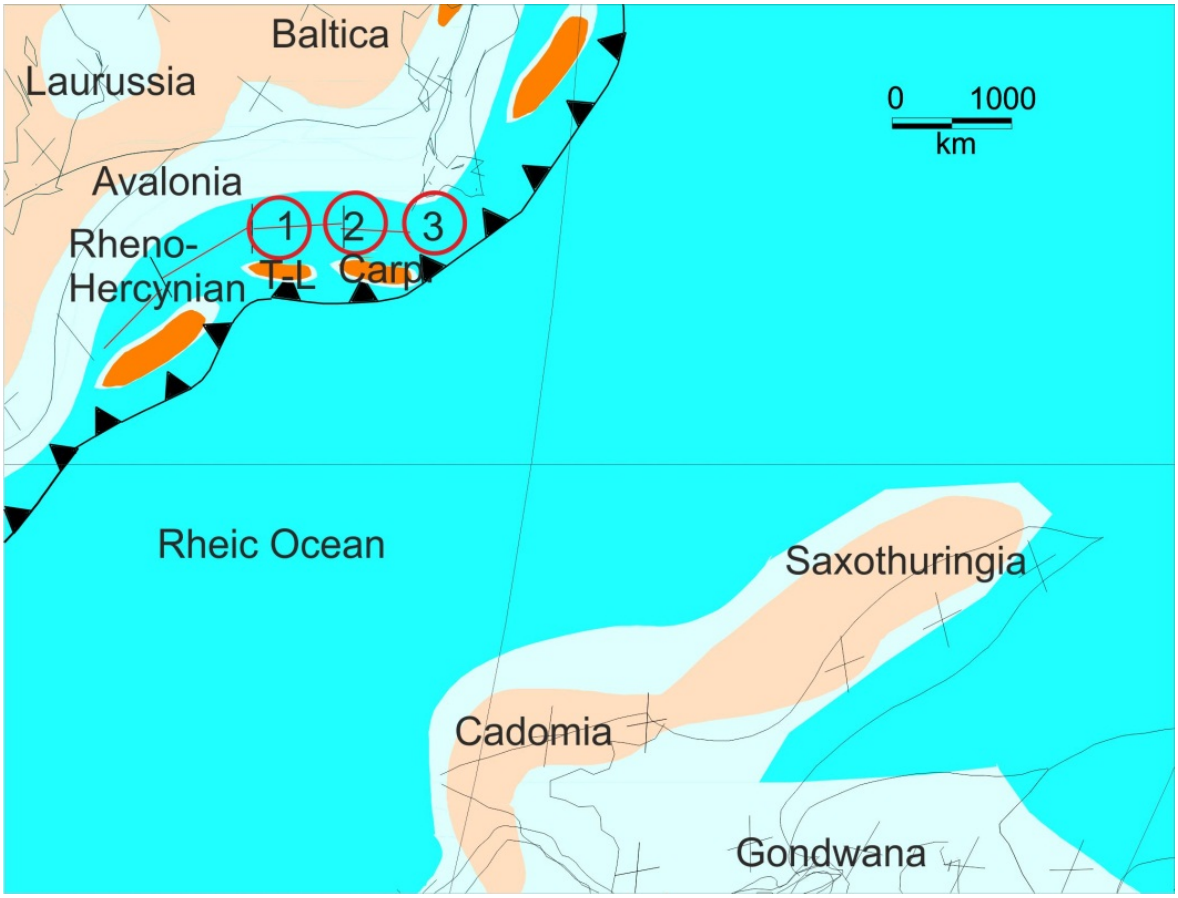

Figure 11. Paleogeography of Laurussia margin in central-eastern Europe during Early Devonian). Mollweide projection. Legend as on Fig. 10. Abbreviations: T – L - Tepla Barrandien – Lugia terranes , Carp. – Central Carpathian and Balkan terranes. Ophiolites: 1- Central-Sudetic ophiolite, 2 - Western Carpathian ophiolite, 3 - Balkan-South Carpathian ophiolite.

The eastern extension of the Rheno-Hercynian Basin is marked by ophiolites in Sudety area in Poland and in the Carpathian-Balkan area (Figs. 10, 11). During Devonian times the Central-Sudetic ophiolites were located between Avalonian terrenes, sutured to Laurussia, and several microplates/terranes now included in the mosaic structure of Bohemian Massif and Sudety Mountains. These terranes are marked on the Fig. 11 as T – L – Tepla-Barrandien – Lugia. They include several small blocks like Tepla-Barrandien, Góry Sowie and others, with uncertain, speculative position between Cadomia- Saxoturungia and Laurussia (see. e.g. Aleksandrowski et. al., 2000, Franke & Żelaźniewicz, 2000, Winchester et al., 2002, Mazur, et al., 2006, Schulmann et al., 2009, Kryza & Pin, 2010, Nanece et al., 2010). According to Kryza & Pin (2000) the SHRIMP zircon data supplied evidence for Devonian age of the Central-Sudetic ophiolites, around 400 Ma.

The age of the ophiolitic remnants within the Carpathians from Tatric and Gemeric units Unit yield various ages: 371 Ma - 385-383 Ma (Putiš et al. 2009), 391 Ma (Gawęda, 2008), and 394 Ma (Kohut et al., 2006). The recorded events are related to the development of a back-arc basin with ocean crust as a result of the slab roll-back and derivation of ribbon-like Proto-Carpathian Terrane from Laurussia (see Gawęda & Golonka, 2011*)*. The associated granitoid magmatism post-dated that event (387 Ma; Burda & Klötzli 2011, Putiš et al., 2008). The Balkan-South Carpathian ophiolite belt yield the isotopic age of 406-399 Ma (Zakariadze et al, 2007), comparable with the Central-Sudetic ophiolites age being around 400 Ma (Kryza, Pin, 2010).

Gondwana drifted northward and rotated clockwise during Devonian times (Scotese and McKerrow, 1990, Scotese and Barret, 1990, Golonka, 2000, 2002, 2007b). At the same time, Laurussia was rotating clockwise (Torsvik et al., 1996) at a somewhat faster rate. Figure 12 depict global paleogeography during the Late Devonian times.

Figure 12. Paleogeographic c map of Late Devonian (plates position as of 370 Ma). Mollweide projection. Legend as on Fig. 10. Modified from Golonka 2007b, 2012) .Ophiolites – 1 Lizard ophiolite, 2 – central and eastern European ophiolites (depicted in details on Fig.13).

The first contact between Laurussia and the Cadomian promontory of Gondwana occurred in Central Europe This contact marks the onset of Hercynian orogeny. The Saxoturingian part of the Cadomian plate collided with small terranes in Germany, Czech Republic and Poland (Fig. 13). Collisional events were marked also in Carpathians and Balkans. The Rheno-Hercynian Basin changed its character from extensional into compressional one. By latest Devonian – Early Carboniferous it displayed synorogenic features, filling with turbiditic flysch and culm facies (Golonka, 2007b).

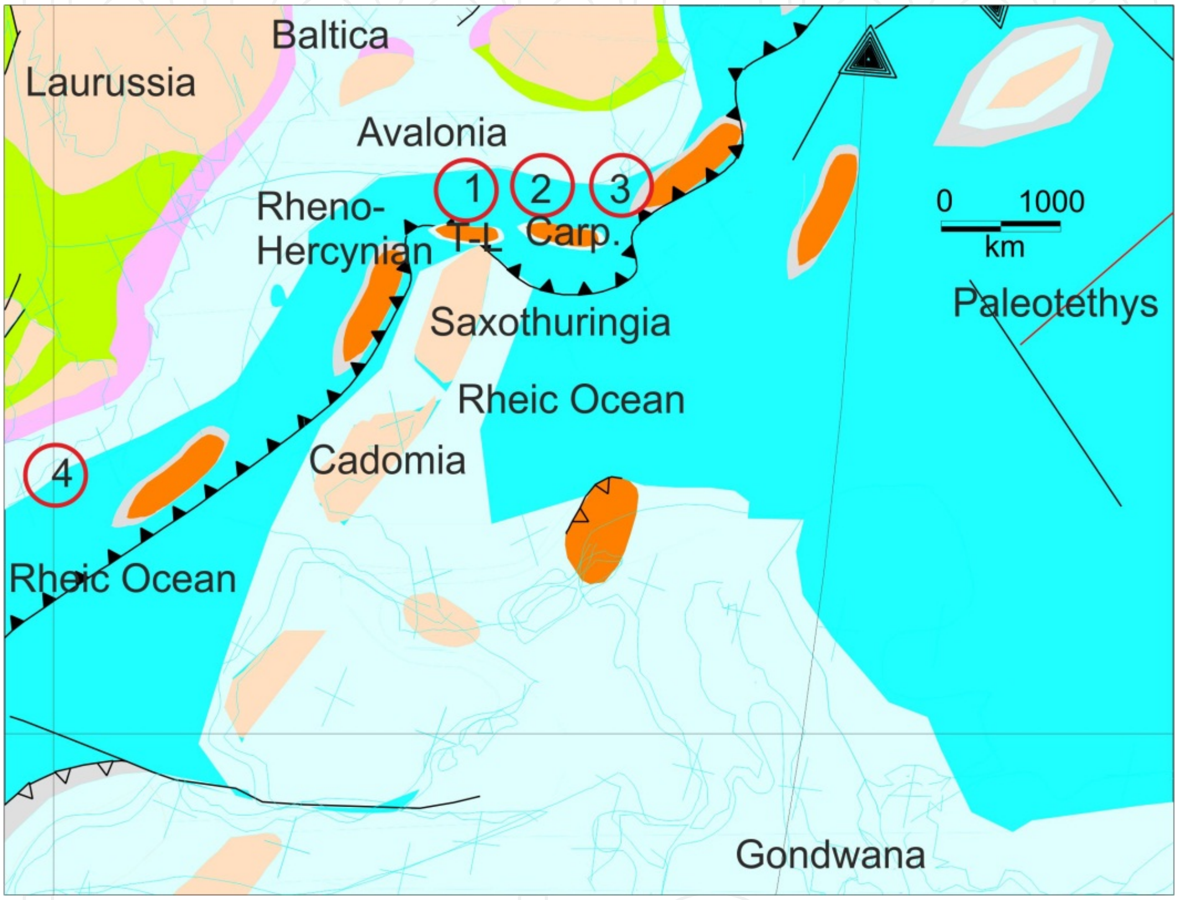

Figure 13. Paleogeography of Laurussia margin in central-eastern Europe during Late Devonian). Mollweide projection. Legend as on Fig. 10. Abbreviations: T – L - Tepla Barrandien – Lugia terranes , Carp. – Central Carpathian and Balkan terranes. Ophiolites: 1- Central-Sudetic ophiolite, 2 - Western Carpathian ophiolite, 3 - Balkan-South Carpathian ophiolite, 4 – Lizard ophiolite.

The new subduction zone on the southern margin Laurussia and the formation of a back-arc resulted in the intensive partial melting and magmatic activity from 370 to 340 Ma (Burda & Gawęda 2009, Schulmann et al. 2009). The continuous subduction along both old and new subduction zones resulted in docking of the Cadomia- Saxoturingia Terrane to Laurussia and significant consumption of the Rheic Ocean (Fig. 10). Finally the subduction caused formation of the Variscan Orogenic Suture, extending from Turkey to Mexico. That event resulted in voluminous granitoid magmatism and amphibolite-granulite facies metamorphism – the most prominent features of all crystalline cores, present in all the Variscan complexes (Stipska et al., 1998; Schulmann et al. 2009). These Variscan granitoid magmas were formed and intruded in the interval of 370-340 Ma, contemporaneously with Variscan nappes formation (Dallmayer et al., 1996; Burda et al., 2011) and synchronous with uplift of the continental blocks during prolonged collision (Janak et al., 1999, Gawęda et al., 2000). The resulting collision was possibly associated with basaltic underplating or slab break-off (Broska & Uher, 2001; Finger et al., 2009). Most of the granitoid bodies show hybrid character, with both mantle and crustal components involved (e.g. Słaby & Martin, 2005, Burda et al. 2011). Their VAG and CAG affinities suggest that melted metasediments, representing crustal component of the magma, were originally deposited both in the volcanic arc and intracontinental basins during subduction at the active, Andean-type continental margin (Schulmann et al., 2009). The melted material represented mainly recycled Proterozoic components, with addition of Paleozoic ones and influence of DM (depleted mantle) component as a source of heat (Poller et al., 2000). The subsequent uplift caused the exhumation of eclogitic remnants (Janak et al., 1996) and caused their retrograde metamorphism in granulite – amphibolite facies regime.

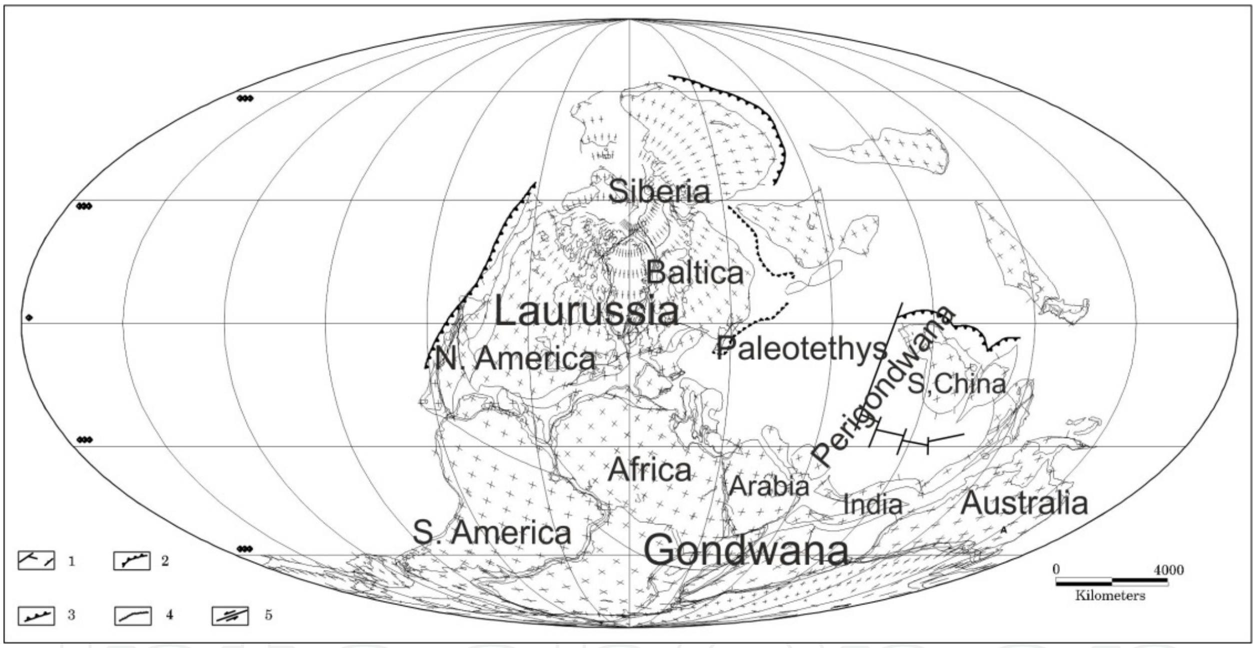

Figure 14. Plate tectonic map of Early Carboniferous (late Visean – Serpukhovian), plates position as of 328 Ma). Mollweide projection. Modified from Golonka (2012). 1 – oceanic spreading center and transform faults, 2 – subduction zone, 3 – thrust fault, 4 – normal fault, 5 – transform fault.

The ongoing Hercynian convergence in Europe led to large scale dextral shortening, overthrusting and emplacement of parts of the accretionary complexes (Edel & Weber, 1995). The amount of convergence was modified by large, dextral and sinistral transfer faults. The thrusting took place in the Tatra Mts. in the Carpathians (Gawęda et al., 2000, Golonka, 2000, 2002, 2007b). The collision between Gondwana and Laurussia continued to develop during Carboniferous times (Figs. 14, 15). The intercontinental collision began to affect the northwestern part of Africa, developing Mauretinides, Bassarides, Rokelides orogens is. The Alleghenian orogeny in North America continued (Hatcher et al., 1989, Rast & Skehan, 1993), prograding westwards to the Ouachita fold belt in Arkansas, Oklahoma, Texas and adjacent part of Mexico (Arbenz, 1990, Golonka, 2000, 2002). The clockwise rotation of Gondwana resulted in the involvement of the deformation. 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. The central Pangean mountain range was formed, which extended from Mexico to Poland (Golonka, 2000, 2002, 2007b). The Laurussia continent ceased its independent existence becoming a part of the supercontinent Pangea.

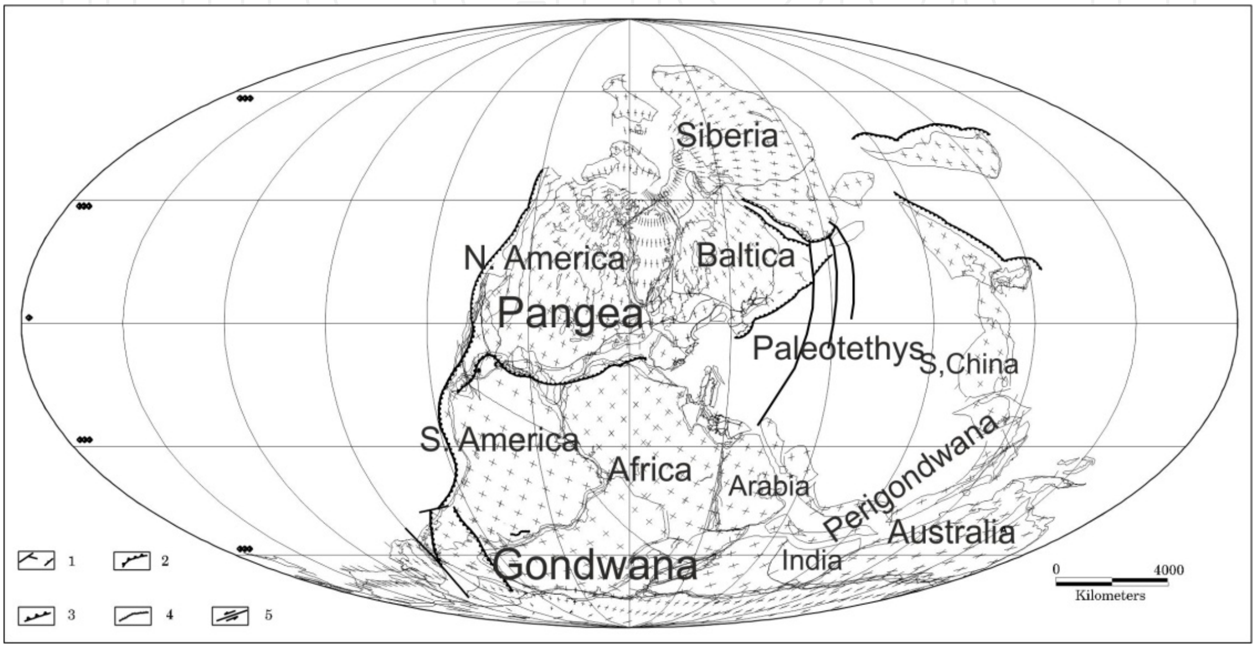

Figure 15. Plate tectonic map of Late Carboniferous (plates position as of 302 Ma). Mollweide projection. Modified from Golonka (2012). 1 – oceanic spreading center and transform faults, 2 – subduction zone, 3 – thrust fault, 4 – normal fault, 5 – transform fault.

6. Conclusions

1. The Late Precambrian (Vendian) to present plate tectonic processes contributed to the complex structure of Western and Central Europe.
2. The supercontinent of Laurussia, originated as a result of a closure of Iapetus Ocean and collision of Baltica, Avalonia and Laurentia.
3. Laurussia originated during Late Silurian times
4. The accretion of Avalonia was followed by the development of north dipping subduction, forming the new Rheno-Hercynian Basin back-arc basin during Devonian times
5. The oceanic crust of the Rheno-Hercynian Basin is recognised by ophiolites in Western, Central and Eastern Europe. The Lizard ophiolite in U.K. and Central-Sudetic ophiolite in Poland represent the best developed Devonian oceanic complexes.
6. The new geological research (including dating) in the Carpathian-Balkan area supports the idea about the prolongation of the Rheic Suture to the east.

7. The new geological research (including dating) in the Carpathian-Balkan area supports the idea about the prolongation of the Rheic Suture to the east.
8. The tectonic events and associated magmatism point out the development of the back-arc at the southern margin of Laurussia in the time interval 406-371 Ma.

Laurussia cease to exist during Hercynian orogeny in Carboniferous times and was included into supercontinent Pangea.

Author details

Jan Golonka
AGH University of Science and Technology, Kraków, Poland

Aleksandra Gawęda
Faculty of Earth Sciences, University of Silesia, Sosnowiec, Poland

Acknowledgement

This research has been partially financially supported by Ministry of Science and Higher Education grants (Statutory Activities) through the AGH University of Science and Technology in Krakow grants no. 11.11.140.447 (J. Golonka) and Ministry of Education and Science grant No N307 027837 (A. Gawęda).

7. References

Aleksandrowski, P., Kryza, R., Mazu,r S., Pin, C. & Zalasiewicz, J.A,. (2000). The Polish Sudetes: Caledonian orVariscan? *Transactions of the Royal Society, Edinburgh, Earth Sciences (1999*), Vol. 90, 127–146.

Arbenz, J. K., 1990, The Ouachita system, *The Geology of North America,* Bally, A. W. & Palmer, A. R., (Eds.,) Vol. . A., 371-396, Boulder, Geological Society of America,

Ballintoni, I., Balica, C., Seghedi, A. & Ducea, M.N. (2010). Avalonian and Cadomian terranes in North Dobrogea, Romania. Precambrian Research, Vol. 182, No. 3, 217-229.

Bełka, Z., Ahrendt, H., Franke, W. & Wemmer, K. (2000). The Baltica-Gondwana suture in central Europe: Evidence from K-Ar ages of detrital muscovites and biogeographical data, *Geological Society, London, Special Publications*, Vol. 179, 87-102.

Besutiu L. (2001). Moesia – a Baltica derived terrane? *Pancardi 2001 II. Abstracts*, pp. CP29. Ádám, A., Szarka, L., Szendröi, J. (Eds.) Hungarian Academy of Sciences, Sopron, Humgary.

Bromley, A.V. (1975). Is the Lizard Complex, South Cornwall, a fragment of Hercynian oceanic crust?. *The Lizard: A Magazine of Field Studies*, Vol., No. 3, 2-11.

Bromley, A.V. (1976). A new interpretation of the Lizard Complex, S. Cornwall, in the light of the ocean crust model. *Proceedings. Geological. Society London*, Vol. 132, 114.

Broska, I, & Uher, P. (2001). Whole-rock chemistry and genetic typology of the West-Carpathian Variscan granites. *Geologica Carpathica,* Vol. 52 no. 2, 79-90.

Burda, J. & Gawęda, A. (2009). Shear-influenced partial melting in the Western Tatra metamorphic complex: geochemistry and geochronology. *Lithos,* Vol. 110, . 373-385.

Clark, A. H., Sandeman, H. A. I., Nutman, A.P., Green, D.H & Cook, A. C.. (2003). Discussion on SHRIMP U–Pb zircon dating of the exhumation of the Lizard Peridotite and its emplacement over crustal rocks: constraints for tectonic models. *Journal of the Geological Society, London*, Vol. 160, 331–335.

Cocks, L.R.M. & Torsvik T.H. (2011). The Palaeozoic geography of Laurentia and western Laurussia: a stable craton with mobile margins. *Earth Science Reviews*, Vol. 106, 1-51.

Cook, C. A., Holdsworth, R.E. & Styles, M.T. (2002). The emplacement of peridotites and associated oceanic rocks from the Lizard Complex, southwest England, *Geological Magazine*, Vol. 139, 27-45.

Dallmeyer, D., Neubauer, F., Handler, R., Fritz, H., Muller, W., Pana, D., & Putis, M. (1996). Tectonothermal evolution of the internal Alps and Carpathians: evidence from ^{40}Ar-^{39}Ar mineral and whole-rock data. In: Schmid S.M., Frey M., Froitzheim N., Heilbronner R., Stuenitz, H. (eds.): Alpine geology, proceedings of the second workshop: 2nd workshop on Alpine geology, *Eclogae Geologica Helvetica,* Vol. 89, pp. 203-227.

Dalziel, I.W.D., Dalla Salda, L.H & Gahagan, L.M. (1994). Paleozoic Laurentia-Gondwana interaction and the origin of the Appalachian-Andean mountain system, *Geological Society of America Bulletin*, Vol. 106, 243-252.

Dewey, J. F. & Burke, V. B. S., (1973). Tibetan, Variscan, and Precambrian basement reactivation, products of continental collision, Journal of Geology, Vol. 81, 683-692.

Dörr, W., Fiala, J., Vejnar, Z., & Zulauf, D. (1998). U-Pb zircon ages and structural development of metagranitoids of the Tepla crystalline complex: evidence for pervasive Cambrian plutonism within the Bohemian Massif (Czech Republiv). *International Journal of Earth Sciences*, Vol. 87, 135-149.

Edel, J. B., Weber, K., 1995. Cadomian terranes, wrench faulting and thrusting in the central Europe Variscides: geophysical and geological evidence, *Geologische Rundschau*, Vol. 84, 412-432.

Finger, F., Gerdes, A., Rene, M., & Riegler G. (2009). The Saxo-Danubian Granite Belt: magmatic response topost-collisional delamination of mantle lithosphere below the south-west sector of the Bohemian Massif (Variscan Orogen). *Geologica Carpathica,* Vol. 60, No. 3, 205-212.

Ford, D. & Golonka J. (2003). Phanerozoic paleogeography, paleoenvironment and lithofacies maps of the circum-Atlantic margins, *Thematic set on paleogeographic reconstruction and hydrocarbon basins: Atlantic, Caribbean, South America, Middle East, Russian Far East, Arctic*. Golonka J. (ed.), *Marine and Petroleum Geology*, Vol. 20, 249-285.

Franke, W. (1992), Phanerozoic structures and events in central Europe, *The European Geotraverse, A continent revealed,* Blundell, D., Freeman, R. & Mueller, S. (Eds.), 164-180, University of Cambridge, Cambridge.

Franke, W. & Żelaźniewicz, A.,. (2000).The eastern termination of the Variscides: terrane correlation and kinematic evolution, *Orogenic processes:quantification and modelling in the Variscan belt*, *Geological Society Special. Publication*, Vol. 179, 63–86.

Franke, W., Dallmeyer, R. D. & Weber, K., 1995, Geodynamic Evolution, *Pre-Permian geology of Central and Eastern Europe, IGCP 233 international conference: Gottingen, Federal Republic of Germany: Berlin*, Dallmeyer, R. D.., Franke, W. & Weber, K., (Eds.), 579-593, Springer-Verlag.

Gaab, A., Poller, U., Todt, W. & Janák M. (2003). Geochemical and isotopic characteristics of the Murán Gneiss Complex, Veporic Unit (Slovakia), *Journal of the Czech Geological Society*, Vol., 48, No. 1-252.

Gallagher, J. J. & Tauver,s P. R. (1992). Tectonic evolution of northwestern South America, *Basement tectonics*. Mason, R. (Ed), 123-137.Kluver Academic Publishers..

Gawęda, A. (2008). An apatite-rich enclave in the High Tatra granite (Western Carpathians): petrological and geochronological study. Geologica Carpathica, Vol. 59, No. 4, 295-306.

Gawęda, A., Golonka J., (2011). Variscan plate dynamics in the Circum-Carpathian area. Travaux Géophysiques XL (2011), Abstracts of the 9th Central European Tectonic Groups meeting, Hotel Skalský Dvůr, Czech Republic, 13 - 17. April 2011, 19. Prague. Institute of Geophysics Academy of Sciences of the Czech Republic,.

Gawęda, A., Kozłowski, K., & Piotrowska, K. (2000). Early-Variscan collision and generation of leucogranite melts in the Western Tatra Mountains (S-Poland, W-Carpathians). *Journal of the Czech Geological Society, Vol.* 45, 230.

Golonka, J. (2000). *Cambrian-Neogene Plate Tectonic Maps*. 1-125, Wydawnictwa Uniwersytetu Jagiellońskiego, Kraków.

Golonka, J. (2002). Plate-tectonic maps of the Phanerozoic. *Phanerozoic reef pattern,* Kiessling W., Flügel E. & Golonka J. (eds.), *SEPM (Society for Sedimentary Geology) Special Publication*, Vol. 72, 21-75.

Golonka, J. (2004). Plate tectonic evolution of the southern margin of Eurasia in the Mesozoic and Cenozoic, *Tectonophysics*, Vol. 381, 235-273.

Golonka, J. (2007a). Late Triassic and Early Jurassic paleogeography of the world. *Palaeogeography, Palaeoclimatology, Palaeoecology*, Vol. 244, 297-307.

Golonka, J. (2007b). Phanerozoic Paleoenvironment and Paleolithofacies Maps. Late Paleozoic. Mapy paleośrodowiska i paleolitofacje fanerozoiku. Późny paleozoik. *Kwartalnik AGH. Geologia,* Vol .33, No. 2,: 145-209.

Golonka, J. (2007c). Phanerozoic Paleoenvironment and Paleolithofacies Maps. Mesozoic. Mapy paleośrodowiska i paleolitofacje fanerozoiku. Późny mezozoik. *Kwartalnik AGH. Geologia*, Vol. 33, No. 2, 211-264.

Golonka, J. (2009a). Phanerozoic Paleoenvironment and Paleolithofacies Maps. Cenozoic. Mapy paleośrodowiska i paleolitofacje fanerozoiku. Kenozoik. *Kwartalnik AGH. Geologia*, , Vol. 35 No. 4, 507-587.

Golonka, J. (2009b). Phanerozoic Paleoenvironment and Paleolithofacies Maps. Early Paleozoic. Mapy paleośrodowiska i paleolitofacje fanerozoiku. Wczesny paleozoik. *Kwartalnik AGH. Geologia*, , Vol. 35, No. 4, 589-654.

Golonka, J. (2012). *Paleozoic paleoenvironment and paleolithofacies maps of Gondwana*, Wydawnictwa AGH Publishing House. Kraków. In press

Golonka, J., Ross M. I. & Scotese C. R., 1994. Phanerozoic paleogeographic and paleoclimatic modeling maps. *Pangea: Global environment and resources*, Embry A. F., Beauchamp, B. & Glass, D. J., (Eds.),. *Canadian Society of Petroleum Geologists Memoir,* 17, 1-47.

Golonka, J., Krobicki, M.,Oszczypko, N., Ślączka, A. & Słomka, T. (2003). Geodynamic evolution and palaeogeography of the Polish Carpathians and adjacent areas during Neo-Cimmerian and preceding events (latest Triassic - earliest Cretaceous), *Tracing tectonic deformation using the sedimentary record*, McCan, T. & Saintot, A. (Eds.),*Geological Society Special Publications*. 208, 138-158.

Golonka J. Gahagan L., Krobicki M., Marko F., Oszczypko N. & Slaczka A. 2006a. Plate Tectonic Evolution and Paleogeography of the Circum-Carpathian Region. In: Golonka, J. & Picha, F. (Eds.) The Carpathians and their foreland: Geology and hydrocarbon resources. *American Association of Petroleum Geologists Memoir*, 84, 11-46.

Golonka, J., Krobicki, M., Pająk, J, Nguyen Van Giang & Zuchiewicz, W. (2006b). *Global plate tectonics and paleogeography of Southeast Asia*. Faculty of Geology, Geophysics and Environmental Protection, AGH University of Science and Technology, Arkadia, Kraków.

Gutiérrez-Alonso G., Murphy J.B., Fernández-Suárez J. & Hamilton M.A. (2008). Rifting along the northern Gondwana margin and the evolution of the Rheic Ocean: A Devonian age for the El Castillo volcanic rocks (Salamanca, Central Iberian Zone). *Tectonophysics*, Vol. 461, 157-165.

Hartz E.H., & Torsvik T.H. (2002). Baltica upside down: a new plate tectonic model for Rodinia and Iapetus Ocean. Geology, Vol. 30, No. 3, 255-258.

Hatcher R. D., Jr, Thomas. W. A., Geiser, P. A., Snoke, A. W., Mosher S. & Wiltschko D. V., (1989). Alleghenian orogen*, The Appalachian-Ouachita Orogen in the United States,* Hatcher R. D., Jr, Thomas, W. A. & Viele, G. W., (Eds.),V. F, . 233-318, Boulder, Geological Society of America, The Geology of North America,

Janák, M., Hurai, V., Ludhova, L., O`Brien, P.J., & Horn, E.E. (1999). Dehydration melting and devolatilization during exhumation of high-grade metapelites: the Tatra Mountains, Western Carpathians. *Journal of Metamorphic Geology,* Vol. 17, 379-395.

Janák, M., Finger, F., Plašienka, D., Petrik, I., Humer, B., Meres, S. & Luptak, B., (2002). Variscan high P-T recrystallization of Ordovician granitoids in Veporic Unit (Nizke Tatry Mountains, Western Carpathians): new petrological and geochronological data. *Geolines*, Vol. 14, 38-39.

Kalvoda, J. & Bábek O. (2010) .The Margins of Laurussia in Central and Southeast Europe and Southwest Asia. *Gondwana Research*, Vol. 17, 526-545.

Kamo S.L., Gowar C.F., & Krogh T.E. (1989). Birthdate for the Iapetus Ocean ? A precise U-Pb zircon and baddeleyite age for Long Range dikes, southeast Labrador. *Geology*, Vol. 17, No. 7, 602-605.

Kent, D. V. & Van der Voo, R., (1990). Palaeozoic palaeogeography from palaeomagnetism of the Atlantic-bordering continents, *Palaeozoic palaeogeography and biogeography*, McKerrow, W. S. & Scotese, C. R., (Eds.), *Geological Society Memoir*, Vol. 12, 49-56.

Keppie, J.D. (1985). The Appalachian collage, The Caledonide orogen, Scandinavia, and related areas, 1217-1226, Gee, D.G., & Sturt, B. (Eds)., New York, J. Wiley and Sons.

Keppie, J. D. (1989). Northern Appalachian terranes and their accretionary history, *Terranes in the Circum-Atlantic Paleozoic orogens*. Dallmeyer, R. D. (Ed), *Geological Society of America, Special Paper*, Vol. 230, 159-192.

Keppie, J. D., Dostal J., Murphy, J. B., & Nance, R. D. (1996). Terrane transfer between eastern Laurentia and western Gondwana in the Early Paleozoic: Constraints on global reconstructions, *Avalonia and Related Peri-Gondwanan Terranes of the Circum-North Atlantic*, Nance R. D. & Thompson M. D. (Eds), *Geological Society of America Special Paper*, Vol. 304, 369-380.

Kirby, G. A. (1979). The Lizard Complex as an ophiolite. *Nature*, Vol. 282, 58-61.

Kohut M., Konecny P. & Siman P. (2006) The first finding of the iron Lahn-Dill mineralization in the Tatric Unit of the Western Carpathians. *Mineralogia Polonica – Special Papers*, Vol.28, 112-114.

Kohut, M., Poller, U., Gurk, Ch. & Todt W. (2008). Geochemistry and U-Pb detrital zircon ages of metasedimentary rocks of the Lower Unit, Western Tatra Mountains (Slovakia), *Acta Geologica Polonica*, Vol. 58, 371-384.

Kryza, R. & Pin C. (2010). The Central Sudetic ophiolites (SW Poland): petrogenetic issues, geochronology and paleotectonic implications. *Gondwana Research*, Vol. 17, 292-305.

Lewandowski, M. (1998). Assembly of Pangea: Combined Paleomagnetic and Paleoclimatic Approach, *Circum-Arctic Palaeozoic Faunas and Facies*, Ginter, M. & Wilson, M. H. (Eds), *Ichtyolith Issues Special Publication*, Vol. 4, 29-32.

Lewandowski, M. (2003). Assembly of Pangea: Combined Paleomagnetic and Paleoclimatic Approach. *Advances in Geophysics*, Vol. 46, 199-236.

Mazur, S., Aleksandrowski, P., Kryza ,R. & Oberc-Dziedzic, T,.(2006). The Variscan Orogen in Poland, *Geological Quarterly*, Vol. 50 89–118.

McKerrow, W. S. , Dewey, J. F. & Scotese, C. R. (1991). The Ordovician and Silurian development of the Iapetus Ocean *The Murchison symposium; proceedings of an international conference on the Silurian System in* Bassett, M. G., Lane, P. D. & Edwards, D. (Eds.), *Special Papers Palaeontology*, Vol. 44, 165-178.

Moczydłowska, M. (1997). Proterozoic and Cambrian successions in Upper Silesia: an Avalonian terrane in southern Poland, *Geological Magazine*, Vol. 134, 679-689.

Munteanu M. & Tatu M. (2003.) The East-Carpathian Crystalline-Mesozoic Zone (Romania): Paleozoic amalgamation of Gondwana- and East European Craton- derived terranes. Gondwana Research, Vol. 6, No. 2, 185-196.

Nance, R.D., Gutiérrez-Alonso, G., Keppie, J.D., Linnemann, U., Murphy, J.B., Quesada, C., Strachan, R.A. & Woodcock, N.H., (2010). Evolution of the Rheic Ocean. *Gondwana Research*, Vol. 17, 194-222.

Pana, D., Ballintoni, I., Heaman, L. & Creaser R. (2002). The U-Pb and Sm-Nd dating of the main lithotectonic assemblages of the East Carpathians, Romania. *Geologica Carpathica*, Vol. 53, 177-180.

Putiš, M, Ivan, P, Kohút, M, Spišiak, J, Siman, P, Radvanec, M, Uher, P, Sergeev, S, Larionov, A, Méres, Š, Demko, R. & Ondrejka M. (2009). Meta-igneous rocks of the West-Carpathian basement, Slovakia: indicators of Early Paleozoic extension and shortening events. *Bulletin Societe Géolologique France*, Vol. 180, No.6, 461-471

Rast, N. & Skehan, J. W., 1993. Mid-Paleozoic orogenesis in the North Atlantic, the Acadian orogeny. *The Acadian Orogeny, recent studies in New England, Maritime Canada, and the autochtohonous foreland*. , Roy C. & Skehan J. W. (Eds), *Geological Society of America Special Paper*, Vol. 275, 1-25.

Robardet, M., Blaise, J., Bouyx, E., Gourvennec, R., Lardeux, H., Le Hérissé, A., Le Menn, J., Melou, M., Paris, F., Plusquellec, Y., Poncet J., Régnault, S., Rioult, M. & Weyant M. (1993). Paléogeographie de l'Europe occidentale de l'Ordovicien au Dévonien; Paleogeography of Western Europe from the Ordovician to the Devonian, *Bulletin Societe géologique de France*, Vol. 164, 683-695.

Schulmann, K., Konopásek, J., Janoušek, V., Lex, O., Lardeaux, J.-M., Ede,l J.-B., Štípská & P., Ulrich S. (2009). An Andean type Palaeozoic convergence in the Bohemian Massif. *Comptes Rendus – Geoscience*, Vol. 341, 266-286.

Scotese, C. R. & McKerrow, W. S. (1990). Revised world maps and introduction, *Palaeozoic palaeogeography and biogeography,* McKerrow W. S. & Scotese C. R. (Eds), *Geological Society of London Memoir*, 12, 1-21.

Scotese, C.R. & Barret, S.F. (1990). Gondwana's movement over the South Pole during the Paleozoic: evidence from lithologic indicators of climate. In: W.S. McKerrow and C.R. Scotese (Eds.) *Paleozoic Paleogeography and Biogeography, , Geological Society of London, Memoir* Vol. 12, pp. 75-85.

Sears, J.W. (2012). Transforming Siberia along the Laurussian margin. *Geology*, doi: 10.1130/G32952.1

Słaby, E., & Martin, H. (2005). Mafic and felsic magma interaction in granites: the karkonosze Hercynian pluton (Sudetes, Bohemian Massif). *Journal of Petrology,* Vol. 49, 353-391.

Štipská, P., Schulmann, K., Kroener, A. (1998). From Cambro-Ordovician rifting to Variscan collision at the NE margin of the Bohemian Massif: petrological, geochronological and structural constraints. *Paleozoic orogenesis and crustal evolution of the European lithosphere – post-conference excursion*, pp. 24-31.

Tichomirova, M., (2002). Zircon inheritance in diatexite granodiorites and its consequence on geochronology – a case study in Lusatia and Erzgebirge (Saxo-Thuringia, eastern Germany). *Chemical Geology*, Vol. 191, 209-224.

Torsvik, T. H. , Smethurst, M. A., Meert, J. G., Van der Voo, R., McKerrow, W. S., Brasier, M. D. & Sturt, B. A., Walderhaug, H. J. (1996). Continental break-up and collision in the Neoproterozoic and Palaeozoic; a tale of Baltica and Laurentia, *Earth-Science Reviews*, Vol. 40, No.3-4, 229-258.

Turniak, K., Mazur, S., & Wysoczański, R. (2000). SHRIMP zircon geochronology and geochemistry of tyhe Orlica snieznik gneisses (Variscan Belt of Central Europe) and their tectonic implications. *Geodinamica Acta*, Vol. 13, 293-312.

Veevers, J.J. (2004). Gondwanaland from 650-500 Ma assembly through 320 Ma merger in Pangea to 185-100 Ma breakup: Supercontinental tectonics via stratigraphy and radiometric dating. *Earth-Science Reviews*, Vol. 68, 1-132.

von Raumer, J.F., & Stampfli, G.M. (2008). The birth of the Rheic Ocean – Early Paleozoic subsidence patterns and subsequent tectonic plate scenario, *Tectonophysics*, Vol. 461, 9-20.

Williams, K. E., (1995). Tectonic Subsidence Analysis and Paleozoic Paleogeography of Gondwana, *Petroleum basins of South America*, Tankard, A.J., Suarez, S. & Welsink, H. J. (Eds),*American Association of Petroleum Geologists Memoir*, Vol. 62, 79-100.

Winchester J.A., Floyd P.A., Crowley Q.G., Piasecki M.A.J., Lee M.K., Pharaoh T.C., Williamson P., Banka D., Verniers J., Samuelsson J., Bayer U., Marotta A.-M., Lamarche J., Franke W., Dörr W., Valverde-Vaquero P., Giese U., Vecoli M., Thybo H., Laigle M., Scheck M., Maluski H., Marheine D., Noble S.R., Paarish R.R., Evans J., Timmerman H., Gerdes A., Guterch A., Grad M., Cwojdzinski S., Cymerman Z., Kozdroj W., Kryza R., Alexandrowsk, P., Mazur S., Stedrá V., Kotková J., Belka Z., Patoćka F. & Kachlik V.,(2002). Palaeozoic amalgamation of Central Europe: New results from recent geological and geophysical investigations. *Tectonophysics*, Vol. 360, 5-21.

Young, G. C., (1990). Devonian vertebrate distribution patterns and cladistic analysis of paleogeographic hypothesis, *Palaeozoic palaeogeography and biogeography*. McKerrow W. S. & Scotese C. R. (Eds), *Geological Society of London Memoir*, Vol. 12, 243-255.

Zakariadze, G. S.; Karamata, S. O. & Dilek, Y. (2007). Significance of E. Paleozoic Paleo-Tethyan Ophiolites in the Balkan Terrane and the Greater Caucasus for the Cadomian-Hercynian Continental Growth of Southern Europe . *American Geophysical Union, Fall Meeting 2007,* Abstract #V43B, 1367, American Geophysical Union, Washigton D.C.

Zeh, A. & Gerdes, A. (2010). Baltica- and Gondwana-derived sediments in the Mid-German Crystalline Rise (Central Europe): Implications for the closure of the Rheic ocean, *Gondwana Research*, Vol. 17, 254-263).

Ziegler, P.A., 1989. *Evolution of Laurussia*. Kluwer Academic Publishers, Dordrecht.

Zonenshain, L. P., Kuzmin, M. L. & Natapov, L. N., 1990. Geology of the USSR: A Plate-Tectonic Synthesis. Page, B. M. (Ed), *Geodynamics Series, American Geophysical Union*, Vol. 21, 1-242.

Żelaźniewicz, A., Seghedi, A., Żaba, J., Fanning, M. &, Buła Z. (2009) More evidence on Neoproterozoic terranes in Southern Poland and southeastern Romania, *Geological Quarterly*, Vol. 51, 93-124.