Palaeogeographical Changes in Sedimentary Environment Extents on Area of the Czech Republic

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Abstract

Palaeogeographical changes in geological environments, represented by extrusions and sedimentation, were assessed among vector models from the Czech Republic (CR) covering Bohemian Massif and Outer Western Carpathians. The vector models contained reconstructions of sedimentation extensions during culminant marine transgressions or regressions since Permian (299 Ma), Jurassic (152 Ma), Cretaceous (93.9 Ma), Eocene (56 Ma), Lower (23 Ma) and Upper Miocene (11.6 Ma) to Upper Pleistocene (18 ka). The assessment was carried out through comparison among changes of the sedimentary environment extension size between sequential layers and with present distribution of the selected stratas. Terrestrial surface during marine regressions extended 70% of the CR. The most spread marine transgression relinquished < 30% of the dry land. The terrestrial surface covered permanently 14.8% of the CR since existence of the Bohemian Massif. Pleistocene was characteristic by terrestrial environment diversification after conclusive sea regression. Permanent land occurrence suggested conditions for long-time ecosystem adaptation to environmental changes in contrast to mobile zones.

Keywords: *palinspatic modelling, vectorisation, environmental changes, (semi)water ecosystem*

1 Introduction

Palaeogeography occupies distribution of lands and oceans on Earth' surface in geological past. It focuses on interpretation of Earth surface development consequences for present geological environment and spreading of living forms (Cox and Moore, 2005). The geological environment development initiates far-reaching environmental changes, during which reproductive-isolation barriers form to support endemism or equilibrium disturbance between natural conditions and ecosystems enhancing evolution of life systems (Eldredge and Gould, 1972). The assessment of relationships between palaeogeographical conditions and living form occurrences is carried out through ecosystem classification. The ecosystem classification suggests relation between geological environment and life community functions connected with bioproduction, species richment and also with adaptation ability to environmental changes (Hamilton, 1988).

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Classification of palaeogeographical conditions are individual or typological as with the fundamental physical geography. While present-time ecosystem classifications are based on direct indication of natural conditions through composition of living forms, the ecosystem structure in geological past is derived through suitable geodata interpretation. Geological data are either factic or interpretative (Kukal *et al.*, 2014). Subsequently, palaeogeographical reconstruction of ancient natural conditions uses presumptions about natural condition uniformity and about plate tectonics (Kalvoda *et al.*, 1998). The natural process uniformity assumes that processes of rock origination, transformation and disruption were same in geological past as in present-time. The lithospherical plate tectonics theory observes movements of land and ocean crust on more dense and hot mantle from origination to destruction of supercontinents (Burke and Wilson, 1976). Reconstruction of natural conditions begins through using of petrographical factic maps, which show present distribution of rocks. The petrographical data are generalised to regionally-geological maps integrating rocks to units with similar development (Davis *et al.*, 2012). Rock unit original extent is subsequently estimated through observations of palaeomagnetism, isotopes and similarities among sediments (including facial analysis) (Kalvoda *et al.*, 1998) (Fig. 1).

Reconstruction process for rock occurrence at origination time is divided with respect to original sedimentation basin preservation rate. Preserved sedimentation basins without tectonical deformations are reconstructed synoptically. The residues from originally larger basin are reconstructed palinspaticly through balance between tectonic move velocity forming rocks and erosion intensity (Pešek *et al.*, 1998). The balance equation is defined either magnetostratigraphically or through gravitional anomalies mapping. Magnetostratigraphical mapping focuses on the best correlation detection between palaeomagnetical anomalies at oceanic crust and equally old igneous rocks on dry land (Ziegler, 1999). The mapping of gravitional anomalies shows differences at Earth crust density, which follow interfaces between sedimentary and crystallic bodies (Yegrorova and Starostenko, 2002). Palaeomagnetism commonly with environmental indicators in sediments suggest climatical conditions in specific period of geological past. Especially, fossils bound to strait climatic zones or minerals forming strictly under favorable climate are environmental indicators suggesting climatic conditions (Barker and Elderfield, 2002).

Tectonical movements keep substance cycling between Earth surface and lithosphere. These cyclings include cycles of rock origination and disruption, uplifts and declenations of lithospherical plates to supercontinental rise and destruction. The lithospherical plate movements are driven (i) by energy from radioactive Earth core, which causes convective heat moves at mantle, (ii) by water presence, which decreases attrition between plates, and (iii) by gravity (Kearey and Frederick, 1996). The movements become evident along interfaces between particular plates, where geodynamical environments form. Geodynamical environments are distinctible along move course as subduct, where one plate replaces under the other, as obduct, where one plate displace over the other, as collisional followed by counter uplifts and as translational followed by skids along the contact axis (Zonenšajn *et al.*, 1976). The supercontinent developmental cycle consists of many geotectonical cycles, which period prolonges according to destruction intensity of united plates. Each geotectonical cycle contains endogenous and exogenous compounds. Endogenous orogenic cycle is a series of mountain-forming processes, when wrinkled mountain systems have change effectivity of atmospherical circulation. Wrinkle-conditioned climate-sedimentation cycles are distinguished to sedimentary environments either along spread of platform area submersion by sea or after sea regression. Exogenous effects of climate-sedimentation cycles are based in sea transgression that enhances climate warming (Levin, 1994).

Lands have formed around cratons (blocks) from less dense crystallic rocks over more heavy indigenous ocean crust. Tendency toward first craton forming rose during setting of hot young Earth surface. As first, the setting surface was covered by sliding crust islands, which

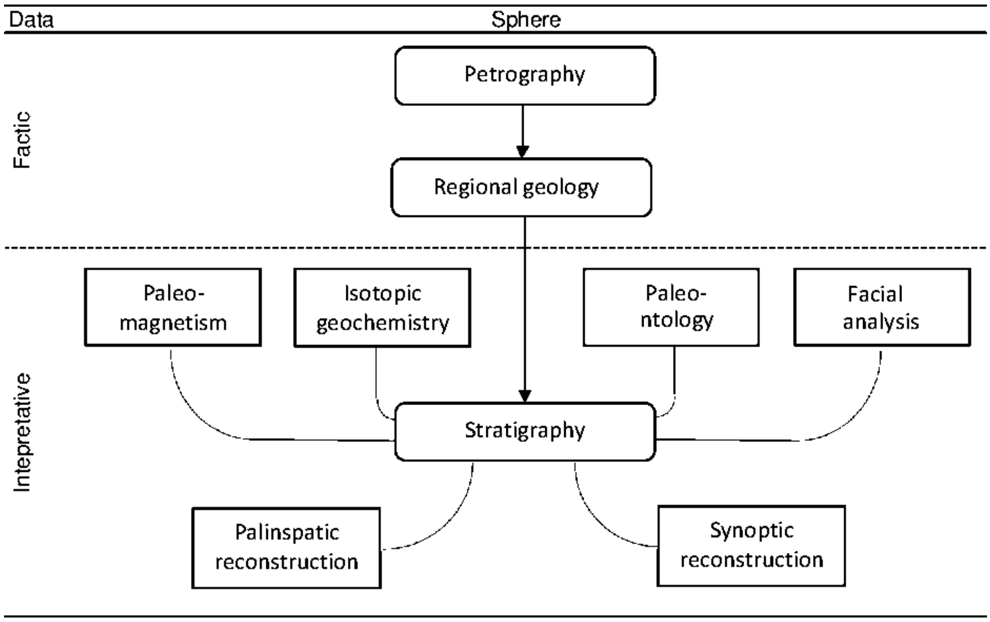

Fig. 1: *Processing flow toward palaeogeographical reconstruction of sedimentary environments*

were ancestral before ocean plates. Convective magma flows left less dense elements close to Earth surface, where they penetrated through forming ocean crust during gravitional differentiation to crystallise as bases for continental crust (Nicoli *et al.*, 2018). Howerer, Earth body gravitional differentiation was markedly enhanced during large impacts at 4.1–3.8 Ga. Impacts periodically tended to melt crust to more effective separation of less dense elements from more heavy, which fell to core. The power after impacts deviated convectional flows at Earth mantle to new magma springs, which warmed crust from below with same differentiation effect. Upto 65% from continental crust has been formed during 3.8–2.5 Ga after least nine large impacts of cosmic bodies with diameter 20–50 km, which caused craters with diameter around 500 km (Simpson, 2010).

Earth' geological past was divided to eons of Precambrian (4.6–0.54 Ga) and Phanerozoic (periods younger than 0.54 Ga). The Earth crust cooled coherently before 3.8 Ga, when it enabled occurrence of surface waters (Nutman *et al.*, 2007). Tectonic movements of lithospherical plates formed protogeological cycles at first, which were followed gradually by development of two praecontinents Protogea and Vaalbara. Precambrian eon was finished by surfacing of Rodinia supercontinent, which covered south hemisphere predominantly before 1.3–0.7 Ga (Pesonen *et al.*, 2021). Destruction of Rodinia contributed to cores for construction of all present continental plates through crystallic rock associations. The construction of major land crust for North and South Americas, Antarctis and Australia was based around separated Precambrian blocks. Africa was composed from three West-African, Kalaharian and Kongo blocks (Begg *et al.*, 2009). In contrast, Eurasia was formed after connection of several originally far lands from north and also from south hemisphere.

The presented study focused on comparison between geological environment changes in mobile Europe during Phanerozoic. Europe was formed through unique way from several microcontinents, which joined to Baltic block from edge of south Gondwana land (Kalvoda et al., 2002). The join caused large wrinkles, but also sediment development division between consolidated platforms and mobile zones (Ziegler, 1999). Alternating geological environments separated variable conditions from stable, where life communities long-timely develop adaptation ways to overcome loads (Cox and Moore, 2005).

2 Material and Methods

Changes at geological environments were assessed in the Czech Republic through vectorised palinspatic reconstructions of periods from Late Paleozoic to Quaternary. The Czech Republic (78,866 km^2; 48.569–51.021N; 12.102–18.863E) covers Bohemian Massif (84.6%) and penetrating West Carpathians (15.4%). Sedimentary basins during individual geological periods were combined into terrestrial, freshwater and marine environments (Kalvoda *et al.*, 1998). Transient wetland (moorland) as well as (peri)glacial ecosystems were assigned to the terrestrial environments. The rock dating was estimated relatively according to Gradstein and Ogg (2012). Sedimentary environment occurrence was vectorised for periods of transient Carboniferous-Permian (299 Ma), Upper Jurassic (152 Ma), Upper Cretaceous (93.9 Ma), Lower Eocene (56 Ma), transient Oligocene-Miocene (23 Ma), Upper Miocene (11.6 Ma) and Upper Pleistocene (18 Ka).

Lower Permian was selected as first period, when the Bohemian Massif was cratonised conclusively after variscan wrinkling to compact area from Moldanubic, Saxothuringian, Rhenohercynian and Brunovistulic lands (Chlupáč *et al.*, 2002). Following Mezozoic to transient period between Paleogene and Neogene (Oligocene-Miocene) were selected due to marine transgressions with intensive sedimentation, while Upper Miocene was characteristic by

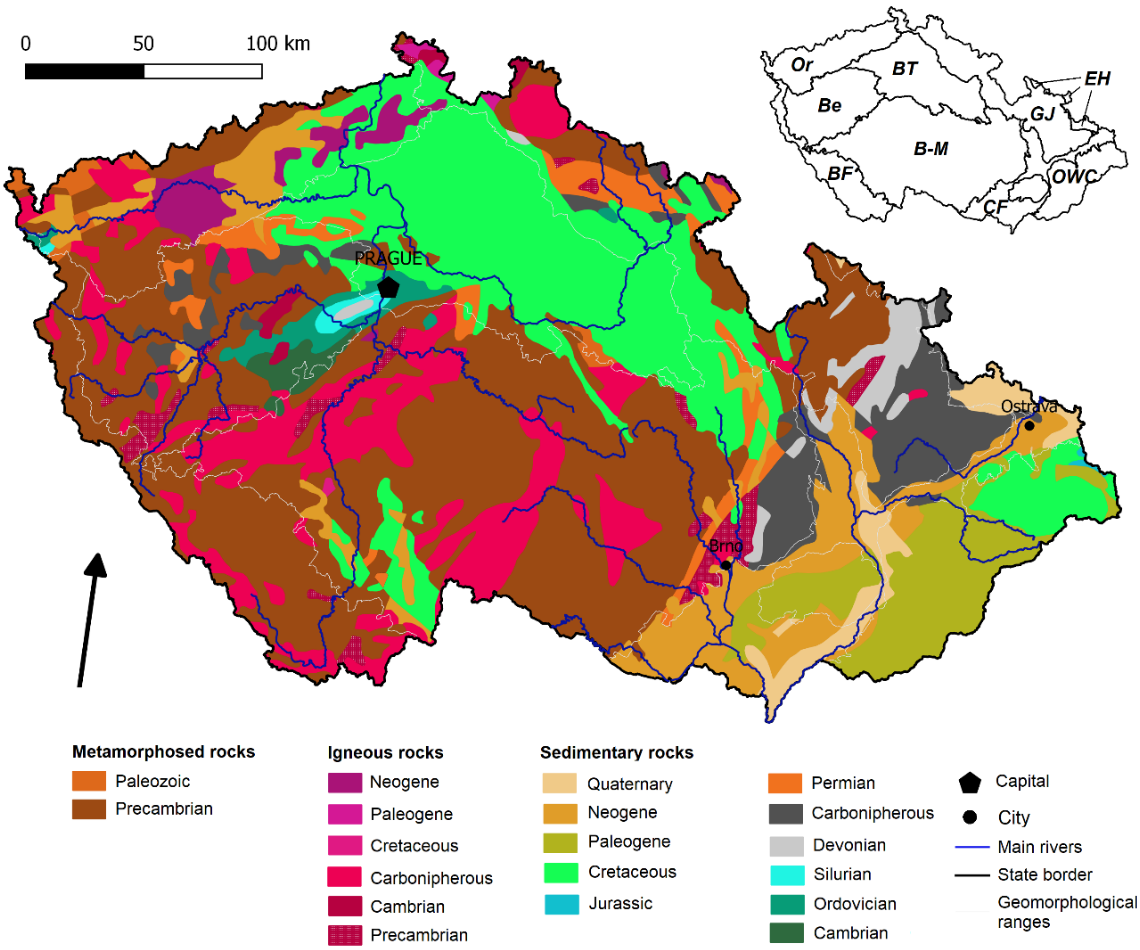

Fig. 2: *Figure 2: Lithostratigraphical division (data according to Pawlewicz et al. 2003) compared with geomorphological units of the Czech Republic (according to Kukal et al. 2014). Or – Ore Mts.; Be – Berounian; BT – Bohemian table; B-M – Bohemian-Moravian; BF – Bohemian Forest; GJ – Giant-Jeseniky Mts.; EH – Epi-Hercynian; CF – Carpathian Foredeep; OWC – Outer Western Carpathians.*

marine sedimentation decline and by global cooling (Zachos *et al.*, 2001). Upper Pleistocene was vectorised from bases covering Late Glacial, after which a gradual development of warming geological present has begun (Robets, 1998).

The assessment of changes in sedimentary environment extents was divided into recognition on changes of palaeogeographical sediment distribution and into recognition of differences between past extents and present distribution. Recognition of sediment distribution changes included combination of vector models, validation and overlays between timely related models. Recognition of the differences with present sedimentary occurrence consisted of overlay analysis and map algebra. The Permian model was vectorised according to Opluštil and Pešek (1998), the Jurassic model according to Adámek (2005), the Cretaceous model according to Čech (2011) and the Eocene model according to reconstructed marine environments (Rögl, 1998) and freshwater sedimentation (Kvaček *et al.*, 2014). The Lower Miocene was reconstructed according to Pálenský and Budil (2009), while the Upper Miocene was composed from models of marine sedimentation (Kováč *et al.*, 2007) and of riverine pattern development (Ložek *et al.*, 2004). The Quaternary model was created through overlay between regional division of Quaternary sedimentation (Růžička a Budil, 2009) and Quaternary rock types occurrences (Culek *et al.*, 2005). Validation was carried out through European rock stratigraphy map (Pawlewicz *et al.*, 2003) and through bedrock structure of the CR (Culek a Grulich, 2009) (Fig. 2–4). Map algebra focused on separation between stable and variable sedimentary environments.

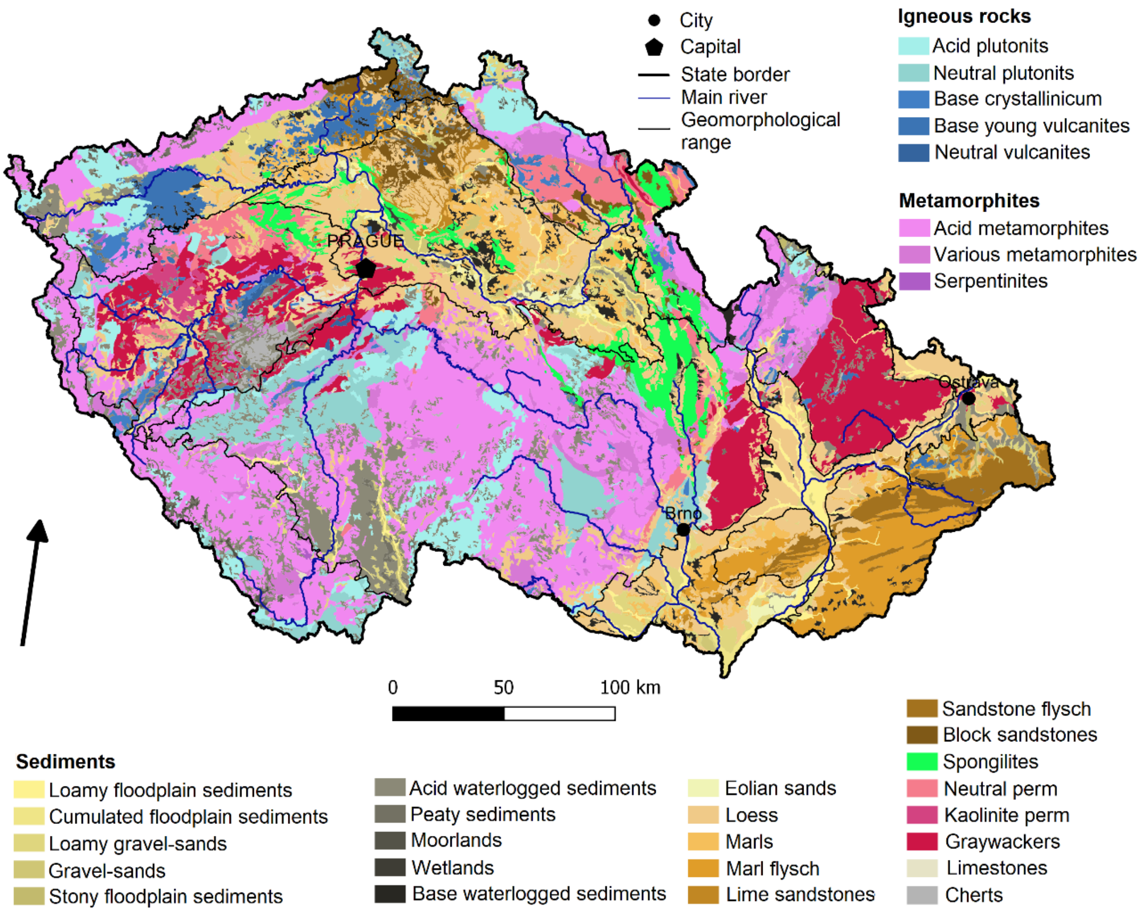

Fig. 3: *Figure 3: Bedrock structure of the Czech Republic (data according to Culek and Grulich 2009).*

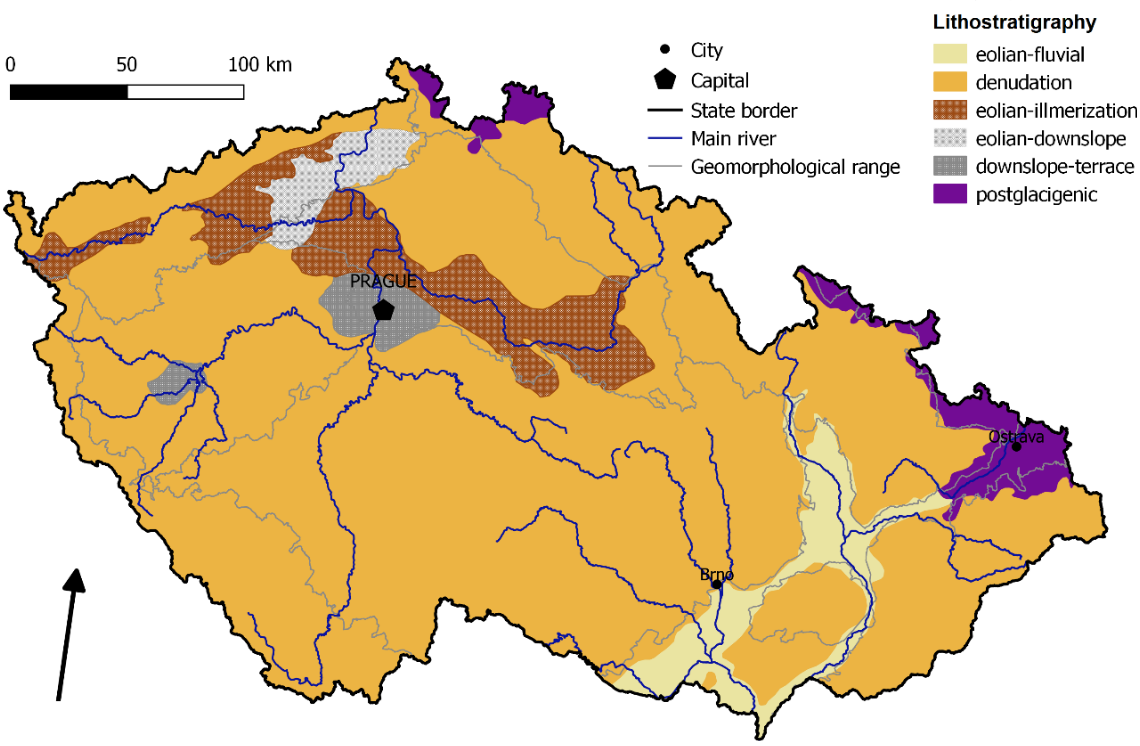

Fig. 4: *Lithostratigraphical division of Quaternary cover in the Czech Republic (data accoding to Růžička and Budil 2009).*

3 Results and discussion

Transitions among sedimentary environments divided ecosystem development between areas with permanent dry land since Late Paleozoic to present-time covering fewer than 14.8% of the CR and variable areas covering 85.2%. This divided sedimentary development suggested gross extents in main differences among adaptations of living forms to global changes. On the other hand, the accuracy of these estimates was limited by input geodata various quality and by discontinuos landscape development between selected periods with large marine transgressions or regressions.

The development of sedimentary environment extents followed plate tectonics global processes, which correspond with relation between geotectonical cycle dating and dominanting rock bodies. The CR is predominantly formed by rocks from Upper Precambrian (almost 36%), when kadomian orogenesis was in progress (Kalvoda *et al.*, 2002), from Carboniferous (19.6%), when variscan orogenesis has proceeded (Opluštil and Pešek, 1998), from Upper Cretaceous (17.2%), when the Pangea desintegration during opening of Atlantic ocean caused mediterranean orogenesis with the largest marine transgression in Phanerozoic era (Levin, 1994), and from Neogene (10.5%), when alpine wrinkling has culminated (Rögl, 1998). In contrast, the Silurian (0.29%) and Jurassic rocks (0.05%) cover CR at least, while the Triassic is almost missing completely (Pešek *et al.*, 1998).

Majority from evident geological periods was mostly represented by sediments. Metamorphic rocks dominate markedly at Precambrian bodies, while igneous rocks preponderated during Carboniferous period. The metamorphic rock occurrence was in the CR limited since Upper Precambrian to Ordivician age, while important igneous bodies rose intermittently since Upper Precambrian to Carboniferous age and continually since the end of Mezozoic era to

Period	Metamorphosed	Igneous	Sedimentary	Total
Quaternary	-	-	100.00	2.29
Neogene	-	18.00	82.00	10.47
Paleogene	-	4.25	95.75	6.22
Cretaceous	-	0.21	99.79	19.58
Jurassic	-	-	100.00	0.05
Triassic	-	-	-	0.00
Permian	-	-	100.00	3.13
Carboniferous	-	64.93	35.07	17.15
Devonian	-	-	100.00	1.65
Silurian	-	-	100.00	0.29
Ordovician	32.73	-	67.27	2.04
Cambrian	3.49	36.14	60.37	1.21
Precambrian	94.38	5.62	-	35.92

Tab. 1 *Proportion of the sedimentary environments in individual geological periods of the Czech Republic (%)*

Environ-ment	Sedimenta-tion	Permi-an	Juras-sic	Creta-ceous	Eoce-ne	Lower Mioce-ne	Upper Mioce-ne	Upper Pleis-tocene
terrestrial	volcanic	0.35	-	-	-	0.97	1.94	0.04
	denudation	70.47	64.70	29.25	66.03	65.94	56.34	77.20
	aeolian	-	-	-	-	-	-	13.74
	freeze	-	-	-	-	-	-	2.19
freshwater	cirques	-	-	-	-	-	-	0.02
	moorland	-	-	-	-	-	-	1.03
	postglacigenic	-	-	-	-	-	-	1.76
	lacustrine	18.29	-	-	13.11	12.92	7.34	0.52
	floodplain	10.89	-	-	4.65	6.43	9.69	4.01
	brackish	-	1.57	-	-	-	-	-
marine	marine	-	33.73	70.75	16.20	13.74	24.69	-

Tab. 2 *Proportion of the sedimentary environments in individual geological periods of the Czech Republic (%)*

Neogene. Sediments predominated altogether in Silurian and Devonian, Permian, Jurassic and Cretaceous and since beginning of the Cenozoic era (Tab. 1). Present surface of the CR is formed the most by acid metamophites (20.6%), greywackes (8.7%), acid waterlogged sediments (7.9%) and loess or loess-loams (13.7%).

Majority from evident geological periods was mostly represented by sediments. Metamorphic rocks dominate markedly at Precambian bodies, while igneous rocks preponderated during Carboniferous period. The metamorphic rock occurrence was in the CR limited since Upper Precambrian to Ordivician age, while important igneous bodies rose intermittently since Upper Precambrian to Carboniferous age and continually since the end of Mezozoic era to Neogene. Sediments predominated altogether in Silurian and Devonian, Permian, Jurassic and Cretaceous and since beginning of the Cenozoic era (Tab. 1). Present surface of the CR is formed the most by acid metamophites (20.6%), greywackes (8.7%), acid waterlogged sediments (7.9%) and loess or loess-loams (13.7%).

The development of sedimentary environments was in the CR influenced by marine transgressions or regressions alternately. Marine transgression spread the most in Cretaceous and in Upper Miocene. Initial as well as final periods, such as Lower Permian and Quaternary, were characteristic by complete sea regression, when denudated environments have exceeded 70% from the country area. In contrast, land proportion decreased the most to 29.3% during Cretaceous and subsequently in Upper Miocene to 56.3%. Upper Jurassic and also Paleogene were followed by terrestrial environment preservation on more than 60% of the CR area (Tab. 2). Marine regression after culmination of variascan wrinkling was followed by Mezozoic transgressions (Fig. 5). Jurassic trangression covered 33.7 of the CR by sea, while Cretaceous 79% in total. Paleogene was followed by slight sea retreat, while Upper Miocene was characteristic by last trangression (Fig. 6). Subsequent permanent sea regression from European mobile zones took continentalisation of the sedimentary conditions.

Environment	**Sedimentation**	**Permian**	**Jurassic**	**Cretaceous**	**Eocene**	**Lower Miocene**	**Upper Miocene**	**Upper Pleistocene**
terrestrial	volcanic	0.00	-	-	-	90.26	2.19	16.62
	denudation	0.16	0.00	0.03	0.00	9.99	11.70	16.14
	aeolian	-	-	-	-	-	-	100.00
	freeze	-	-	-	-	-	-	0.00
freshwater	cirques	-	-	-	-	-	-	0.00
	moorland	-	-	-	-	-	-	63.03
	postglacigenic	-	-	-	-	-	-	0.00
	lacustrine	0.03	-	-	0.00	6.86	0.09	100.00
	floodplain	4.26	-	-	0.49	0.78	81.50	21.16
	brackish	-	0.00	-	-	-	-	-
marine	marine	-	0.05	14.39	20.66	6.87	3.62	-

Tab. 3 *Ratio of ancestral sedimentary environment extents at present-time residues in the Czech Republic (%)*

Alpine orogenesis spread terrestrial sedimentation the most from Phanerozoic geotectonical cycles due to wrinkling of pan-American mountains and of Alpian-Himalayan arc (Zachos et al., 2001). Culminating laramian phase caused sea retreat in Eocene around 54.6% from the CR area, while terrestrial environment proportion expanded about 49.9%. Terrestrial environments spread about 36.8% and remnant expansion about 13.1% contained lakes. Transition between Oligocene and Miocene was followed by penetration of volcanic environments about 1% and of floodplains about 1.8%. The Miocene transgression expanded sea over 11% and floodplains over 3%, while lakes decreased around 5.6%. Late alpine wrinkling has supported Quarternary diversification of terrestral environments in relation with climate differentation during ice ages and also with volcanic aktivity reload (Růžička and Budil, 2009). Upper Pleistocene was followed by the largest loess sedimentation spreading, frost weathering and also by (mountain) glacier activities in the CR (Samec, 2014). The aeolian sediments covered upto 14% of the CR, glaciers around 1.8% and moorlands 1%, while lakes and floodplains decreased about more than 12% in comparison with Neogene (Tab. 3).

Development of typified sedimentation extents has confirmed that the CR majority was elevated from sea or big river reach during mountain-forming processes. Totally 81.2% of the CR was after elevation dried, but at least 4% of the area was flooded by freshwaters during Quaternary period again. Remnant disseminated areas from the Praděd mountain range in Hrubý Jeseník Mts., Králický Sněžník, Rychleby Mts. to west Giant Mts., core of the Karlovarská Highland, west foothill of Plzeň Upland, Central-Bohemian Upand, Modrava, Boletice and Javořice Highland seem as permanent dry land since Lower Permian (Fig. 7). Nevertheless, the distinction between permanently denudated areas and variable sedimentation basins was loaded by inaccuracies at input data and discontinuity among periods compared.

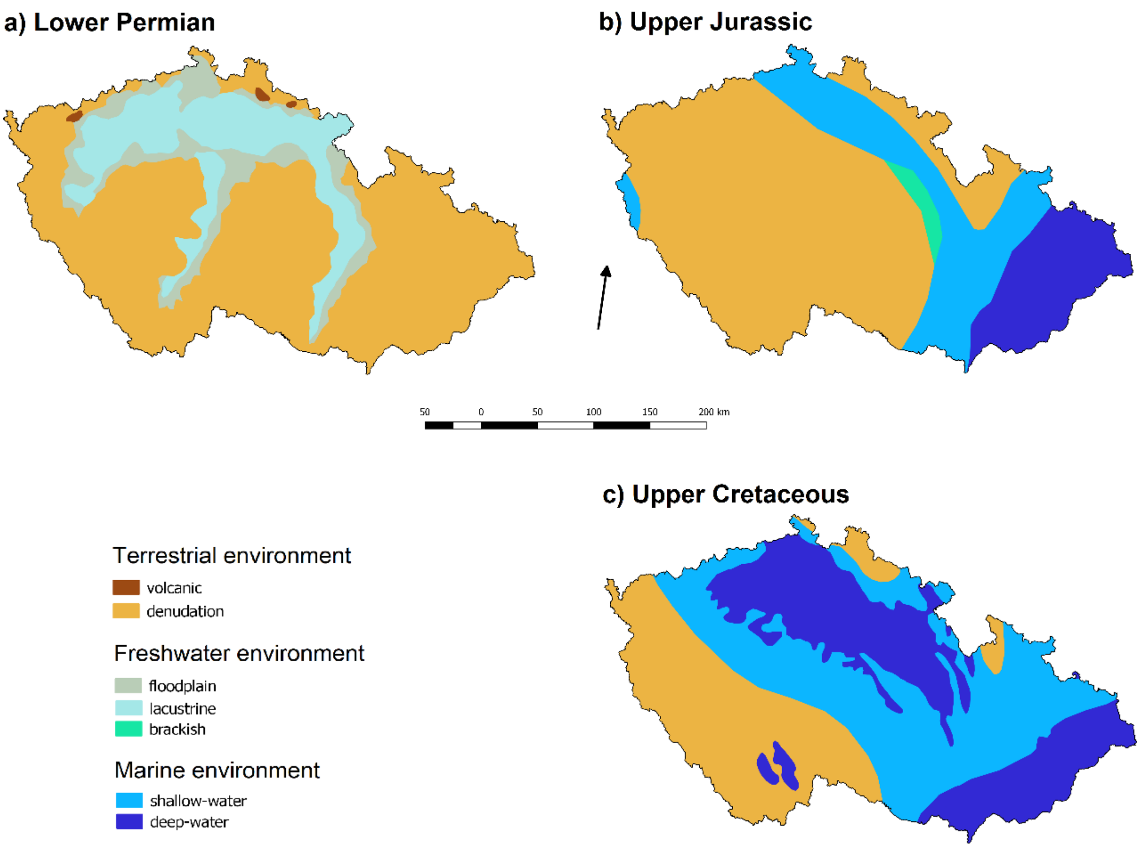

Fig. 5: *Simplified sedimentary environment extents from Upper Paleozoic to Mezozoic in the Czech Republic.*

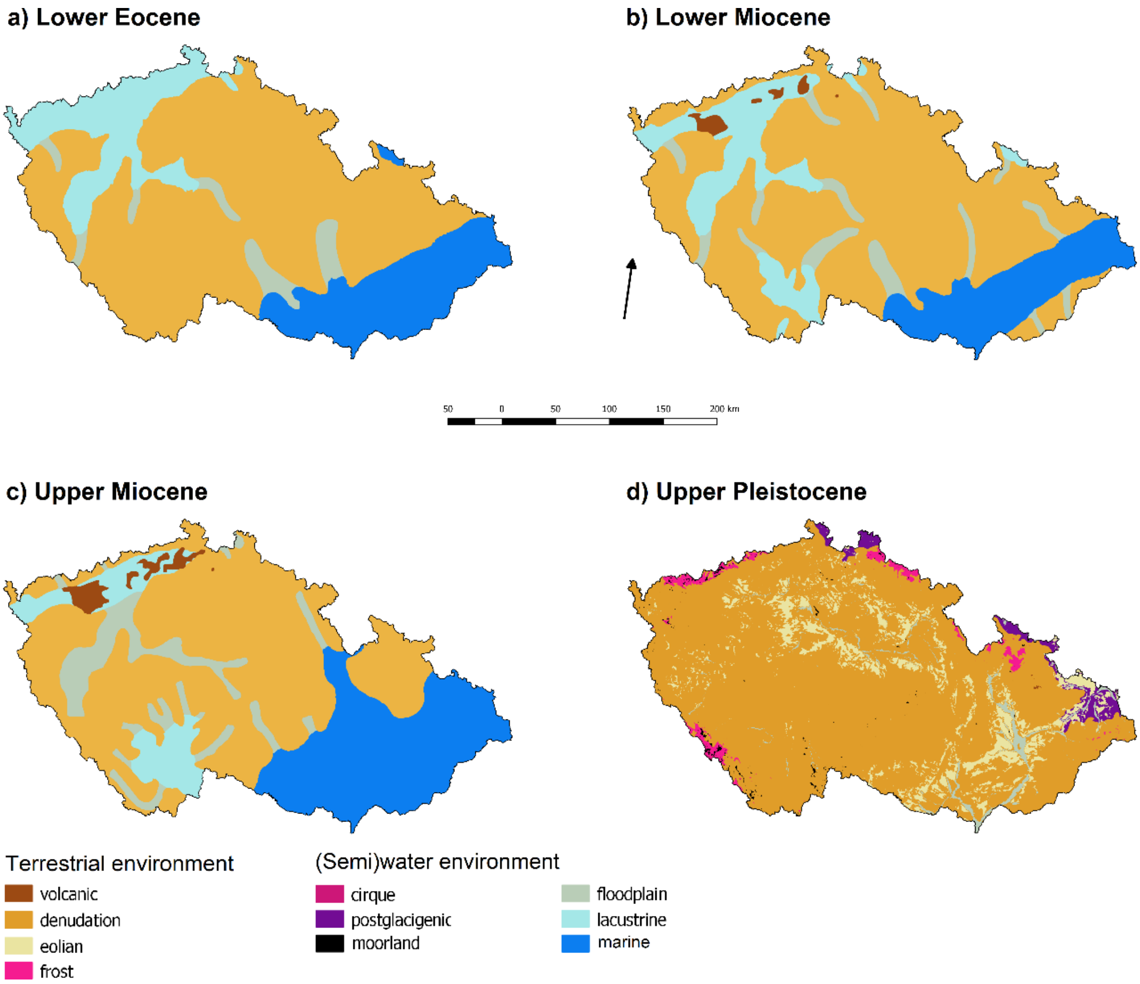

Fig. 6: *Simplified sedimentary environment extents during Cenozoic era in the Czech Republic*

The accuracy in input geodata depended both on well-obtained rock occurrence, and on various definitions about sedimentary environments. Variously detail maps and scatterly occured rocks from observed periods have caused uncertainies at interpolated transitions among particular sedimentary types (Yegorova and Starostenko, 2002). The most significant differences appeared among maps showing rock distribution between Upper Paleozoic and Mezozoic and between Neogene and Quaternary. While Lower Carboniferous was mapped during detail survey, the Upper Carboniferous to Mezozoic era were mapped through surface outcrops, irregular boreholes and geophysical measurements. Although Lower Carboniferous was mapped in detail, its rocks were sampled by small borehole number, so primary rock thickness forming indigenous relief cannot be derived credibly. Despite lower survey accuracy, the Upper-Carboniferous deposits were mapped mostly synoptically except Ostrava and Upper-Silesian basins (Pešek *et al.*, 1998). The least precise was map of Upper Jurassic due to small sediment proportion concentrated into bar zone in the Outer Western Carpathians, which conditioned layer scale 1:10,000,000 (Chlupáč *et al.*, 2002).

In contrast, Quaternary sediments were mapped in most detail, although its polygons were connected through different way than older sedimentary types. Different way for the Quaternary model composition was based on connections among variously mapped bodies. While denudated or (post)glacigenic conditions were delimited at scale 1:500,000, another Quaternary sediment types were clarified at scale 1:50,000 (Culek *et al.*, 2005). The different approach toward the Quaternary sediment modelling was affected by different rock definitions. Quaternary rocks

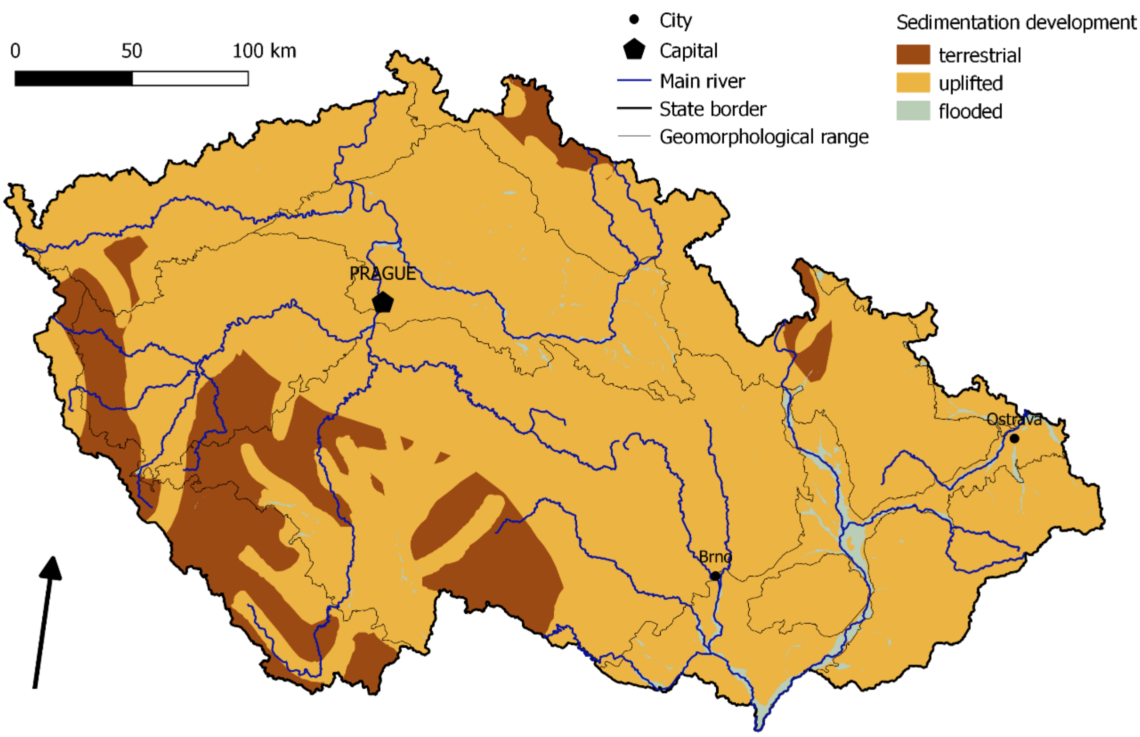

Fig. 7: *Distribution of stable terrestrial environments and mobile zones in the Czech Republic*

are unconsolidated and forming surface bodies under direct vegetation effects in contrast to older periods. Connections between rocks and vegetation liken Quaternary sediment definitions to soils formed due to reactions between living and lifeless matter. Simultaneously, they suggest that similar relationships between environment and vegetation affected sediment forming also in geological past (Cox and Moore, 2005). From this point of view, consolidated pre-Quaternary sediments demonstrate residual soils predominantly, where intensive reactions with life communities had passed.

When we could compare Quaternary sediments with previous periods, then extent of denudation conditions should be redefined. The application of denudation characteristics has used mapping of hillwashes presented allochthonously on older bedrock with different composition. If denudated cover includes also parautothonous rock residues on compact subsoil with same composition, the ratio between present and Pleistocene occurrence of slope environments could suggest preservation about 81.6% from Pleistocene hillwashes under present-time conditions.

The redefinition of relationships between sediments and soils was based on continual transition between Upper Pleistocene and geological present in Holocene. Similar redefinition in older periods was unable by discontinuity at geological time. The discontinuity caused uncertainies at accuracies of variability estimates on particular sedimentary environment extents. On the other hand, the observation on continual sedimentary environment development was limited by data amount and quality got for individual periods. Small borehole number impeded macrorelief development estimates, while data missing between Pleistocene and Holocene was displaceable by indications with different spatial resolution.

4 Summary

Palaeogeographical changes in sedimentary environment extents were assessed through comparison among vector models including periods with culminating marine transgressions or regressions since rise of the Bohemian Massif at Upper Paleozoic to Upper Pleistocene. Rock dominance in the Czech Republic is directly proportional to estimated age of its formation. The CR is predominantly formed by Precambrian, Carboniferous, Cretaceous and Neogene rocks. The Precambrian rocks are mostly metamorphosed, while Carboniferous rocks are predominantly igneous. The other geological periods were predominantly formed by sediments.

Dry land between Upper Paleozoic and geological present covered permanently upto 15% from the CR area. The land area during marine regressions exceeded 70% of Czechia. Maximum marine transgression forsook less than 30% of dry land. Quaternary period was contrarily characterised by diversification in terrestrial environments due to climatic changes and volcanic reactivation. The Pleistocene denudation environments remained in Holocene as preserved on 16.14% of slopes with allothonous hillwashes and on 65.5% of slopes with parachthonous hillwashes.

References

ADÁMEK, J. 2005. The Jurassic floor of the Bohemian Massif in Moravia – geology and paleogeography. *Bulletin of Geosciences.* 80, 291–305.

BARKER, S., ELDERFIELD, H. 2002. Foraminiferal Calcification Response to Glacial-Interglacial Changes in Atmopheric CO2. *Science.* 297, 833–836.

BURKE, K. C., WILSON, J. T. 1976. Hot Spots on the Earth's Surface. *Scientific American.* 235, 46–59.

ČECH S. 2011. Palaeogeography and Stratigraphy of the Bohemian Cretaceous Basin (Czech Republic) – An Overview. *Geologické výzkumy na Moravě a ve Slezsku*. 18, 18–21.

CHLUPÁČ I., BRZOBOHATÝ R., KOVANDA J., STRÁNÍK Z. 2002. *Geologická minulost České republiky*. Praha: Academia.

COX, C. B., MOORE, P. D. 2005. *Biogeography. An Ecological and Evolutionary Approach*. Malden-Oxford-Carlton: Blackwell Publishing Ltd.

CULEK, M., BUČEK, A., GRULICH, V., HARTL, P., HRABICA, A., KOCIÁN, J., KYJOVSKÝ, Š., LACINA, J. 2005. *Biogeografické členění České republiky*. II. díl. Praha: AOPK ČR.

CULEK, M., GRULICH, V. 2009. Biogeographical division. 1:500,000. In: HRČIANOVÁ, T., MACKOVČIN, P., ZVARA, I. (eds.). *Landscape Atlas of the Czech Republic*. Prague: Ministry of Environment, The Silva Tarouca Research Institute for Landscape and Ornamental Gardering, 195–196.

DAVIS, G. H., REYNOLDS, S. J., KLUTH, C. F. 2012. Structural geology of rocks and regions. Wiley, Hoboken.

ELDREDGE N., GOULD S. J. 1972. Punctuated equilibria: an alternative to phyletic gradualism. In: SCHOPF, T. J. M. (ed.). *Models in Paleobiology*. San Francisco: Freeman, Cooper and Company, 82–115.

GRADSTEIN F. M., OGG J. G. 2012. The Chronostratigraphic Scale. In: GRADSTEIN, F. M., OGG, J. G., SCHMITZ, M. D., OGG, G. M. (eds.). *The Geological Time Scale 2012*. Boston: Elsevier B.V., pp. 31–42.

HAMILTON, E. I. 1988. Geobiocoenosis: the chemical elements and relative abundances in biotic and abiotic systems. *The Science of the Total Environment.* 71, 253–267.

KALVODA, J., BÁBEK, O., BRZOBOHATÝ, R. 1998. *Historická geologie*. Univerzita Palackého v Olomouci.

KALVODA, J., MELICHAR, R., BÁBEK, O., LEICHMANN, J. 2002. Late Proterozoic – Paleozoic Tectonostratigraphic Development and Palaeogeography of Brunovistulian Terrane and Comparison with Other Terranes at the SE Margin of Baltica-Laurussia. *Journal of the Czech Geological Society.* 47, 81–102.

KEAREY, P., FREDERICK, J. V. 1996. Global Tectonics. Malden – Oxford – Carlton: Blackwell Publishing Ltd.

KOVÁČ, M., ANDREYEVA-GRIGOROVICH, A., BAJRAKTAREVIČ, Z., BRZOBOHATÝ, R., FILIPESCU, S., FODOR, L., HARZHAUSER ,M., NAGYMAROSY, A., OSZCZYPKO, N., PAVELIĆ, D., RÖGL, F., SAFTIĆ, B., SLIVA, Ľ, STUDENCKA, B. 2007. Badenian evolution of the Central Paratethys Sea: paleogeography, climate and eustatic sea-level changes. *Geologica Carpathica.* 58, 579–606.

KUKAL, Z., NĚMEC, J., POŠMOURNÝ, K. 2014. *Geologická paměť krajiny*. Praha: Česká geologická služba.

KVAČEK, Z., TEODORIDIS, V., MACH, K., PŘIKRYL, T., DVOŘÁK, Z. 2014. Tracing the Eocene–Oligocene transition: a case study from North Bohemia. *Bulletin of Geosciences*. 89: 21–66.

LEVIN, H. L. 1994. *The Earth Through Time*. Saunders College Publishing, Fort Worth.

LOŽEK, V., ŽÁK, K., CÍLEK, V. 2004. Z minulosti českých řek. Jak se do řeky volá, tak se z řeky ozývá. *Vesmír.* 83, 450–451.

NICOLI, G., THOMASSOT, E., SCHANNOR, M., VEZINET, A., JOVOVIC, I. 2018. Constraining a Precambrian Wilson Cycle lifespan: an example from the ca. 1.8 Ga Nagssugtoqidian Orogen, Southeastern Greenland. *Lithos.* 296–299, 1–16.

NUTMAN, A. P., FRIEND, C. R. L., HORIE, K., HIDAKA, H. 2007. The Itsaq Gneiss Complex of Southern West Greenland and the Construction of Eoarchean Crust at Convergent Plate Boundaries. *Developments in Precambrian Geology.* 15, 187–218.

OPLUŠTIL, S., PEŠEK, J. 1998. Stratigraphy, palaeoclimatology and palaeogeography of the Late Palaeozoic continental deposits in the Czech Republic. *Geodiversitas.* 20, 597–620.

PÁLENSKÝ, P. BUDIL, P. 2009. Lower Miocene. In: HRČIANOVÁ, T., MACKOVČIN, P., ZVARA, I. (eds.). *Landscape Atlas of the Czech Republic. Ministry of Environment*. Prague: The Silva Tarouca Research Institute for Landscape and Ornamental Gardering.

PAWLEWICZ, M. J., WILLIAMS, A. J., WALDEN, S. M., STEINSHOUER, D. W. 2003. *Generalized Geology of Europe including Turkey*. U.S. Geological Survey, Central Energy Resources Team. http://certmapper.cr.usgs.gov/data/we/ofr97470i/spatial/shape/geo4_2l.zip

PEŠEK, J., OPLUŠTIL, S., KUMPERA, O., HOLUB, V., SKOČEK, V., DVOŘÁK, J., PROUZA, V., TÁSLER, R. 1998. *Paleogeographic Atlas. Late Paleozoic and Triassic Formations, Czech Republic*. Prague: Czech Geological Survey.

PESONEN, L. J., SALMINEN, J., ELMING, S.-A., EVANS, D. A. D., VEIKKOLAINEN ,T. (eds.). 2021. *Ancient Supercontinents and the Paleogeography of Earth*. Amsterdam-Oxford-Cambridge: Elsevier.

ROBERTS N. 1998. The Holocene: An Environmental Study. Blackwell Publishers Ltd., Oxford – Malden.

RÖGL F. 1998. Das Werden der Zentralen Paratethys im Tertiär. In: SCHULTZ O. (ed.). T*ertiärfossilien Österreichs*. Goldschneck, Verlag.

RŮŽIČKA, M., BUDIL, P. 2009. Quaternary. In: HRČIANOVÁ, T., MACKOVČIN, P., ZVARA, I. (eds.). L*andscape Atlas of the Czech Republic*. Prague: Ministry of Environment, The Silva Tarouca Research Institute for Landscape and Ornamental Gardering.

SAMEC, P. 2014. *Proměny přírodního prostředí ve čtvrtohorách*. Mendelova univerzita v Brně.

SIMPSON, S. 2010. How Asteroids Built the Continents. *Scientific American.* 302, 60–67.

YEGOROVA, T. P., STAROSTENKO, V. I. 2002. Litosphere structure of Europe and Northern Atlantic from regional three-dimensional gravity modelling. *Geophysical Journal International.* 151, 11–31.

ZACHOS, J., PAGANI, M., SLOAN, L., THOMAS, E., BILLUPS, K. 2001. Trends, Rhytms, and Abberations in Global Climate 65 Ma to Present. *Science.* 292, 686–693.

ZIEGLER, P. A. 1999. Evolution of the Arctic-North Atlantic and the Western Tethys – a Visual Presentation of a Series of Paleogeographic-Paleotectonic Maps. *AAPG Memoir,* 43, #30002.

ZONENŠAJN, L. P., KUZMIN, M. I., MORAJEV, V. M. 1976. *Globaľnaja tektonika, magmatizm y metalogenija*. Moscow: Izd. Nezdra.

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