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MALACOSTRATIGRAPHY OF VISTULIAN AND HOLOCENE IN POLAND

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Abstract

Structure and composition of molluscan assemblages depend on natural factors such as: climate, vegetation, character of background, environmental conditions and, intensity of geological processes as well as on the human impact. Vistulian and Holocene communities of snails and bivalves exactly reflect changes of habitats. Sequences of these fauna can be used for biostratigraphy and stratigraphical schedule. The oldest part of the presented scheme corresponds with Last Pleniglacial characterized by poor communities with a high content of open country species accepting the arctic and subarctic climate. Climatic fluctuations during the Late Glacial caused a substantial recomposition of assemblages. In colder phases communities abounding in open country species of high ecological tolerance occur commonly. Fauna connected with warmer stages usually contains woodland species. At the beginning of the Holocene, a rapid warming was followed by the expansion of forests. Shade-loving species increased in number, while cold tolerant snails gradually disappeared. The maximal expansion of woodland snails is connected with the Atlantic Phase. During the Upper Holocene molluscan communities indicate the progress of human impact. The proposal of malacostratigraphical subdivision presented below can be correlated with similar schemes defined in neighboring countries. It supplement palynological schemes or even can be used as main way to stratigraphical reconstructions.

Key words: molluscs, malacostratigraphy, Vistulian, Holocene, Poland

INTRODUCTION

Well preserved shells of snails and bivalves occur in different types of Quaternary sediments particularly those containing a sufficient quantity of calcium carbonate. Numerous sites of deposits rich in subfossil molluscs are found in areas composed of carbonate rocks, mainly limestones and also marls, dolomites as well as sandstones with limy matrix. In geological regions rich in mollusc-bearing deposits palaeobotanical data are relatively rare, so they can be significantly supplemented by results of malacological investigations. In such deposits snails and bivalves are usually much more numerous than other subfossil organisms (vertebrates, ostracoda).

Mollusc shells occur commonly both in terrestrial and in freshwater sediments, often throughout the whole depositional sequence. Their assemblages correspond with local habitats and reflect almost original composition of malacocenoses living during deposition of sediments. Most of species living recently in Central Europe are known in this area since the Eemian Interglacial. Due to that, malacofauna appeared very useful in palaeogeographical and stratigraphical analyses of Late Quaternary formations (see *e.g.* Ložek 1964, 1973; S.W. Alexandrowicz 1987a; W.P. Alexandrowicz 2004). In this respect the knowledge of the ecology and geographical distribution of modern molluscs could be used for interpretation of subfossil assemblages.

During the last Pleniglacial, Late Glacial and Holocene climatic oscillations forced substantial changes of habitats and biocenoses including more or less fundamental rearrangement of mollusc assemblages, expressed by the appearance and extinction of particular species and their groups. Cyclic alternations of warmer and cooler and/or dryer and more humid phases were the first factor responsible for the intensity of geomorphological processes as well as the evolution of habitats, fitocenoses and finally malacocenoses. The human impact manifested mostly in the Middle and Late Holocene was the second factor of these changes (S.W. Alexandrowicz 1987a; W.P. Alexandrowicz 2004).

The classical subdivisions of Vistulian and Holocene reflect changes of climate. The dependence of snails and bivalves on prevalent climatic conditions makes molluscs as important material in stratigraphical investigations particularly in climatostratigraphy.

Sequences of mollusc assemblages described from numerous localities in Central Europe provided principles for paleogeographical reconstructions and enabled construction of more or less generalized malacostratigraphic schemes (Ložek 1964, 1982; Kerney 1977; S.W. Alexandrowicz 1987a; W.P. Alexandrowicz 2004) of regional importance.

Application of biostratigraphical units (different types of biostratigraphical zones) in the construction of stratigraphical subdivisions in older geological formations (Cam-

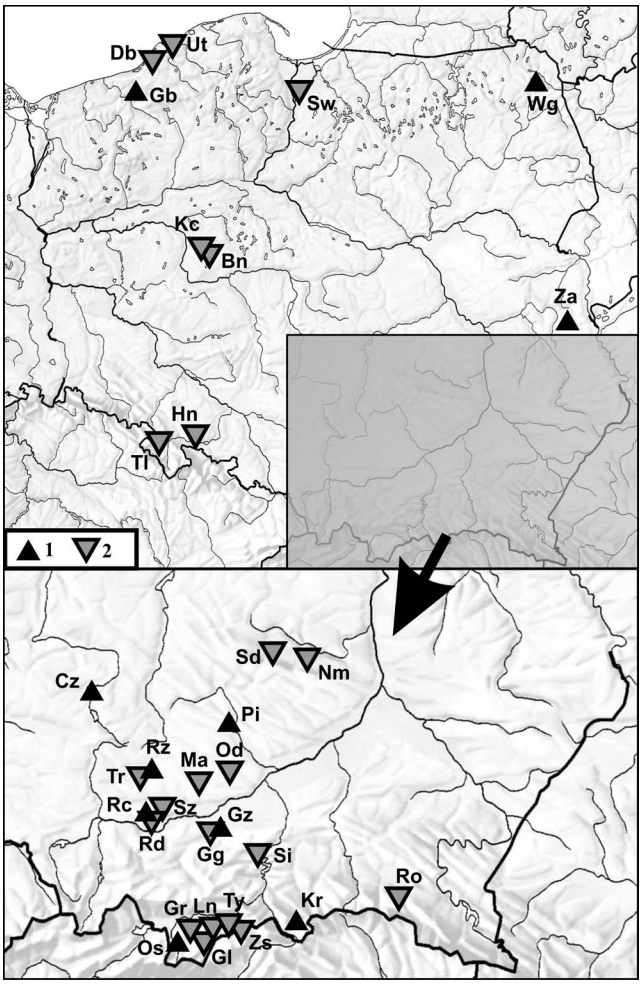

Fig. 1. Distribution of stratotype profiles of mollusc bearing deposits in Poland. 1. Stratotype profiles: Cz – Częstochowa, Gb – Grabowo, Gz – Gdów-Zabłocie, Kr – Krynica, Os – Ostrysz, Pi – Pińczów, Rc –Racławka Stream Valley, Rz – Rzeżuśnia, Wg – Wigry Lake, Za – Zawadówka; 2. Hypostratotype profiles: Bn – Bnin Lake, Db – Dąbki, Gg – Gdów-Zagórze, Gl – Gliczarów, Gr – Groń, Hn – Henryków, Kc – Kórnickie Lake, Ln – Łapsze Niżne, Ma – Maszków, Nm – Nietulisko Małe, Od – Odonów, Rd – Rudawa, Ro – Roztoki, Sd – Sieradowice, Si – Sienna, Sw – Skowarcz, Sz – Szklarka Stream Valley, Tl – Tłumaczów, Tr – Trzebienice, Ty – Tylka, Ut – Ustka, Zs – Zaskale.

brian, Ordovician *etc*.) (Kutek 1972, Racki Narkiewicz (eds) 2006) is restricted or even useless in the respect to the Late Quaternary due to the short duration of this period. These units can be replaced by "nominal zones" – unformal units proposed by S.W. Alexandrowicz (1987a) regarded as ecostratigraphical ones.

This paper presents a new proposal of malacostratigraphical subdivision of Late Glacial and Holocene. This subdivision can be used as a basis for correlations, both in the local and regional scale, between malacological sequences representing profiles of sediments of different genesis. Majority of older proposals of such subdivisions are of local significance (*e.g.* Gedda 2001, Meyrick 2002) or can be used only to particular types of deposits (for example: S.W. Alexandrowicz 1995a; W.P. Alexandrowicz 2004). The presented scheme, in contrast to the older ones (*e.g.* S.W. Alexandrowicz 1987a; Skompski 1996), contains malacostratigraphical units defined basing on detailed description of the molluscan communities. It contains also, for the first time, appointed stratotype and hipostratotype profiles. Malacostratigraphical subdivision of fresh-water environments is the first such proposal not only in Poland, but also in the whole Europe.

DESCRIPTIONS OF ZONES

The proposed scheme is based on detailed analyses of numerous profiles of Late Glacial and Holocene molluscs-bearing deposits from Poland. The age of particular zones has been established according to radiocarbon data (cited by: S.W. Alexandrowicz 1983, 1995a; S.W. Alexandrowicz, W.P. Alexandrowicz 1995a, 1995b; Skompski 1996; W.P. Alexandrowicz 1999a, 2004, 2007; and references therein). The scheme consists of two elements: the first one including zones distinguished in faunal successions in terrestrial habitats, and the second related to successions in water biotopes. For each malacostratigraphical unit described below, the typical profile (stratotype) is pointed. In the stratotype profile the molluscan community used to define the zone is described in detail, and its stratigraphical position is well determined by radiocarbon dating. Other, well elaborated profiles are regarded as supplementary (hypostratotype) ones (Fig. 1, Tabs 1, 2).

Malacostratigraphic subdivision of terrestrial environments (Fig. 2-L)

Trichia hispida zone – 32,000–25,000 ^{14}C years BP (Early Plenivistulian) (Fig. 2-L)

The tolerant open country and catholic species adapted to the cold, continental climate are the main component of the assemblage. It corresponds with the phase of open-country environments of the tundra or steppe-tundra type. The admixture of mesophilous snails indicate the occurrence of shrubs or even light forests and relatively humid habitats. The low intensity of loess accumulation is observed during the phase in question. The most characteristic assemblage is composed of the nominal taxon and typical loess species: *Pupilla muscorum* (L.), *Succinea oblonga* Drap., *Arianta arbustorum* (L.) and some others.

Pupilla muscorum loessica zone – 25,000–21,000 ^{14}C years BP (Middle Plenivistulian) (Fig. 2-L)

The poor community with predominance of cold tolerant snails is typical for this zone. It corresponds with cold, severe and dry continental climate and indicates the environment of subarctic steppes with limited humidity. The most typical community contains only loess species such as: *Pupilla muscorum loessica* Ložek, *Pupilla muscorum densegyrata* Ložek, *Pupilla muscorum* (L.), *Vallonia tenuilabris* (Brown) and *Succinea oblonga* Drap. Progressive cooling of climate during the Pleniglacial and occurrence of stages of intensive loess accumulation are marked by the decrease of species diversity. In special cases the nominal taxon occurs as the only one in the assemblage. *Pupilla muscorum loessica* Ložek was defined by Ložek (1965) as a distinct species but according to the results of biometrical studies the mentioned taxon

Table 1

Stratotype and hypostratotype profiles of malacofauna of terrestrial environments

Zone	Main localities (stratotypes)	Supplementary localities (hypostratotypes)
Trichia hispida	Pińczów (loess)	Tłumaczów (loess)
Pupilla muscorum loessica		Maszków (loess) Odonów (loess)
Succinea oblonga		Sienna (slope deposits)
Vertigo parcedentata	Częstochowa (aeolian sand and silt)	Nietulisko Małe (loess) Ustka (peat)
Semilimax kotulae	Krynica (slope deposits)	Groń (slope deposits) Gliczarów (slope deposits)
Vertigo genesii	Gdów-Zabłocie (calcareous tufa)	Szklarka Stream Valley (calcareous tufa) Gliczarów (calcareous tufa) Sieradowice (calcareous tufa)
Discus ruderatus	Racławka Stream Valley (calcareous tufa)	Łapsze Niżne (fluviatile deposits) Gliczarów (calcareous tufa) Sieradowice (calcareous tufa) Trzebienice (calcareous tufa)
Discus perspectivus	Racławka Steram Valley (calcareous tufa)	Łapsze Niżne (fluviatile deposits) Gliczarów (calcareous tufa) Trzebienice (calcareous tufa)
Vallonia pulchella	Racławka Stream Valley (calcareous tufa)	Sieradowice (calcareous tufa) Trzebienice (calcareous tufa)
Perforatella vicina	Ostrysz (calcareous tufa)	Gliczarów (calcareous tufa) Zaskale (calcareous tufa)
Cecilioides acicula	Racławka Stream Valley (calcareous tufa)	Gdów-Zagórze (fluviatile deposits) Henryków (fluviatile deposits) Rudawa (fluviatile deposits)

Table 2

Stratotype and hypostratotype profiles of malacofauna of fresh-water environments

Zone	Main localities (stratotypes)	Supplementary localities (hypostratotypes)
Pisidium obtusale laponicum	Zawadówka (peat and calcareous tufa)	Ustka (lacustrine chalk) Roztoki (lacustrine chalk) Skowarcz (lacustrine chalk)
Gyraulus laevis	Rzeżuśnia (calcareous tufa)	Roztoki (lacustrine chalk) Skowarcz (lacustrine chalk) Szklarka Stream Valley (calcareous tufa)
Bithynia tentaculata	Grabowo (calcareous tufa)	Roztoki (lacustrine chalk) Dąbki (lacustrine chalk) Skowarcz (lacustrine chalk)
Bythyniella austriaca	Ostrysz (calcareous tufa)	Gliczarów (calcareous tufa) Zaskale (calcareous tufa) Tylka (calcareous tufa)
Dreissena polymorpha	Wigry Lake (lacustrine chalk)	Kórnickie Lake (calcareous gytia) Bnin Lake (calcareous gytia)

can be regarded as subspecies or even only as ecoform of *Pupilla muscorum* (L.) adapted to a very cold climate and high intensity of aeolian accumulation (Łopuszyńska 2002). The described community is similar to the "Pupilla-fauna" described by Ložek (1965).

***Succinea oblonga* zone – 21,000 – 15,000 ^{14}C years BP (Late Plenivistulian) (Fig. 2-L)**

This zone represents gradual warming of climate and decrease of intensity of loess deposition. The phase in questions corresponds with the expansion of wet or semi-wet, open habitats. The nominal species usually predominates. Other cold tolerant snails: *Pupilla muscorum* (L.), *Semilimax kotulae* (West.), *Vertigo genesii* (Gredl.) and others occur as accessory components. *Succinea oblonga* Drap. found in loess deposits was earlier identified as *Succinea oblonga elongata* Standb. (Ložek 1965). However, according to recent biometrical analysis distinguishing the last mentioned taxon is not justified (Łopuszyńska 2002). The described community is similar to the "Succinea-fauna" (Ložek 1965).

The zones described above (Trichia hispida, Pupilla muscorum loessica and Succinea oblonga) could be distinguished in numerous profiles of loess and loess-like deposits

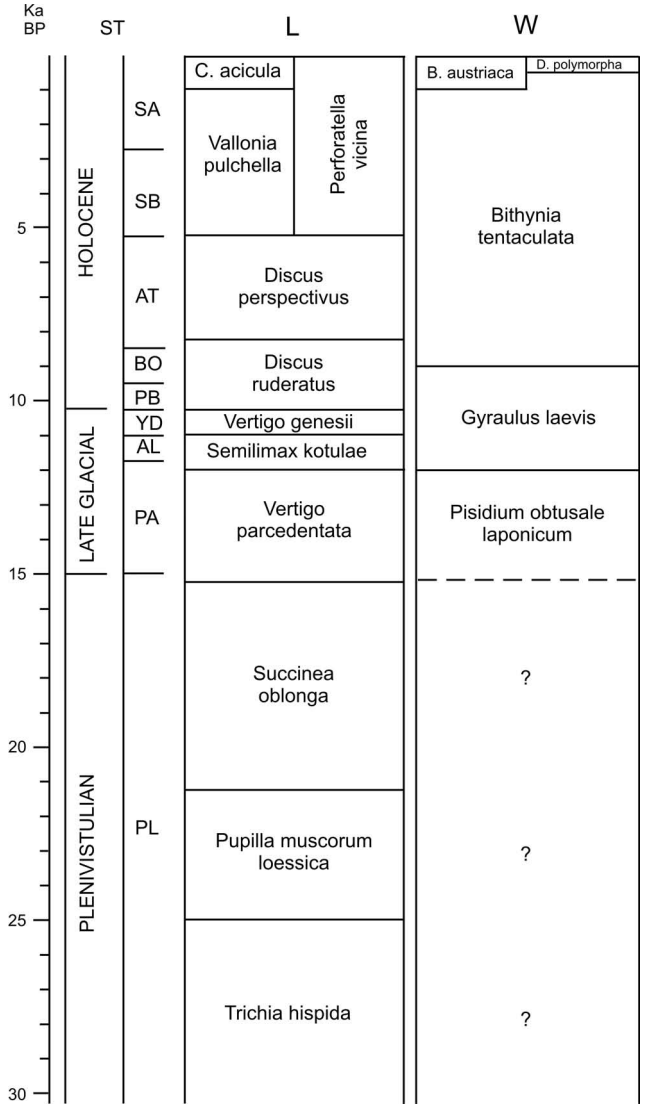

Fig. 2 Malacostratigraphic scheme of the Last Plaeniglacial. Late Glacial and Holocene in Poland. Ka – ^{14}C age BP in thousands years; ST – stratigraphy: PL – Last Pleniglacial, PA – Pre-Alleröd Period (*sensu* W.P. Alexandrowicz 1997, 2004), AL – Alleröd, YD – Younger Dryas, PB – Preboreal Phase, BO – Boreal Phase, AT – Atlantic Phase, SB – Subboreal Phase, SA – Subatlantic Phase; L – terrestrial snails, W – fresh-water molluscs.

described in Southern Poland. The most complete sequences were found in Pińczów (Nida Basin) (W.P. Alexandrowicz, Urban 2002) – stratotype profile. Profiles in Tłumaczów (Sudety Mts.) (W.P. Alexandrowicz 1999b), Maszków and Odonów (Małopolska Upland) (S.W. Alexandrowicz 1986, 1991a, 1995a) and in Sienna (Flysch Carpathians) (S.W. Alexandrowicz 1988, S.W. Alexandrowicz *et al.* 1991) can be regarded as supplementary (hypostratotype) ones (Fig. 1, Tab. 1).

Vertigo parcedentata zone – 15,000–11,800 ^{14}C years BP (Pre-Alleröd) (Fig. 2-L)

This is the phase of cool climate with intensive development of humid, wet and swampy habitats. The typical community contains cold tolerant species, preferring wet habitats such as: *Vertigo genesii* (Gredl.), *Vertigo geyeri* Lindh., *Columella columella* (G. Mart.). Loess taxa which were the main components of Pleniglacial malacocenoses gradually decreased. In a single localities more diverse communities enriched in catholic snails are noted. These profiles could be probably correlated with Bølling Interphase, however, according to malacological data this warmer episode practically cannot be distinguished. Stratotype succession – Częstochowa (Cracow-Częstochowa Upland) (W.P. Alexandrowicz, Kobojek 1997). Profiles in Nietulisko Małe (Holy Cross Mts) (S.W. Alexandrowicz 1987b) and Ustka (Baltic coast) (S.W. Alexandrowicz *et al.* 1989) are hypostratotypes (Fig. 1, Tab. 1).

Semilimax kotulae zone – 11,800–11,000 ^{14}C years BP (Alleröd Interphase) (Fig. 2-L)

This zone represents warming of climate and consequent expansion of shady habitats, most probably bushes or light coniferous forests. The typical assemblages contain shade-loving, cold-tolerant species such as: *Semilimax kotulae* (West.), *Arianta arbustorum* (L.) accompanied by mesophilous snails: *Nesovitrea hammonis* (Ström), *Euconulus fulvus* (Müll.) and others. Species characteristic for cold, arctic climate like *Vertigo genesii* (Gredl.), *Vertigo geyeri* Lindh, *Columella columella* (G.Mart.) as well as forest snails appear occasionally. Stratotype succession – Krynica (Flysch Carpathians) (S.W. Alexandrowicz, Z. Alexandrowicz 1998, 1999; W.P. Alexandrowicz 2004), hypostratoype profiles are located in Podhale Basin – Groń (W.P. Alexandrowicz 1997) and Gliczarów (W.P. Alexandrowicz 1997, 2003) (Fig. 1, Tab. 1).

Vertigo genesii zone – 11,000–10,250 ^{14}C years BP (Younger Dryas) (Fig. 2-L)

This zone represents woodless, open tundra-type habitats with marshes and swamps generally reflecting cooling of climate. Bushes and light forests decrease. The mollusc fauna comprises mainly cold tolerant, hygrophilous snails: *Vertigo genesii* (Gredl.), *Vertigo geyeri* Lindh. and *Columella columella* (G. Mart.). Catholic species: *Nesovitrea hammonis* (Ström), *Euconulus fulvus* (Müll.) supplement this community. Forest and shade-loving snails occur sporadically. Stratotype succession – Gdów-Zabłocie (Flysch Carpathians) (S.W. Alexandrowicz, Chmielowiec 1992). Profiles in Gliczarów (Podhale Basin) (W.P. Alexandrowicz 1997, 2003), Sieradowice (Holy Cross Mts) (S.W. Alexandrowicz *et al.* 1987, W.P. Alexandrowicz 2004) and in Szklarka Stream Valley (Cracow-Częstochowa Upland) (S.W. Alexandrowicz 1983, 1989; W.P. Alexandrowicz 2004) can be regarded as hypostratotypes (Fig. 1, Tab. 1).

Discus ruderatus zone – 10,250–8,400 ^{14}C years BP (Early Holocene) (Fig. 2-L)

This zone corresponds to amelioration of climate and significant rearrangment of plant formations. Open and wet tundra-type biotopes are replaced by shady ones. Dominance of forest habitats with significant proportion of conifer trees growing in climate of strong continental influence is com-

monly observed. These changes lead to extension of taxonomical diversity of molluscan assemblages. Woodland species become dominant components of the communities, and are supplemented with snails living in shady or partly shady, wet biotopes: *Perforatella bidentata* (Gmel.) and *Vertigo substriata* (Jeffr.) as well as with mesophilous taxa. Occurrences of single shells of glacial relicts: *Vertigo genesii* (Gredl.), *Vertigo geyeri* Lindh. and *Columella columella* (G. Mart.) are noted. The described community is similar to the "Ruderatus-fauna" (Dehm 1967). Stratotype profile: Racławka Stream Valley (Cracow-Częstochowa Upland) (S.W. Alexandrowicz 1983; S.W. Alexandrowicz, Stworzewicz 1983; W.P. Alexandrowicz 2004). Hypostratotypes are located in: Łapsze Niżne and Gliczarów (Podhale Basin) (W.P. Alexandrowicz 1997, 2003), Sieradowice (Holy Cross Mts) (S.W. Alexandrowicz *et al.* 1987; W.P. Alexandrowicz 2004) and Trzebienice (Cracow-Częstochowa Upland) (W.P. Alexandrowicz 2004) (Fig. 1, Tab. 1).

***Discus perspectivus* zone – 8,400–5,100 ^{14}C years BP (Middle Holocene) (Fig. 2-L)**

This zone corresponds with the postglacial climatic optimum and increasing influence of oceanic climate. In consequence expansion of dense deciduous forests appears. Communities of molluscs are supplied by many species of high ecological preferences. Rich and differentiated malacocenoses are composed of woodland snails such as: *Discus perspectivus* (Mülhf.), *Ruthenica filograna* (Rossm.), *Aegopinella minor* (Stab.) and many others. Mesophilous and hygrophilous species are accessory components of this fauna, while the meadow taxa are practically absent. The described community is similar to the "Perspectivus-fauna" described by Dehm (1987). Stratotype profile: Racławka Stream Valley (Cracow-Częstochowa Upland) (S.W. Alexandrowicz 1983; S.W. Alexandrowicz, Stworzewicz 1983; W.P. Alexandrowicz 2004). Hypostratotype profiles have been described from: Łapsze Niżne and Gliczarów (Podhale Basin) (W.P. Alexandrowicz 1997, 2003) and Trzebienice (Cracow-Częstochowa Upland) (W.P. Alexandrowicz 2004) (Fig. 1, Tab. 1).

***Vallonia pulchella* zone – 5,100–1,000 ^{14}C years BP (Late Holocene) (Fig. 2-L)**

This zone is connected with the development of human activity and settlements, in particular with deforestation and related transformation of forest biotopes into open grasslands. Taxonomical diversity of molluscan assemblages markedly decrease. Rich communities of woodland snails are replaced by relatively poor assemblages dominated by open-country taxa (*Vallonia pulchella* (Müll.), *Vallonia costata* (Müll.) and others). Shade-loving forms typical for bushes as well as mesophilous species are only subordinate components of the fauna. The described zone can be distinguished mainly in Mid-Polish Uplands. Stratotype profile: Racławka Stream Valley (Cracow-Częstochowa Upland) (S.W. Alexandrowicz 1983; S.W. Alexandrowicz, Stworzewicz 1983; W.P. Alexandrowicz 2004), hypostratotypes: Sieradowice (Holy Cross Mts) (S.W. Alexandrowicz *et al.* 1987; W.P. Alexandrowicz 2004) and Trzebienice (Cracow-Częstochowa Upland) (W.P. Alexandrowicz 2004) (Fig. 1, Tab. 1).

***Cecilioides acicula* zone – 1,000–0 ^{14}C years BP (historical epoch) (Fig. 2-L)**

This zone represents extension of plough-fields and farmlands *i.e.* areas remaining under the intensive landuse and anthropopressure. Mollusc assemblages are very poor and contain species inhabiting agriculture areas (*Oxychilus inopinatus* (Uli.), *Cecilioides acicula* (Müll.)) as well as grasslands (*Vallonia pulchella* (Müll.), *Vallonia costata* (Müll.). The mentioned zone can be distinguished in areas transformed by human activity, mainly agriculture (Mid-Polish Uplands, Carpathian Foothills). Stratotype profile: Racławka Stream Valley (Cracow-Częstochowa Upland) (S.W. Alexandrowicz 1983; S.W. Alexandrowicz, Stworzewicz 1983; W.P. Alexandrowicz 2004), hypostratotype ones are located in: Rudawa (Cracow-Częstochowa Upland) (Rutkowski 1991; W.P. Alexandrowicz 2004), Gdów-Zagórze (Flysch Carpathians) (S.W. Alexandrowicz, Chmielowiec 1992) and Henryków (Sudety Foothill) (S.W. Alexandrowicz, Teisseyre 1997) (Fig. 1, Tab. 1).

***Perforatella vicina* zone – 5,100–0 ^{14}C years BP (Late Holocene) (Fig. 2-L)**

This zone corresponds with areas of low human impact covered in significant part with natural forests. Communities of molluscs are relatively rich and differentiated. They comprise shadow-loving species: *Perforatella vicina* (Rossm.), *Ena montana* (Drap.), *Eucobresia nivalis* (Dum et Mort.) and others, accompanied by catholic snails such as: *Nesovitrea hammonis* (Ström) and *Euconulus fulvus* (Müll.). The mentioned zone can be distinguished mainly in Carpathians. The profile in Ostrysz (Podhale Basin) (W.P. Alexandrowicz 1997, 2001) is the stratotype one. Profiles in Gliczarów (Podhale Basin) (W.P. Alexandrowicz 1997, 2003) and in Zaskale (Pieniny Mts) (W.P. Alexandrowicz 2004) can be regarded as hypostratotype sequences (Fig. 1, Tab. 1).

Malacostratigraphic subdivision of fresh-water environments (Fig. 2-W)

***Pisidium obtusale laponicum* zone – older than 12,000 ^{14}C years BP (Plenivistulian, Prealleröd) (Fig. 2-W)**

This zone corresponds with severe, subarctic or even arctic climate. Communities of molluscs comprise mainly cold tolerant bivalves such as: the nominal taxon, *Pisidium stevarti* Peterson, *Pisidium lillieborgi* Cless., accompanied by water snail: *Gyraulus laevis* (Ald.). Land species are represented by hygrophilous taxa inhabiting swamps and marshes (*Vertigo genesii* (Gredl.), *Vertigo geyeri* Lindh.). The described fauna developed in small and shallow fresh-water bodies with initial carbonate accumulations. Stratotype succession – Zawadówka (Lublin Upland) (W.P. Alexandrowicz 2004; Dobrowolski *et al*. 2005), hypostratotype profiles: Skowarcz (Żuławy Wiślane) (W.P. Alexandrowicz 1999a, 2002), Ustka (Baltic coast) (S.W. Alexandrowicz *et al.* 1989) and Roztoki near Jasło (Flysch Carpathians) (S.W. Alexandrowicz 1987c) (Fig. 1, Tab. 2).

***Gyraulus laevis* zone – 12,000 – 9,300 ^{14}C years BP (Alleröd, Younger Dryas, Preboreal Phase) (Fig. 2-W)**

This zone characterises cold climate with strong continental influence. Relatively poorly diversified assemblage includes cold tolerant and euryecological water species. *Gyraulus laevis* (Ald.), *Pisidium stevarti* Peterson, *Pisidium obtusale laponicum* Cless. belongs to the first mentioned group, while *Galba truncatula* (Müll), *Valvata piscinalis* (Müll.) and some others represent the second one. This community is usually supplemented by hygrophilous land taxa (*Vertigo genesii* (Gredl.), *Vertigo geyeri* Lindh.). The described fauna developed in small and shallow freshwater basins or flat zones of bigger lakes. Stratotype succession – Rzeżuśnia (Cracow-Częstochowa Upland) (W.P. Alexandrowicz 2004), hypostratotype profiles: Roztoki near Jasło (Flysch Carpathians) (S.W. Alexandrowicz 1987c), Szklarka Stream Valley (Cracow-Częstochowa Upland) (S.W. Alexandrowicz 1983, 1989; W.P. Alexandrowicz 2004) and Skowarcz (Żuławy Wiślane) (W.P. Alexandrowicz 1999a, 2002) (Fig. 1, Tab. 2).

***Bithynia tentaculata* zone – 9,300–1,000 ^{14}C years BP (Boreal, Atlantic, Subboreal, Subatlantic Phases) (Fig. 2-W)**

This zone represents different types of freshwater reservoirs developed in temperate or relatively warm climate. Rich and diverse assemblage comprises numerous water species of limited climatic tolerance: *Anisus contortus* (L.), *Anisus vortex* (L.), *Gyraulus albus* (Müll.) and many others. Single shells of cold tolerant taxa: *Gyraulus laevis* (Ald.), *Gyraulus acronicus* (Fér.) are sometimes found, too. Two types of the described communities can be distinguished. The first one contains snails and bivalves inhabiting large lakes (*Lymnaeidae, Unioidae*), while the second one is composed of taxa preferring shallow or even temporary water bodies (*Anisus vorticulus* (Trosch.), *Armiger crista* (L.) and others). Stratotype succession is located in Grabowo near Koszalin (Middle Pomerania) (S.W. Alexandrowicz 1995b). Profiles in Roztoki near Jasło (Flysch Carpathians), (S.W. Alexandrowicz 1987c), Dąbki near Darłowo (Baltic coast) (S.W. Alexandrowicz 1991b) and Skowarcz (Żuławy Wiślane) (W.P. Alexandrowicz 1999a, 2002) are hypostratotypes (Fig. 1, Tab. 2).

***Bythinella austriaca* zone – 1,000–0 ^{14}C years BP (historical period) (Fig. 2-W)**

This zone can be distinguished in recently deposited travertines and calcareous tufa. Typical feature of this assemblage is a very common occurrence of stenotopic snail *Bythinella austriaca* (Frfld.) which constitutes from 60 to 90% of taxa and may even exceed 95%. The malacocenoses includes also rare specimens of terrestrial species, *i.e.* hygrophilous, open-country forms (*Succinea putris* (L.)) or shade-loving ones (*Perforatella bidentata* (Gmel.)), and even less abundant taxa typical of more dry habitats. Important members of the assemblage are other freshwater molluscs the most common of which is usually *Pisidium personatum* Malm.. The described fauna is typical of cold waters of constant temperature and was encountered mainly in spring zones rich in calcium carbonate. However, this assemblage may appear also in fast-flowing streams of pebbly channels. Stratotype succession – Ostrysz (Podhale Basin) (W.P. Alexandrowicz 1997, 2001). Hypostratotypes are located in Gliczarów (Podhale Basin) (W.P. Alexandrowicz 1997, 2003), Zaskale (Pieniny Mts) (W.P. Alexandrowicz 2004) and in Tylka (Pieniny Mts) (W.P. Alexandrowicz 2004, 2009) (Fig. 1, Tab. 2).

***Dreissena polimorpha* zone – 300–0 ^{14}C years BP (historical period) (Fig. 2-W)**

This zone corresponds with period of strong anthropopressure. One result of human activity is the increased migration of molluscs. During the last 300 years the native water fauna became supplemented by numerous taxa of high ecological tolerance (*Dreissena polymorpha* (Pallas), *Potamopyrgus antipodarum* (Grey), *Physa acuta* Drap.). These species are noted from both artificial and natural habitats. They are usually well developed in polluted environments, and gradually pass into freshwater reservoirs and rivers. Stratotype succession – Wigry Lake (North-East Poland) (W.P. Alexandrowicz 2000), hypostratotype profiles: Kórnickie Lake and Bnin Lake (Wielkopolska Lowland) (Wojciechowski 1999) (Fig. 1, Tab. 1).

CONCLUSIONS

The malacostratigraphic subdivisions of the Last Pleniglacial, Late Glacial and the Holocene, in Poland is based upon analyses of molluscs assemblages and selected species, which occur in different types of sediments like loess, slopewash, hillwash, calcareous tufa, lacustrine chalk, as well as deposits accumulated by rivers and streams or filling caves and niches. Schemes of more or less regional extent were just proposed in several European countries.

Malacostratigraphical subdivisions elaborated in Western Europe are usually based on single localities or on several profiles of deposits of similar genesis distributed in a single geographical region (Mania 1973, 1995; Kerney 1977; Kerney *et al.* 1980; Keen 1987; Limondin-Lozouet, Rousseau 1991; Rousseau *et al.* 1993, 1994; Gedda 2001; Meyrick 2001, 2002; Limondin-Lozouet, Preece 2004). Fot that reason they have only local importance, and regional stratigraphical correlation between particular schemes is difficult, or even impossible.

Subdivisions worked out in Hungary, Czech and Slovakia (Ložek 1967, 1983, 2000; Krolopp 1983; Fükök 1993, 2000; Fükök *et al.* 1995) have more regional importance and can be used to the regional correlation. However they show substantial differences with respect to the scheme presented above, most probably because of distinctly different climatic regimens. In consequence malacostratigraphical zones are defined by different nominal species, different stratigraphical position and time spans of zones (Fig. 3). These differences occur particularly in the Holocene, while in Plenivistulian and Late Glacial succession and composition of molluscan assemblages are quite similar in the whole Central Europe.

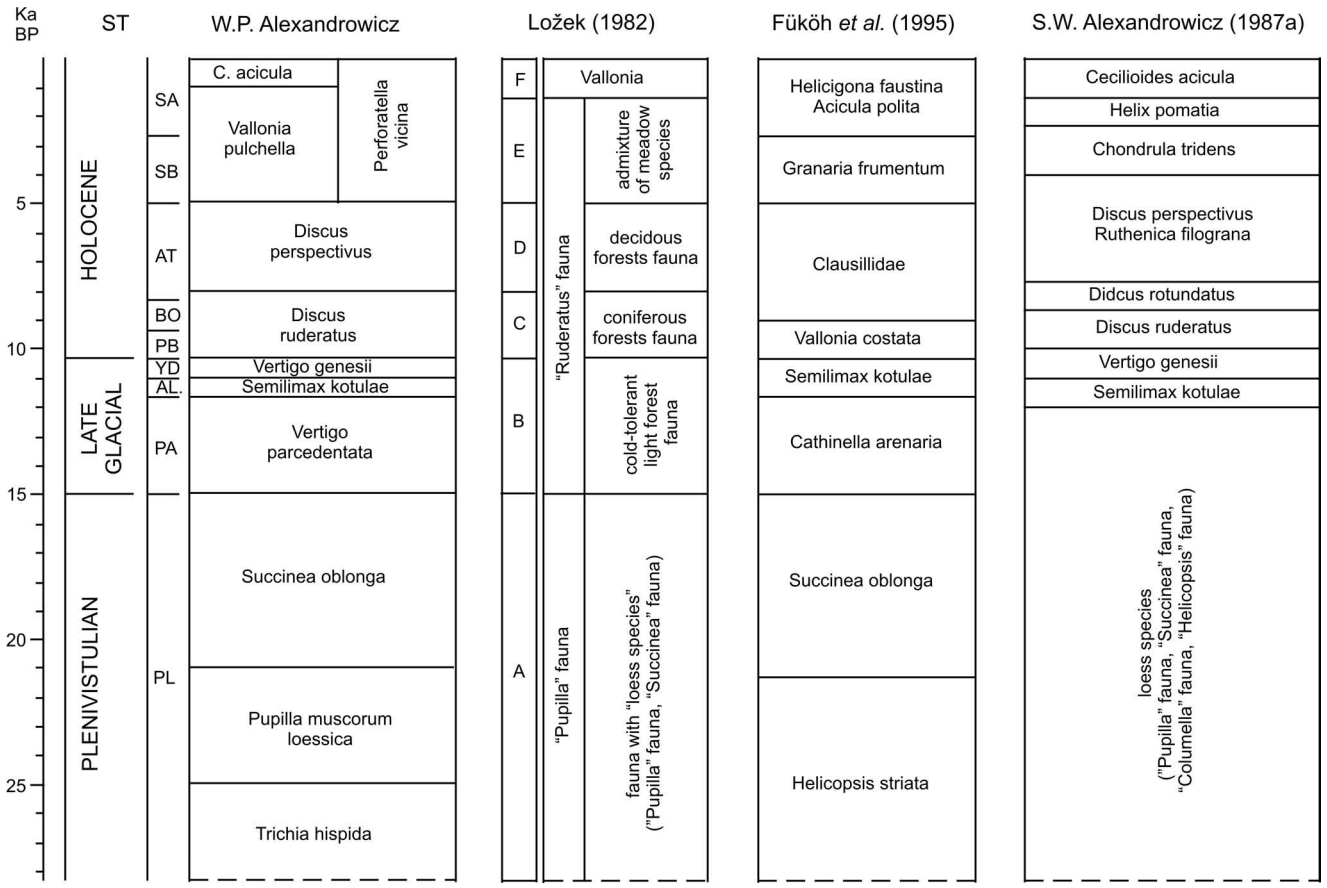

Fig. 3. Comparison of malacostratigraphic schemes in Central Europe. Ka – ^{14}C age BP in thousands years; ST – stratigraphy: PL – Last Pleniglacial, PA – Pre-Alleröd Period (*sensu* W.P. Alexandrowicz 1997, 2004), AL – Alleröd, YD – Younger Dryas, PB – Preboreal Phase, BO – Boreal Phase, AT – Atlantic Phase, SB – Subboreal Phase, SA – Subatlantic Phase.

The scheme presented here is improved in relation to Polish subdivisions elaborated formerly (S.W. Alexandrowicz 1987a; Skompski 1996; W.P. Alexandrowicz 1997, 2004) since it is composed of well defined malacostratigraphical units, while in the previous subdivisions, the zones were distinguished basing on single species (usually one) only (Fig. 3).

Malacostratigraphical subdivision of fresh-water environments presented here (Fig. 2-W, Tab. 2) may be applicable over the large area of Central and Western Europe, because communities of fresh-water molluscs depend on environmental and climatic conditions in a limited range. Climatic fluctuations lead only to more or less important changes of the structure of assemblages, but usually do not induce (like as in terrestrial environments) essential recombination of taxonomical composition of the fauna. During the last 30 000 years, in particular climatic phases, similar communities of fresh-water molluscs occurred on the whole territory of Central and West Europe (Preece, Robinson 1982; S.W. Alexandrowicz 1987b; Walker *et al.* 1993; Griffiths *et al.* 1994; Willis *et al*. 1995; Schwalb *et al.* 1998; W.P. Alexandrowicz 1999a, 2007; Gaigalas *et al.* 2007). For this reason stratigraphical correlation among geographical regions seems to be relatively easy.

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REFERENCES

Alexandrowicz S.W. 1983. Malacofauna of Holocene calcareous sediments of the Cracow Upland. *Acta Geologica Polonica* 33, 117–158.

Alexandrowicz S.W. 1986. Molluscan assemblages from a loess profile at Odonów (Malopolska Upland). *Biuletyn Peryglacjalny* 31, 7–17.

Alexandrowicz S.W. 1987a. Malacological analysis in Quaternary research. *Geologia Kwartalnik AGH* 12, 3–240 (in Polish with English summary).

Alexandrowicz S.W. 1987b. Malacofauna of the Late Vistulian and Holocene in the middle part of the Małopolska Upland. *Prace Naukowe Uniwersytetu Śląskiego* 712, 25–58 (in Polish with English summary).

Alexandrowicz S.W. 1987c. Malacofauna of the Late Vistulian and Early Holocene Lacustrine Chalk from Roztoki near Jasło (Jasło-Sanok Depression). *Acta Palaeobotanica* 27, 67–74.

Alexandrowicz S.W. 1988. Malacofauna of the Late Quaternary loess-like deposits in the Polish Carpathians. *Acta Geologica Polonica* 38, 85–106.

Alexandrowicz S.W. 1989. Stratigraphy and Malacofauna of the Upper Vistulian and Holocene Deposits of the Szklarka River Valley, Cracow Upland. *Bulletin of the Polish Academy of Sciences, Earth Sciences* 37, 247–260.

Alexandrowicz S.W. 1991a. Malacofauna and age of loess series at Maszków in the Dlubnia River Valley (South Poland). In Kostrzewski A. (ed.), Geneza, litologia i stratygrafia utworów czwartorzędowych. *Geografia* 50, 379–387. Wydawnictwo UAM Poznań (in Polish with English summary).

Alexandrowicz S.W. 1991b. The malacofauna of the Holocene lacustrine sediments of Dąbki near Darłowo. *Przegląd Archeologiczny* 28, 19–24.

Alexandrowicz S.W. 1995a. Malacofauna of the Vistulian loess in the Cracow Region (S Poland). *Annales Universitatis Mariae Curie-Skłodowska* sec. B, 50, 1–28.

Alexandrowicz S.W. 1995b. Malacofauna of the Holocene sediments in Grabowo near Koszalin (Pomerania, North Poland). *Quaestiones Geographicae* 4, 13–20.

Alexandrowicz S.W., Alexandrowicz W.P. 1995a. Quaternary molluscan assemblages of the Polish Carpathians. *Studia Geomorphologica Carpatho-Balcanica* 29, 41–54.

Alexandrowicz S.W., Alexandrowicz W.P. 1995b. Molluscan fauna of the Upper Vistulian and Early Holocene sediments of South Poland. *Biuletyn Peryglacjalny* 34, 5–19.

Alexandrowicz S.W., Alexandrowicz Z. 1998. Landslide at the Parkowa Góra Mt. in Krynica (Polish Carpathians) – sediments, malacofauna and phases of the development. *Geologia Kwartalnik AGH* 24, 341–402 (in Polish with English summary).

Alexandrowicz S.W., Alexandrowicz Z. 1999. Recurrent Holocene landslides: a case study of the Krynica landslide in the Polish Carpathians. *The Holocene* 9, 91–99.

Alexandrowicz S.W, Awsiuk R, Pazdur A., Pazdur M.F., Śnieszko Z. 1987. Holocene calcareous tufa in Sieradowice – geology, malacology, radiochronology and stable isotopes. *Geochronometria* 4, 43–60.

Alexandrowicz S.W., Butrym J., Krysowska-Iwaszkiewicz M., Zuchiewicz W. 1991. On New Sections of Loess-like Deposits of the Rożnów Foothills, West Carpathians, Poland. *Annales Universitatis Mariae Curie-Skłodowska* sec. B, 46, 1–19.

Alexandrowicz S.W., Chmielowiec S. 1992. Late Vistulian and Holocene molluscan assemblages of the Bochnia Foothill near Gdów (Southern Poland). *Bulletin of the Polish Academy of Sciences, Earth Sciences* 40, 165–176.

Alexandrowicz S.W., Cichosz-Kostecka A., Florek E., Florek W., Orłowski A., Rączkowski W., Zachowicz A. 1989. The Evolution of the Słupia River Valley in the Late Vistulian and Holocene. *Geologia Kwartalnik AGH* 15, 5–218 (in Polish with English summary).

Alexandrowicz S.W., Stworzewicz E. 1983. Molluscan fauna from Holocene tufa in The Racławka Valley near Krzeszowice. *Acta Zoologica Cracoviensis* 26, 243–250 (in Polish with English summary).

Alexandrowicz S.W., Teisseyre A.K. 1997. Holocene Overbank Deposits and Mollusc Fauna, Ołowa River Valley, (Sudety Foothills, Western Poland). *Bulletin of the Polish Academy of Sciences, Earth Sciences* 45, 47–58.

Alexandrowicz W.P. 1997. Malacofauna of Quaternary deposits and environmental changes of the Podhale Basin during the Late Glacial and Holocene. *Folia Quaternaria* 68, 7–132 (in Polish with English summary).

Alexandrowicz W.P. 1999a. Evolution of the malacological assemblages in North Poland during the Late Glacial and Early Holocene. *Folia Quaternaria* 70, 39–69.

Alexandrowicz W.P. 1999b. Malacofauna of loess-like sediments in Tłumaczów (original: Malakofauna pylastych osadów w Tłumaczowie). Conference Proceedings "Geneza i wiek pokrywowych utworów pylastych południowo-zachodniej Polski" 3–4 (in Polish).

Alexandrowicz W.P. 2000. The malacofauna of the Upper Holocene lacustrine sediments of the Wigry Lake (N Poland). *Folia Malacologica* 8, 141–149.

Alexandrowicz W.P. 2001. Late Vistulian and Holocene molluscan assemblages from calcareous tufa at Ostrysz Hill (Podhale Basin). *Folia Malacologica* 9, 159–169.

Alexandrowicz W.P. 2002. Molluscs assemblages of an ancient lake in Różyny near Skowarcz (Żuławy Wiślane, N Poland). *Folia Malacologica* 10, 215–224.

Alexandrowicz W.P. 2003. The exposure of calcareous tufa in Gliczarów in the Podhale Basin. *Chrońmy Przyrodę Ojczystą* 59, 17–31 (in Polish with English summary).

Alexandrowicz W.P. 2004. Molluscan assemblages of Late Glacial and Holocene calcareous tufa in Southern Poland. *Folia Quaternaria* 75, 3–309.

Alexandrowicz W.P. 2007. Malacofauna of Late Glacial and Holocene calcareous lake deposits in North Poland. *Geologia Kwartalnik AGH* 33, 395–420 (in Polish with English summary).

Alexandrowicz W.P. 2009. Malacofauna and phases of development of landslide in Tylka near Krościenko (Pieniny Mts). *Geologia Kwartalnik AGH* 35, 69–75 (in Polish with English summary).

Alexandrowicz W.P., Kobojek S. 1997. The malacofauna of Upper Vistulian and Holocene sediments at Błeszno near Częstochowa. *Folia Quaternaria* 68, 179–201.

Alexandrowicz W.P., Urban. J. 2002. Documentary sites of less in Kozubów Landscape Park. *Chrońmy Przyrodę Ojczystą* 58, 5–36 (in Polish with English summary).

Dehm R. 1967. Die landschnecke *Discus ruderatus* im Postglazial Süddeutschlands. *Mitteilungen der Bayerische Staatssammlung für Paläontologie historische Geologie* 7, 135–155.

Dehm R. 1987. Die landschnecke *Discus perspectivus* im Postglazial Südbayerns. *Mitteilungen der Bayerische Staatssammlung für Paläontologie historische Geologie* 27, 21–30.

Dobrowolski R., Hajdas I., Melke J., Alexandrowicz W.P. 2004. Chronostratigraphy of calcareous mire sediments at Zawadówka (Eastern Poland) and their use in palaeogeographical reconstruction. *Geochronometria* 24, 69–80.

Fükön L. 1993. Holocene malakofaunal assemblages in Hungary. *Scripta Geologica*, *Special Issue* 2, 121–125.

Fükön L. 2000. Main characteristic of development of gastropod fauna the Carpathian Basin during the Late Quaternary. *Folia Historico-Naturalia Musei Matranenis* 24, 31–38.

Fükön L., Krolopp E., Sümegi P. 1995. Quaternary malacostratigraphy in Hungary. *Malacological Newsletter, Supplement* 1, 5–219.

Gaigalas A, Sanko A., Pazdur A., Pawlyta J., Michczyński A., Budënaitë S. 2007. Buried oaks and malacofauna of Holocene oxbow Lake sediments in the Valakupiai section, Lithuania. *Geologija* 58, 34–48.

Gedda B. 2001. Environmental and climatic aspects of the Early and Mid Holocene calcareous tufa and land mollusc fauna in southern Sweden. *Lundqua Thesis* 45, 1–50.

Griffiths H.I., Ringwood V., Evans J.G. 1994. Weichselian Lateglacial and early Holocene molluscan and ostracod sequences from lake sediments at Stellmoor, north Germany. *Archiv für Hydrobiologie* 99, 357–380.

Keen D.H. 1987. Non-marine molluscan faunas of periglacial deposits in Britan. In Boardman J. (ed.), Periglacial processes and landform in Britan and Irland, 257–263. Cambridge.

Kerney M.P. 1977. A proposed zonation scheme for Late Glacial and postglacial deposits using land Mollusca. *Journal of Ar-*

chaeological Sciences 4, 387–390.

Kerney M.P., Preece R.C., Turner C. 1980. Mollusccan and plant biostratigraphy of some late Devensian and Flandrian deposits in Kent. *Philosophical Transactions of the Royal Society of London*, 1–43.

Krolopp E. 1983. Biostratigraphic division of Hungarian Pleistocene formations according to their mollusc fauna. *Acta Geologica Hungarica* 26, 69–82.

Kutek J. 1972. Biostratigraphical zones – outline of problems. (original: Poziomy biostratygraficzne – zarys problematyki). *Postępy Nauk Geologicznych* 4, 5–43 (in Polish).

Limondin-Lozouet N., Preece R.C. 2004. Molluscan successions from the Holocene tufa of St Germain-le-Vasson, Normandy (France) and their biogeographical significance. *Journal of Quaternary Sciences* 19, 55–71.

Limondin-Lozouet N., Rousseau D.D. 1991. Holocene climate as reflected by a malacological sequence at Verriers, France. *Boreas* 20, 207–229.

Ložek V. 1964. Quatärmollusken der Tschechoslowakei. Rozpravy Ustředniho Ustavu Geologického 31, 1–374. Praha.

Ložek V. 1965. Das Problem der Lössbildung und die Lössmollusken. *Eiszeit und Gegenwart* 16, 61–75.

Ložek V. 1967. Holozäne Binnenwasserkalke und klastiche Hangsedimente in Böhmischen Karst. In Kliewe H. (ed.), *Probleme und Befunde der Holozänstratigraphie in Türingen, Sachsen und Böhmen*, 137–178.

Ložek V. 1973. Nature in Quaternary (original: Přiroda ve Čtvertohorach). Academia Praha (in Czech).

Ložek V. 1982. Contribution of Malacology to the Chronological Subdivision of the Central European Holocene. *Striae* 16, 84–87.

Ložek V. 1983. Quaternary malacology and fauna genesis in Central Europe. 8th International Malacological Congress, Procedings, 143–145.

Ložek V. 2000. Palaeoecology of Quaternary Mollusca. *Antropozoikum* 24, 35–59.

Łopuszyńska M. 2002. Differentiation of subfossil populations of snails from Vistulian loesses of Southern Poland. *Folia Quaternaria* 73, 101–189.

Mania D. 1973. Paläoökologie, Faunenentwicklung und Stratigraphie des Eiszeitalters im mittleren Elb-Saalegebiet auf Grund von Molluskengesellschaften. *Geologie* 21, *Beiheft* 78–79, 1–175.

Mania D. 1995. The influence of Quaternary Climatic development on the Central European mollusc fauna. *Acta Zoologica Cracoviensis* 38, 17–34.

Meyrick R.A. 2001. The development of terrestrial mollusc faunas in the 'Rheinland region' (western Germany and Luxembourg) during the Lateglacial and Holocene. *Quaternary Science Reviews* 20, 1667–1675.

Meyrick R.A. 2002. Holocene molluscan faunal history and environmental change at Kloster Mühle, Rheinland-Pfalz, western Germany. *Journal of Quaternary Science* 18, 121–132.

Preece R.C., Robinson J.E., 1982. Molluscan and ostracod faunas from post-glacial tufaceous deposits in county Offaly. *Proceedings oft he Royal Irish Academy* sec B, 82, 115–131.

Racki G., Narkiewicz M. (eds) 2006. Polish principles of stratigraphy (original: Polskie zasady stratygrafii). Państwowy Instytut Gologiczny (in Polish).

Rousseau D.D., Limondin-Lozouet N., Puissegur J.J. 1993. Holocene environmental signals from mollusc assemblages in Burgundy (France). *Quaternary Research* 40, 237–253.

Rousseau D.D., Limondin-Lozouet N., Magnin F., Puissegur J.J. 1994. Temperature oscillations over the last 10,000 years in western Europe estimated from terrestrial mollusc assemblages. *Boreas* 23, 66–73.

Rutkowski J. 1991. Holocene deposits of the Racławka River Valley. *Geologia Kwartalnik AGH* 17, 173–191 (in Polish with English summary).

Schwalb A., Hardon P., Thew N., Straub F. 1998. Evidence for Glacial and Holocene environmental changes from subfossil assemblages in sediments of Lake Neuchâtel, Switzerland. *Palaeogeography, Palaeoclimatology, Palaeoecology* 140, 307–323.

Skompski S. 1996. Standard assemblages of malacofauna in different Quaternary stratigraphic units. *Prace Państwowego Instytutu Geologicznego* 91, 3–47. (in Polish with English summary).

Walker M.J.C., Griffiths H.I., Ringwood V., Evans J.G. 1993. An early-Holocene pollen, mollusk and ostracod sequence from lake marl at Llangorse Lake, South Wales, UK. *The Holocene* 3, 138–149.

Willis K.J., Sümegi P., Braun M., Tóth A. 1995. The late Quaternary environmental history of Bátorliget, N.E. Hungary. *Palaeogeography, Palaeoclimatology, Palaeoecology* 118, 25–47.

Wojciechowski A. 1999. Late Glacial and Holocene lake-level fluctuations in the Kórnik-Zaniemyśl Lakes Area, Great Poland Lowland. *Quaternary Studies in Poland* 16, 81–101.