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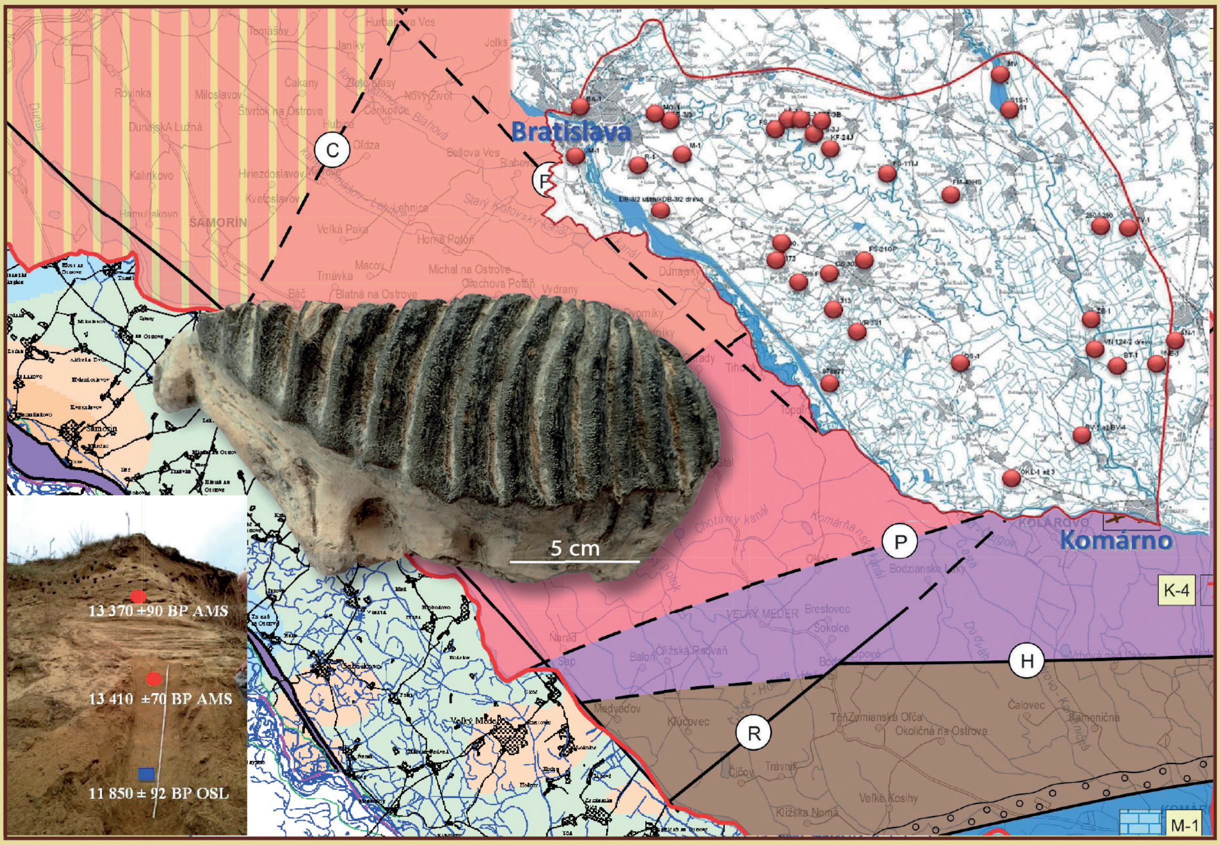
DANUBIAN FLAT – BRAND NEW RESULTS OF REGIONAL GEOLOGICAL RESEARCH



2/2018

State Geological Institute of Dionýz Štúr Bratislava

SLOVAK GEOLOGICAL MAGAZINE

Periodical journal of the State Geological Institute of Dionýz Štúr is a biyearly presenting the results of investigation and researches in wide range of topics:

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- palaeontology
- geochemistry and isotope geology
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The journal is thematically focused in the issues of the Alpine-Carpathian region.

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DANUBIAN FLAT – BRAND NEW RESULTS OF REGIONAL GEOLOGICAL RESEARCH

Content

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Preface

Basic and regional geological research is carried out in the territory of Slovakia through projects of the *regional geological research and mapping at scale 1 : 50,000*, which are realized and conceptually steered from approximately the second half of the 1960s to the present. These are scientific and research projects financed from the state budget of the Slovak Republic and their main implementer is the State Geological Institute of Dionýz Štúr in Bratislava in cooperation with subcontractors.

One of the recently solved research projects was the geological task entitled "Geological Map of the Region of the Danubian Lowland – Danubian Flat at Scale 1 : 50,000". It was carried out in the years 2013 – 2017. Its basis was the implementation and evaluation of field geological research, based on basic geological mapping at scale of 1: 25,000. Within the delimited map area, the research focused mainly in a new complex geological mapping of predominantly Quaternary sediments and on the evaluation of the latest knowledge about the Tertiary sedimentary fill in the Slovak part of the Danube Basin.

The result of the geological task is a printed Geological Map of the Danubian Lowland – Danubian Flat at scale 1 : 50,000, including legend, graphical appendices and text explanations. It is a surface map, based on the genetic-stratigraphic principle and lithological filling of mainly surface and near-surface non-consolidated Quaternary deposits. Older basinal (Late Miocene) deposits emerge to the surface only at one site and the Palaeozoic rocks are exposed on the foothills of the Malé Karpaty Mts. The map depicts Holocene and transient Pleistocene-Holocene geological structure to a depth of about 2 m. The predominant grain size fraction of the sediment is depicted within this horizon. Each fraction shown on the map passes into the subsoil of fluvial sandy gravel. The third dimension of the representation of the geological structure is expressed by geological cross-sections.

Given that the potential of the region under review has been and is enormously significant, in particular in terms of groundwater reserves, the use of geothermal energy, the supply of building materials, agriculture, and water management, as well as environmental protection and creation, taking into account potential threats, caused by climate change, Slovak Geological Magazine no. 2/2018 presents 5 selected contributions, a selection of fundamental results of the research carried out with a potential impact on the forecast of further development of the surveyed region.

RNDr. Juraj Maglay, PhD.

LIST OF ACRONYMS

AD	Anno Domini
AMS	Accelerator Mass Spectrometry
b.s.	Below Surface
BP	Before Present
cal BP	Before Present Calibrated
b2k	before 2 kilo (years before AD 2000)
CAM1	Crassulacean Acid Metabolism
CAM2	Central Age Model
DBTF	Danube Basin Transversal Fault
E-MORB	Enriched Mid-Ocean Ridge Basalts
GC	Gas Chromatography
GRIP	Greenland Ice Core Project
GISP/GISP2	Greenland Ice Sheet Project (GISP)/Greenland Ice Sheet Project Two (GISP2)
GS/GI	(Greenland Stadial/Greenland Interstadial
HF	Hydrofluoric Acid
IAEA	International Atomic Energy Agency
IMK	Integrated Landscape Management (Integrovaný manažment krajiny)
INTIMATE	INtegration of Ice-core, MArine and TErrestrial records
IRMS	Isotope Ratio Mass Spectrometer
ka	Kiloannus (Kiloannum)
MAT	Mean Annual Temperature
MCE	Maximum Calibration Error
NEEM	North Greenland Eemian Ice Drilling
NGRIP	North Greenland Ice Core Project (or NorthGRIP).
N-MORB	Normal Mid-Ocean Ridge Basalts
OIS/MIS	Oxygen Isotope Stage/Marine Isotope Stage
OSL	Optically Stimulated Luminescence
PDB	Pee Dee Belemnite
s.l.	in the broad sense (from Latin "sensu lato")
s.s.	in the narrow sense (from Latin "sensu stricto")
SAR	Single-Aliquot Regenerative-dose
SGR	Spiš-Gemer Ore Mountains (Spišsko-gemerské rudohorie)
SHMI	Slovak Hydrometeorological Institute
TC/EA	Temperature Conversion Elemental Analyzer
TDS	Total Dissolved Solids
VSMOW	Vienna Standard Mean Ocean Water
WMO	World Meteorological Organization,
WS	Water Source
WW	Waterworks

1. Geological Structure of Pre-Cenozoic Units – from the Edge of the Malé Karpaty Mts. to the Deep Basement of the Danubian Flat

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Abstract: Biotitic gneisses with sillimanite, amphibolites (s.s.), laminated metatuffites, calcium-silicate rocks with diopside and occasionally gabbro-dioritic rocks were found locally in the uncovered border of the mostly granitic crystalline area of the Malé Karpaty Mts. The periplutonic effect of the Hercynian Bratislava granitoid pluton caused metamorphic reworking of the pre-granite substrate. Relatively abundant pegmatites are characterized by dark K-feldspar, occasionally also with fan-shaped muscovite aggregates, typical of the investigated part of the Western Carpathians granite crystalline. Poly-deformation inventory of the crystalline rocks indicates Hercynian to Pliocene-Quaternary diapason of deformation structures.

Within the concept of the pre-Cenozoic basement of the Danubian Flat region, five basic tectonic (mega) units were suggested. The arrangement of these tectonic units is evaluated as Alpine (Cretaceous) with the fact that the higher structure, especially of the southern parts, was significantly modified by Tertiary tectonics. Discussions were devoted to their mutual tectonic relationship, Pannonian and Intra-Carpathian Palaeogene sediments, tectonic relationship with the neighbouring regions, etc. It can be assumed that the South-Veporicum unit forms the tectonic underlier of the Palaeozoic of the Komárno Block. The final part of the paper is devoted to discussion on Cenozoic tectonic events with an impact on the wider area of the area studied. The chronology of important fault lines is outlined, although it is often to be count on their repeated rejuvenilization.

Key words: Slovak part of Danubian Flat, pre-Cenozoic basement, Cenozoic tectonics, deformation phases, Malé Karpaty Mts., fault lines, Inner Western Carpathians

1.1 Introduction

The contribution deals with geological problems of the pre-Cenozoic units of the exposed south-west edge of the Malé Karpaty Mts. to the deep-covered basement in the SE part of the Danube Lowland – Danubian Flat region. The subject of the first part of the paper (1.2) is geological mapping, connected with the structural and petrographic studies of the narrow strip of emerging crystalline basement of the Malé Karpaty Mts., which form the NW border of the region under study (Maglay et al., 2018). The Crystalline, consisting mainly of granitoid rocks and metamorphites in part, crops out to the surface along the Malé Karpaty fault system between the towns of Bratislava and Svätý Jur. The second part of the paper (1.3) deals with considerably hypothetical issues of composition and tectonic development of the buried pre-Cenozoic basement of the Danubian Flat. Apart from several deep wells that have reached the crystalline basement at the edge of the Danube Flat, the area is filled with Cenozoic deposits reaching up to several kilometres in thickness. As to the variegated compilation sources, differing in topics and age of issuing, not directly dealing with the Cenozoic stratigraphy in this work, there are referred the original chronostratigraphic terms (mostly central Paratethys).

1.2 Malé Karpaty Mts. Crystalline rim

1.2.1 Overview of geological research

The Malé Karpaty Mts. form the Neo-Alpine horst of the SW-NE direction and together with the Hundsheim Hills (in Austria) represent the westernmost mountain range of the Western Carpathians, following the Eastern Alps units (Maheľ, 1986). The Crystalline core of the Malé Karpaty Mts. belongs to the northern domain of Tatricum megaunit situated in the overburden of the Borinka unit, affiliated to Infra-Tatricum (Plašienka et al., 1989). The Crystalline under investigation with its envelope successions (outside the region) is a part of the Alpine Bratislava nappe, namely the Bratislava sub-nappe s.s. (Plašienka et al., 1991). From the point of view of the primary Hercynian geological setting, the granitoid rocks in question build so-called Bratislava Granitoid Massif, differing in its composition and structural features from the more basic Modra Granitoid Massif (Adrian & Paul, 1864; Cambel & Valach, 1956). The residues of the metamorphic substrate conventionally belong to the so-called Pezinok-Pernek Crystalline (Cambel, 1958).

The geology of the south-eastern border of the Malé Karpaty Mts. is shown on three published regional geological maps (Koutek & Zoubek, 1936; 1936a; Maheľ & Cambel, 1972 and Polák et al., 2011; 2012). Basic information about the geological setting, lithology as well as supplementary bibliographic references can be obtained mainly from the explanatory notes to the above-mentioned geological maps. The first systematic work devoted mainly to the southern parts of the Malé Karpaty Mts. crystalline comes from Richarz (1908). Of the many published data on the geology of the crystalline and its composition, the important work was done by Cambel, who divided the Malé Karpaty Mts. metamorphic rocks into so-called Pezinok-Pernek crystalline Series and the Harmónia Series, locally admitting transitional relationships between these series (Cambel, 1958; Cambel in Buday et al., 1962). The granitoid rocks of the Malé Karpaty Mts. are divided into Bratislava and Modra granitoid massifs. The first consists of acidic and more coarse-grained granites-granodiorites, the substrate of which is formed by the Pezinok-Pernek Crystalline. The Modra Granitoid Massif is build of more basic granodiorites to tonalites and is bound to metasediments of the Harmónia Series. The basic work on the spatial distribution of the granitoid rocks, their petrography and petrochemical classification (Cambel & Valach, 1956) was later followed by a geochemical-petrological study on the typology and petrogenetic differentiation of the Malé Karpaty Mts. granitoids (Cambel & Vilinovič, 1987). Isotopic geochronological assays of the Malé Karpaty Mts. granites are summarized by Cambel et al. (1990) and report mostly the Early Carboniferous ages. The most recent dating specified the age of the Bratislava Granitoid Massif at approximately 355 ± 5 mil. years (Kohút et al., 2009).

The Harmónia Series was stratigraphically classified into the Devonian on the basis of the findings of sporadic remnants of tentaculites (Horný & Chlupáč in Buday et al., 1962). The Silurian-Devonian age range is judged on the basis of a palynological study of crystalline schist in the area of the Bratislava Massif (Čorná, 1968; Planderová & Pahr, 1983). This was later supported by the geochronological dating of synsedimentary basic magmatism situated in the upper parts of the Early Palaeozoic formation (in the Pernek area), set at 371 million years (Putiš et al., 2009a). Based on the geochemical study, Ivan et al. (2001) proposed to redefine the division of the Early Palaeozoic formations of the Malé Karpaty Mts. i.e. the Harmónia Series and the Pezinok-Pernek Crystalline (sensu Cambel, 1958) into Pernek (metabasalts of the N-MORB type) and Pezinok Groups (metabasalts of the E-MORB type, intra-continental or island arches), which should occupy a different spatial configuration.

The pre-granitoid Hercynian regional metamorphic fabrics of the Early Palaeozoic volcanic-sedimentary complexes reached only low-grade conditions, while the periplutonic metamorphosis left a fundamental metamorphic seal in the crystalline schists. The so-called regional periplutonic metamorphosis in the area of the Bratislava Granitoid Massif was characterized by the separation into four metamorphic zones – from the lowest biotite zone to the highest staurolite-sillimanite zone – based on a petrological study (Korikovskij et al., 1984). Alpine metamorphosis is manifested mainly in mylonite zones in the crystalline and reached anchimetamorphosis conditions (Putiš, 1987; Plašienka et al., 1993). The age of the Alpine deformation in the Bratislava Granitoid Massif is geochronologically determined at 77 mil. years, or 81 mil. years (Kantor et al., 1987; Putiš et al., 2009).

1.2.2 Results of geological mapping and petrography

The rim of the Malé Karpaty Mts. belonging to the Danubian Flat was geologically mapped in the width of 0.5 to 1 km, starting from the surroundings of Svätý Jur to the area opposite the island Sihoť in Karlova Ves (district of Bratislava). The geological mapping was mostly carried out in the environment of disappearing vineyards by means of mapping of eluvial debris, which, however, is often obscured by new as well as historical anthropogenic landfills and recultivations. Structural data were measured on the rocky outcrops (approx. 80 documentary points), of which a considerable part arose due to the current development construction activity in the area. On the other hand, some of the traditional rock exposures in Bratislava could not be re-assessed due to development activities, earthworks, or sites have been inaccessible because of new property rights.

Crystalline rocks are exposed at the foot of the mountain range – especially various types of granitoid and pegmatitoid rocks, which are largely covered by Quaternary deluvial, fluvial sediments and sporadically loess horizons. The following description of basic crystalline rocks proceeds from relatively oldest to younger rock types.

Biotite gneisses (massive gneisses, schistose mica gneisses, migmatitized gneisses)

The designation of biotite gneiss includes rock types ranging from fine-grained biotite phyllites to gneisses with black shiny biotite foliation planes to coarse-grained banded types with migmatitic textures (Fig. 1.1). The lower metamorphosed fine-grained gneisses as well as migmatitic gneisses cannot be strictly differentiated in the given map image for the rather small territorial extent as well as obscure interrelationships. The intensity of the grey coloration of metamorphites depends on the proportions of biotite and feldspar-silica mass (in local cases also on the presence of organic substance). In the scale of the map displayable occurrences of dark biotitic ores can be found e.g. in fresh excavations in the area of the Chapel of J. Nepomucký in the southern part of Svätý Jur (Fig. 1.1a). High-metamorphic "injection" migmatitic gneisses are best seen in the Svätý Jur area (Figs. 1.1b,c), but in fragments sporadically also in other places of the Rača district, in excavations above the railway depot in Bratislava).

Petrographically, the rocks have a lepido-granoblastic texture; with increasing metamorphosis the oriented but dispersed biotite is more segregated into continuous foliation planes. Small garnet is present in small quantities, reaching up to about 1 mm. The degree of metamorphosis is closely related to the injection manifestations of the granites, which is petrographically documented by blastesis of orders of magnitude larger biotite flakes against the biotite of the "matrix" in contact with the bands of penetrating coarse-grained granitic leucosome. The periplutonic/near-contact effect on the primary structure of the biotite gneiss also leads to the origination of transverse muscovite flakes, in which fibrolithic sillimanite is often formed.

Amphibolic rocks/basic tuffs, amphibolites, local gabbrodiorites

Rocks containing amphibole, starting from the north, begin to appear from the valley of the Vajnorský potok Brook. The amphibolic rocks usually have a dark green to grey-green colour and are mostly fine-grained. In the small natural exposures, they can be identified around the Bratislava – Rača district. From the spatial as well as from the lithological point of view it is probably a rock complex stretching from the area of the altitudinal

Fig. 1.1 Biotite gneisses: a) subvertically dipping biotite gneiss, loc. injected with leucocratic material (excavation of the family estate SW part of Svätý Jur); (b) demonstration of ptygmatitic folding in a migmatitized biotitic gneiss (a fragment in the vineyard between Grinava and Svätý Jur villages); c) stromatitic migmatite with two phases of leucocratic material (local rubble to the SW of the centre of Svätý Jur)

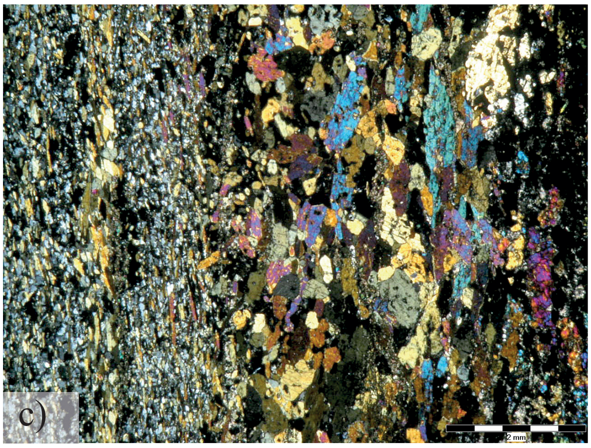

Fig. 1.2 Amphibolic rocks: a) chorismite texture composed of portions of amphibolite (dark) and calcium-silicate rock (light green) injected by aplitic vein in an advanced Hercynian -magmatic process (stone from the unpaved vineyard wall in Rača); b, c) different strips can be distinguished in the banded basic metatuffite (microscope image at II and X nicols, sample 194b): very fine-grained epidote in dark-shaded matrix; a minor epidote in association with amphibole; stripe composed of 1 – 2 mm olive-green amphibole and stripe of fine-grained amphibole and grains of quartz (locality: small exposure on a hill about 500 m NE of the terminal tram station in Rača)

points of Veľká and Malá baňa (north of Rača, beyond the investigated territory of the Danubian Flat, Maglay et al., 2018). Fragments of the amphibolic rocks are sporadically encountered at the foot of the slopes belonging to the Vinohrady district. Some fragments resemble the gabbrodioritic rocks of the type sporadically found in the wider area of the Horský park.

The predominant banded metamorphic texture first reflects the fine lamination of the primary pyroclastic rock. In contrasting amphibolic rocks, the pale veins of aplites and pegmatites penetrate into them (Fig. 1.2a). The alternation of light green and dark bands illustrates the composite lamination of basic tuff-tuffite (Fig. 1.2b,c. The basic mineral content – common amphibole, actinolite, plagioclase, epidote (clinozoisite), diopside or titanite and ilmenite was determined by petrography. The composition suggests that the carbonate component also built the primary composition, so the rocks studied can be genetically compared to the calcium-silicate rocks described from some sites of the Malé Karpaty Mts. metamorphic crystalline (Koutek & Zoubek, 1936; Cambel et al., 1989). The rocks underwent intense changes – plagioclase is practically replaced by dark clay minerals, sericite and fine clinozoisite; amphibole or clinopyroxene are mostly substituted by epidote and chlorite.

Granites-granodiorites

a) medium- to coarse-grained two-mica granites, locally fine-grained biotite granodiorite

Within the granitic rocks, the dominant position is occupied by medium to coarse-grained granites, usually of two-mica, sometimes biotitic types. We encounter them in practically the entire mapped zone, although in the southern half of the area, they are more abundantly leucocratic, muscovite types (see b). In the area of granites there are sporadically occurring small remnants of gneiss, sometimes only the oriented biotite relics in the granite mass. Basic ***two-mica granites*** have light grey to white shades, omnidirectional texture and used to be systematically dotted with black biotite. The granites are usually two-mica, but in places they contain only biotite (rarely just muscovite). In the exposures they are fractured by a complex network of fissures, often appearing in the form of irregular 0.5 – 1 m thick positions, separated by shallowly sloping plate jointing (Fig. 1.3a). From natural exposures or former quarries based in Bratislava granites we mention e.g. localities from Svätý Jur, northern edge of Rača and partly Roessler quarry in the Vinohrady district.

In the composition of these granites light components prevail – quartz, acid plagioclase and K-feldspar. The average mineral grain size of these granites is about 3 – 5 mm, while K-feldspar tends to form poikilitic phenocrysts, in places reaching up to 1 – 1.5 cm. In this way, the granite shows an indistinct porphyric character at places. Pertitization is frequently observed in K-feldspar phenocrysts, and often domains with a transition to a triclinic structure in the form of microcline lattice. Enclosures in K-feldspar are plagioclase and biotite, to a lesser extent quartz, muscovite and, in the case of acid members, the remnants of the older K-feldspar. Enclosed plagioclase is usually rimmed by albite, which, like albite grains with myrmekite, originated in the final stages of magmatic rock evolution.

A relatively rare, spatially limited, but at the same time characteristic granitoid member is represented by fine to medium-grained ***biotite granodiorites*** or granites. They have usually free igneous contacts with predominant granites, from which they differ macroscopically, apart from the granularity, in deeper grey shades and higher content of biotite and plagioclase. In fine-grained, equigranular textures, biotite phenocryst, sometimes also feldspar, in size up to 1 cm, can be observed at places (Fig. 1.3b). The microscopic structure of these rocks is clearly hypidiomorphic ("granitic"), which is documented by regularly limited crystal shapes of plagioclase. In a mineral composition with a grain size of about 1 mm, strongly sericitized plagioclase predominates over quartz. Rock can also be referred to as microgranodiorite, in places we do not exclude primary tonalite composition. In some cases, the finer-grained varieties with sporadic phenocrysts resemble granodiorite porphyrite. Dark-shaded, directly constrained fine-grained clinozoisite aggregates, usually bounded by a clear albite rim, suggest higher plagioclase basicity than commonly occurring granites. The mineral composition is sometimes enriched by muscovite and/or a K-feldspar phenocryst; in such a case the rock approaches the above mentioned granite.

The Bratislava granites often underwent *secondary fabric and deformation changes* of different intensity. Sericitization of plagioclase and chloritization of biotite in common types of granites imparts a green colour to the rocks; we can observe this phenomenon e.g. in fragments NE of the Svätý Jur's proluvial cone. Saussuritized more basic types of granitoids or mylonitization in general, change the colour of the rocks to dark grey shades. Cataclastic deformation of the granitic rocks is usually manifested in the form of so-called kakiritization. The local increase in deformation leads to the formation of mylonites and quartz blastomylonites, where it is difficult to determine the original character of the rock. Mineral changes are reflected in the formation of epidote-zoisite group minerals (especially at the expense of biotite and plagioclase), albitization, sericitization up to the origination of small muscovite crystals (at the expense of plagioclase), baueritization with simultaneous formation of Fe-oxides or chloritization (biotite alteration) and generally formation of clay minerals, as well as secondary enrichment in quartz.

b) leucocratic (pegmatitoid) granites

Field and petrographic observations of leucocratic granites point to gradual progression from the basic granites of the Bratislava Massif (Figs. 1.3c,e). They often pass into coarse-grained pegmatitoid nests. In general, they are poorer in micas, but in many cases contain conspicuous muscovite, and sometimes biotite also appears. By comparison with the slopes of the wider area of Svätý Jur, the leucocratic types occur more abundantly from the surroundings of Rača to the south. In the SE part of the territory, the pegmatitoid rocks occurring along with leucocratic granites indicate that both rocks are interrelated and represent the final stages of granitoid pluton evolution. In many places, the leucocratic granites also bear distinct signs of dynamic magmatic flow (Figs. 1.3c,f) or Late-Hercynian semiductile deformation (Fig. 1.4a), prior to the youngest stage of pegmatite formation. In the wider area of Bratislava, where these rocks are more widespread, there is a typical occurrence of fan-like muscovite aggregates (Fig. 1.4b), which are rare in other parts of the Western Carpathians granite crystalline.

Light coarse-grained granitic derivatives predominate both in surface debris and in the form of resistant natural exposures. However, it is obvious from the excavation material in the wider area of Koliba, the Bratislava Castle Hill or from the rare natural exposures that common types

Fig. 1.3 a) characteristic disintegration of granites of the Bratislava Massif (excavation of the northern edge of the Svätý Jur Town); (b) fine-grained biotite granodiorite with biotite phenocryst (ditto); c) penetration of the leucocratic melt into the "basic" granites (Račí potok Brook); d) accumulation of coarse-grained K-feldspars in a leucocratic granite (a fragment at the church in Neštich); e) contact of the three most widespread granite rocks: leucocratic granite (upper left corner), darker two-mica granite (in the middle) in direct contact with pegmatite (rubble dumps SE of altitudinal point Vtáčnik, Bratislava-Vinohrady); (f) diatextite rich in pegmatitoid leucosome (blocks on the ridge between the Fanglovský and Račí potok streams)

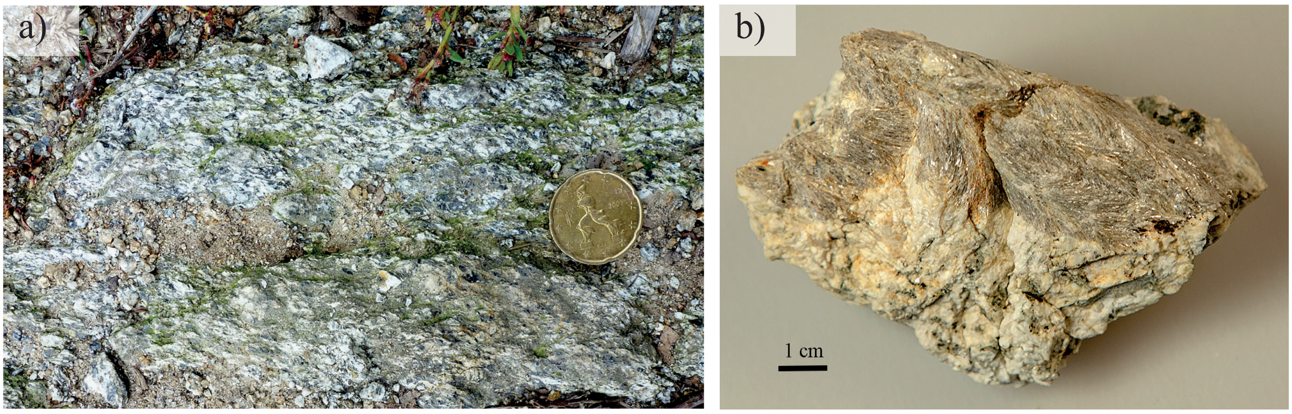

Fig. 1.4 a) leucocratic granite with pre-Alpine s-c structure (outcrop of the vineyard road bottom SW of Grinava); (b) fan-shaped muscovite aggregate in light pegmatitoid granite

of granites, biotite gneisses, and local amphibolites are also to be found. We assume that the neoid alpinotype deformation, which has more pronounced manifestations on the south-eastern tip of the Malé Karpaty Mts. contributed to this picture. Deformation rather affects regionally extended granites-granodiorites, which are then more liable to weathering than the coarse-grained quartzose pegmatitoids.

Coarse-grained muscovite pegmatites and massive aplites

Coarse-grained pegmatites appear in the form of veins penetrating along brittle joints in the apical parts of the Bratislava Granitoid Massif. Pegmatites most often range in thickness from x-dm to first m. Macroscopically, they are characterized by an increased proportion of quartz, albite, K-feldspar (up to 6 – 8 cm) and often 3 – 4 cm flakes of muscovite, which is sometimes alternated by biotite (Fig. 1.5). Characteristic is the grey-coloured microcline, the product of primary crystallization of residual granitic solutions. We separate pegmatites from the above-mentioned leucocratic ("pegmatitoid") granites on the basis of a direct venous course, characterized by a coarse-grained, sometimes partially graphitic or zonal pegmatite texture (zone of clear quartz crystals concentrated in the middle vein). They were formed after solidification of the basic granites, although we admit that in the case of weakly crystallized pegmatite, the structural or mineralogical difference is not always strict in comparison with the leucocratic granite.

Fine-grained white aplites with an average grain size of approximately 1 mm occur commonly along with pegmatites. In a light, "sugary" homogeneous mass of aplites, almost mica-free, a reddish garnet sometimes appears, occasionally we can observe a 2 – 3 mm K- feldspar phenocryst, too.

1.2.3 Summarized geological development and deformations on the SE edge of the Malé Karpaty Mts. Crystalline

The oldest geological unit is formed by Lower Palaeozoic crystalline schists, representing the metamorphic mantle of the Malé Karpaty Mts. granitoids. These rock sequences underwent a low-degree metamorphosis at the boundary of the Devonian-Carboniferous period ("Hercynian regional

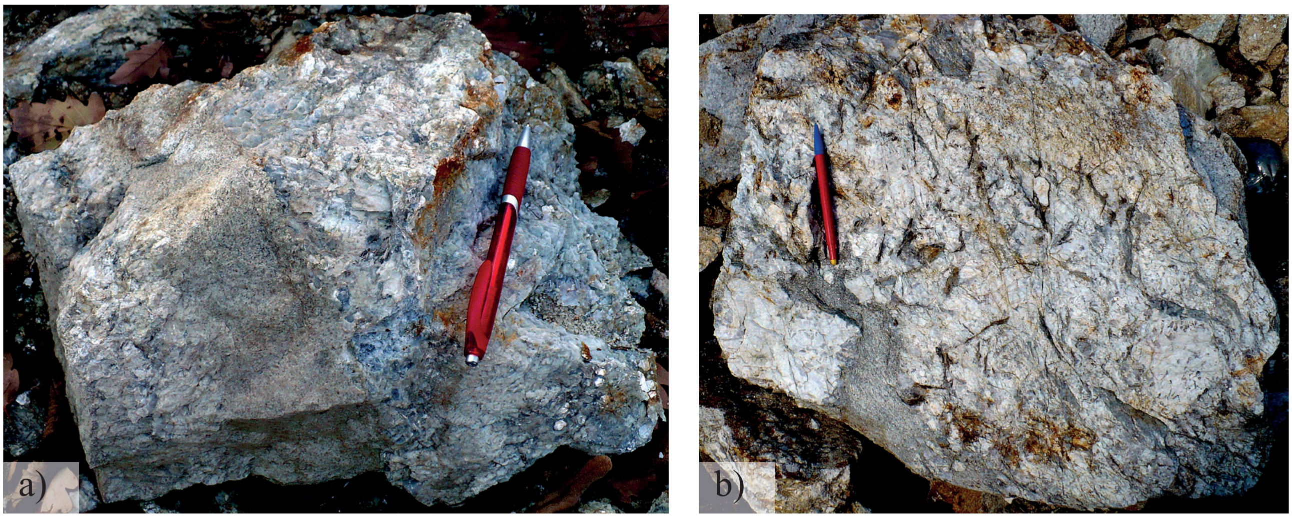

Fig. 1.5 a) coarse-grained muscovite-rich pegmatite in a sharp contact with granite (a construction pit of a family house, Pekná cesta Street); b) feldspar pegmatite melt with biotite phenocrysts enclosing high-temperature mixed residue of grey granite (construction work NE of the railway depot in Bratislava)

metamorphosis") by forming various types of phyllites. This event was followed by a dominant metamorphic recrystallization, caused by the penetration of the Hercynian granitoid rocks (approx. 350 million years ago). High temperatures as well as fluid contribution from the granitoid rocks of the Bratislava Massif fundamentally reworked the Lower Palaeozoic rock complexes ("periplutonic regional metamorphosis").

In the vicinity of the intruding granitoids and the phyllites of a clayey-sandy protolith, garnet-biotite gneisses formed. In the gneisses with a temperature increase, the phenocrysts of biotite grew in size, the muscovite flakes formed and in the mica the formation of fibrous sillimanite took place. This metamorphosis of the medium to higher grade of the low-pressure type amphibolite facies was accompanied by the formation of biotite foliation planes. Due to the penetrating leucocratic melt and the ductile folding, various textural forms of migmatite developed in localized zones.

Syndepositional basic volcanism, often mixed with the sedimentary component, was metamorphosed into varied textural and mineral types of amphibolic rocks. Sometimes even primary characters can be identified – e.g. light phenocrysts of the original plagioclase, magmatic minerals or the original banding of basic tuff to tuffite. Common amphiboles along with plagioclase, titanite, etc., represent a metamorphic transformation of the basic magmatic protolith. Clastic, pelitic and calcareous sedimentary components took part in the formation of strips composed of quartz, muscovite or diopside, clinozoisite, etc. Near the border of the investigated region, bodies of amphibolic diorites (even gabbrodiorites) are known enclosed in the granitoid massif, which have in our view a primary connection with the basic magmatites of the metamorphic mantle.

From a broader geological view, the metamorphic mantle rock composition of the Malé Karpaty Mts. Crystalline has even more peculiarities – there are no products of acidic magmatism ("orthogneisses"), which could occur prior to the Hercynian granitization, or high-metamorphic banded volcanogenic complexes ("leptinite-amphibolite complex"), which are common in the other areas of the Western Carpathians Crystalline. It is likely that the material derived from this "older" crystalline is the major sedimentary source of the crystalline schists of the Malé Karpaty Mts., which has been varied with by concurrent underwater volcanic activity. The composition, age and type of metamorphosis make it possible to consider these crystalline schists as representative of the "young" (upper) crystalline within the Western Carpathians crystalline units (Kováčik, 2005).

The basic granitoid mass is built of two-mica to biotite granite, and local granodiorite. Local occurrence of fine-grained biotitic granodiorites (formerly tonalites?) is understood in terms of penetrating of more basic melt into the crustal substratum, from which granites of the Bratislava Massif are melted by partial anatexis (however, the primary character of these rocks is mostly obscured by the mixing of granite magmas). Following from Rača to the centre of Bratislava, the presence of pegmatitoid material, in the form of leucocratic pegmatitoid granites, quartz-enriched granites or coarse-muscovite pegmatites themselves, becomes increasingly striking. Sometimes they have free relationship – one type slowly transits into the other, sometimes they are marked by sharp contact. For instance, notable is sharply bounded leucocratic granitic melt on contact with another type of granite or migmatite, indicating its penetration into a cooled, brittle-deformed environment. The described phenomena document the complex polyphase tectonic and magmatic Late-Hercynian evolution, which apparently relates to differential uplift processes.

The crystalline mass of the Bratislava Massif is greatly disturbed by the *"young" tectonics*, and the failure intensity appears to be increasing southwards. In the rock exposures, we often observe an opaque network of irregular brittle failures that mask older structural elements. The bearer of the oldest structural record is the gneiss (locally the amphibolite) substrate. Its deformation structures are expressed by basic metamorphic foliation, or fold-shear reworking, which can be identified with textural features of migmatitization. The dominant metamorphic structures have approximately E-W directions (ranging from 70 – 250° to 120 – 300°), usually dipping in moderate to steep angles to the south. This Hercynian metamorphic structure was in many cases injected with granitoid rocks, usually leucocratic granites. Mostly they conform to the structural pattern of the metamorphic substrate, which is copied by the basic separation of granite slabs, rarely biotite relics fabrics, or the ductile deformation texture of granitoids. Pre-Alpine rock succession ceased by the veins of pegmatites and aplites intersecting the already solidified basic granitoids of the Bratislava Massif. The course of these veins also ranges roughly in the direction E-W and NE-SW.

As a relatively widespread subsequent deformation process we consider Alpine (Cretaceous) secondary schistosity, which is more readable in granites and pegmatites than in the gneiss material. In particular, it manifests itself in the form of irregular, shallowly inclined cataclastic to mylonitic (partly blastomylonitic) schistosity. These deformations follow in particular the aforementioned older directions, but only with slight southern dips. Often, they also dip to the east or north-west directions. This deformation process can first be identified with the structural manifestations associated with the overthrust of the so-called Bratislava nappe.

We assume the tangle of various fracture failures as gradual manifestations of Neo-Alpine (Cenozoic) tectonics. For example, they can be studied in excavation works at the Bratislava Castle Hill (Figs. 1.6a,b; see also Madarás et al., 2014). In a microscale, the deformation of granites along such failures can usually be referred to as so-called kakiritization and occasionally even narrow mylonitic bands appear. The variously-oriented fissures are predominantly steep to subvertical. Informatively examined main failures are usually oriented in NW-SE and N-S directions, but one can also observe NE-SW and E-W course.

Fig. 1.6 The excavation works in the area of the Bratislava Castle testify to a multiphase neoid tectonic failures of the Castle Cliff; a) brittle deformation, prevailing failure directions dipping to the east; (b) young failure accompanied by the development of a light tectonic clay (scale – geological hammer)

The orientation of the first three mentioned failure directions in the marginal part of the Malé Karpaty Mts. is significantly reflected in the dominant tectonic lines of the pre-Neogene basement of the investigated region. In the structural plan of fault failures of the Neogene age, the inheritance of the E-W directions no longer occurs in such a frequency as in the previous deformation processes. A mylonite failure zone of irregular sub-horizontal course (Fig. 1.6) intersecting steep failures was recorded in the fresh excavation for multi-storey garages below the Bratislava Castle. This points to relatively young fault-controlled movements of the crystalline mass blocks.

Late manifestations of the Malé Karpaty Mts. uplift fault tectonics are also signalized by a slight inclination (about 10°) of sporadic loess sediments, irregularly preserved on the sunken granitic blocks (e.g. the western part of the Castle Hill above Lafranconi). The other geological argumentation of the relatively young tectonic activity provides the presence of grey calcareous clays in the direct basement of the Quaternary slopes in the lower part of the vineyards in Rača and Krasňany suburbs (ascertained from a shallow borehole and excavation of a residential house at Jurajov dvor tram station area). It is a Vráble formation of the Sarmatian age (oral information by K. Fordinál), which proves for the significant Late Miocene to younger uplift movements of this part of the mountain range, probably along the *Malé Karpaty Mts. fault*.

1.3 Covered pre-Cenozoic basement of the Danubian Flat

The Danube Basin represents a tectonically inhomogeneous unit – a superposed Neogene basin with genetically and tectonically diverse crystalline and Mesozoic basement (Buday et al., 1967). The eastern part of the region in question forms a depression with the greatest depth in the area of the Gabčíkovo Depression, estimated on the basis of geophysical data to be about 5,500 m (Fusán et al, 1987) or up to 8,500 – 9,000 m (Hrušecký, 1999). It is obvious that imaging of the pre-Cenozoic basement of the Danube Basin is burdened by a high degree of uncertainty due to the lack of necessary data. The construction of the basement structure depends not only on the quality of geophysical data, but also on the development of regional geological knowledge on a wider scale. Indirect and incomplete information on the nature of the pre-Cenozoic substrate often leads to diverse, often contradictory interpretations, which are mostly influenced by the ideas of tectogenesis of the Western Carpathians of a particular researcher. Similarly, the present study, together with the basement scheme (Fig. 1.7), bears a seal of subjective view. We are aware that the outline of the Cenozoic tectonics in the demarcated area is just one of the attempts to schematicize the continuous geodynamic events in a regional scale. In the following text we rely mainly on supporting geological publications dealing with the fundament of the central part of the Danube Basin and from other works we select data that we consider to be the most relevant.

1.3.1 Overview of pre-Cenozoic basement research and maps

Substantial progress in the knowledge of the geological structure of the Danube Basin basement was brought by deep drillings, which were largely realized in the 50 – 60s of the 20th century. They were focused on the prospecting for hydrocarbon sources, later also for geothermal purposes. In our territory, such boreholes extending into the pre-Mesozoic basement are summarized above all in the work of Biela (1978). Any further information can be found in the references cited here, mostly manuscripts. The first significant works, based primarily on the gravimetric image of the Danubian Lowland as well as the initial seismic, magnetometric data and knowledge from deep wells were published by Adam & Dlabač (1961), Pagáč (1964) and Buday & Špička (1967). The then tectonic interpretations were connected with the current knowledge gained during the compilation of the first edition of the general geological maps at a scale of 1: 200,000. The latter work presented a comprehensive view of the geological setting of the basement, in rough terms in the sense of today's regional geological understanding of the Inner Western Carpathians, and pointed out the importance of NW-SE and S-N tectonic lines.

From a comprehensive study of the SE part of the Danubian Plain (Gaža & Beinhauerová, 1977) it follows that the normal-slip movements of the faults do not have a significant effect on the Early Badenian deposits, since the faults are generally considered to be younger. Near the village of Zelený Háj (borehole ZH-1 in Biela, 1978) north of Komárno, various facies types of fossiliferous limestones were found below the Pannonian deposits at the depth of 1,608 m, whose age was determined on stratigraphy of tentaculites to be Devonian, most likely the Middle Devonian (Biely & Kullmanová, 1979). In the discussion about the tectonic affiliation of these, almost non-metamorphosed sediments, this work considered them to be part of the basement of the Transdanubian Mountains, which has an affinity to the Northern Greywacke Zone or the Spiš-Gemer Ore Mountains (SGR). The results of the Danube Basin basement research together with other Cenozoic basins in the Inner Carpathian Cenozoic basins were summarized and tectonically evaluated in the comprehensive work by Fusán et al. (1987).

Hrušecký (1999) provides an integrated study from the central part of the Danube Basin, emphasizing the importance of the Čertovica-Mojmírovce fault system and the Hurbanovo line, particularly on the basis of the results of reflective seismic profiles. He also draws attention to the Kolárovo, Ripňany, Medveďov and Cífer faults, but he does not consider the NW-SE fault lines to be well-documented, such as the Pezinok, Dobrá Voda or Danube faults. On the other hand, the *Dobrá Voda (Ludince) line* is regarded as a major fault line forming the Danube Basin (Fusán et al., 1987), which is conjoined by the parallel Pezinok and Danube faults, along which the basin gradually sinks in the southwest direction. Recent work in the Danube Basin (Hók et al., 2016) also attributes considerable importance to the faults in this direction, and along the Ludince line, which the authors refer to as the transverse fault in the Danube Basin; they suggest the Late Oligocene shift of the Malé Karpaty Mts. to the northwest.

Available geological and geophysical data from the basement also include a 3D geological model of the Danube Basin created within the TRANSENERGY project (Kronome et al., 2014), which was preceded by the tripartite project DANREG (Matura et al., 2000). The DANREG basement map shows the greater part of the Danubian Flat as the Greywacke Zone and in particular it is correlated with the Graz Palaeozoic. The contact with the south-eastern unit of *Pelsö* (see below) and its relationship with other Western Carpathian units are expressed along the Rába and Hurbanovo fault zones with white zones depicting an unknown basement (Matura et al., l.c.), which, despite cross-border cooperation, underlines the inconsistency in regional geological conceptions.

The southern part of Slovak Danube Basin area was also a part of the paper on Hungary's pre-Neogene basement (Wein, 1973). In the enclosed schemes the NE-SW fault lines separate the main tectonic units, which apparently pass further into the Slovak territory. Towards the Hungarian-Austrian border, it is the Lower-Austroalpine Sopron Crystalline, which is replaced by the Koeszeg-Rechnitz Palaeozoic east of Mosonmagyaróvár (the author was aware that many Austrian geologists consider the Rechnitz phyllites as a Jurassic unit of the of Penninic; which is now a reliable fact – note). Approximately east of the connection between Györ and Nové Zámky, the basement is defined within the vast zone of the Transdanubian Mountains, which is approximately delimited in the area between the Rába and Balaton (sometimes also the Mid-Hungarian) lines. This geological structure is built of epicontinental Oligocene-Eocene sediments with Mesozoic islands, which point to slice tectonics along fault lines.

A more or less similar picture provides the Hungary's pre-Cenozoic basement scheme (Fülöp, 1989), where the "Rába low-graded metamorphites" are depicted also north of the Danube in the section from Šamorín till the inflow of Rába into the Danube – it means approximately in the deepest depression of the investigated part of the Danube Basin. Geophysical-geological characteristics of the Danube Basin, together with a relatively detailed elaboration of its Slovak part, are provided by Balla (1994). The inventive elements of this work include an unconventional conception of phyllite rocks in the wider area of the Mihalyi Elevation as a possible continuation of the Penninic Mesozoic. The Penninic zone also includes calcareous-shale rocks of unclear lithostratigraphic affiliation from deep wells in the Sereď area. The tectonic conception of Leško & Varga (1980) supposes the presence of *Penninic* in the Central Depression of the Danube Basin and Fusán et. al. (1987) do not exclude such a solution in the discussion, too.

In the new geological map of the pre-Cenozoic units of Hungary (Haas et al., 2010), till the Mosonmagyaróvár, the Lower Austro-Alpine Crystalline is depicted. Furthermore, in the area of the largest deepening of the Danube Basin (up to 7,000 m approx. in the polygon of Mosonmagyaróvár – Csorna – Györ), an unknown basement is marked and so-called *Transdanubic*, consisting mainly of Mesozoic rocks, is present east of Györ. From the west, the *Transdanubic* creates a narrow strip of the low-metamorphosed Variscan lithological complex, followed by Permian continental deposits, probably in the envelope position. The Jurassic-Cretaceous Penninic unit – the Rechnitz Tectonic Outlier – emerges between the towns of Szombathely and Község beneath this rock complex. East of the confluence of the Danube and the Mosoni Danube, the Mesozoic rocks are present in the Transdanubic zone, divided into different age and facies categories, such as the indicated alternations of deep-water and shallow-water facies even within adjacent chronostratigraphically identical units (Haas et al., l.c.).

A mega-block north of the Mid-Hungarian (Transdanubian) line is defined in most recent Alpine-Carpathian-Pannonian syntheses as a Pelsö composite unit (named after the Latin name of Lake Balaton, sensu Fülöp et al., 1987), or the Transdanubic (Haas et al., 2010). The presence of Cretaceous deposits, similar facies development of many Mesozoic members, and very low metamorphic imprint of both the Palaeozoic and Mesozoic rocks, led to a correlation of the area south of the Diosjenö-Hurbanovo line with the Dinarides, or Southern Alpine tectonic units (e.g. Haas & Kovács in Haas, 2013). However, the tectonic-province affiliation of the Mesozoic unit of the Transdanubian Mountains, Tari et al. (2010) traditionally incorporate into the Upper Austroalpine Unit.

1.3.2 Construction of the basement scheme – basic principles

In the submitted sketch-scheme of the pre-Mesozoic basement of the Danubian Flat (Fig. 1.7) we start from the conventional conception of the geological structure of the Inner Western Carpathians (e. g. Maheľ, 1986; Fusán et al., 1987). Based on geophysical, spatial and drilling data the fundamental tectonic units (designated as numbers 3 to 5 in Fig. 1.7) consist from the Crystalline, although the presence of Mesozoic relics may be considered in the area north of the Ludince fault (Dobrá Voda line) towards Nitra. To the aforementioned usual basement schemes of the Danube Basin we associate the *South-Veporicum Crystalline* and, in terms of the ubiquitous Neo-Alpine deformation west of the Cífer faults (sensu Hrušecký, 1999) we suggest *the external domain of Tatricum*. From an indicative study of available thin-sections material as well as geophysical information this part of the Tatricum Crystalline seems to be affected by intense cataclastic deformation, often healed by calcite veins. This is likely to be associated with a more intensive activity of younger N-S fault system in this segment, as well as with manifestations of NNE-SSW failures at the edge of the Malé Karpaty Horst. The course of these failures, including the Cífer faults, can be perceived as being approximately parallel to the direction of the "Mur-Mürz-Leitha" lineament (e.g. Bada et al., 1999, Hók et al., 2000). From the Crystalline itself, it is difficult to deduce its affiliation to the basic Central Carpathian tectonic units – the interaction of the crystalline units was primarily derived from the extrapolation of the basic tectonic lines found at the surface north of the Danube Basin.

In the southern part of the territory in question depicted unit of the Southern Veporicum belongs to the basement composition not only for its tectonic position, but also for its peculiarities in the Crystalline rock composition, in the intensity of Alpine metamorphosis and because of its difference in the Triassic lithology of the Mesozoic cover compared to the Northern Veporicum (it is an overall regional concept that does not directly follow from the data from the pre-Cenozoic basement). We believe that the basic superposition relations of the Palaeoalpine (Cretaceous) structure are also preserved towards the covered basement in the south. The Southern Veporicum rests below the low-metamorphosed older Palaeozoic – Gemericum fundament or Greywacke Series with its Upper-Palaeozoic cover (indicated by information from the borehole Modrany 2, outside the region, Biela, 1978), which is further covered by the Mesozoic of the Transdanubian (Mid-Hungarian) Mountains (s.l.). These relationships of Palaeoalpine nappe tectonics are camouflaged by younger fault-tectonics, which also formed a Cenozoic basinal filling.

In Fig. 1.7 there are depicted only the basic fault lines that are assumed to be related to the basement and to a greater or lesser extent illustrate the separation of the underlying tectonic basement units. The faults under the Danube Basin can be pinnate, they can change direction, slope, or interfere with each other and their appearance at the surface may not fully reflect the situation in the pre-Neogene basement. For the repetition of structurally similarly oriented tectonic movements during geological evolution, we can speak of the age of fault only within a certain time limit. Thus, e.g. the connection of the Rába line to the relatively younger(?) system of Šurany faults cannot be excluded.

The basic intra-Carpathian (Palaeoalpine) NE-SW tectonic lines appear to represent the Mojmírovce faults (a certain analogy of the Čertovica Line) as well as the assumed continuation of the Pohorelá fault system. Possible continuation of the Cretaceous tectonic lines of the 1st order in the basement of the Danube Basin is difficult to discern due to Palaeogene to Early Miocene collision processes and younger failure disturbances, but in the pre-Alpine basement their juvenile record can be assumed. The tectonic arrangement of the basement of the northern parts of the Vienna Basin, as well as the Transdanubic, shows that the Tertiary collision structure did not include the crystalline ("Lower Austroalpine" units), suggesting certain preservation of older, albeit partially remobilized deep-seated lines in the pre-Cenozoic basement.

The crystalline basement under the Cenozoic fill of the Danubian Flat defines roughly the Ludince fault from the north, and the Hurbanovo and Rába(?) faults in the south. The faults of the NW-SE ("Sudeten") direction have a transverse course to the basic intra-Carpathian lines. They also pass through the Malé Karpaty mountain range and are relatively younger than its basic structural pattern. The Danubian Flat region from the south delimits a young system of the Danube faults of the same direction. In the middle part, we can assume the Pezinok fault, which could has been primarily established in the Palaeozoic (it follows the synclinorium of the Pezinok-Pernek productive zone) and, last but not least, it was reactivated in the Late Miocene period.

1.3.3 Interpretation and discussion notes

1.3.3.1 Sketch of pre-Cenozoic basement

Concerning the affiliation of the Palaeozoic rocks (No. 2 in the legend, Fig. 1.7) in the SE part of the Danubian Flat we are in favour of interpretation, that it is a higher tectonic unit of the Inner Western Carpathians, which can be compared to the Upper Austro-Alpine nappes, namely the Greywacke Zone unit or Spiš-Gemer Ore Mountains (Biely & Kullmanová, l.c.). Due to the lithostratigraphic nature of rocks from the ZH-1 deep well, correlation relations could be sought in the area of the Graz Palaeozoic rather than in the uncovered parts of the Spiš-Gemer Ore Mountains. There is a varied suite of carbonate and lydite horizons with biostratigraphically documented Devonian age in the units of the Graz Palaeozoic (Flügel & Neubauer, 1984). To the south of the western edge of the Danubian Flat region, phyllites, traditionally regarded as the Palaeozoic of the (Northern) Greywacke Zone are found in the Mihályi Elevation (near Csorna). The appearance of low-metamorphic rocks, starting from the Gemericum fundament in the east, through the Devonian limestone from the ZH-1 well, the Mihályi, St. Gotthard or Ikervár occurrences to the Graz Palaeozoic in the west,

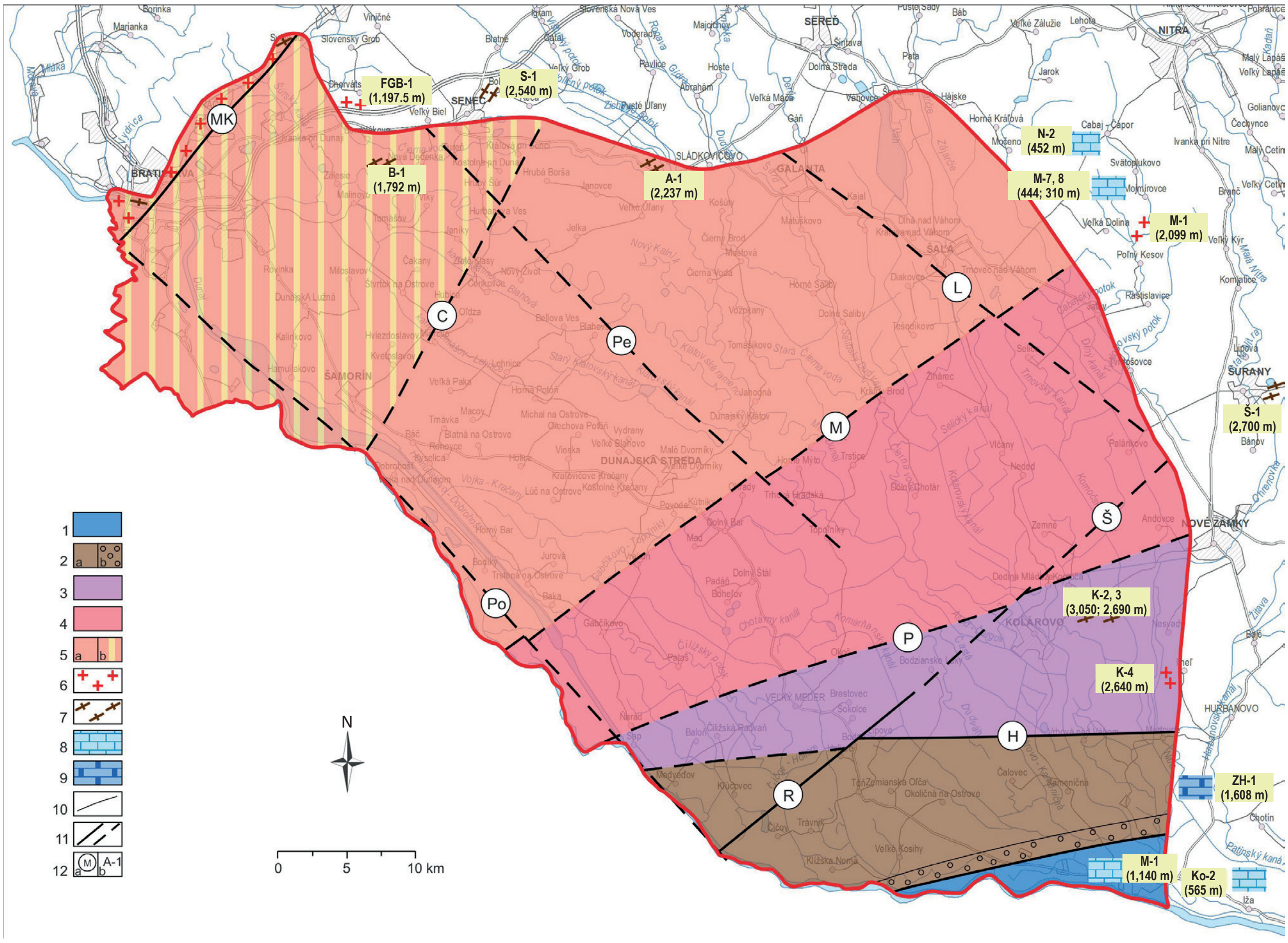

Fig. 1.7 Scheme of covered geological units of pre-Cenozoic basement of the investigated part of the Danube Basin

Legend to the scheme of covered geological units of the pre-Cenozoic basement of the Danubian Flat (Fig. 1.7)

Tectonic units:

1. *Mesozoic of the Mid-Hungarian Mountains: upper nappes of the Western Carpathians (?Silicicum, s.l.) – Upper Austroalpine*

2a. *Devonian (Lower Palaeozoic) (meta)sediments (Northern Greywacke Zone – Gemericum?)*

2b. *Permian sediments (envelope of Lower Palaeozoic)*

3. *Southern Veporicum – metamorphites, less granitoids, relics of Mesozoic?*

4. *Northern Veporicum – granitoid and metamorphic crystalline, Mesozoic*

5a. *Tatricum – granitoid and metamorphic crystalline, Mesozoic (“inner zone”)*

5b. *Tatricum – granitoid and metamorphic crystalline, Mesozoic? (“outer zone”, cataclasites)*

Exposed crystalline (Malé Karpaty Mts.) and in deep boreholes (the number corresponds to the depth of the reached basement):

6. *granitoids*

7. *metamorphites*

Labelling of rocks in deep boreholes (the number corresponds to the depth of the reached basement):

8. *Mesozoic carbonates*

9. *Devonian limestones*

General:

10. *geological boundaries*

11. *deep-seated fault lines: highly probable; assumed*

12a. *designation of main fault lines:*
R – Rába line, L – Ludince (Dobrá Voda) line, H – Hurbanovo line, MK – Malé Karpaty Mts. marginal fault, Po – Danube faults, Š – Šurany faults, M – Mojmírovce line, P – Pohorelá line, Pe – Pezinok fault, C – Cífer faults

12 b. *deep boreholes reaching into basement*

can be imagined as part of the later tectonically disrupted SW-NE zone of the Lower Palaeozoic rock suites, located tectonically on Central-Alpine or Inner Carpathian units. In the case of Devonian rocks from the borehole ZH-1, however, the idea of the presence of higher parts of the Gemericum – e.g. Drnava Fm. (sensu Snopko, 1967) cannot be excluded, although the Gelnica Group is slightly higher metamorphosed.

In the vicinity of Komárno at the SE border of the Danubian Flat and further towards Štúrovo (outside the region) the presence of the Mesozoic carbonates is evidenced by the drilling works, which apparently overlie the Palaeozoic complex. They build up so-called Komárno Block and behind the Danube they follow the Mesozoic complex of the Transdanubian Mountains, as shown in the wider area of Komárom in the pre-Cenozoic basement maps (most recently Haas et al., 2010). The inconsistency in the tectonic classification of this Mesozoic unit, outlined above, is difficult to elucidate at the current level of knowledge. In spite of the South-Alpine facies affinity or significant presentation of the Lower Cretaceous members, we tend to favour the system of the highest Eastern – or highest Inner Carpathian nappes with respect to the configuration of the regional geological structure.

The crystalline units located northwest of the Komárno Block are considered (even in the absence of other data) in the sense of the Palaeoalpine (Cretaceous) tectonic arrangement, which has roughly features of NE-SW belt-structure. To the north of the Hurbanovo fault, the crystalline, composed predominantly of metamorphic rocks, is perceived as the Southern Veporicum. It is likely that the Southern Veporicum Crystalline, with any relics of the Upper Palaeozoic or Mesozoic envelope, is the tectonic underlay of the Palaeozoic of the Komárno Block. This could create some analogy to the surface contact of the Southern Veporicum (especially the Kohút zone) and the Gemericum.

In the basement sketch (Fig. 1.7), behind the Southern Veporicum unit, the Northern Veporicum unit continues in the north-west direction, characterized by a considerable extent of granitoid rocks. The Northern Veporicum domain is characterized by better preserved Mesozoic succession and is also signalled by a massive outlier of the Hronicum Mesozoic in the area of the Levice tectonic block. Beyond the Čertovica-Mojmírovce line the Tatricum basement followed conventionally the Veporicum zone, but with the fact that the Northern Veporicum and Tatricum crystalline basement are considered as practically identical. In this context, there is another issue raised – where in the uncovered crystalline basement a tectonic scar of Fatricum Unit, if, of course, we respect its existence is placed.

Within the Tatricum, a more deformed domain of the "Tatricum Outer Zone" is indicated in its western part. The above-mentioned conspicuous and almost ubiquitous cataclastic deformation can be observed not only in the lower parts of the drill cores (e.g. deep boreholes in the wider area of Senec, Sereď), but also in the southern parts of the Malé Karpaty Mts. Crystalline. A complex spectrum of young failures in the crystalline may be related to tectonic processes of a wide age range – from the fold deformations recorded in the Lower Miocene sediments at the northern edge of the Dobrá Voda Depression in the Karpatian (Kováč et al., 1991) till the Pliocene – (Quaternary) movements of the southern parts of the Malé Karpaty Mts.

1.3.3.2 Pre-Cenozoic basement and Tertiary tectonics

The Tertiary tectonic events are difficult to assess in the central part of the investigated area because of the fact that (except for the so-called Komárno Block) on the pre-Cenozoic basement only Middle-, but mainly Late Miocene deposits were identified. The quasi-western continuation of the Hurbanovo line (dashed in Fig. 1.7) may hypothetically divide the crystalline in the north and the Upper-Austroalpine units in the form of the Palaeozoic Greywacke Zone and/or the Mesozoic in the south. The north-situated, dominantly Variscan crystalline in the East Alpine terminology corresponds to the Lower or Middle Austroalpine. In this case, the contact of the low- to non-metamorphosed Palaeozoic – Mesozoic tectonic overburden compared to the lower mega-units of the internal Western Carpathians would be independent of their Palaeoalpine arrangement. Through an imaginary western extension of the Hurbanovo line, which is likely to be of a Late-Oligocene – Early-Miocene age (Kováč et al., 2016; Kľučiar et al., 2016), could be transferred to the north-eastern sector of the Tertiary contact zone of the Eastern Alps. From this point of view, it is possible to admit in the southern zone of the Danube Basin (even north of the Hurbanovo line) the structural manifestations, that formed the Northern Limestone Alps.

The Palaeogene of the southern facies, also known as Buda or Pannonian facies, plays the role in the reflections on the pre-Cenozoic basement of the Danube Basin, which is best examined by the drilling works in the Komárno Block (Seneš et al., 1962, Brestenská & Lehotayová, 1960, Zlinská, 2016). To the oldest member of the discordantly deposited Buda Palaeogene the Kiscelian age is attributed and the sediments are well correlated with the Palaeogene of the Esztergom region (Brestenská & Lehotayová, 1960; Zlinská, 2017; Kľučiar et al., 2016). The highest stratigraphic horizons of the "Štúrovo Palaeogene" are of the Egerian Age (Seneš in Andrusov, 1965, Vass, 2002). The Komárno tectonic block is constrained by the Hurbanovo fault from the north and from the west probably by a failure of the Rába system. Data on the nature of the fauna in the Bánovská kotlina Basin, in the "Bojnice Palaeogene" (Maheľ & Gross, 1975 in Gross, 1978), in the Handlovská kotlina Basin (Zlinská & Gross, 2013), evidence for some biofacies kinship with the Buda Palaeogene, even north of the Hurbanovo fault or west of the northern continuation of the Rába fault system. This suggests the interconnection of the Buda, Central Carpathian and Magura Oceans, which is affiliated to the Middle Eocene period (Kováč et al., 2016; Soták et al., 2016). The Hurbanovo fault shows a considerable vertical amplitude, because to the north of it there were not found neither Mesozoic nor Palaeozoic units of the Transdanubian (Mid-Hungarian) Mountains. However, it can be assumed that the Danube Basin was covered with Palaeogene deposits of the Buda facies even to the north of the Hurbanovo fault, which were later denuded.

The tectonic events in the Danubian Flat region are difficult to perceive without any connection with the sedimentary and structural record in the area of the Malé Karpaty Mts. and data from the adjacent part of the Vienna Basin. The Tertiary development of the basement of the Vienna Basin is indicated by the deformation of the Late Cretaceous to Early Palaeocene sediments, which are an integral part of the Eastern Alpine nappes. The classical question of where the boundary between the Eastern Alps type of structure and the Inner Carpathian (Cretaceous) tectonic units runs is far from being concluded (based on drilling and geophysical work in the Záhorská nížina Lowland, a certain status quo between the Alps and the Western Carpathians creates at least the Senica – Lakšárska Nová Ves – Láb line, Kysela, 1988). From the configuration and content of the higher Mesozoic nappes, the idea that the Palaeoalpine primary structure of the Malé Karpaty Mts. could later be partially covered by the Northern Limestone Alps units could not be rejected with certainty. In this part of the Danube Basin, the overburden composition was eroded down to the crystalline, but in the case of the Malé Karpaty Mts. the relics of such a structure could be preserved in the form of the highest nappe relics of the Mesozoic. These have long complicated their tectonic affiliation, since they can be correlated well with the Eastern Alps nappe units (Vetters, 1904; Biely et al., 1980; Michalík, 1991). Neither from the basement of the northern part of the Vienna Basin nor from the northern edge of the Transdanubian Mountains, there is any evidence to support the Tertiary movements of the crystalline basement. Provided, the Tertiary thrust tectonics had taken place in the discussed area, it was probably only within the higher tectonic units.

In the following lines we will try to outline the structural-tectonic evolution in the Tertiary period, which concluded the formation of the pre-Cenozoic basement of the Danubian Flat and its surroundings. There are assumed four basic, in some cases differential uplift events that do not contradict the generalized succession of deformation events during Tertiary collision. Such deformations are indicated in our territory, in the north-eastern part of the Eastern Alps, or in the southern basins with the Buda evolution of Palaeogene. A look at these events suggests the complexity of Cenozoic fault tectonics and, overall, we can assume that the rejuvenation of faults is more a rule than an exception.

From the geological position, biostratigraphic and facies data it follows that in the Tertiary period the *first* uplift of the "Malé Karpaty Mts. block" (s.l.) occurred after the deposition of the Late Cretaceous strata, in the period prior to the late Palaeocene transgression (Gross & Köhler, 1989). The *second* uplift event can be attributed to the elevation structures created in the Late Eocene period, when the southern part of the contemporary "Malé Karpaty Mts. Block" was uplifted. The development of the given elevation structure probably took place along with the uplifting of the north-eastern East-Alpine domains (e.g. Sopron Crystalline, maybe even Penninic in the Rechnitz outlier?). On a wider palaeographic scale, the supposed uplifted threshold rampart in this domain inhibited to link the Eastern Alps and Buda sedimentation areas (as opposed to the communication between the Buda and the "Central Carpathian" Palaeogene deposition in that period). The elevation movements of the second stage are supported by the Late Palaeocene – Middle Eocene age range of the Malé Karpaty Mts. Palaeogene sedimentation, which also shows a strong affinity for the "peri-Klippen Palaeogene" (Gross & Köhler, l.c.). Late-Eocene kinematic events could be activated in response to the emplacement of the Northern Limestone Alps on the Flysch zone, dated since the Eocene period (Tollmann, 1978).

Tectonic or latent discordance between Eocene and Oligocene sediments is often noted in the Buda Palaeogene sedimentation areas (Vass, 2002, Nagymarosi, 1990). The Oligocene sediments of the Buda development, deposited directly on the pre-Cenozoic basement, are also indicative of the Eocene uplift of the area of the Komárno High Block area and its subsequent subsidence. The tectonic events at the Eocene-Oligocene interface may be documented in the western domain of the Buda Palaeogene areal by the Early Oligocene uplift accompanied by denudation of the Eocene basement (e.g. Nagymarosy in Haas, 2013). In the Buková Furrow, in the north-western part of the Malé Karpaty Mts., Hrabník Formation of the Kiscelian age is present (Marko et al., 1990), which also does not follow the Eocene basement.

The Oligocene Hrabník Formation was folded in the Early Miocene period, as indicated by the non-folded top-horizon of the Karpatian (Early Badenian) age (Marko et al., 1990). It is remarkable that the Eocene sediments of the so-called Buková Palaeogene are deformed only insignificantly compared to the Hrabník Formation. From the biostratigraphic and superposition data, the period around the border of the Oligocene – Lower Miocene (e.g. Kováč, 2000) can be considered as the fundamental Cenozoic uplift of the "previous" Malé Karpaty Mts. In the sequence of the tectonic events outlined, this is the *third* uplift phase. The south-western edge of the Malé Karpaty Mts. adjacent part of the Vienna Basin does not contain Eggenburgian sediments (Jiříček & Seifert, 1990), unlike its western part, which could also suggest the Early Miocene uplift of the area. Predominantly on the basis of indirect indications, it can be assumed that in an area situated roughly between the fault lines bounded by the northern Ludince and the southerly elongated Hurbanovo line, a west-declining east-west ridge elevation formed in the Egerian (Early Miocene) period. The continental Egerian sedimentation in the north-western area of the Buda Palaeogene (Tari et al., 1993) may also support such an uplift structure. It was probably created as a result of the post-collision (late-collision) strike-slip shear kinematics advancing in the direction of the Northern Limestone Alps, through the then overburden of the Malé Karpaty Mts., up to the southern domains of the Danube Basin. It is possible that the failures close to the Hurbanovo line represented a structure in that period, restricting the central part of the

Danube Basin from the south. On the northern edge of the Eastern Alps, especially north of the Danube, deformation processes in the age diapason Egerian to Karpatian were documented (Brix et al., 1977; Wachtel & Wessely, 1981). The supposed elevation zone in rough features is surrounded by Eggenburgian transgressive sedimentation, documented on the north-western edge of the Vienna Basin, in the Blatné Depression, the Ipelská kotlina Basin, or in the Upper Nitra Basin or at the southern foothills of the Sopron Mountains.

Polymict Jablonica Conglomerate of the (Late) Karpatian (Mišík, 1986; Fordinál et al., 2012), as well as its deep-water equivalents, represent the link between the Vienna and northern parts of the Danube Basin (Kováč & Baráth, 1995). A study of the source material of the shallow-water facies, including the Jablonica Conglomerate from the NW part of the Danube Basin (Pagáč, 1964a; Csibri et al., 2018), suggests that it originates from the Malé Karpaty Mts. rock inventory, partly also from the Alpine units, whereas the transport of the pebble material is expected from south to north (Mišík, 1986). From the given circumstances it can be assumed that the material of the Early Miocene units originated from the elevation (elevations), which can be temporally joined with the uplifted Danube ridge elevation (approximately the central part of the Danube Basin today).

The supposed east-west elevation structure, to which the Malé Karpaty Mts. probably also belonged, was eroded during significant tectonic events in the Karpatian – Early Badenian period (traditionally the "Styrian Phase"). The tectonic processes of this period Kováč (2000) associates with the process of extrusion of the Central Western Carpathians in the Karpatian phase of rifting. In the deep morphostructures along the faults, the (Early)-Badenian units were subsequently deposited – represented by the Bajtava Formation from the east, Špačince and Devínska Nová Ves Fms. in the west (Fordinál et al. in Polák et al., 2012).

The Hurbanovo line ceased its major kinematic activity before or during the deposition of the Bajtava and Špačince Fms., which are spread, according to available data (Vaškovský & Halouzka, 1976; Biela, 1978; Vass, 2002; Zlinská, 2016), south as well as north of this line, which proves for its (Early) Badenian termination. Subsequently, the Hurbanovo line became inverse, as evidenced by the subsidence of the Crystalline and the uplift of the Komárno Block. However, it is a relative movement – probably both blocks were subsiding, as indicated by virtually the same Middle- to Late-Miocene overburden on both sides of the line.

This debate naturally raises the question of the existence of the Malé Karpaty Mts. between the Vienna and Danube Basins. The Malé Karpaty Mts. elevation morphological structure in its then form had developed in parallel with the rapid subsidence of the Danubian Flat territory since the Early Badenian period. The character of its pre-Neogene rock inventory (crystalline with the relics of autochthonous and allochthonous Mesozoic units), from the point of view of the after-Karpatian tectonics, ranks it to the interface with the Vienna Basin, which is characterized by a considerable thickness of folded Mesozoic sequences, and the Danubian Flat with exposed pre-Badenian crystalline. The Karpatian-Early Badenian processes, in the form of "basin and range tectonics", caused due to the deep-seated normal faults the extension collapse till the crystalline-eroded Danubian ridge, with the "Palaeo-Malé Karpaty Mts." segment not subsiding but creating a new horst structure. We associate this with the *fourth*, last major Tertiary uplift event in the surveyed area. The basic features of the Malé Karpaty Mts. horst of today's form developed along the NE-SW shear system, which was probably related to the parallel Malé Karpaty Mts. marginal faults, separating the mountains from the Danube Basin. In elucidating the composition and evolution of the pre-Cenozoic basement, the post-Badenian tectonic events have no longer played an essential role.

1.4 Conclusions

The Malé Karpaty Mts. crystalline complex situated on the western edge of the investigated area is built of mainly biotite granites to granodiorites with local bodies of biotite gneisses and amphibolitic rocks. In addition to amphibolites (s.s.), laminated metatuffites, calcium-silicate rocks with diopside and occasionally gabbrodioritic rocks were identified in the fragments. The periplutonic effect of the Bratislava Granitoid Pluton caused a metamorphic reworking (maximum in the amphibolite facies) of the pre-granite substrate, which represents the second regional Hercynian metamorphic phase. In the south, there are more-and-more abundant pegmatitoid varieties with striking dark K-feldspar or fan-shaped muscovite aggregates, which are typical for this region. In the polydeformation inventory of the Lower Palaeozoic to Carboniferous crystalline rocks, it is possible to distinguish Hercynian, Alpine (Cretaceous) and Cenozoic deformation structures. In an artificial excavation at the Bratislava Castle, a complex tangle of brittle failures was observed, which is likely to indicate "young" tectonics reaching up the Pliocene-Quaternary period.

The following tectonic units (from north-west to south-east) have been suggested within the composition of the pre-Cenozoic basement of the Danubian Flat region: Tatricum (external and internal zone), northern Veporicum, southern Veporicum, Palaeozoic nappe of the Northern Greywacke Zone (Graz Palaeozoic) – Lower Gemericum ("Drnava Fm.") and overlying Oberostalpin – Silicicum (s.l.). The first three units are apparently built of crystalline, while the Southern Veporicum is considered to be more distinctive against the Northern Veporicum than the Northern Veporicum to Tatricum. It is likely that the Southern Veporicum crystalline, with possible relics of the Upper Palaeozoic-Mesozoic envelope, forms the tectonic basement of the Upper Palaeozoic nappe of the Komárno Block.

Discussions were devoted to the deposits of the Pannonian and Central Carpathian Palaeogene as well as to the comparison with the tectonic pattern in the north-eastern part of the Vienna Basin. It is likely that before the

Early Badenian inversion there had existed in the central part of the Danube Basin an E-W elevation zone, when the crystalline basement was exposed along with the (then) domain of the Malé Karpaty Mts.

The arrangement of basic tectonic units is understand as Alpine (Cretaceous) with the fact that the higher structure, especially the southern parts, was significantly modified by Tertiary tectonics. However, in overall there is no indication in favour of crystalline basement overthrusting during this period.

The final part of the article is devoted to the discussion of the tectonic events with an impact on the wider area of the territory under study. Based on inter-regional compilation data, four tectonic phases associated with uplift movements were earmarked in the Tertiary period.

References

Adam, Z. & Dlabač, M., 1961: Nové poznatky o tektonice Čs. části Malé dunajské nížiny. Věstník ÚÚG, 36., 3, Praha, p. 188 – 198. (In Czech).

Adrian, F. F. & Paul, K. M., 1864: Die geologischen Verhältnisse der kleinen Karpathen und der angrenzenden Landgebiete im nordwestliche Ungarn. Jb. K.-Kön. geol.Reichsanst., (Wien), , Bd. 14, p. 325 – 366.

Andrusov, D., 1965: Geológia Československých Karpát. Slovak Academy of Sciences, Bratislava, 392 p. (In Slovak).

Bada, G., Horváth, F., Gerner, P. & Fejes, I., 1999: Review of the present day geodynamics of the Pannonian basin: progress and problems, Geodynamics 27, p. 501 – 527.

Balla, Z., 1994: Basement tectonics of the Danube Lowlands. Geol. Carpath., 45, p. 271 – 281.

Biela, A., 1978: Hlboké vrty v zakrytých oblastiach vnútorných Západných Karpát. Region. geol. Západ. Karpát (Bratislava), 10, 224 p. (In Slovak).

Biely, A. & Kullmanová, A., 1979: Výskyt devónskych sedimentov v podloží podunajskej panvy. Geol. práce, Správy, 73, p. 29 – 38. (In Slovak).

Biely, A., Bystrický, J. & Mello, J., 1980: Problematika hronika a "gemerika" v Malých Karpatoch a vo viedenskej panve. In: Fusán, O., Samuel, O. (Eds.): Materiály 23. celoštátnej geologickej konferencie slovenskej geologickej spoločnosti, Prednášky a exkurzní sprievodcovia. Konf. Symp. Sem., GIDŠ, Bratislava, p. 17 – 30. (In Slovak).

Brix, F., Kroell, A. & Wessely, G., 1977: Die Molassezone und deren Untergrund in Niederoestereich. Erdöl-Erdgas Z., 93, Hamburg/Wien, p. 12-35.

Buday, T., Cambel, B., Maheľ, M., Brestenská, E., Kamenický, J., Kullman, E., Matějka, A., Salaj, J. & Zaťko, M., 1962: Vysvetlivky k prehľadnej geologickej mape ČSSR 1:200 000 M-33-XXXV M-33-XXXVI Wien-Bratislava. GIDŠ Bratislava, 249 p. (In Slovak).

Buday, T. & Špička, V., 1967: Vliv podloží na stavbu a vývoj mezihorských depresí se zřetelem k poměrum v podunajské pánvi. Sbor. Geol. věd, Záp. Karpaty, 2, GIDŠ Bratislava, p. 153 – 187. (In Czech).

Buday, T., Cicha, I., Hanzlíková, E., Chmelík, F., Koráb, T., Kuthan, M., Nemčok, J., Pícha, F., Roth, Z., Seneš, J., Scheibner, E., Stráník, Z., Vaškovský, I. & Žebera, K., 1967: Regionální geologie ČSSR II., Západní Karpaty, sv. 2., p. 7 – 624. (In Czech).

Cambel, B., 1958: Príspevok ku geológii pezinsko-pernec-kého kryštalinika. Acta geol. Univ. Com., Geologica, 1, p. 137 – 260. (In Slovak).

Cambel, B. & Valach, J., 1956: Granitoidné horniny v Malých Karpatoch, ich geológia, petrografia a petrochémia. Geol. Práce, zoš. 42, p. 113 – 268. (In Slovak).

Cambel, B. & Vilinovič, V., 1987: Geochémia a petrológia granitoidných hornín Malých Karpát. Veda, Bratislava, 248 p. (In Slovak).

Cambel, B., Korikovsky, S. P., Miklóš, J. & Boronikhin, V. A., 1989: Calc-silicate hornfelses (erlans and Ca-skarns) in the Malé Karpaty Mts. region. Geol. Carpath., 40, p. 281 – 304.

Cambel, B., Kráľ, J. & Burchart, J., 1990: Isotopic geochronology of the Western Carpathian crystalline complex. Veda, Bratislava, 183 p. (In Slovak with English summary).

Csibri, T., Rybár, S., Šarinová, K., Jamrich, M., Sliva, L. & Kováč, M., 2018: Miocene fan delta conglomerates in the north-western part of the Danube Basin: provenance, paleoenvironment, paleotransport and depositional mechanisms. Geol. Carpath., 69, p. 467 – 482.

Čorná , O., 1968: Sur la trouvaille de restes d´organisme dans les roches graphitique du cristallin des Petites Carpathes. Geol. Zbor. Geol. Carpath., 19, p. 303 – 309.

Flügel, H. W. & Neubauer, F., 1984: Steiermark. Erleuterung zur geologischen Karte der Steiermark 1 : 200 000. Wien, 127 p.

Fordinál, K. (ed.), Maglay, J., Elečko, M., Nagy, A., Moravcová, M., Vlačiky, M., Kohút, M., Németh, Z., Bezák, V., Polák, M., Plašienka, D., Olšavský, M., Buček, S., Havrila, M., Hók, J., Pešková, I., Kucharič, Ľ., Kubeš, P., Malík, P., Baláž, P., Liščák, P., Madarás, J., Šefčík, P., Baráth, I., Boorová, D., Uher, P., Zlinská, A. & Žecová, K., 2012: Vysvetlivky ku geologickej mape Záhorskej nížiny 1 : 50 000. Bratislava, Št. GIDŠ, p. 7 – 232. (In Slovak with English summary).

Fülöp, J., 1989: Bevezetés Magyarország geológiájába. Akadémia Kiadó, Budapest, 246 p.

Fülöp, J. & Dank, V., (eds.), 1987: Geological map of Hungary without the Cenozoic cover. 1 : 500 000. Hung. Geol. Inst., Budapest.

Fusán, O., Biely, A., Ibrmajer, J., Plančár, J. & Rozložník, L., 1987: Podložie terciéru vnútorných Západných Karpát. GIDŠ Publishers, Bratislava, 123 p. (In Slovak with English summary)

Gaža, B. & Beinhauerová, M., 1977: Tektonika neogénu juhovýchodnej časti podunajskej panvy. Min. slovaca, 9, p. 259 – 274. (In Slovak with English summary).

Gross, P., 1978: Paleogén pod stredoslovenskými neovulkanitmi. In Paleografický vývoj Západných Karpát. (Eds. Vozár, J. et al.). GIDŠ Bratislava, p. 121 – 145. (In Slovak).

Gross, P. & Köhler, E., 1989: Nové poznatky o paleogénnych sedimentoch Malých Karpát. Geol. práce, Správy 90, p. 23 – 41. (In Slovak).

Haas, J. (ed.), Budai, T., Csontos, L., Fodor, L. & Konrád, G., 2010: Pre-Cenozoic geological map of Hungary, 1: 500,000. Geological Institute of Hungary Publishers.

Haas, J. (ed.), Hámor, G., Jámbor, Á., Kovács, S., Nagymarosy, A. & Szederkényi, T., 2013: Geology of Hungary. Springer Vg. Berlin-Heidelberg, 244 p.

Hók, J., Bielik, M., Kováč, P. & Šujan, M., 2000: Neotectonic character of Slovakia. Miner. Slovaca 32, p. 459 – 470 (In Slovak with English summary).

Hók, J., Kováč, M., Pelech, O., Pešková, I., Vojtko, R. & Králiková, S., 2016: The Alpine tectonic evolution of the Danube Basin and its northern periphery (SW Slovakia). Geol. Carpath., 67, p. 495 – 505.

Hrušecký, I., 1999: Central part of the Danube Basin in Slovakia: Geophysical and Geological Model in Regard to Hydrocarbon Prospection. Exploration Geophysics, Remote Sensing and Environment, 6.1., Praha, p. 2 – 55.

Ivan, P., Méres, Š., Putiš, M. & Kohút, M., 2001: Early Palaeozoic metabasalts and metasedimentary rocks from the Malé Karpaty Mts. (Western Carpatahians): evidence for rift basin and ancient oceanic crust. Geol Carpath. 52, 2, p. 67 – 78.

Jiříček, R. & Seifert, P., 1990: Paleography of the Neogene in the Vienna Basin and the adjacent part of the foredeep. In: Minaříková, H. & Lobitzer, H. (Eds.): Thirty years of geological cooperation between Austria and Czechoslovakia, p. 89 – 102. Vienna (GBA) – Prague (CzGI).

Kantor, J., Harčová, E. & Rúčka, I., 1987: Izotopový výskum a rádiometrické datovanie z oblasti Veľkej Bratislavy. Manuscript – SGIDŠ Archive, Bratislava. (In Slovak).

Kľučiar, T., Kováč, M., Vojtko, R., Rybár, S., Šujan, M. & Králiková, S., 2016: The Hurbanovo–Diösjenő Fault: A crustal-scale weakness zone at the boundary between the Central Western Carpathians and Northern Pannonian Domain. Acta Geologica Slovaca, 8, 1, p. 59 – 70.

Kohút, M., Uher, P., Putiš, M., Ondrejka, M., Sergeev, V. S., Larionov, A. & Paderin, I., 2009: SHRIMP U-Th-Pb zircon dating of the granitoid massifs in the Malé Karpaty Mountains (Western Carpathians): evidence of Meso-Hercynian successive S- to I-type granitic magmatism. Geol. Carpath., 60/5, p. 345 – 350.

Korikovskij, S. P., Cambel, B., Miklóš, J. & Janák, M., 1984: Metamorphism of the crystalline basement of the Malé Karpaty Mts.: stages, zonality and relation to granitoid rocks. Geol. Carpath., 35, 4, p. 437 – 462. (In Russian, English abstract).

Koutek, J. & Zoubek, V., 1936: Geologická mapa Československé republiky, list Bratislava (4758) v mierke 1:75 000. SGÚ, Praha. (In Slovak).

Koutek, J. & Zoubek, V., 1936a: Vysvětlivky ke geologické mapě v měřítku 1 : 75 000, list Bratislava 4758. Knih. St. geol. ústavu ČSR, sv. 18, p. 7 – 150. (In Czech).

Kováč, M., 2000: Geodynamický, paleogeografický a štruktúrny vývoj Karpatsko-Panónskeho regiónu v miocéne: nový pohľad na neogénne panvy Slovenska. Veda, Bratislava, 202 p. (In Slovak).

Kováč, M., Baráth, I., Šútovská, K. & Uher, P., 1991: Zmeny v sedimentárnom zázname spodného miocénu v dobrovodskej depresii. Miner. Slovaca, 23, p. 201 – 213. (In Slovak with English summary).

Kováč, M. a Baráth, I., 1995: Tektonicko-sedimentárny vývoj alpsko-karpatsko-panónskej styčnej zóny počas miocénu. Miner. Slovaca, 28, p. 1 – 11. (In Slovak with English summary).

Kováč, M., Plašienka, D., Soták, J., Vojtko, R., Oszcypko, N., Less, Gy., Cosovic, V., Fügenschuh, B. & Králiková, S., 2016: Paleogene paleogeography and basin evolution of the Western Carpathians, Northern Pannonian domain and adjoining areas. Global and Planetary Change 140, p. 9 – 27.

Kováčik, M., 2005: Príspevok k tektonickej rekonštrukcii západokarpatských magmaticko-sedimentárnych formácií v predvrchnokarbónskom období. Miner. Slovaca, 37, p. 189 – 192. (In Slovak with English summary).

Kronome, B, Baráth, I., Nagy, A., Uhrin, A., Maros, G., Berka, R. & Černák, R., 2014: Geological Model of the Danube Basin; Transboundary Correlation of Geological and Geophysical Data. Slov. Geol. Magazine, SGIDŠ, Bratislava, 14, 2, p. 17 – 36.

Kysela, J., 1988: Reinterpretácia geologickej stavby predneogénneho podložia slovenskej časti viedenskej panvy. Záp. Karpaty, séria geológia, p. 7 – 51.

Leško, B. & Varga, I., 1980: Alpine elements in the West Carpathian structure and their significance. Miner. Slovaca, 12, p. 97 – 130.

Madarás, J., Bučová, J., Broska, I. & Petrík, I., 2014: Petrografia a tektonika historického žulového lomu na severnej terase Bratislavského hradu. In: Musilová, K., Barta, P. & Herucová, A. (eds.) Bratislavský hrad – dejiny, výskum a obnova. Kolektívna monografia prednášok z konferencie konanej v dňoch 22.-23.9. 2014 na Bratislavskom hrade v rámci projektu Európskej únie Danube Limes Brand. MúOP a SNM – HM, Bratislava, p. 277 – 284, ISBN 978-80-971923-7-2.

Maglay, J., Fordinál, K., Nagy, A., Vláčiky, M., Šefčík, P., Fričovská, J., Moravcová, M., Kováčik, M., Baráth, I. & Zlocha, M., 2018: Geologická mapa Podunajskej nížiny – Podunajskej roviny. Publishers MoE – SGIDŠ Bratislava, ISBN 978-80-8194-035-0. (In Slovak).

Maheľ, M., 1986: Geologická stavba československých Karpát. Predalpínske jednotky 1. Publishers Veda. Slovak Academy of Sciences, 503 p. (In Slovak).

Maheľ, M. & Cambel, B., 1972: Geologická mapa Malých Karpát 1: 50 000. GIDŠ, Bratislava.

Marko, F., Kováč, M., Šutovská, K. & Fodor, L., 1990: Deformation and kinematics of Lower Miocene shear zone (Hrabník beds, Buková depression). Miner. Slovaca, 22, p. 399 – 410.

Matura, A. (ed.), Wessely, G., Kröll, A., Czászár, G. & Vozár, J., 2000: Danube Region Vienna – Bratislava - Budapest. Explanatory for Map of the Pre-Tertiary basement. DANREG (Danube region Environmental Geology Programme). Jb. Geol. B.A., 142, p. 466 – 482.

Michalík, J., 1991: Upper Createous cover. In: Kováč, M. et al. (eds.): Malé Karpaty Mts.-Geology of the Alpine – Carpathian junction. Excursion Guide Smolenice 1991, GIDŠ Publishers Bratislava, p. 53 – 55.

Mišík, M., 1986: Petrographic – microfacial analysis of pebbles and interpretation of source areas of the Jablonica conglomerates (Lower Miocene of the NW margin of the Malé Karpaty Mts.). Geol. Carpath., 37, p. 405 – 449.

Nagymarosy, A., 1990: From Tethys to Paratethys, a way of survival. — Acta Geodaetica Geophysica et Montanistica Hungarica 25(3-4): p. 373 – 385.

Pagáč, I., 1964: Perspektíva živíc v mezozoiku pod neogénom Podunajskej panvy. Geologický pruzkum, 12, Praha. (In Slovak).

Pagáč, I., 1964a: Zhodnotenie perspektívy a návrh prieskumných prác na naftu a zemný plyn v podloží podunajskej panvy. Manuscript, SGIDŠ-Geofond, 198 p. (In Slovak).

Planderová, E. & Pahr, A., 1983: Biostratigraphical evaluation of weakly metamorphosed sediments of Wechsel Series and their possible correlation with Harmónia Group in Malé Karpaty Mts. Miner. Slovaca 15, p. 385 – 436.

Plašienka, D., Reháková, D., Michalík, J., Mikleová, J., Planderová, E. & Hacura, A., 1989: Tektonika a paleotektonika mezozoických komplexov tatrika Malých Karpát. Manuscript, Archive of GI Slovak Academy of Sciences Bratislava, 374 p. (In Slovak).

Plašienka, D., Michalík, J., Kováč, M., Gross, P. & Putiš, M., 1991: Paleotectonic evolution of the Malé Karpaty Mts. – an overwiev. Geol. Carpath., 42, p. 195 – 208.

Plašienka, D., Korikovsky, S. P. & Hacura, A., 1993: Anchizonal Alpine metamorphism of Tatric cover sediments in the Malé Karpaty Mts. (Western Carpathians). Geol. Carpath., 44, p. 365 – 371.

Polák, M. (ed.), Plašienka, D., Kohút, M., Putiš, M., Bezák, V., Filo, I., Olšavský, M., Havrila, M., Buček, S., Maglay, J., Elečko, M., Fordinál, K., Nagy, A., Hraško, Ľ., Németh, Z., Ivanička, J. & Broska, I., 2011: Geologická mapa Malých Karpát 1:50 000. MoE SR – SGIDŠ, Bratislava, ISBN 978-8089343-45-4. (In Slovak with English summary).

Polák, M. (ed.), Plašienka, D., Kohút, M., Putiš, M., Bezák, V., Maglay, J., Olšavský, M., Havrila, M., Buček, S., Elečko, M., Fordinál, K., Nagy, A., Hraško, Ľ., Németh, Z. Malík, P., Liščák, P., Madarás, J., Slavkay, M., Kubeš, P., Kucharič, Ľ., Boorová, D., Zlinská, A., †Siráňová, Z. & Žecová, K., 2012: Vysvetlivky ku geologickej mape regiónu Malé Karpaty 1 : 50 000. Bratislava, SGIDŠ, p. 7 – 287. ISBN 978-80-89343-67-6. (In Slovak with English summary).

Putiš, M., 1987: Geológia a tektonika juhozápadnej a severnej časti kryštalinika Malých Karpát. Miner. Slovaca, 19, 2, p. 135 – 157. (In Slovak with English summary).

Putiš, M., Frank, W., Plašienka, D., Siman, P., Sulák, M. & Biroň, A., 2009: Progradation of the Alpidic Central Western Carpathians orogenic wedge related to two subductions: constrained by ^{40}Ar/^{39}Ar ages of white micas. Geodyn. Acta 22, p. 55 – 80.

Putiš, M., Ivan, P., Kohút, M., Spišiak, J., Siman, P., Radvanec, M., Uher, P., Sergeev, S., Larionov, A., Méres, Š., Demko, R. & Ondrejka, M., 2009a: Meta-igneous rocks of the West-Carpathian basement, Slovakia: indicator of Early Paleozoic extension and shortening events. Bull. Soc. Géol. France 180, 6, p. 461 – 471.

Richarz, P. S., 1908: Die südlichen Teil der Kleinen Karpaten und die Hainburger Berge. Jb. K.- kön. geol. Reichanst., Wien, 58, p. 1 – 48.

Seneš, J., Brestenská, B., Lehotayová, E., Vaňová, L., Volfová, J., Mincová, M. & Karolus, C., 1960: Vysvetlivky k prehľadnej geologickej mape ČSR. List L-34-I, Nové Zámky, Manuscript. Geofond Archive, 164 p. (In Slovak).

Seneš, J., Franko, O., Košťálik, J. & Porubský, A., 1962: Vysvetlivky k prehľadnej geologickej mape ČSSR 1:200 000 L-34-I Nové Zámky a L-33-VI Čalovo. GIDŠ Bratislava, 151 p. (In Slovak).

Snopko, L., 1967: Litologická charakteristika gelnickej série. Západ. Karpaty, 7, GIDŠ, Bratislava, p. 103 – 152. (In Slovak).

Soták, J., Kováč, M., Plašienka, D. & Vojtko, R., 2016: Stredoslovenský zlomový systém a jeho úloha v tektogenéze a paleogeografii paleogénnych paniev Západných Karpát: Nové údaje z Hornonitrianskej a Turčianskej kotliny. Mente et Maleo, 1, spravodajca SGS, Bratislava, p. 28 – 29. (In Slovak).

Tari, G., Báldi, T. & Báldi-Béke, M., 1993: Paleogene retroarc flexural basin beneath the Paleogene Pannonian Basin: a geodynamic model. Tectonophysics, 226, p. 433 – 456.

Tari, G. & Horváth, F., 2010: Eo-Alpine evolution of the Transdanubian range in the nappe system of the Eastern Alps: revival of a 15 years old tectonic model. Földt Közl., 140, p. 483 – 510.

Tollmann, A., 1977: Geologie von Österreich. Band 1. Wien, Franz Deuticke, 766 p.

Vass, D., 2002: Litostratigrafia Západných Karpát: neogén a budínsky paleogén. SGIDŠ, Bratislava, 202 p. (In Slovak).

Vaškovský, I. & Halouzka, R., 1976: Geologická mapa Podunajskej nížiny – juhovýchodná časť 1: 50 000. GIDŠ, Bratislava. (In Slovak).

Vetters, H., 1904: Die Kleinen Karpathen als geologisches Bindeglied zwischen Alpen und Karpathen. Verhandlungen der kaiserlich-königlich geologischen Reichsanstalt, Jahrgang 1904, Nr. 5, Wien, p. 134 – 143.

Wachtel, G. & Wessely, G., 1981: Die Tiefbohrung Berndorf 1 in den östlichen Kalkalpen und ihr geologischer Rahmen. Mitt. Oester. Geol. Ges., 74/75, p. 167 – 165.

Wein, Gy., 1973: Zur Kenntnis der tektonischen Strukturen im Untergrund des Neogens von Ungarn. Jb. Geol. B.-A., 116, p. 85 – 101.

Zlinská, A. & Gross, P., 2013: Vek a litologická charakteristika paleogénnych usadenín Handlovskej kotliny na základe reinterpretácie vrtu FGHn-1 Handlová. AGEOS, Acta Geologica Slovaca. 5, p. 141 – 153. (In Slovak with English summary).

Zlinská, A., 2016: Terciérna mikrofauna z hlbokých vrtov v želiezovskej priehlbine (Dunajská panva), Miner. Slovaca, 48, p. 61 – 82. (In Slovak with English summary).

2. Neogene and Palaeogene Fill of the Slovak Part of the Dunajská Panva Basin within the Region 1: 50,000 Podunajská Nížina Lowland – Podunajská Rovina Flat

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Abstract: Palaeogene and Middle Miocene sediments are probably involved in the basal Cenozoic fill. We do not have any direct evidence, we conclude this from seismic profiles. The oldest documented rocks are volcanic products of various varieties of andesites of the Lower Badenian (Seravallian) age. The oldest documented rocks are volcanic products of various varieties of andesites of the Early Badenian (Langhian) age. Above them are sediments of marine facies in the form of pelitic and sandy sediments of the Badenian (Langhian-Serravallian) age, which are overlain by the brackish deposits of the Sarmatian (Serravallian) and Early Pannonian (Tortonian) ages of the same lithological composition. The end of the pre-Quaternary sedimentation period is represented by sand-clay deposits of the continental environment with interlayers of coal clays to lignites and in the upper parts with dominating gravel-sand deposits, Pliocene in age.

Key words: Neogene and Palaeogene fill, biostratigraphy, lithological composition

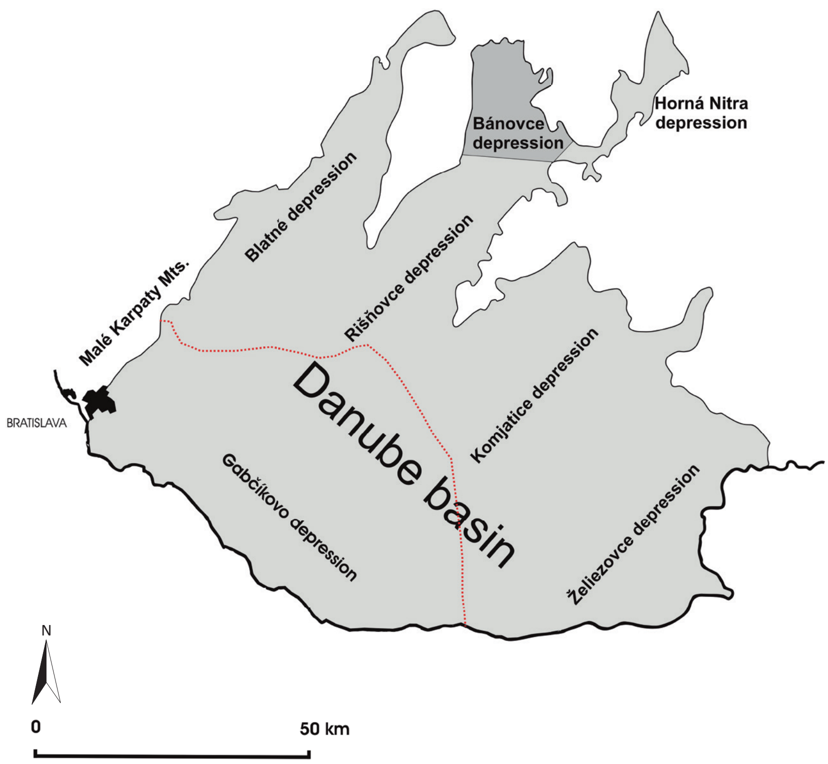


Fig. 2.1 Location of the Danube Basin sensu Vass (2002). The red-dotted contour delimits the studied region of the Danube Flat at a scale of 1: 50,000

2.1 Introduction

From the structural-tectonic point of view, with an exemption of a narrow part of the foothills of the Malé Karpaty Mts. the area of the Danube Lowland-Danube Flat region is an intra-arc basin, which consists of a system of "smaller" sub-basins (Royden et al., 1983). The sub-basins underwent partially different evolution during the Miocene and Pliocene, as a result of which they differ not only in the overall thickness of their Neogene sedimentary fill, but also in the chronostratigraphic sequence of the formations within individual sedimentary sequences, in representation, or absence of some complexes and their lithological character and thickness (Kováč, 2000).

The current shape of the *Danube Basin* (Fig. 2.1) as a body is the result of complex tectonic and complex geological evolution in time and space (Adam & Dlabač, 1961, 1969; Pagáč et al., 1995). One manifestation of this facies within its territory is the occurrence of several other tectonically different depocentres (depressions), which recorded maximum subsidence activity in different time periods and in different intensity (Keith et al., 1989; 1994; Hók et al., 2016; 2019). One of these depressions, representing the largest part of the region, is the Gabčíkovo Basin. It represents its deepest part, where the thickness of the Neogene sediments reaches over 8,500 m (Kilényi & Šefara, 1989; Hrušecký et al., 1996).

According to the latest research and interpretations (Hók et al., 2016; 2019) during the Early Miocene, the paleostress regimen changed from transtension into transpression mode in the pre-rift stage. The Danube Basin Transversal Fault (DBTF) and parallel NW – SE oriented failures were activated as normal faults. The area southwest of the DBFT was then eroded up to crystalline basement. In the Middle Miocene in the syn-rift stage, the extension was oriented in the NW – SE direction and caused the opening of the finger-like depressions in the NW part of the Slovak part of the Danube basin.

The extension mode of the NW – SE direction persists also in the post-rift stage up to the Early Pleistocene.

2.2 Sedimentary fill of the Basin

According to data from seismic sections (Hrušecký et al., 1993, 1996, 1998; Hrušecký, 1999), the thickness of sedimentary rocks in the central Gabčíkovo Depression reaches about 8,000 – 9,000 m. However, the sum of the thicknesses of the Neogene sediments verified by boreholes and partly also by seismic measurements is only about 6,000 m.

Since the seismic image shows the presence of sedimentary rocks in the overburden of the pre-Cenozoic bedrock, the above-mentioned authors assigned the lower part of the fill to the presence of sediments of the ***Palaeogene to Early Miocene*** age. Although the data on their existence are indisputable, there is no direct evidence, so we do not discuss their closer characteristics.

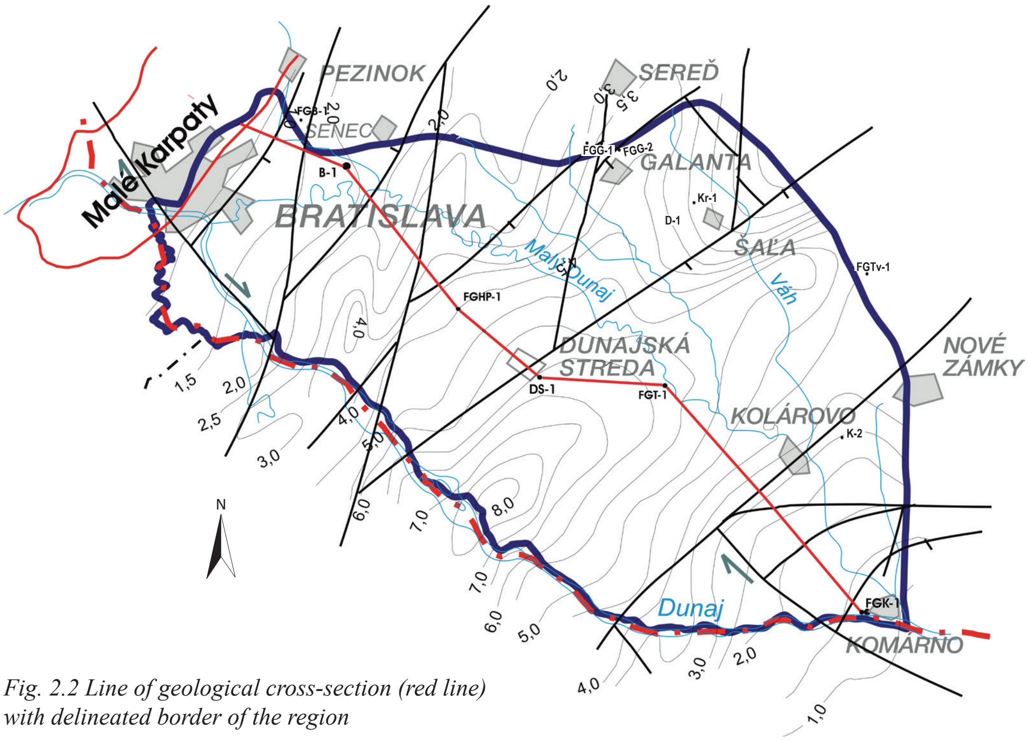


Fig. 2.2 Line of geological cross-section (red line) with delineated border of the region

Based on the works of Šefara & Kováč (in Šujan et al., 1996) and Pereszlényi, Vass, Elečko & Vozár (in Tkáčová et al., 1996) we compile the geological cross-section of the sedimentary fill (Fig. 2.2).

The sediments and volcanic rocks of Middle Miocene age do not crop out to the surface of the studied region. They are covered by thick fluvial deposits of Quaternary age.

In the isolated occurrences, only sediments of the ***Late Miocene*** to ***Pliocene*** age are exposed, particularly in NE parts of the geological map of the region.

Despite the fact that sedimentation in the *Gabčíkovo Basin* generally began only in the Early Badenian, since it continued more or less smoothly up to the Pliocene and Quaternary, the oldest Neogene sediments so far found in this part of the basin are considered volcanic breccias of Early Badenian age, formed by fragments of andesites (Pálfalvi, 1975). In the overburden of these sediments on W outskirts of the Basin near Rusovce the HGB-1 borehole (Kantor et al., 1987) proved the presence of Early Badenian (Langhian) volcanites, referred to as *Šurany volcanites* (Vass, 2002. They are represented by amphibolic andesites, passing into hornblende-pyroxenic andesites.

The oldest Neogene rocks (Figs. 2.3, 2.4) are represented in the Slovak part of the Danube Basin (range of the described region) by Šurany volcanites, caught by exploration wells. Based on radiometric dating the Early Badenian (Langhian) age was assigned to them. The oldest Neogene sediments are of the Early Badenian age (in terms of Kováč et al., 2007, Rybár et al.,

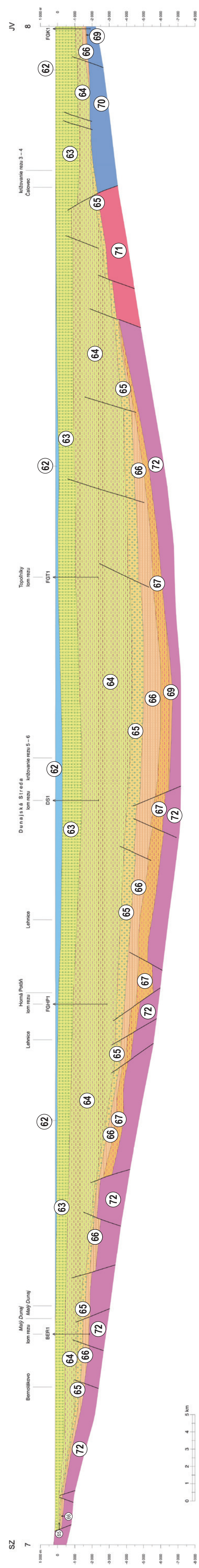


Fig. 2.3 Geological section of the Tertiary fill of the Slovak Part of the Dunajská panva Basin (Danube Basin within the Region 1: 50,000 Podunajská nížina Lowland – Podunajská Rovina Flat (Danubian Flat).
62 – Quaternary undivided; 63 – Late Miocene-Pliocene; 64 – Pannonian (Tortonian); 65 – Sarmatian (Serravallian); 66 – Late Badenian (Serravallian); 67 – Early Badenian (Langhian); 69 – Palaeogene-Neogene; 70 – Mesozoic (Silicicum s.l.); 71 – Palaeozoic-Mesozoic (Veporicum undivided); 72 – Palaeozoic-Mesozoic (Tatricum undivided)

2015) and belong to the Špačince Formation. In their overburden there are sediments of the Late Badenian (Serravallian, Báhoň Fm.), Sarmatian (Serravallian, Vráble Fm.), Late Miocene (Pannonian – Tortonian; Ivanka, Beladice, Volkovce Fms.) and Pliocene age (Kolárovo Fm.).

2.2.1 Badenian (Langhian-Serravallian)

The chronostratigraphic regional stage of the Central Paratethys – Badenian, approved at the 1st Symposium of the Subcommittee for Paratethys in 1968 in Bratislava, was divided into three sub-stages – the Early (morav), the Middle (vielič) and the Late (kosov). Since that time, there have been implemented several refinements of its duration and division (Kováč et al., 2007; Hohenegger et al., 2014; Rybár et al., 2015). In this work we use a two-part division of Badenian in terms of Kováč et al., (2007); Rybár et al., (2015) and a lithostratigraphic division of the Neogene deposits of the Danube Basin sensu Vass (2002).

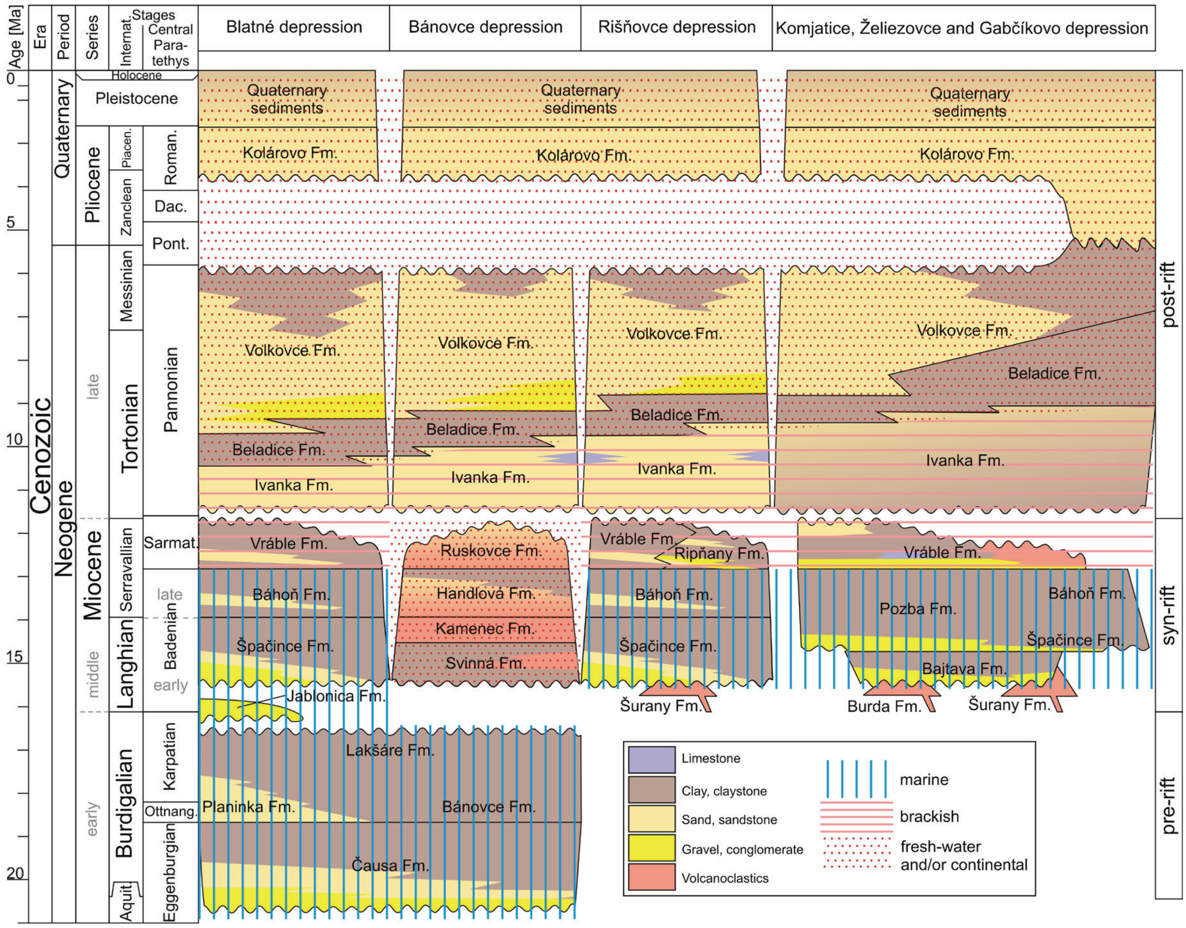
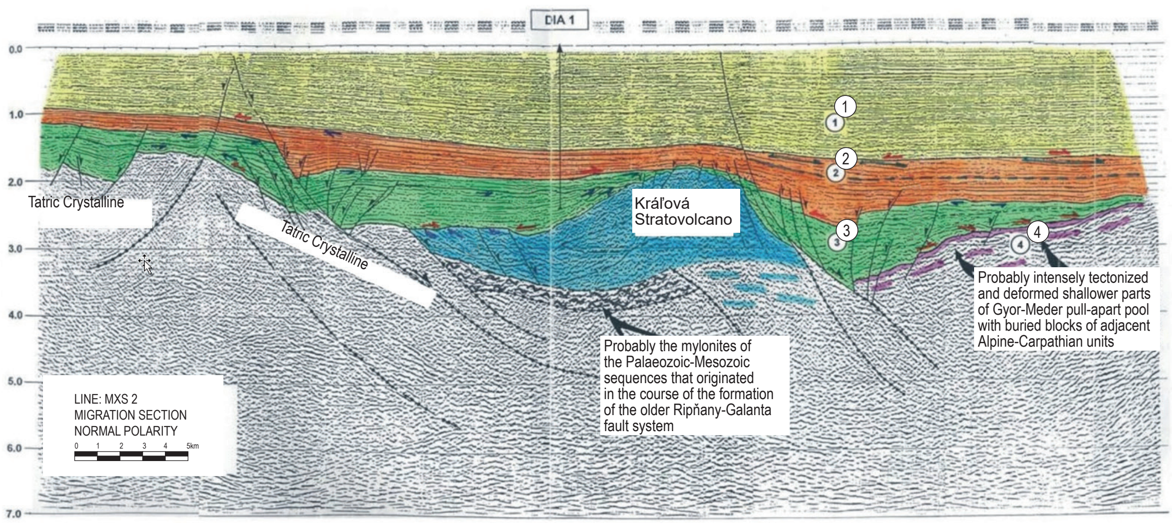


Fig. 2.4. Lithostratigraphic column of the sedimentary fill of the Slovak part of the Danube Basin (Hók et al., 2019, edited by Nagy & Fordinál)



1 – Middle Pannonian (Tortonian) – Quaternary; 2 – Early Pannonian (Tortonian); 3 – Early Badenian (Langhian) – Sarmatian (Serravallian); 4 – Pre-Cenozoic basement

Fig. 2.5 Geological section of a part of the Danube Basin (wider surroundings of the Kráľová borehole, Hrušecký, 1997)

2.2.1.1 Early Badenian (Langhian)

Šurany volcanites

In the Danube Basin there are buried andesite volcanites below the sediments of the Late Badenian age. They are widespread in the central part of the basin and also at its western edge and represent *Šurany volcanites* (Vass, 2002). In the basement of younger Neogene sediments of the Danube Basin they build a buried ridge in the space between Šurany and Šaľa. This is shown by the results of magnetic measurements (Filo in Šefara et al., 1987; Gnojek & Kubeš, 1988; Šutora et al., 1988). They are widespread in the central part of the Danube Basin and near Rusovce, at its western edge.

The volcanites were drilled by the borehole Šurany-1 near the town of Šurany north of Nové Zámky, at a depth of about 1,820 – 2,700 m as well as by the borehole Kráľová-1 near the village Kráľová nad Váhom, NW of Šaľa, but it did not drill through the volcanics (Fig. 2.5). Similar rocks were drilled by the borehole HGB-1 near Rusovce, S of Bratislava.

Stratotype profile provided incoherent core recovery borehole Šurany-1. As the Šurany-1 well showed, the volcanites overlie the pre-Cenozoic bedrock and are covered by the Špačince Fm. In the Kráľová-1 borehole, the volcanic rocks are covered by the Báhoň Fm. The drilled thickness of the volcanites in the Šurany-1 borehole is about 890 m (1,810 – 2,700 m).

The Šurany volcanites are represented by black greenish amphibolic andesites passing into the overburden made of the amphibolic-pyroxenic andesites penetrated by tiny calcite veins. The above mentioned andesites were drilled by HGB-1 borehole (1,027 – 1,124 m) in Rusovce. In their subsoil, at a depth interval of 1,124 – 1,259 m, there were found volcanic breccia formed by sharp-edged fragments of white-grey and green-black andesite cemented with a grey solid matrix (Pálfalvi, 1975). Based on argon radiometric dating, the age of andesite from the HGB-1 borehole was determined to be 16.2 ± 0.5 million years, which corresponds to Early Badenian (Kantor et al., 1984; 1987).

The Šurany volcanites are part of the Badenian volcanic arc, which continues eastwards through Burda, Börzsöny, Dunazug, Krupinská planina Plateau, Cserhát, and Mátra into NE Hungary, where the arc is buried in the Transtissia area, similarly to the Danube Basin (Vass, 2002).

Špačince Formation

The sediments of the Špačince Fm. are formed in the marginal part of the basin by sandstones, which in the direction of the basin pass into clay or claystones.

In the Blatné Depression, which extends to the region from the north, the sediments consist of sandstone, limestone, rarely organogenic sandy limestone (Jiříček in Papp et al., 1978; Vass, 1989 and Vass in Keith et al., 1989).

The basinal development is represented by grey calcareous clay with a slate disintegration, siltstone and claystone. The thickness of the lithological complex within the area of the geological map reaches about 600 m. The age of the Formation is documented by foraminifer communities from the *Spiroplectammina carinata* zone (sensu Grill, 1941).

The sediments of the Špačince Fm. originated in the marine environment, whose depth and salinity had gradually decreased.

2.2.1.2 Late Badenian (Serravallian)

Báhoň Formation

The sediments of the Late Badenian age represented by the Báhoň Fm. are preserved almost throughout the Danube Basin. On the base of the complex, in the marginal part of the basin, there are light green and green-grey breccias, formed by sharp-edged granitoid fragments and gravel with abundant intercalations of grey calcareous clays. Light grey fine- to coarse-grained sandstones are found in their overburden. In the above clays (FGB-1, Chorvátsky Grob), foraminifer communities of the Bulimina-Bolivina zone of the Late Badenian were found. The following species have been identified: *Bulimina elongata* (Orb.), *Bolivina dilatata* Reuss, *Ammonia beccarii* (L.), etc. In addition to the foraminifers, presence of molluscs *Nucula nucleus* L., *Turritella spirata* (Br.), *Megaxinus incrassatus* (Dub.) (Franko et al., 1976) was identified.

The white sand and grey-white limestones, drilled by the HGB-1 borehole near Rusovce, belong likely to the Báhoň Fm. There are small andesite fragments in the basal limestone. The presence of bryozoans and fragments of both macro and microfauna were found in limestones (Pálfalvi, 1975).

The sediments of the Báhoň Fm. in the region were found in the FGB-1 (Chorvátsky Grob) borehole at a depth range of 734.5 – 1,197.5 m (Franko et al., 1976), G-1 (Grob) at a depth range of 708 – 1,283 m (Gaža, 1970), HGB-1 (Rusovce) at a depth interval of 1,027 – 1,011 m (Pálfalvi, 1975; Brestenská in Vaškovský et al., 1984) and probably in a well drilled in Pezinok (Svoboda in Dlugi & Svoboda, 1958).

2.2.2 Sarmatian (Serravallian)

Vráble Formation

At the beginning of the Sarmatian, a sea level retreat (Grill, 1941) was documented throughout the Alpine – Carpathian region, associated with the erosion of Badenian marginal sediments (Hudáčková & Kováč, 1993; Baráth, 1993).

The sediments of the Sarmatian age are represented in the Danube Basin by the Vráble Fm. (Priechodská & Harčár, 1988; Vass, 1989 and Vass in Keith et al., 1989). On its basis, in the periphery of the basin (Bratislava region) there are coarse-grained quartz sands and sandstones, in which there occur at places horizons of gravel with pebbles composed of granitoids and crystalline schists. The thickness of the basal sediments reaches about 5 m. The above deposits overlie directly the crystalline bedrock (Cílek, 1960; Toula, 1915). Towards the overburden, the basal sediments of the Vráble Fm. pass into grey clays with unique tiny sandstone layers and into green-grey, sporadically light green sandy clays, which are strongly spotted at the bottom. This led to the earmarking of the so-called variegated and grey development of Sarmatian sediments. Varicoloured sediments and the lower part of the grey sediments belong from the stratigraphic point of view to the Early Sarmatian (Cílek, 1960).

A rich fauna of various fossil groups of organisms was found in marginal Early Sarmatian sediments.

The following foraminifers were detected: *Elphidium crispum* (L.), *E. reginum* (Orb.), *E. aculeatum* (Orb.), *Quinqueloculina karreri* (Reuss), etc., ostracods *Cytheridea mülleri* (Münst.), *Cyamocytheridea leptostigma* (Reuss), *Loxoconcha* sp., *Leptocythere* sp., gastropods *Mohrensternia pseudoangulata* (Hlb.), *M. inflata* (Andrz.), *Rissoa inflata inflata* (Andrz.) and bivalves *Cardium vindobonense vindobonense* (Partsch) and *Musculus sarmaticus* (Gat.) (Cílek, 1960; Pokorný, 1946). In the Middle Sarmatian sediments – zone *Elphidium hauerinum* there were identified foraminifers *Elphidium hauerinum* (Orb.), *E.* cf. *josephinum* (Orb.), *E.* cf. *aculeatum* (Orb.), *Nonion granosum* (Orb.) and in the Late Sarmatian deposits the foraminifers *Nonion granosum* (Orb.), *Ammonia beccarii* (L.), *Triloculina* sp. and gastropods *Acteocina lajonkaireana* (Bast.) and *Hydrobia* sp. (Cílek, 1960).

In the basin part of the Danube Basin, the terminal sediments of the Vráble Fm. consist of calcareous sandstones alternating with calcareous claystones. Thickness of the sandstone layers reaches from 3 to 13 m and claystone from 11 to 20 m. Calcareous claystones predominate, as a rule. The $CaCO_3$ content varied from 18.8% to 39% in these sediments (Priechodská in Franko et al., 1985). Foraminifers were found in microfauna from Sarmatian sediments, mainly taxa *Protelphidium* ex gr. *granosum* and *Elphidium* ex. gr. *macellum* (Brestenská in Franko et al., 1985). In the above-mentioned sediments, the highest amount of heavy minerals was represented by garnet (19.31%), tourmaline, staurolite, apatite, biotite, chlorite, ilmenite and magnetite in the amount from 1 to 5%. Minerals such as hypersthene, epidote, zoisite, zirconium, rutile and leucoxene had less than 1% share (Franko et al., 1985). Based on the above-mentioned minerals occurring in the deposits of the Vráble Fm., it can be concluded that the clastic material originates mainly from metamorphic and sedimentary rocks.

The Vráble Fm. sediments were found in the studied area in boreholes HGB-1 (902 – 1,027 m) in Rusovce (Pálfalvi, 1975), FGG-2 (2,032 – 2,101 m) in Galanta (Franko et al., 1985), in the well FGČ-1 (2,300 – 2,500 m) in Čilistov (Franko et al., 1981).

2.2.3 Late Miocene

In the past, the sediments of the Late Miocene and Pliocene age in the Danube Basin were divided into several lithostratigraphic units. Early and Middle Pannonian sediments were incorporated into the Ivanka Fm., the Late Pannonian sediments into the Beladice and Volkovce Formations and the Pliocene sediments into the Kolárovo Fm. (Kováč et al., 2011; Priechodská in Harčár et al., 1988; Vass, 2002).

New studies (dating $^{10}Be/^{9}Be$) have pointed to the heterochronous age of the aforementioned lithostratigraphic units. Sediments of the Ivanka Fm. deposited in the time interval 11.6 – 9.0 Ma, sediments of the Beladice Fm. in the interval 11.0 – 8.7 Ma and sediments of the Volkovce Fm. in the interval 10.5 to 5.0 Ma (Šujan et al., 2016).

2.2.3.1 Pannonian (Tortonian)

Ivanka Formation

At the end of the Sarmatian (Seravallian) and the beginning of the Pannonian (Tortonian), the Carpathian Mountains were uplifted, which caused the separation of the Pannonian region from the Paratethys. The Pannonian Lake was formed, which was gradually desalinised as a result of the inflow of fresh waters (Kázmér, 1990). The Pannonian (Tortonian) age sediments represented by the Ivanka Fm. deposited in a lake of caspi-brackish character, which was filled with sediments transported by rivers from the uplifted Alpine-Carpathian orogeny (Priechodská & Harčár, 1988; Vass, 1989 and Vass in Keith et al., 1989). Shallow-water and deep-water lake sediments, sediments of shelf slope and turbidites can be distinguished within the Ivanka Fm. (Šujan et al., 2016).

In the northern part of the Gabčíkovo Depression, the Ivanka Fm. is represented by layers of sand alternating with calcareous clay and silt (Pagáč et al., 1991; Hrušecký et al., 1996; Nagy et al., 1998 in Czászár (ed.) et al., 2001). Coal clays and seams of lignite are rarely found in the terminal part of the formation (Vass & Gašparik et al., 1978). The layer thickness is up to 2,500 m.

Marginal sediments of the Ivanka Fm. (Bratislava area) consist of sand of various colours (yellow, grey, brown) and sandstone with granitoid fragments, which alternate with large blocks and fragments of granitoids and pegmatites (Koutek & Zoubek, 1936). In this area, biozones C and D of Pannonian with rich fauna of molluscs, ostracods, fish and calcareous nanoplankton have been identified in the sediments of the Ivanka Fm.

Sediments of the Pannonian C biozone, predominantly formed by sands, are found directly on the granitoid bedrock (Nagy et al., 1995). They contain rich communities of molluscs (gastropods, bivalves), rarely fish otoliths and calcareous nanoplankton. Taxa of *Congeria martonfii pseudoauricularis* (Lörenthey), *Parvidacna tinnyana* (Lörenthey) and *Lymnocardium spinosum* (Lörenthey) were identified among biostratigraphically significant bivalve species (Fordinál, 1995; Fordinál in Nagy et al., 1995). Among the fish, otoliths of the species "*Raniceps" pannonicus* Pana were found (Brzobohatý in Nagy et al., 1995). Calcareous nanoplankton was represented by the species *Coccolithus pelagicus* (Wallich) Schiller, *Noelaerhabdus bozinovicae* Jerkovic and *N. jerkovici* Bóna et Gál (Raková in Nagy et al., 1995).

Sediments of biozone D formed by sand with thin layers of clay and silt contained, similarly as deposits of biozone C, rich mollusc communities (gastropods, bivalves), to a lesser extent fish otoliths and calcareous nanoplankton. Among the gastropods the species *Melanopsis varicosa nodifera* Handman, *M. pumila* Brusina, *M. lebedai* Lueger, *M. austriaca* Handmann and bivalves *Lymnocardium conjungens* (Hoernes), *Caladacna ornata bisepta* (Papp) and *Parvidacna loerenthey* (Pavlović) (Fordinál, 1993 1995; Fordinál in Nagy et al., 1995) have been identified. The fish otoliths of the species *"Raniceps" pannonicus* Pana, *Atherina* sp., "Genus aff. *Umbrina* "(Schubert), *Scianidae indet*., *Perciformes indet*. and button-shape teeth of fish, probably of the *Sparidae* family (Brzobohatý in Nagy et al., 1995) were found. In the calcium nanoplankton community there were found species *Coccolithus pelagicus* (Wallich) Schiller, *Thoracosphaera deflandrei* Kamptner, *Reticulofenestra pseudoumbilica* (Gartner), *Noelaerhabdus bozinovicae* Jerković and *N. jerkovici* Bóna et Gál (Raková in Nagy et al., 1995).

In the sediments of both biozones heavy minerals were found coming from moderate to high-metamorphic rocks of paragneiss and mica schist nature. The following minerals have been identified: garnet, staurolite, muscovite chlorite and biotite (Uher in Nagy et al., 1995).

The sediments of the Pannonian E biozone of the peripheral part of the Danube Basin are predominantly composed of green-lime calcareous clays with interlayers of sand, lignite and occasionally gravel.

In the basinal part, the basal sediments of the Ivanka Fm. (Biozone A) consisted of fine-grained calcareous sandstones and grey and brownish clays/claystones. The above-mentioned lithological types alternate irregularly, with clays slightly prevailing over sandstones. The thickness of clay layers reaches 2 to 68 m, the thickness of sandstone ranges from 3 to 23 m. The $CaCO_3$ content ranged from 13.7 – 15.5%. In these sediments, ostracods communities represented by species were found: *Amplocypris* cf. *abscissa* (Reuss), *Cyprideis tuberculata* (Méhes), *Candona reticulata* (Méhes), *Hemicytheria hungarica* (Méhes), *Hungarocypris* sp. (Franko et al., 1985; Pálfalvi, 1975). In addition to ostracods, the foraminifers of *Miliammina subvelatina* Venglinski (Brestenská in Franko et al., 1985) were also found in these sediments. In the association of heavy minerals garnet prevailed (18.2 – 20,1%), in larger quantities minerals biotite (2.7 – 7.6%), chlorite (7.7%) and pyrite (1.7 – 14.1%) were also represented. Rarely, tourmaline, zoisite, ilmenite and magnetite have been reported (1 – 5%; Priechodská in Franko et al., 1985).

The Pannonian B biozone deposits in the basin are predominantly made up of light green to green-green, slightly sandy calcareous clays with charred plant residues. Sandy sediments are found only to a small extent at the eastern edge of the Slovak part of the basin. The fossil residues found in the pelitic sediments of the Pannonian B biozone were represented by sporadically occurring molluscs (bivalves) and in greater numbers represented by ostracods. From bivalves, the tests of the genera *Congeria* and *Lymnocardium* were identified (Dlugi & Svoboda, 1958).

The Pannonian C biozone sediments in the basin consist mainly of light green, light grey calcareous clays with intercalations of light grey, sometimes greenish fine- to medium-grained calcareous sandstones and sandstones. The deposits of the Pannonian D-E biozones consist mostly of greenish and light grey calcareous clays with interlayers of light grey, fine- to medium-grained calcareous sandstones and sandstones.

Beladice Formation

In the sediments of the Beladice Fm. (Priechodská & Harčár, 1988; Vass, 1989 and Vass in Keith et al., 1989), the predominant lithotype is greenish calcareous clay with silt and sand admixture, or with layers of sand. The type profile is in borehole D-1, W of the village Diakovce, depth interval 282 – 1,447 m (Homola, 1960 fide Biela, 1978).

The Beladice Fm. is characterized by dark coal clay and seams of lignite found in the area around Svätý Jur and Vajnory (Cílek, 1960). At the edges of the basin gravel/conglomerate is also present, especially at the base (Buday in Buday et al. 1962, 1967; Priechodská & Harčár, 1988; Hrušecký et al.,1991, 1996; Fordinál & Nagy, 1997). In the Sereď area, the sediments of this zone are largely developed in variegated facies and are formed by lightgreen as well as grey-green calcareous clays, often containing charred plant residues or lignite fragments (Čermák, 1969; Gaža, 1962).

The sediments of the Beladice Fm. include the Pannonian biozone F (formerly a Coal Series) and correspond to the II[nd] Pannonian zone, which was earmarked in the vicinity of Ivanka near Bratislava by Pokorný (1946).

In the periphery of the Danube Basin (Bratislava area), brackish, freshwater and terrestrial molluscs were found in the sediments of the Beladice Fm. Among the brackish molluscs gastropods *Theodoxus soceni* Jekelius, *Melanopsis sturii* Fuchs, *M. affinis* Handmann, among bivalves *Congeria neumayri* Andrusov and *C. zahalkai* Špalek were identified. Among the freshwater molluscs the gastropods of the genera *Lymnaea, Planorbis, Anisus* were detected; among the terrestrial ones *Carychium pachychilus* (Sandberger), *Carychium* sp., *Vertigo oecsensis* (Halaváts). There were also found ostracods *Cyprideis pannonica* (Méhes), *C.* cf. *heterostigma* (Reuss), *Leptocythere* (*Amnicythere*) aff. *larga* Krstić, *Limnocythere sanctipatrici* Brady et Robertson (Fordinál & Tuba, 1992; Gaža, 1962; Grünnerová in Cílek, 1960).

During the deposition of the Beladice Fm., there was a fluctuation of the water level, which caused the rotation of the communities of freshwater and terrestrial gastropods with the transitional communities. Level fluctuations caused flooding of coastal marsh taxodium forests and consequently the formation of shallow lakes with a rich representation of aquatic plants (*Nymphaceae, Potamogetonaceae, Sparganiaceae-Typhaceae*; Papšíková, 1989).

Sediments containing lignite layers were formed in the delta plain environ (Vass in Keith et al., 1994). The layer thickness is several 100 m, in the D-1 (Dubník) borehole up to 1,165 m.

2.2.3.2 Late Miocene – Pliocene

Volkovce Formation

The sediments of the Volkovce Fm. (Priechodská & Harčár, 1988) of the Late Pannonian (Tortonian) to Pliocene age represent the final episodes of sedimentation in the Danube Basin under continental conditions in the river and partially lake environment (Kováč et al., 2010, 2011). In the marginal parts of the Danube Basin, the Volkovce Fm. consists of gravel and sand, and the central part of the Basin is formed with varicoloured clay, silt and sand.

Type profile of pelitic sediments is represented by borehole K-2, NE of Kolárovo, depth interval 250 – 1,500 m (Gaža 1966, fide Biela, 1978). We assume that in the region in the central part of the Danube Basin, the Volkovce Fm. reaches a thickness of up to 1,200 m.

Kolárovo Formation

The Kolárovo Fm. is represented on the territory of the region by medium- and coarse-grained sands, in which there are layers of fine-grained, sporadically medium-grained gravel and calcareous clays. The sands are the main component of the formation. The coloration of the sands and gravels of the Kolárovo Fm. is grey to greenish, strikingly different from the overburdened rusty brown Danube gravels of the Pleistocene age (Janáček, 1969). The characteristic feature of the sandstone formation is the unique occurrence of pebbles up to 15 cm in diameter. The pebbles are made of quartz, chert, sandstone, rare quartzite and crystalline schist. Another typical feature is the local nodular lithification of sands with lime cement (Buday, 1959).

The clays of the Kolárovo Fm. are facially stable and attain a thickness of 10 to 40 m. They are light grey, grey and light green in colour, only locally brownish-spotted. Varicoloured clays are rare and their thickness is small.

Tests of *Unio* bivalves and representatives of the genera *Planorbis*, *Viviparus* and *Melanopsis* were found in the deposits of the Kolárovo Fm. (Buday, 1959).

The sediments of the Kolárovo Fm. overlie transgressively and with a slight discordance (Janáček, 1969) the clays of the Late Miocene Volkovce Fm. (Late Pannonian-Pontian) age (Kováč et al., 2011).

2.3 Conclusions

Although the sedimentary fill of the area was not the subject of research, we present a brief characteristic of the individual Tertiary age geological units involved in its setting.

Palaeogene and Early Miocene age units are also likely to occur upon the pre-Cenozoic bedrock. In the marginal parts there are locally products of andesite volcanism of Early Badenian age.

The main part of the sedimentary fill consists of marine Badenian (Langhian) sediments, the Sarmatian (Serravallian) brackish and of the Pannonian (Tortonian) to Pliocene freshwater deposits.

References

Adam, Z. & Dlabač, M., 1961: Nové poznatky o tektonice Čs. části Malé dunajské nížiny. Věstník ÚÚG, 36., 3, Praha, p. 188 – 198.

Adam, Z. & Dlabač, M., 1969: Vysvětlivky k mapám mocností a litofaciálního vývoje Podunajské nížiny. Zbor. geol. Vied, Západ. Karpaty, rad ZK, zv. 11 (Bratislava), p. 156 – 172.

Baráth, I., 1993: Podmienky sedimentácie a zdrojové oblasti spodno a strednomiocénnych hrubých klastík v zóne alpsko – karpatského styku. Thesis. Manuscript. Bratislava, Archive of Geological Institute of SAS.

Biela, A., 1978: Hlboké vrty v zakrytých oblastiach vnútorných Západných Karpát. Region. geol. Západ. Karpát (Bratislava), 10, 224 p.

Buday, T., 1959: Vysvětlivky pro generální mapu ČSR list L – 33 – 6 (Čalovo). Manuscript. Archive of SGIDŠ, Bratislava.

Buday, T., Cambel, B., Maheľ, M., Brestenská, E., Kamenický, J., Kullmann, E., Matějka, A., Salaj, J. & Zaťko, M., 1962: Vysvetlivky k prehľadnej geologickej mape ČSSR 1:200 000 M – 33 -XXXV M – 33 – XXXVI, Wien-Bratislava. Geofond – Vyd. Bratislava, p. 5 – 248.

Buday, T., Cicha, I., Hanzlíková, E., Chmelík, F., Koráb, T., Kuthan, M., Nemčok, J., Pícha, F., Roth, Z., Seneš, J., Scheibner, E., Stráník, Z., Vaškovský, I. & Žebera, K., 1967: Regionální geologie ČSSR II., Západní Karpaty, sv. 2., p. 7 – 624.

Cílek, V., 1960: Neogén v severovýchodním okolí Bratislavy. Geol. Sbor. (Bratislava), 11, 2, p. 213 – 237.

Császár, G. (ed.) Pistotnik, J., Scharek, P., Kaiser, M., Darida-Tichy, M., Nagy, E., Szurkos, G., Síkhegyi, F., Budai, T., Marsi, I., Gyalog, L., Ivancsics, I., Pristaš, J., Horniš, J., Halouzka, R., Elečko, M., Konečný, V., Lexa, J., Nagy, A., Vass, D. & Vozár, J., 1998: Surface geological map, 1: 100 000. Atlas of Danube Region Environmental Geology Program (DANREG), Mag. áll. földt. Intéz., Budapest.

Čermák, D., 1969: Plytký a stredne hlboký štruktúrny prieskum v Piešťanskom výbežku. Manuscript – SGIDŠ Archive, Bratislava.

Dlugi, A. & Svoboda, S., 1958: Příspěvek k biostratigrafické charakteristice neogénu západní části Malé dunajské nížiny. In: Dlugi, A., Fischer, J., Homola, V., Janák, J., Mořkovský, M., Slavík, J., Svoboda, S., Šmeral, J. & Uhman, J.: Opěrná vrtba Báhoň – 1 v západní části Malé dunajské nížiny. Práce úst. pro naftový výskum (Brno), sv. 12, publ. 43, p. 41 – 58.

Fordinál, K., 1993a: Genus Melanopsis (Gastropoda) in Upper Miocene sediments in the Bratislava area. Západ. Karpaty, sér. Paleont. (Bratislava), 17, p. 57 – 69.

Fordinál, K., 1993b: Representatives of genus Parvidacna (Bivalvia) in Pannonian sediments of the Bratislava area. Západ. Karpaty, sér. Palaeont. (Bratislava), 17, p. 71 – 79.

Fordinál, K., 1995: Bivalvia (Dreissenidae, Cardiidae) from Upper Miocene Sediments in Bratislava. Geol. práce, Spr. (Bratislava), 100, p. 27 – 36.

Fordinál, K. & Tuba, Ľ., 1992: Biostratigrafické a palaeoekologické vyhodnotenie sedimentov územia centrálnej časti Bratislavy. Geol. Práce, Spr. (Bratislava), 96, p. 63 – 68.

Fordinál, K. & Nagy, A., 1997: Hlavinské vrstvy – okrajové vrchnopanónske sedimenty rišňovskej priehlbiny. Miner. Slovaca, 29, 6, p. 401 – 406.

Franko, O., Bodiš, D., Brestenská, E., Harča, V., Onrejičková, A., Priechodsjňká, Z., Remšík, A. & Vass, D., 1981: Správa o výskumnom geotermálnom vrte FGČ-1 v Čilistove. MS, Archive of Geofond, Bratislava.

Franko, O., Fendek, M., Bodiš, D., Brestenská, E., Priechodská, Z. & Vass, D., 1985: Správa o výskumnom geotermálnom vrte FGG-2 Galanta. Manuscript – SGIDŠ Archive, Bratislava.

Franko, O., Zbořil, O. & Mateovič, Ľ., 1976: Správa o výskumných geotermálnych vrtoch FGB-1 a FGB-1A v Chorvátskom Grobe. Manuscript – SGIDŠ Archive, Bratislava.

Gaža, B., 1962: Zpráva o štruktúrnom prieskume v oblasti Sereď v r. 1961. Manuscript – SGIDŠ Archive, Bratislava.

Gaža, B., 1970: Záverečná geologická správa o pionierskom vrte Grob -1, Manuscript, Archive of Nafta a.s., Plavecký Štvrtok.

Grill, R., 1941: Stratigraphische Untersuchungen mit Hilfe von Mikrofaunen im Wiener Becken und den benachbarten Molasse-Anteilen. Öl. u. Kohle (Berlin), 37, 595 – 602.

Vysvetlivky ku geologickej mape severovýchodnej časti Podunajskej nížiny 1: 50 000. GÚDŠ, Bratislava, p. 7 – 114.

Hohenegger, J., Ćorić, S. & Wagreich, M., 2014: Timing of the Middle Miocene Badenian Stage of the Central Paratethys. Geol. Carpath., 65, 1, p. 55 – 66.

Hók, J., Pelech, O., Teťák, F., Németh, Z., & Nagy, A., 2019: Outline of the geology of Slovakia (W. Carpathians). Miner. Slovaca, 51/1, Bratislava. p. 31 – 60.

Hrušecký, I., 1997: Centrálna časť dunajskej panvy na Slovensku – geofyzikálno-geologický model stavby a jeho vplyv na uhľovodíkové perspektívy oblasti. Thesis. Department of applied and environmental geophysics FNS CU Bratislava, 159 p.

Hrušecký, I., 1999: Central part of the Danube Basin in Slovakia: Geophysical and Geological Model in Regard to Hydrocarbon Prospection. Exploration Geophysics, Remote Sensing and Environment,VI, 1, p. 2 – 55.

Hrušecký, I., Pagáč, I. & Pereszlényi, M. et al., 1991: Vyhľadávanie a prieskum na ropu a zemný plyn v podunajskej panve. MS, Archive of Geofond, Bratislava

Hrušecký, I., Pereszlényi, M., Hók, J., Šefara, J. & Vass, D., 1993: The Danube Basin geological pattern in the light of new and reinterpretation of old geophysical data. In: Rakús M. & Vozár J. (eds.): Geodynamický model a hlbinná stavba Západných Karpát, GIDŠ, (Bratislava), p. 291 – 296.

Hrušecký, I., Šefara, J., Masaryk, P. & Lintnerová, O., 1996: The structural and facies development and exploratioon potential of the Slovak part of the Danube Basin In: Wesely, G. & Liebl, W. (eds.): Oil and Gas in Alpidic Thrustbelts and Basin of Central and Eastern Europe. EAGE Spec. Publ. N. 5, p. 417 – 429.

Hrušecký, I., Bielik, M., Šefara, J. & Kúšik, D., 1998: Slovak part of the Danube Basin – From geological structure to lithospheric dynamics-defined from seismic profiles. Contribution to Geophysics and Geodesy, 28, 4, p. 205 – 226.

Hudáčková, N. & Kováč, M., 1993: Zmeny sedimentačného prostredia východnej časti Viedenskej panvy vo vrchnom bádene a sarmate. Miner. Slovaca, 25, 3, p. 202 – 210.

Janáček, J., 1969: Nové stratigrafické poznatky o pliocenní a pleistocenní výplni centrální části Podunajské nížiny. Geol. Práce, Spr. 50, p. 113 – 131.

Kantor, J., Harčová, E. & Rúčka, I., 1987: Izotopový výskum a rádiometrické datovanie z oblasti Veľkej Bratislavy. Manuscript – SGIDŠ Archive, Bratislava.

Kantor, J., Repčok, I., Ďurkovičová, J., Eliáš, K. & Wiegerová, V., 1984: Časový vývoj vybraných oblastí Západných Karpát podľa radiometrického datovania. Manuscript – SGIDŠ Archive, Bratislava.

Kázmér, M., 1990: Birth, Life and Death of the Pannonian Lake. Palaeogeography, Palaeoclimatology, Palaeoecology 79, p. 171 – 188.

Keith, J. F. JR., Vass, D., Kanes, W. H., Pereszlényi, M., Kováč, M. & Kráľ, J., 1989: Sedimentary basins of Slovakia, Part II., Final report on the Hydrocarbon pontenial of Danube Lowland Basin, vol. 1. Manuscript Univ. South Carolina, ESRI, Technical Report 89-0019, p. 1 – 143.

Keith, F. Jr., Vass, D. & Kováč, M., 1994: The Danube Lowland Basin. ESRI, Univ. S.C., Occasional Publ. 11 A, Columbia, p. 63 – 87.

Kilényi, E. & Šefara, J. (eds.), 1989: Pre-Tertiary basement contour map of the Carpathian Basin beneath Austria, Czechoslovakia and Hungary, 1: 500,000. Eötvös Lóránd Geophysical Institute, Budapest, Hungary.

Kováč, M., Andreyeva-Grigorovich, A., Bajraktarević, 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: palaeogeography, climate and eustatic sea-level changes. Geol. Carpath., 58, 6, p. 579 – 606.

Kováč, M., Synak, R., Fordinál, K. & Joniak, P., 2010: Významné eventy v palaeogeografii severnej časti Dunajskej panvy – nástroj na upresnenie stratigrafie jej vrchnomiocénnej a pliocénnej výplne. Acta Geologica Slovaca, 2, 1, p. 23 – 35.

Kováč, M., Synak, R., Fordinál, K., Joniak, P., Toth, Cs., Vojtko, R., Nagy, A., Baráth, I., Maglay, J. & Minár, J., 2011: Late Miocene and Pliocene history of the Danube Basin: inferred from development of depositional systems and timing of sedimentary facies changes. Geol. Carpath., 62, 6, p. 519 – 534.

Koutek, J. & Zoubek, V., 1936: Vysvětlivky ke geologické mapě v měřítku 1 : 75 000, list Bratislava 4758. Knih. St. geol. ústavu ČSR, sv. 18, p. 7 – 150.

Maglay, J., Fordinál, K., Nagy, A., Vlačiky, M. Šefčík, P., Fričovská, J., Moravcová, M., Kováčik, M., Baráth, I. & Zlocha, M., 2018: Geologická mapa Podunajskej nížiny – Podunajskej roviny; Geological map of the Danube Lowland – Danube Flat. Reg. geol. mapy Slovenska 1: 50 000. ME SR & SGIDŠ, Bratislava.

Nagy, A., Fordinál, K., Brzobohatý, R., Uher, P. & Raková, J., 1995: Vrchný miocén juhovýchodného okraja Malých Karpát (vrt Ma-1, Bratislava). Miner. Slovaca, 27, 2, p. 113 – 132.

Pagáč, I. et al., 1995: Zhodnotenie perspektív vyhľadávania uhľovodíkov vo vybraných oblastiach Západných Karpát geofyzikálnymi metódami – časť geotermika. Archive of VVNP, Bratislava.

Pagáč, I., Hrušecký, I., Pereszlényi, M., Bartková, J., Trgiňa, P., Šatalová, M., Vitáloš, R., Kováčik, M., Balucha, M., Matisová, E., Rajec, M., Vaškor, I., Országh, M. & Slávik, M., 1991: Perspektívy vyhľadávacieho prieskumu na ropu a zemný plyn v Podunajskej panve. Manuscript – SGIDŠ Archive, Bratislava.

Papp, A., Cicha, I., Seneš, J. & Steininger, F. P., (eds.), 1978: Chronostratigraphie und Neostratotypen, Miozän M_4, Badenien, Veda Bratislava, p. 1 – 594.

Papšíková, M., 1989: Biostratigrafické vyhodnotenie vrtov z územia Bratislavy (centrálna mestská zóna) na základe palynomorf. Reg. geol. Západ. Karpát, (Bratislava) 25, p. 41 – 42.

Pálfalvi, F., 1975: Geotermálny vrt Bratislava. HGB-1. Manuscript – SGIDŠ Archive,Bratislava.

Pokorný, V., 1946: K mikrostratigrafii neogénu pannonské pánve v okolí Ivánky na Slovensku. Věstník St. geol. úst. Čs. Rep., (Praha), 21, p. 262 – 273.

Priechodská, Z., Harčár, J. (eds.), Karolus, K., Karolusová, E., Remšík, A. & Šucha, P., 1988: Vysvetlivky ku geologickej mape severovýchodnej časti Podunajskej nížiny 1: 50 000. GIDŠ, Bratislava, 114 p.

Royden, L. H., Horváth, F., & Rumpler, J., 1983: Evolution of the Pannonian basin system. I. Tectonics, 2, p. 61 – 90.

Rybár, S., Halásová, E., Hudáčková, N., Kováč, M., Kováčová, M., Šarinová, K. & Šujan, M., 2015: Biostratigraphy, sedimentology and palaeoenvironments of the northern Danube Basin: Ratkovce 1 well case study. Geol. Carpath., 66, 1, p. 51 – 67.

Šefara, J. & Kováč, M., 1996: Reliéf predterciérneho podložia s vyznačením hlavných zón krehkých deformácií in Šujan, M. et al., 1996: Geologické zhodnotenie oblasti atómovej elektrárne Bohunice. Manuscript – SGIDŠ Archive, Bratislava.

Šefara, J., Bielik, M., Bodnár, J., Čížek, P., Filo, M., Gnojek, I., Grecula, P., Halmešová, S., Husák, Ľ., Janoštík, M., Kráľ, M., Kubeš, P., Kucharič, Ľ., Kurkin, M., Leško, B., Mikuška, J., Muška, P., Obernauer, D., Pospíšil, L., Putiš, M., Šutora, A. & Velich, R., 1987: Štruktúrno-tektonická mapa vnútorných Západných Karpát pre účely prognózovania ložísk – geofyzikálne interpretácie. Final report. Manuscript, SGÚ Bratislava, 267 p.

Šujan, M., Braucher, R., Kováč, M., Bourles, D. L., Rybár, S., Guillou, V. & Hudáčková, N., 2016: Application of the authigenic $^{10}Be/^{9}Be$ dating method to Late Miocene-Pliocene sequences in the northern Danube Basin (Pannonian Basin System): Confirmation of heterochronous evolution of sedimentary environments. Global and Planetary Change

Tkáčová, H., Kováčik, M., Caudt, Ľ., Elečko, M., Halouzka, R., Hušták, J., Kubeš, P., Malík, P., Nagy, A., Petro, Ľ., Piovarči, M., Pristaš, J., Rapant, S., Remšík, A., Šefara, J. & Vozár, J., 1996: Podunajsko – Danreg. Čiast. záv. spr. GS SR, Geokomplex, ME SR, MS Geofond, Bratislava, 266 p.

Toula, F., 1915. Tiefbohrung bei Pressburg. Verh. K.-Kön. geol. Reichsanst. (Wien), 14, p. 265 – 271.

Vass, D., 1989: Alpine Molase basins as a mirror of genesis and development of block structure in the West Carpathians. Z. geol. Wiss. (Berlin), 17, 9, p. 879 – 885.

Vass, D., 2002: Litostratigrafia Západných Karpát: neogén a budínsky palaeogén. Št. geol. ústav D. Štúra, Bratislava, 202 p.

Vass, D. & Gašparik, J. et al., 1978: Štúdia o pevných palivách v Západných Karpatoch. Manuscript – SGIDŠ Archive, Bratislava.

Vass, D. & Pereszlényi, M., 1998: Assymetric lithospheric stretching in Danube Basin. Slovak Geol. Mag. 4, p. 61 – 74.

Vaškovský, I., Bárta, R., Hanzel, V., Halouzka, R., Harčár, J., Karolus, K., Pristaš, J., Remšík, A., Šucha, P., Vass, D. & Vaškovská, E., 1982: Vysvetlivky ku geologickej mape juhovýchodnej časti Podunajskej nížiny 1: 50 000. GIDŠ, Bratislava, 115 p.

Slovak Geol. Mag., 18, 2 (2018), 31 – 70

3. Late Quaternary History and Palaeoclimatic Implications of Danubian Flat Based on Dating, Geochemistry, Lithology, Isotope Analyses and Land Snail Assemblages

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Abstract: The paper presents the results of geological research of the Podunajská rovina Flat (hereinafter Danubian Flat) in terms of stratigraphy of near-surface and surface sediments and palaeo-environmental changes in the period from the last interglacial period (Eemian, about 127,000 years BP) to the present. The period of Late Glacial to Holocene was studied in more detail because the climatic transition of the Last Glacial to postglacial had the greatest influence on the formation of the present natural environment, fauna and flora. In this context, the possibility of using isotopic analyses of oxygen and carbon from gastropods shells was also investigated in the reconstruction of palaeoclimatic changes and the natural environment in the past.
Using the AMS ^{14}C method, 24 samples from 16 localities dating from the Late Glacial to Holocene succession were dated. The observed age of dated samples by this method ranged from 135 ± 30 years BP to 14,410 ± 90 years BP. The OSL method of the studied profiles of 15 localities of the Danubian Flat territory dated 22 samples. The age of these dated samples ranged from 127,000 to 314 years BP. The time period from the Eemian Interglacial (i.e. the penultimate glacial period) to the present has been recorded. Both methods specified the stratigraphic position of fluvial and aeolian sediments in the area studied.
Research shows that the climate has never been stable in the past. The alternation of climate cycles during the last (Weichselian) glacial was reflected in the formation of sediments, to which flora, fauna and naturally also human society responded.
The article also highlights the importance and merits of the study of climate change by various scientific disciplines. Without an interdisciplinary approach to the study of climate change, it is not possible to detect, record and accurately interpret minor climate oscillations in the past. Knowledge of climate history and its impact on the natural environment and human civilization is therefore essential for the forecast of future climate change.

Key words: Late Pleistocene, climate, environment, dating, land snails, oxygen isotopes, carbon isotopes

3.1 Introduction

The article presents a synthesis and interpretation of the results of research and laboratory analyses obtained in the framework of the project “Geological map of the region Danube Lowland – Danubian Flat – in scale 1: 50,000”.

Thanks to its sedimentary records in fluvial, aeolian and organogenic deposits as well as soils (including fossil soils) the area of the Danubian Flat provided the possibility of detailed study and evaluation of samples from the above mentioned genetic types of the Quaternary sediments and weathering scree not only from stratigraphic, but also palaeoecological point of view.

The article characterizes climate change from the last interglacial (Eemian) to the present (MIS 5 to MIS 1). This is a period of time that had a great influence on the formation of the current natural environment not only in the area under investigation (Fig. 3.1). The article also deals with the possibilities of using isotopic analyses of oxygen and carbon in land snail shells for reconstructions of climate changes and natural environment in the past.

Fig. 3.1 The area of the Podunajská rovina Flat

3.2 Geological and climate setting

From the geological point of view, the surveyed area is a part of the northwest depocentre of the Neogene Danube Basin termed as the “Slovak part of the Danube Basin”. This basin in the area under investigation is represented by Gabčíkovo Basin.

The sedimentary fill of the Gabčíkovo Basin consists of sub-horizontally deposited, marine, towards the surface brackish to freshwater deposits, generally overlying the pre-Mesozoic bedrock, built mainly of the crystalline rocks. The assumed local Palaeogene part of the basin fill consists of sandstone and claystone. The substantial Neogene sequence consists of sand to sandstone, clay, gravel and locally also volcaniclastics, Miocene to Pliocene in age. The Neogene sequences overlie relatively coarse deposits of the Quaternary fluvial gravel and sand. Fluvial accumulations represent a unique inland delta of the Danube, laterally limited by a smaller delta of the Váh, or Nitra and Žitava rivers. The character of the deposition is superpositional and transitional (Šujan et al., 2018) only at the edges of the flat and along the mountain range foothills there is a terrace development of accumulation. The Holocene fluvial accumulation, aeolian sediments are deposited on the Pleistocene fluvial sediments, and occurrences of organogenic sediments are also common. (Maglay et al., in press).

The total sedimentary fill of the basin reaches a maximum of 8,000 to 9,000 m according to seismic sections (sensu Hrušecký, 1999). The basin was formed by active arc extension and subsequent thermal subsidence in the post-rift stage of development (Hók et al., 2001; Horvath et al., 2006; Kováč et al., 2011; Kováč et al., 2017).

The area of the Gabčíkovo Basin roughly corresponds to the on the surface geomorphologically delimited area of the Danubian Flat (Mazúr & Lukniš, 1986; Fig. 3.2). Its fluvial relief is morphotectonically undifferentiated, planar, slightly undulated with an average slope of 1.5° (max. to 2°). According to Mazúr (in Mazúr & Jakál – eds., l.c.), the horizontal structure of the relief is in the range of 0 – 0.5 km/km^2. It is a fluvial plain, sometimes even fluvial and peat wetland with recent, locally erosive, mostly laterally acting processes.

The low height segmentation of the Danubian Flat is reflected in the small climatic differences among its individual parts. Most of the territory under study belongs to a warm, slightly dry to dry climate area with a warm, slightly dry to dry lowland climate with temperature inversion (Konček, in Mazúr & Jakál – eds., 1980; Lapin et al., in Atlas of the Slovak Republic, 2002). It is characterized by a mild winter (up to 90 days) with an average temperature in January of -3 °C and higher; a warm summer with a number of summer days (above 25 °C) of more than 50 per year. The mean annual temperature (MAT) in the lowland ranges from 8 to 10 °C (Šťastný et al., in Atlas in the Slovak Republic, 2002). A characteristic feature of the Danubian Flat is its aridity. Average annual rainfall totals range between 530 – 700 mm/year, which is the lowest in Slovakia, only at the edge of the Malé Karpaty Mts. the values reach between 600 – 900 mm/year. In January, average totals range from 30 to 50 mm. The July totals for the whole territory reach values in the range of 60 – 80 mm (Faško & Šťastný in Atlas of the

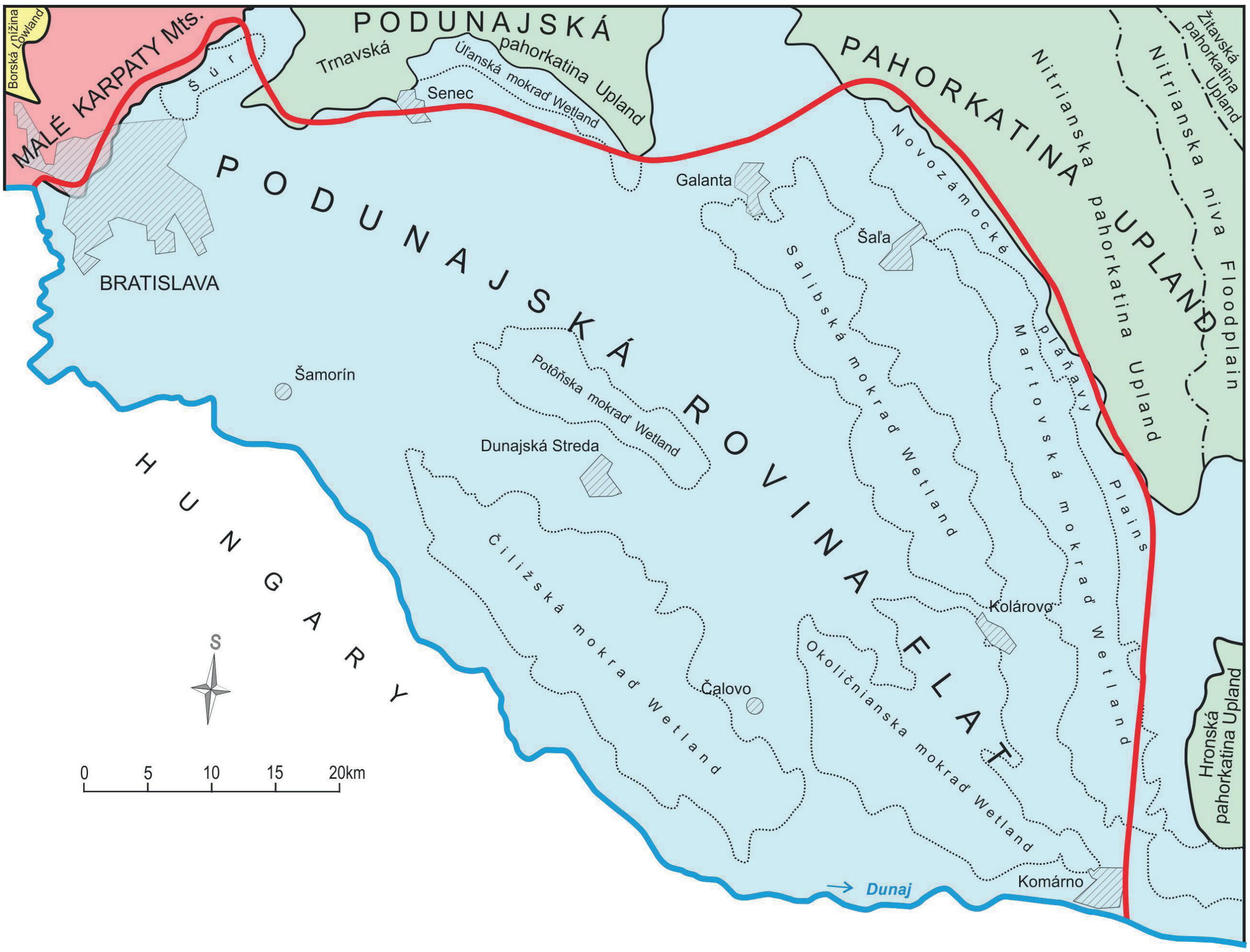

Fig. 3.2 Schematic outline of the geomorphological division of the Danube Flat (According to Mazúr & Lukniš, 1980, revised by Maglay, 2017). The red line indicates the studied area of the Danube Flat.

Slovak Republic, 2002). The average dry period lasts 30 – 50 days a year (Tarábek in Mazúr & Jakál – eds., 1980). The whole area is dominated by NW winds; less frequent are N and S winds. Their average speed ranges from 2 to 4 m.s^{-1}.

3.3. Materials and methods

Field research

Within geological mapping and field research, 13 sites with fluvial sands, 3 sites with aeolian sands, 13 sites with well-preserved fossil soils and 1 site with humoliths in oxbows fills. From 2 sites the gastropods were dated and studied and from 1 site the wood fragment.

Detailed field research included the preparation and cleaning of sampling profiles, macroscopic sedimentological analysis, GPS positioning with photodocumentation, sediment colour determination according to the Munsell scale, precise and systematic sampling – sampling for malacofauna analyses, geochemical analyses and dating by OSL and ^{14}C AMS dating methods (Fig. 3.3). Samples for analyses were also taken in some cases from hand drilled probes with a depth of up to 1.2 m.

^{14}C dating with the AMS technique

^{14}C AMS dating was performed in the AMS ^{14}C laboratory of the a Mickiewicz Unoversity in Poznań, Poland. Procedure of ^{14}C dating with the AMS technique, consists of a few stages:

a) chemical pre-treatment
b) production of CO_2 and graphitisation
c) AMS ^{14}C measurement
d) calculation of ^{14}C age and calibration of ^{14}C age

a) Methods of chemical pre-treatment generally follow those used in the Oxford Radiocarbon Accelerator Unit, as described by Brock et al. (2010). Samples of charcoal, wood, or other plant remains (after mechanical removal of macroscopic contamination visible under binocular) are treated with 1M (UW, ZR) HCl (80 °C, 20+ min), 0.025-0.1M NaO-Hand – if needed – 80 °C for wood and charcoal (UW, ZR) and then 0.25M HCl (80 °C, 1 hour). After treatment with each reagent, the samples are rinsed with deionised water (Millipore) until pH=7. For the first HCl treatment, longer time (20+ min) is applied, if emanation of gas bubbles from sample is still visible. The step of NaOH treatment is repeated a few times, generally until no more coloration of the NaOH solution appears (coloration of solution is caused by humic acids dissolved in NaOH), but the NaOH treatment is interrupted if there is a danger of complete dissolution of the sample.
In case of wood samples (UW), additional treatment with 5% $NaClO_2$ (room temperature, 30 min) is applied.
Samples of sediments (and soils) are usually treated with 1M HCl (80 °C, 1+ hour), 0.1M NaOH (80 °C,

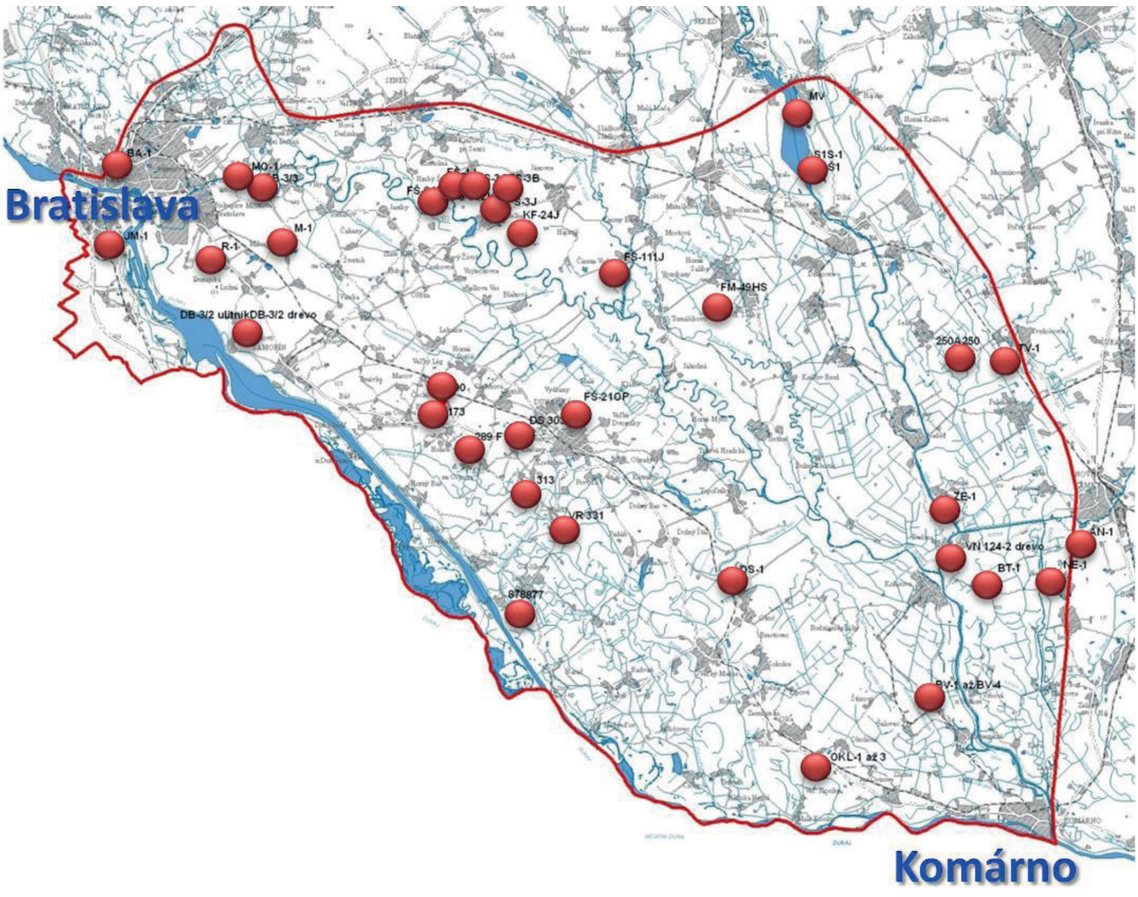

Fig. 3.3 Sites with ^{14}C AMS and OSL methods dating

10+ min) and then 0.25M HCl (80 °C, 1 hour) (SRa). After treatment with each reagent, the samples are rinsed with deionised water (Millipore) until pH=7. For the first HCl treatment, longer time (1+) is applied, if emanation of gas bubbles from a sample is still visible. The step of NaOH treatment is repeated a few times, generally until no more coloration of the NaOH solution appears (coloration of solution is caused by humic acids dissolved in NaOH).

Samples of shells (and other carbonate features) are checked and mechanically cleaned under binocular. The organic coating, if visible, is removed with H_2O_2 (15 – 30%) in an ultrasonic bath. Then the outer carbonate layer (ca. 30%) is removed in 0.5M HCl (if the sample is large enough), the remaining material is treated in 15% H_2O_2 again (for 10 min in a ultrasonic bath) and the remaining carbonate is leached with concentrated H_3PO_4 in a vacuum line.

b) In case of organic samples, CO_2 is produced by combusting the sample. Combustion of organic samples is performed in closed (sealed under vacuum) quartz tubes, together with CuO and Ag wool, in 900 °C over 10 hours. CO_2 from carbonate samples is leached by treating with concentrated orto-phosphoric acid (H_3PO_4) in a vacuum line.

The obtained gas (CO_2 + water vapour) is then dried in a vacuum line, and reduced with hydrogen (H_2), using 2 mg of Fe powder as a catalyst. The obtained mixture of carbon and iron is then pressed into special aluminium holder, according to the description provided by Czernik & Goslar (2001).

In the same way were prepared the standard samples, i.e. samples not containing ^{14}C (coal or IAEA C1 Carrara Marble) and samples international modern ^{14}C standard (Oxalic Acid II).

c) Measurements described in this point, are performed in the AMS ^{14}C Laboratory of the A. Mickiewicz University in Poznań. Cooperation between the Poznań Radiocarbon Laboratory and the AMS ^{14}C Laboratory is regulated by the Agreement between Foundation of the A. Mickiewicz University and the A. Mickiewicz University.

Content of ^{14}C in a sample of carbon is measured using the spectrometer "Compact Carbon AMS" (produced by: National Electrostatics Corporation, USA) described in the paper: Goslar & Czernik (2001), Goslar (2004). The measurement is performed by comparing intensities of ionic beams of ^{14}C, ^{13}C and ^{12}C measured for each sample and for standard samples (modern standard: "Oxalic Acid II" and standard of ^{14}C-free carbon: "background"). In each AMS run, 30 – 33 samples of unknown age are measured, alternated with measurements of 3 – 4 samples of modern standard and 1 – 2 samples of background. In case, where organic samples are dated, the background is represented by coal, while in case of carbonate samples, the background is represented by the sample IAEA C1.

d) Conventional ^{14}C age is calculated using correction for isotopic fractionation (according to Stuiver&Polach, 1977), basing on ratio $^{13}C/^{12}C$ measured in the AMS spectrometer simultaneously with the ratio $^{14}C/^{12}C$ (note: the measured values of $\delta^{13}C$ depend on isotopic fractionation during CO_2 reduction and isotopic fractionation inside the AMS spectrometer, and as such, they cannot be compared with values of $\delta^{13}C$ determined with conventional mass spectrometers on gas samples). Uncertainty of calculated ^{14}C age is determined using uncertainty implied from counting statistics, and also spread (standard deviation) of partial $^{14}C/^{12}C$ results, whichever is bigger. Uncertainties of $^{14}C/^{12}C$ ratios measured on standard samples are additionally taken into account. The 1-sigma uncertainty of conventional ^{14}C age given in Poznań Laboratory reports is the best estimate of the total uncertainty of measurement.

Calibration of ^{14}C age is performed using the program OxCal ver. 4.2 (2014), the ground of which is described by Bronk Ramsey (2001), while the recent version – by Bronk Ramsey (2009), and Bronk Ramsey and Lee (2013). Calibration is performed against the newest version of ^{14}C calibration curve, i.e. INTCAL13 (Reimer et al. 2013).

Optically stimulated luminescence (OSL)

OSL dating was performed in Silesian University of Technology, Institute of Physics, Gadam Centre, Gliwice, Poland. The annual dose was calculated using Canberra spectrometer equipped with HPGe detector. Typical mass of dry sample was about 800 g, which was measured at least 24 hours. Dose rates were calculated using the conversion factors devised by Guerin et al. (2011). For beta dose rates, the cosmic ray dose-rate at the site was determined as described by Prescott & Stephan (1982). We assumed that the average water content was no higher than 20% and consequently used a value of (15±5) %.

For standard OSL measurements, medium sized grains (45 – 63 µm) of quartz were extracted from the sediment samples. Laboratory protocol includes few steps of chemical treatment such as 20% hydrochloric acid (HCl), 20% hydrogen peroxide (H_2O_2) and finally concentrated hydrofluoric acid (HF). The quartz grains were also separated using density separation with the application of sodium polytungstate solutions leaving grains of densities between 2.62 $g.cm^{-3}$ and 2.75 $g.cm^{-3}$. The quartz fraction discs were prepared by spraying silicone oil on to 10-mm-diameter stainless steel discs through a mask with holes of a diameter of ca. 6 mm allowing for ca. 1 mg of grains be stuck on them.

All OSL measurements were made using an automated Daybreak 2200 TL/OSL reader (Bortolot, 2000). This reader uses blue diodes (470±4 nm) delivering about 60 $mW.cm^{-2}$ at the sample position and is equipped with 6 mm Hoya U-340 filter for the OSL measurements. Laboratory irradiations were made using a calibrated $^{90}Sr/^{90}Y$ beta source mounted onto the reader with a dose rate of 3.0 $Gy.min^{-1}$.

For the medium grain quartz fraction, equivalent doses were determined using the single-aliquot regenerative-dose (SAR) protocol (Murray & Wintle, 2000). Ages calculated using the Central Age Model (CAM) (Galbraith et al., 1999).

Stable isotopes

Stable isotope analyses were preformed in the laboratory of isotope geology, State Geological Institute of Dionýz Štúr, Bratislava, Slovakia.

Measurement principle for carbon

Isotope ratio mass spectrometry (IRMS) represents the preferred method for analyses of the bulk $^{13}C/^{12}C$ carbon isotope ratio at natural abundance, because of the relative high accuracy (0.1‰) and sensitivity (up to 0.01‰). The element of interest must be isolated from the sample matrix and converted to a gas that is stable and unreactive at room temperature. In the case of carbon, samples are analyzed as CO_2 (Fry, 1991). In the EA/IRMS technique, the sample is instantaneously melted and cracked by thermal treatment, oxidized (in the presence of O_2) and converted into homogenous combustion gases (CO_2, N_2 and H_2O) in amounts stoichiometrically equivalent to its elemental components in the sample. These effluent gases (A water removal trap filled with anhydrous magnesium perchlorate [$Mg(ClO_4)_2$] removes H_2O present in the mixture) are carried in a stream of He and introduced into the IRMS as transient peaks. Unlike the GB technique, which allows determination of $\delta^{13}C$ and $\delta^{18}O$ of sample CO_2 gas during a single run, the EA technique only allows determination of $\delta^{13}C$ of sample CO_2 during a single run. The analytical circuit of the EA comprises of a combustion reactor (Cr_2O_3 catalyst and Co_3O_4 coated with silver), a reduction reactor (reduced copper wire, 0.7 mm diameter) and a GC column (Paul & Skrzypek, 2006).

All carbon isotopic compositions of samples are reported in the standard δ -notation in the $^{13}C_{V\text{-}PDB}$ scale:

$$\delta_e = \left(\frac{R_{sample}}{R_{reference}} - 1 \right) \times 1000$$

δ_e is defined as the relative difference, in parts per mille (‰), between the isotope ratio of the sample and the VPDB carbonate standard (established by the International Atomic Energy Authority, IAEA, Vienna) (Werner & Brand, 2001).

Measurement procedure

For sample combustion, the peripheral EA unit (Flash HT 2000, Thermo Fisher) was connected to IRMS spectrometer (Delta V Advantage, Thermo Fisher). A small amount of the sample (about 350 µg) was wrapped into a silver capsule, which was dropped through the autosampler (AS2000, Thermo Fisher) to the furnace tube heated to 1,020 °C. The sample was flash-combusted with the assistance of oxygen pulse and the resulting gases were flown through a silica column packed with chromium oxide, reduced copper and silver cobaltous-cobaltic oxide, which served as further oxygen donors to ensure complete sample combustion. By this way, all carbon was fully oxidised to CO_2 and $\delta^{13}C$ was measured by the mass spectrometer (Grolmusová et al., 2012). The ion currents of mass/proton number 44–46 were registered and the results were calculated relative to a CO reference gas. The duration of one sample run was 500 s.

Samples and standardization

The calibration samples were internationally distributed reference materials and standards. 350 µg of $CaCO_3$ samples and standards were weighed into silver capsules (3.3 x 5 mm, Säntis Analytical. Standards used were IA-R022 (Iso-Analytical, $\delta^{13}C_{V\text{-}PDB}$ = -28.63‰), NBS 19 (IAEA, $\delta^{13}C_{V\text{-}PDB}$ = 1.95‰) and IAEA KST (IAEA, $\delta^{13}C_{V\text{-}PDB}$ = -5.76‰). Used laboratory standards are intended to provide a samples of known isotope composition with $^{13}C/^{12}C$ and $^{18}O/^{16}O$ isotope ratios stated in parts per thousand difference (‰) from the V-PDB (Pee Dee Belemnite) isotope ratio standard.

Measurement principle for oxygen

Precise $\delta^{18}O$ analyses of carbonate samples can be performed with the high-temperature pyrolysis method in an Elemental Analyzer (using CO as the analyte gas) (Gehre et al., 2003) coupled with isotope ratio mass spectrometer (IRMS). A prerequisite for an on-line technique for $\delta^{18}O$ measurement is a fast and quantitative conversion of the sample oxygen to a single gaseous product (Kornexl et al., 1999). The precision of TC/EA-IRMS is in general close to or slightly lower than other methods, but it has the combined advantages of minimal sample amount requirement, easy operation, high throughput, and most importantly, the capability to measure the $\delta^{18}O$ value of different types of substances (Yin & Chen, 2014). The apparatus consists of a thermal conversion — elemental analyzer (TC/EA) unit, which is a graphite crucible (composed of an outer reaction tube made of Al_2O_3 ceramic and an inner glassy carbon tube) inserted in the hottest zone of the reaction furnace, and heated to 1,450 °C. At these temperatures, carbon from the inner tube and glassy carbon grit, which partially fill the reactor, primes the reduction of the analyzed compounds following the reaction

$$O\ compound_{(s)} + C_{(s)} = CO_{(g)} + [residuals]_{(s,g,l)}$$

For such measurements on inorganic compounds it is necessary to have a reactive carbon source near the sample (Boschetti & Iacumin, 2005). The mass spectrometer software calculates their isotope ratio and the final result for the sample in the δ notation, given in ‰ deviation from the reference :

$$\delta_e = \left(\frac{R_{sample}}{R_{reference}} - 1 \right) \times 1000$$

In practice, a series of standardization runs are performed to calibrate the reference CO gas, which will subsequently be used as a standard during the measurement (Koziet, 1997).

Measurement procedure

The reaction furnace is heated to maximum temperature of 1,450 °C. With command given by software (ISODAT3.0, Thermo Fisher), the autosampler (AS2000, Thermo Fisher) dropped the samples into the reaction tube, flushed with the constant flow (140 mL/min) of carrier gas (He, 99.999%). Carrier gas transported the main gaseous products of pyrolysis through $MgClO_4$ trap (for retention of H_2O) and GC column held at 90 °C, where CO was separated from other gases. Consequently, CO was transferred via a ConFlo IV open split interface to the Delta V Advantage isotope ratio mass spectrometer (both Thermo Fisher). The ion currents of mass/proton number 28–30 were registered and the results were calculated relative to a CO reference gas (Fig. 3.4). The duration of one sample run was 360 s.

Samples and standardization

The calibration samples were internationally distributed reference materials and standards. 150 µg of $CaCO_3$ samples and standards were weighed into silver capsules (3.3 x 5 mm, Säntis Analytical) with addition of 200 µg of carbon (internal laboratory grade) for better thermal conversion. Standards used were IA-R022 (Iso-Analytical, $\delta^{18}O_{V\text{-}PDB}$ = -22.69‰) and NBS 19 (IAEA, $\delta^{18}O_{V\text{-}PDB}$ = -2.2‰). Used laboratory standards are intended to provide a samples of known isotope composition with $^{13}C/^{12}C$ and $^{18}O/^{16}O$ isotope ratios stated in parts per thousand difference (‰) from the V-PDB (Pee Dee Belemnite) isotope ratio standard.

3.4 Results and discussion

3.4.1 Sites dating using ^{14}C AMS and OSL dating methods

To determine the age of fossil soils, gastropods and woods we used mass spectrometry of the ^{14}C AMS dating method. Altogether 24 samples from 16 localities were dated by this method (Tab. 3.1).

The age of the dated samples ranged from 135 ± 30 years BP to 14,410 ± 90 years BP. One sample was outside the ^{14}C AMS dating method range. It came from the well VN 124-2 (Kolárovo). Its age was more than 50,000 years BP (Tab. 3.1).

The samples were dated in AMS ^{14}C Laboratory of A. Mickiewicz University in Poznań, Poland.

Optically stimulated luminescence (OSL dating) was used to determine the age of aeolian and fluvial sands. Altogether 22 samples from 17 sites were dated by this method.

The age of the dated samples ranged from 314 to 127,000 years BP (Tab. 3.1).

The age of all dated samples by ^{14}C AMS and OSL ranged from 135 ± 30 years BP to 127,000 ± 1000 years BP. The dated samples captured the time period from the Eemian Interglacial (i.e. the last interglacial period) to the present (Tab. 3.1).

A description of the sedimentary development of dated sites is discussed in more detail in the summary work Maglay et al. (in press).

We used time data according to Musil (2014) to classify them into timescale.

3.4.2 The character of climate in the period of origin of dated soils and organic residues

For better understanding and orientation in the timelines presented in this article, we compare $\delta^{18}O$ records of the NGRIP and GRIP glacier core for the last 123,000 years in 20 year resolution (Fig. 3.5), the last 30,000 years in 50 year resolution (Fig 3.6) and the last 19 000 years in 20 year resolution (Fig. 3.7; according to Lowe et al., 2008). Fig. 3.5 displays a detailed comparison of Greenlandic Glacier Chronology (GICC05) records at 20 years (blue curve) and ^{14}C AMS dating samples from the Danubian Flat.

In Fig. 3.7 a detailed comparison of Greenland Glacier Chronology (GICC05) records at 20 years (blue curve)

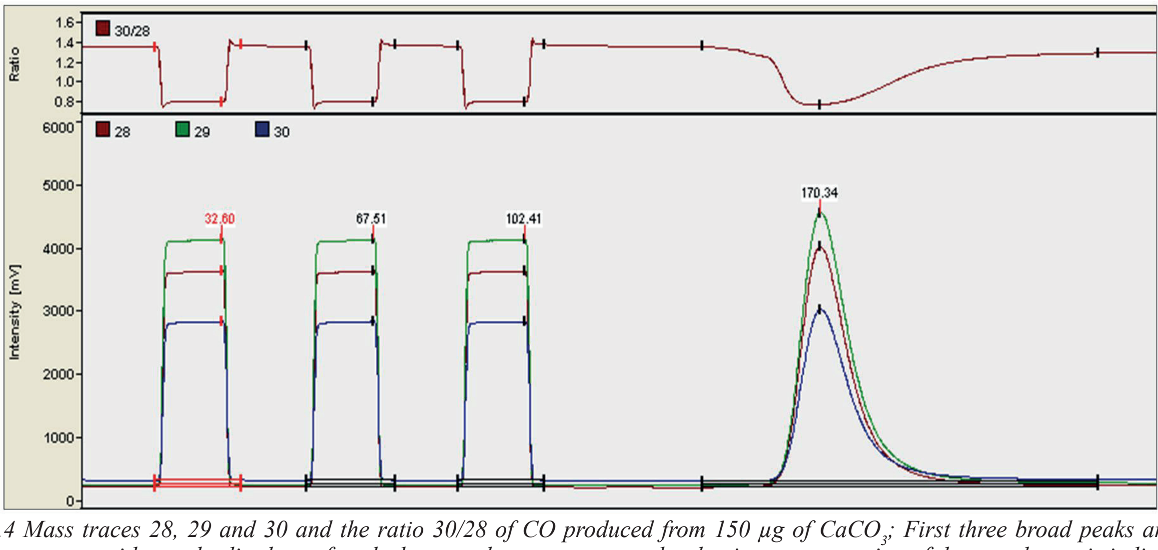

Fig. 3.4 Mass traces 28, 29 and 30 and the ratio 30/28 of CO produced from 150 µg of $CaCO_3$; First three broad peaks are zero enrichment tests with standardized gas, fourth sharp peak represents sample; the time programming of the sample run is indicated at the top of peaks

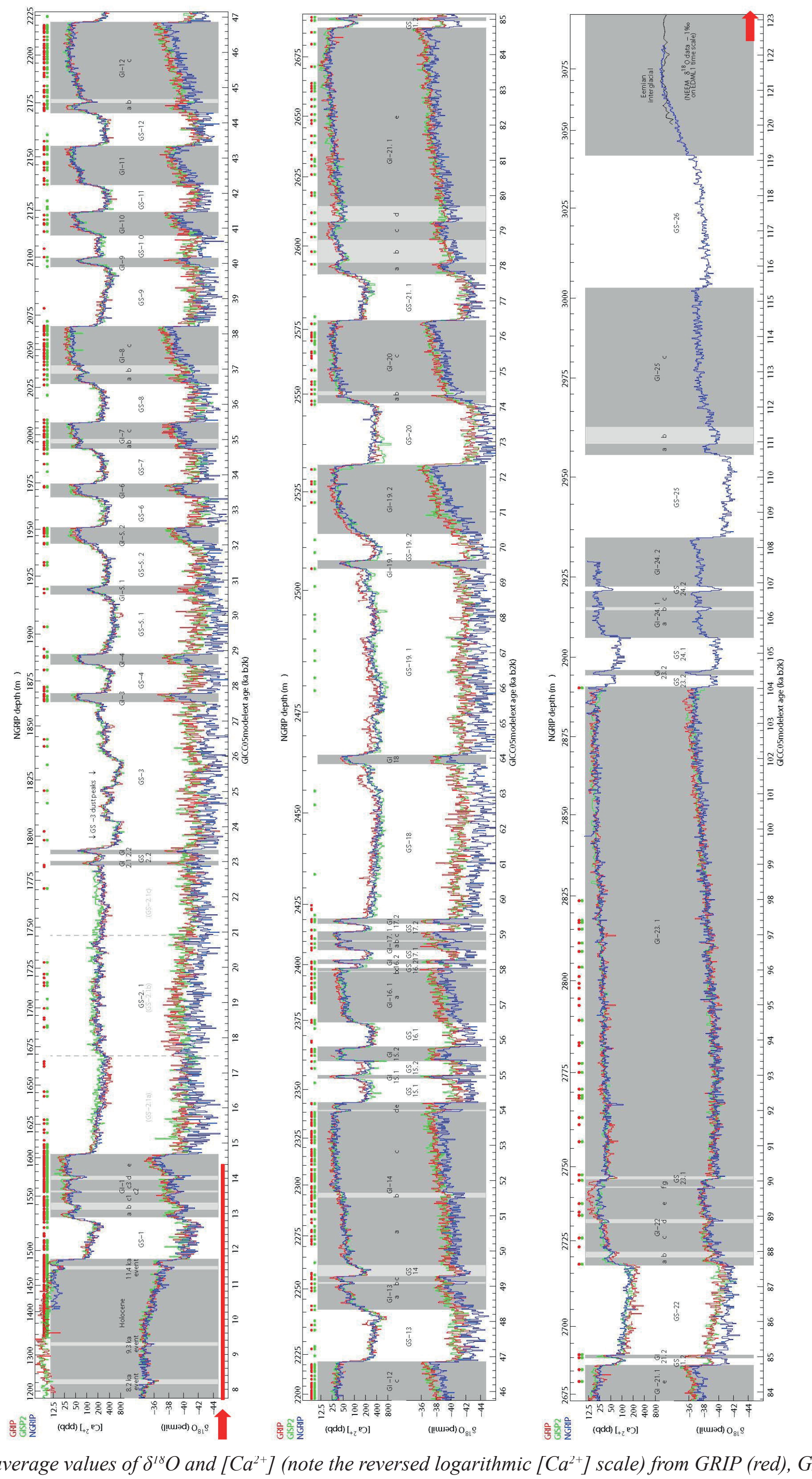

Fig. 3.5. 20-year average values of $\delta^{18}O$ and $[Ca^{2+}]$ (note the reversed logarithmic $[Ca^{2+}]$ scale) from GRIP (red), GISP2 (green), and NGRIP (blue) on the GICC05modelext time scale. The dots just below the upper NGRIP depth axis show the position of the match points used to transfer the GICC05 modelext time scale from NGRIP to the GRIP (red dots) and GISP2 (green dots) records. The proposed extension of the INTIMATE event stratigraphy scheme is shown with interstadials illustrated by grey shading (light grey indicates cold sub-events). In the Eemian Interglacial, NGRIP data are extended by NEEM $\delta^{18}O$ data offset by 2‰ (NEEM community members, 2013). Note the small time overlap between the three panels introduced to ease interpretation (see above for a detailed description.) (Rassmussen, et al., 2014). The red bars with the red arrow indicate the periods in which dated fluvial sands, aeolian sands, fossil soils, timber, and gastropod shells from the Danubian Flat study area fall.

Tab. 3.1 Results of dating fluvial sands, aeolian sands, fossil soils, woods and gastropod shells from the studied area using OSL and ^{14}C AMS methods

lab. code	design ation	localisation	depth (m)	coordinates N	coordinates E	age (years BP)	deviation (years BP)	age (years cal. BP)	sediment type	dating method	chronozone (BP, cal BP)	Holocene stages	series
Poz-74252	DB-3/2	Most	1.5	48° 03′ 10.5′′	17° 15′ 44.1′′	**135**	± 30 BP	240 – 38	wood	^{14}C AMS	Younger Subatlantic (920 BP – present)	Meghalayan	HOLOCENE
GdTL-2542	FS-3B	Jelka	0.6	48°09′54′′	17°30′58′′	**314**	± 28 BP	-	aeolian sand	OSL			
Poz-74920	FS-3j	Jelka	1.05 – 1.1	48° 09′ 23.99′′	17° 30′ 58.0′′	**835**	± 30 BP	777 – 717	soil	^{14}C AMS			
Poz-74922	FS-4j	Jelka	0.45 – 0.58	48° 09′ 58.99′′	17° 28′ 31.0′′	**960**	± 30 BP	918 – 824	soil	^{14}C AMS	Older Subatlantic (2,750 – 920 BP)		
GdTL-2544	MO-1	Most pri Bratislave	2.3	48° 09′ 21.0′′	17° 14′ 56.8′	**1,230**	± 120 BP	-	fluvial sand	OSL			
GdTL-2543	R-1	Rovinka	1.5	48° 05′ 53.4′′	17° 13′ 33.0′	**1,690**	± 120 BP	-	fluvial sand	OSL			
GdTL-2670	ZE-1	Zemné	2.1	47° 58′ 22.99′′	18° 0′ 23.35′′	**1,690**	± 210 BP	-	fluvial sand	OSL			
Poz-73939	DB-3/2	Most pri Bratislave	0.8	48° 03′ 10.5′′	17° 15′ 44.1′′	**1,835**	± 30 BP	1,794 – 1,716	gastropod shell *Arianta arbustorum*	^{14}C AMS			
Poz-75138	KF-24j	Jelka	0.35-0.70	48° 08′ 25.99′′	17° 32′ 05.0′′	**2,340**	± 30 BP	2,646 – 2,346	soil	^{14}C AMS			
Poz-75133	878	Gabčíkovo	0.6 – 0.8	47° 52′ 39.99′′	17° 34′ 32.0′′	**2,595**	± 30 BP	2,755 – 2,729	soil	^{14}C AMS			
Poz-85102	250	Jánošíkovo	0.65 – 0.75	48° 04′ 52.18′′	18° 0′ 05.06′′	**2,790**	± 30 BP	2,934 – 2,862	soil	^{14}C AMS	Subboreal (4,950 – 2,750 BP)		
Poz-75137	FS-64zk	Hurbanova Ves	0.6-0.9	48° 09′ 06.99′′	17°27′ 08.0′′	**2,830**	± 30 BP	2,977 – 2,895	soil	^{14}C AMS			
Poz-75135	FS-21op	Malé Blahovo	0.75 – 1.1	48° 09′ 06.99′′	17°27′ 08.0′′	**2,862**	± 30 BP	3,044 – 2,946	oxbow fill	^{14}C AMS			
Poz-78072	MV-20	Šoporňa	2.45	48° 01′ 06.2′′	17° 36′ 58.2′′	**2,935**	± 35 BP	3,162 – 3,032	soil	^{14}C AMS			
Poz-78071	S1	Štrkovec	1.5 – 1.6	48° 14′ 29.0′′	17° 49′ 11,66′	**3,750**	± 30 BP	4,155 – 4,035	humoliths	^{14}C AMS			
Poz-75132	877	Gabčíkovo	0.4 – 0.6	48° 12′ 06.87′′	17° 50′ 37.89′′	**3,780**	± 35 BP	4,222 – 4,106	soil	^{14}C AMS			
Poz-78079	173	Čechová	0.6 – 0.7	47° 52′ 38.99′′	17° 34′ 33.0′′	**4,010**	± 30 BP	4,515 – 4,445	soil	^{14}C AMS			
Poz-78073	FM-49C	Horné Saliby	0.6-0.85	48°00′32′′	17°28′29′′	**4,250**	± 40 BP	4,852 – 4,730	soil	^{14}C AMS		Northgrippian	
Poz-75131	DB-3/3	Most	1.15	48° 06′ 11.7′′	17° 44′ 48.2′′	**4,760**	± 35 BP	5,568 – 5,472	soil	^{14}C AMS			
Poz-78078	313	Okrúhle Jazero-Moravské Kračany	2-2.3	48° 03′ 10.5′′	17°15′44.1′′	**4,890**	± 40 BP	5,658 – 5,606	soil	^{14}C AMS			
Poz-74923	JM-1	Bratislava Petržalka	0.8 – 0.9	47°57′28′′	17° 34′ 30′′	**4,970**	± 35 BP	5,736 – 5,660	soil	^{14}C AMS	Late Atlantic (7,050 – 4,950 BP)		
Poz-85103	250A	Jánošíkovo	0.85 – 1	48° 04′ 52.18′′	18° 0′ 05.06′′	**5,155**	± 35 BP	4,011 – 3,941	soil	^{14}C AMS			
Poz-75134	FS-53zk	Nový Život-Šalamúnove polia	0.5 – 1	48° 7’ 2,1”	17° 28’ 30,7”	**5,600**	± 40 BP	6,420 – 6,334	soil	^{14}C AMS			
GdTL-2674	BV-4	Balvany	1.8	47° 50′ 27.47′′	18° 0′ 18.23′′	**5,660**	± 460 BP	-	aeolian sand	OSL			
GdTL-2677	BT-1	Batoňa	1.6	47° 55′ 33.27′′	18° 03′ 30.84′′	**5,870**	± 400 BP	-	fluvial sand	OSL			
GdTL-2666	OKL-1	Okoličná na Ostrove	3.9	47° 47′ 03.8′′	17° 54′ 14.1′′	**6,240**	± 460 BP	-	fluvial sand	OSL			
Poz-78076	190 F	Čechová	1.1 – 1.2	48° 00′ 57′′	17°28′29′′	**7,110**	± 50 BP	7,980 – 7,884	soil	^{14}C AMS	Early Atlantic (7,900 – 7,050 BP)		
GdTL-2669	OS-1	Opatovský Sokolec	0.9	47° 54′ 32.7′′	17° 47′ 32.58′′	**7,170**	± 530 BP	-	fluvial sand	OSL			
GdTL-2678	NE-1	Nesvady	3.8	47° 55′ 56.53′′	18° 07′ 35.06′′	**7,170**	± 420 BP	-	aeolian sand	OSL			
GdTL-2668	OKL-3	Okoličná na Ostrove	2.55	47° 47′ 03.8′′	17° 54′ 14.1′′	**7,880**	± 580 BP	-	fluvial sand	OSL			
GdTL-2541	FS-3A	Jelka	2.45	48° 09′ 54′′	17°30′58′′	**8,040**	± 520 BP	-	aeolian sand	OSL	Boreal (9,000 – 8,000 BP; 10,203 – 8,900 cal. BP)		
GdTL-2667	OKL-2	Okoličná na Ostrove	3.1	47° 47′ 03.8′′	17° 54′ 14.1′′	**8,460**	± 470 BP	-	fluvial sand	OSL		Greenlandian	
GdTL-2533	M-1	Miloslavov	2.5	48° 06′ 57.9′′	17° 17′ 58.11′′	**8,470**	± 680 BP	-	fluvial sand	OSL			
GdTL-2530	DS 303	Dunajská Streda	1.7	47° 59′ 55′′	17°33′43′′	**8,520**	± 470 BP	-	fluvial sand	OSL			
GdTL-2673	BV-3	Balvany	1.7	47° 50′ 27.47′′	18° 0′ 18. 23′′	**9,540**	± 770 BP	-	aeolian sand	OSL	Preboreal 10,000 – 9,000 BP; 11,734 – 10,203 cal. BP)		
GdTL-2671	BV-1	Balvany	5.4	47° 50′ 27.47′′	18° 0′ 18.23′′	**9,610**	± 930 BP	-	aeolian sand	OSL			
GdTL-2545	O-1	Oldza	0.85	48° 04′ 21.0 ″	17° 25′ 12.8 ″	**9,840**	± 470 BP		fluvial sand	OSL			
GdTL-2672	BV-2	Balvany	0.55	47° 50′ 27.47′′	18° 0′ 18. 23′′	**10,320**	± 970 BP	-	fluvial sand	OSL			
GdTL-2531	VR 331	Vrakúň	0.7	47°56′06′′	17°36′41′′	**11,530**	± 840 BP	-	fluvial sand	OSL			

Tab. 3.1 – Continue

lab. code	designation	localisation	depth (m)	coordinates N	coordinates E	age (years BP)	deviation (years BP)	age (years cal. BP)	sediment type	dating method	chronozone (BP, cal BP)	Holocene stages	series
GdTL-2532	S-1	Štrkovec	4.2	48° 12´ 06.87´´	17° 50´ 37.89´´	**11,850**	± 920 BP	-	fluvial sand	OSL	Late Glacial 15,000 – 11,700 years BP (18,252 – 11,734 cal. BP)		PLEISTOCENE
GdTL-2675	TV-1	Tvrdošovce	1.7	48° 04´ 46.82´´	18° 03´ 34.66´´	**12,630**	± 930 BP	-	fluvial sand	OSL			
GdTL-2676	AN-1	Aňala	1.6	47° 57´ 23.7´´	18° 08´ 58.37´´	**12,700**	± 1,100 BP	-	fluvial sand	OSL			
Poz-78074	FŠ-111	Čierna Voda	0.65-1.1	47° 07´ 04.7´´	17° 38´ 36.6´´	**13,020**	± 800 BP	16,303 – 15,483	soil	^{14}C AMS			
Poz-78131	Š-1	Štrkovec	1	48° 12´ 06.87´´	17° 50´ 37.89´´	**13,370**	± 900 BP	16,730 – 15,874	gastropod	^{14}C AMS			
Poz-78132	Š-2	Štrkovec	3.5	48° 12´ 06.87´´	17° 50´ 37.89´´	**13,410**	± 700 BP	16,722 – 15,938	gastropod	^{14}C AMS			
Poz-78075	289F	Lúč na Ostrove	0.8-1.2	47° 59´ 0,1”	17° 30´ 24,5”	**14,410**	± 900 BP	17,814 – 17,300	soil	^{14}C AMS			
Poz-74329	VN 124-2	Kolárovo	30.0-30.2	47° 56´ 21.09´´	18° 01´ 23.26´´	**>50,000 BP**		-	wood	^{14}C AMS			
GdTL-2529	BA-1	Bratislava		48° 09´ 21.5´´	17° 07´ 05.7´	**127,000**	± 1,000	-	fluvial sand	OSL	EemianIntergla-cial(Riss-Würmint-erglacial) (130,000 – 115,000 years BP)		

and ^{14}C AMS dating of samples (red lines) and OSL dating (blue lines) from the Danubian Flat region is shown.

3.4.2.1 Pleistocene

Dated sediments and organic residues from the Danube Lowland study area cover the period from the last interglacial (Eemian or Riss/Würm), the Last Glacial (Weichselian Glacial, Würm) (delimited in the marine isotopic MIS 5-2 stages) untill the Holocene period (MIS 1). The period of the Last Glacial is traditionally divided into Early Glacial (Eoglacial, ~ 100–70 ka BP, MIS 5d-5a), Pleniglacial (~ 70–15 ka BP, MIS 4-2) and Late Glacial (~ 15–11.7 ka BP).

Eemian Interglacial (Riss-Würm Interglacial) (130,000 – 115,000 years BP)

The onset of the Eemian Interglacial (MIS 5e, 130,000 years BP) was very sudden and pronounced compared to Holocene. In less than 2,000 years, fully involved, highly diversified forest communities had probably originated. A characteristic difference from Holocene Interglacial is the high proportion of Atlanto-Mediterranean elements (e.g. holly, hackberry, yew, ivy) in traditional European stands (oak, ash, elm, linden, hazel, etc.), while some of the leading vegetation elements of the Holocene hardly ever appeared here (e.g. beech). The climate of the Eemian Interglacial was probably a little warmer and significantly wetter than the Holocene climate. This is also reflected in higher ocean levels (Eemian transgression). The Eemian Interglacial itself (sensu stricto), i.e. the section of the stable climate optimum regime (MIS 5e), ends approximately 116,000 years BP with a distinct global cooling (MIS 5d). This is clearly recorded in Antarctic drillings (Vostok), and there are significant changes in Europe with some time lag. The sudden loosening of the vegetation cover and the disintegration of the contiguous forest communities are still documented only at the end of MIS 5d (107,000 years BP). During the MIS 5c-5a sections (105,000 – 75,000 years BP) several phases of significant warming and cold sections with massive retreat of woody vegetation were alternating. This is a period of considerable climatic instability, when both the climate regime and the vegetation structure have changed significantly over several years or decades (Kukla et al., 2002).

One of the OSL datings of fluvial sand dates back to the period of the Eemian Interglacial from the Danube Lowland: BA-1 Bratislava: 127,000 ± 10 BP (Maglay et al., in press).

Based on this dating, the age of the Danube terrace fluvial sediments was included in the younger part of the Middle Pleistocene (Maglay et al., in press).

Late Glacial 15,000 – 11,700 years/10,200 BP (18,252 – 11,734 cal. BP)

The Late Glacial represents the end of the Weichselian Glacial. Three cooler climate episodes (Older, Middle and Younger Dryas) are divided by relatively warmer climatic fluctuations (Bølling = Dansgaard-Oeschger event 1 and Allerød = Dansgaard-Oeschger event A; Mangerud et al.,

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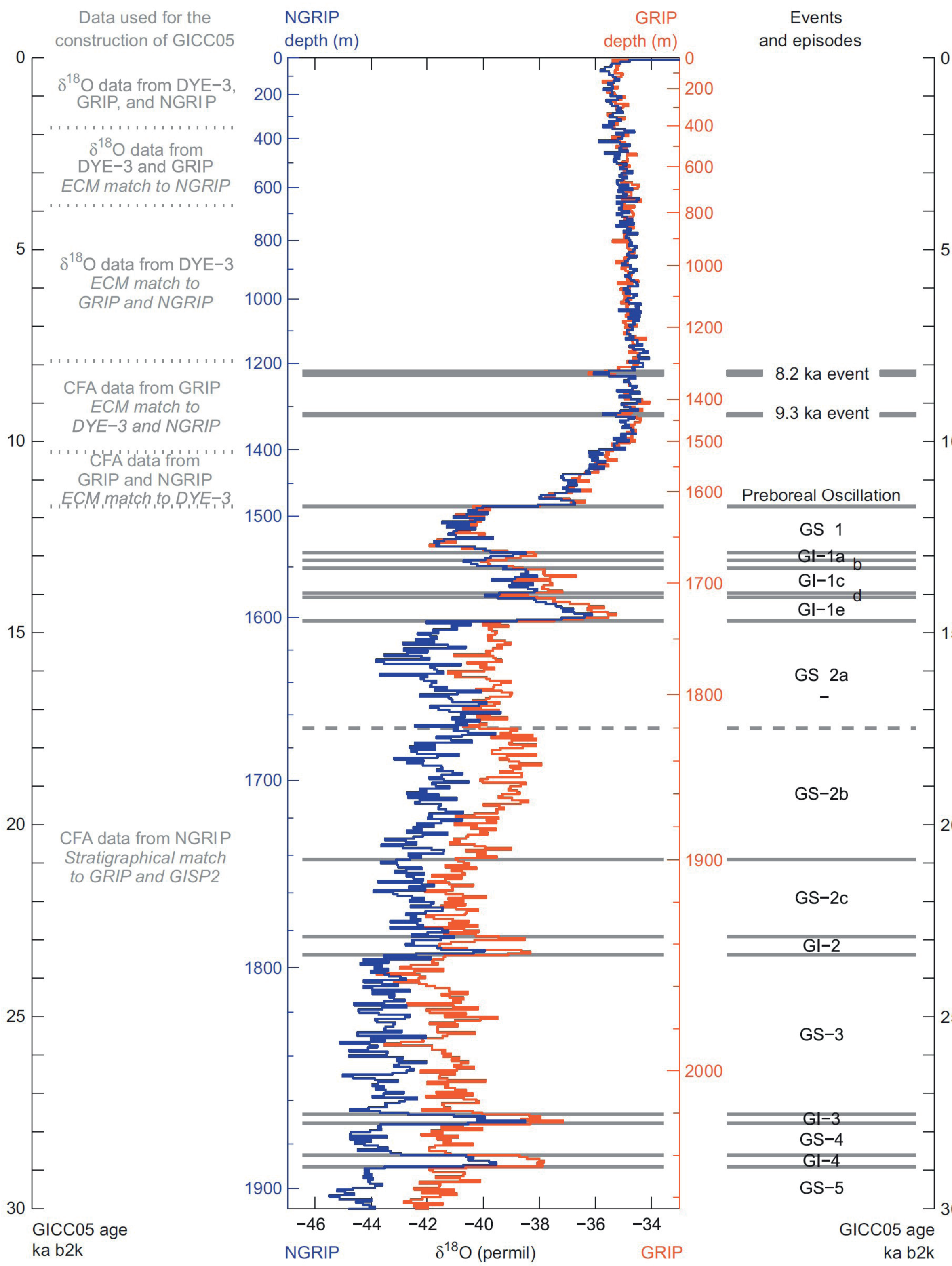
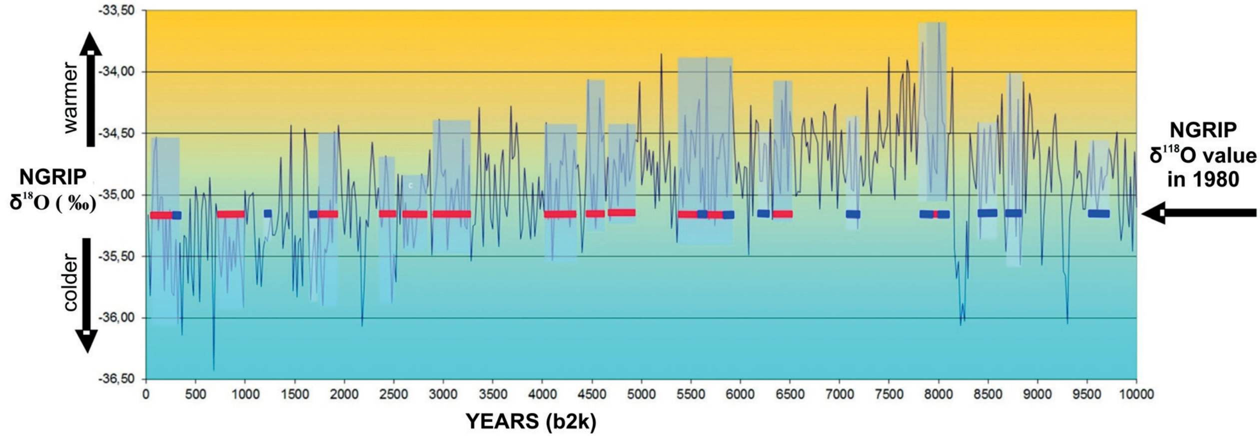
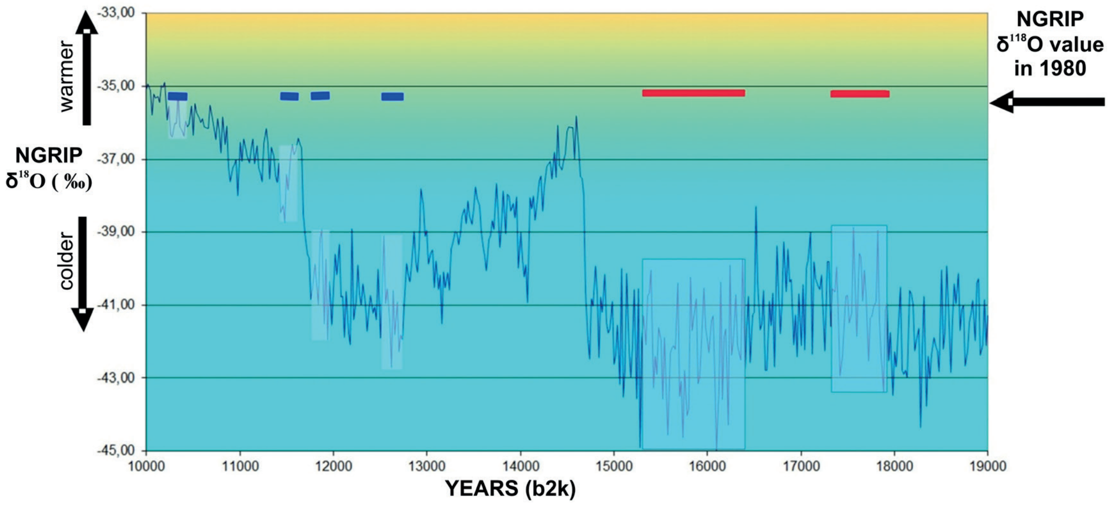


Fig. 3.6 Comparison of δ¹⁸O records of glacier core NGRIP and GRIP for the last 30,000 years in 50 year resolution. Microtephra allows correlation of archaeological events with climatic cycles (according to Lowe et al., 2008). GS – Greenlandic stadials, GI – Greenlandic interstadials.

1974). This is the period of transition from Pleniglacial to Holocene. There were recorded many cold oscillations with sudden warm events. From 15,000 years BP, temperature began to rise, but between 14,000 – 13,000 years BP, this temperature rise was interrupted by a cold episode. Between 16,000 and 15,000 years BP loess accumulated in Normandy (France), England, Belgium, the Netherlands and throughout the Central Europe. This period between 16,000 and 15,000 years of BP has not yet received as much attention in our country and is underinvestigated so far. This is a time period that is important not only in terms of flora and fauna, but also in terms of humans. At





Note: the red bars represent the extent of the AMS dating in the Podunajská rovina Flat, the blue bars represent the extent of the OSL dating in the Podunajská rovina Flat.

Fig. 3.7 Detailed comparison of Greenlandic Glacier Chronology (GICC05) records at 20 years (blue curve) and ^{14}C AMS dating of samples (red lines) and OSL dating (blue lines) from the Danubian Flat. The red bars show the extent of ^{14}C AMS dating in b2k years (years before A.D. 2000). Red and blue lines showing the range of ^{14}C AMS and OSL dating are located at $\delta^{18}O$ from 1980 (-35.16‰). Pale blue translucent rectangles represent the theoretical range of $\delta^{18}O$ at the time the samples were dated. It can thus be clearly seen that e.g. soils from 10,000 years ago had to be formed at much lower temperatures than at present (chronology of the glacier core: http://www.iceandclimate.nbi.ku.dk/research/strat_dating/annual_layer_count/gicc05_time_scale/).

this time, the lasting ecosystem of the Last Glacial, which was replaced by the present ecosystem at the beginning of the Holocene, disappeared. Even in this period, climatic fluctuations were evident. Palaeoclimatic records e.g. from the Central and Western European stalagmites, witness for warmer periods between 20,000 – 17,000 years BP and then around 14,000 BP (e.g. Alley et al., 1993; Musil, 2005; Severinghaus & Brook, 1999; Taylor et al., 1993). In north-western Europe, the January palaeo-temperature increased by more than 20 °C from values between -25 °C and -15 °C in Older Dryas (12,700 BP; about 14,700 cal. BP) and Younger Dryas (around 10,000 BP; 11,500 cal. BP) to temperatures between -5 °C and 5 °C (in Bølling and Preboreal). The changes were minor during July. The July temperature rose in North-West Europe by 3 – 5 °C, from 10 °C to 15 °C (in Older Dryas and Younger Dryas) to values from 13 °C to 17 °C (in Bølling and Preboreal). In southern Europe, the rise in July's temperature was less intense. The precipitation remained the same at the turn of the Older Dryas and Bølling (around 14,700 cal. BP). However, in some areas, there is a small increase in precipitation during the transition of the Younger Dryasto the Preboreal (11,500 cal. BP) (Renssen & Isarin, 2001).

In the **Late Glacial** period, the following datings were gained from the Danube Lowland area (Fig. 3.8):

- BV-2 Balvany – fluvial sand (10,320 ± 970 BP), OSL dating (Fig. 3.14)
- VR 331 Vrakúň – fluvial sand (11,530 ± 840), OSL dating (Fig. 3.12)
- S-1 Štrkovec – fluvial sand (11,850 ± 920), OSL dating
- TV-1 Tvrdošovce – fluvial sand (12,630 ± 930), OSL dating
- AN-1 Aňala – fluvial sand (12,700 ± 11), OSL dating
- FŠ-111 FS-111 Čierna Voda (Poz-78074) (13,020 ± 80 BP), 15,483 – 16,303 cal. BP ^{14}C AMS dating

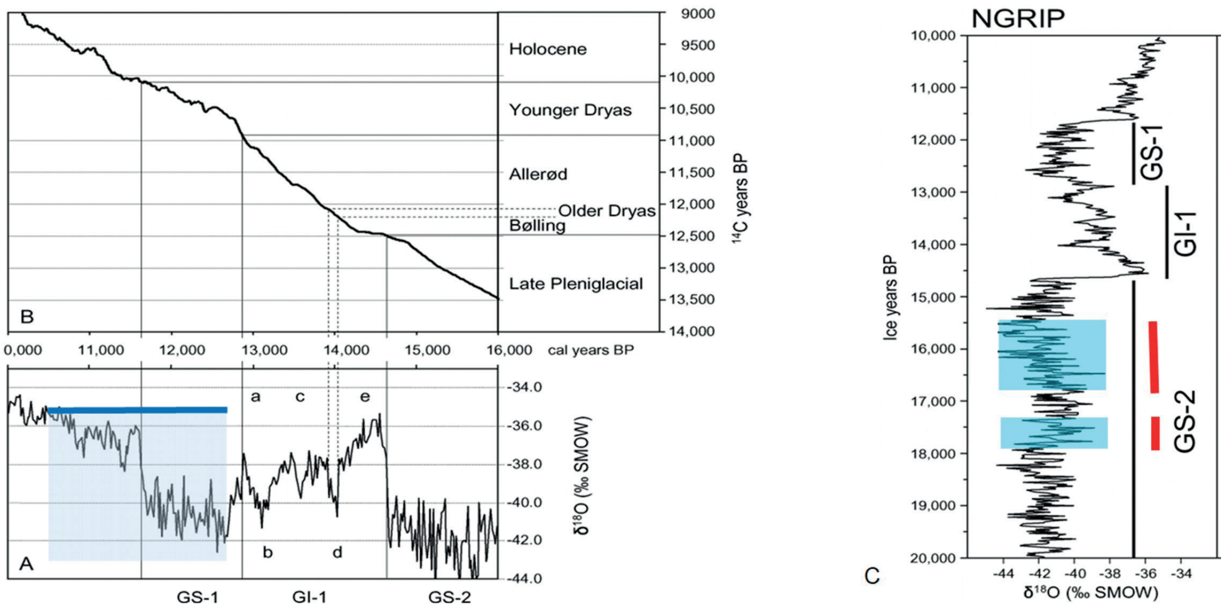


*Fig. 3.8 The correlation between event stratigraphy of the transition of the Last Glacial to the Holocene after Lowe et al. (2008) depicted on the time scale of glacial layers calculated in BP (= 1,950 AD) (**A**) and the classical late-glacial stratigraphy of NW Europe (**B**) depicted in the ^{14}C time scale. Correlation is generated using the INTCAL04 calibration curve (Reimer et al., 2004). A: NGRIP oxygen isotopes and INTIMATE event stratigraphy (Lowe et al., 2008), B: INTCAL09 calibration curve (Reimer et al., 2010). (**C**) Oxygen isotope record from the Greenland Glacier Core NGRIP (according to Rasmussen et al., 2006 and Lowe et al., 2008). Shown events are: Greenland GS-1, Greenland Interstadial GI-1, and Greenland GS-2.*
The red bars with blue rectangles show the span to which fall the dated gastropods Štrkovec – gastropod – 1 m (Poz-78131) (13,370 ± 90 BP) and Štrkovec – gastropod – 3.5 m (Poz-78132) (13,410 ± 70 BP), dated soil F-111, Čierna Voda (Poz-78074) (13,020 ± 80 BP) and 289 F Lúč na Ostrove (Pos-78075) (14,410 ± 90 BP). The figure shows calibrated data from dated gastropods and soils.
The blue line with the blue rectangle shows the range to which the dated aeolian and fluvial sands fall: BV-2 Balvany– aeolian sand (10,320 ± 97 BP), VR 331 Vrakúň – fluvial sand (11,530 ± 84 BP), TV-1 Tvrdošovce – fluvial sand (12,630 ± 93 BP), S-1 Štrkovec – fluvial sand (11,850 ± 92 BP), AN-1 Aňala – fluvial sand (12,700 ± 11 BP).
The blue and red bars showing the extent of OSL and ^{14}C AMS dating are placed at $\delta^{18}O$ from 1980 (-35.16‰) to better compare the climatic conditions at present and in the period of dated sands, soils and organic residues.

- Štrkovec – gastropod – 1 m (Poz-78131) (13,370 ± 90 BP), 16,730 – 15,874 cal. BP, ^{14}C AMS dating
- Štrkovec – gastropod– 3.5 m (Poz-78132), (13,410 ± 70 BP), 16,722 – 15,938 cal. BP, ^{14}C AMS dating
- 289 F Lúč na Ostrove (Poz-78075), (14,410 ± 90 BP), 17,814 – 17,300 cal. BP, ^{14}C AMS dating

The studied gastropods from the locality Štrkovec – from a depth of 1 m (Poz-78131) (13,370 ± 90 BP) and from a depth of 3.5 m (Poz-78132) (13,410 ± 70 BP) as well as dated soils FŠ-111 Čierna Voda (Poz-78074) (13,020 ± 80 BP) and 289 F Lúč na Ostrove (Poz-78075) (14,410 ± 90 BP) (Fig. 3.9), fluvial sand BV-2 Balvany (10,320 ± 970 BP; (Fig. 3.14) and fluvial sands VR 331 Vrakúň (11,530 ± 840 BP), S-1 Štrkovec (11,850 ± 920 BP) (Fig. 3.11), TV-1 Tvrdošovce (12,630 ± 93 BP) and AN-1 Aňala (12,700 ± 1100 BP) originate from the Late Glacial period, namely the Greenlandic GS-2 (Older Dryas/Oldest Dryas), namely GS-2.1b and GS-2.1a (Fig. 3.13).

At the locality of Lúč na Ostrove there were developed sediments of moor and transitional type of mire peats (Fig. 3.9). They represent the fill of the old fossilized oxbow of the Danube. Organogeneous deposits are located in the longitudinal up to 700 m long and 100 m wide zone tracking the course of the old sunken river bed. The thickness of this accumulation of humus-rich, very porous peat loams containing both decomposed and semi-decomposed plant matter reaches a value of about 2.5 – 3 m. The sediments were formed and developed above impermeable grey-blue plastic clayey-silty fluvial sediments of the bottom layers of the oxbow fill and are mostly wetted with infiltrated water from the surroundings. On the basis of ^{14}C AMS dating they were deposited in the Late Glacial period (^{14}C AMS dating 14,410 ± 90 BP).

In the Štrkovec gravel pit, which is located on the left bank of the river Váh in the cadastre of the village of Šoporňa, species of Pleistocene fauna *Mammuthus primigenius* – wolly mammoth and bos/bison sp. – aurochs or wisent (Fig. 3.10) were found. The palaeontological material originates from the upper part of the Váh bottom accumulation, consisting of sandy gravel and gravel sand. The material is extracted partly from the western edge of the Late Pleistocene low terrace of Váh, where the fluvial sands of the point bar are located on the sandy gravel, with local occurrence over a short distance wind-blown aeolian sands. Using the OSL and ^{14}C AMS methods, a layer of fluvial sands at the Štrkovec site was dated 11,000 to 13,000 years BP, i.e. the end of the Last Glacial. Thus, the fossil findings of Pleistocene mammals originate from underlying gravel of either approximately the same or slightly older age. According to Vlačiky (2017), the redeposited fluvial material containing fauna was washed out of its own lower middle terraces of the younger part of the Middle Pleistocene (Younger Riss) by lateral erosion eroded, along with the washed-out loamy material of the overlying loess series of the Upper and Middle Pleistocene as it had occurred on the higher downstream of the river

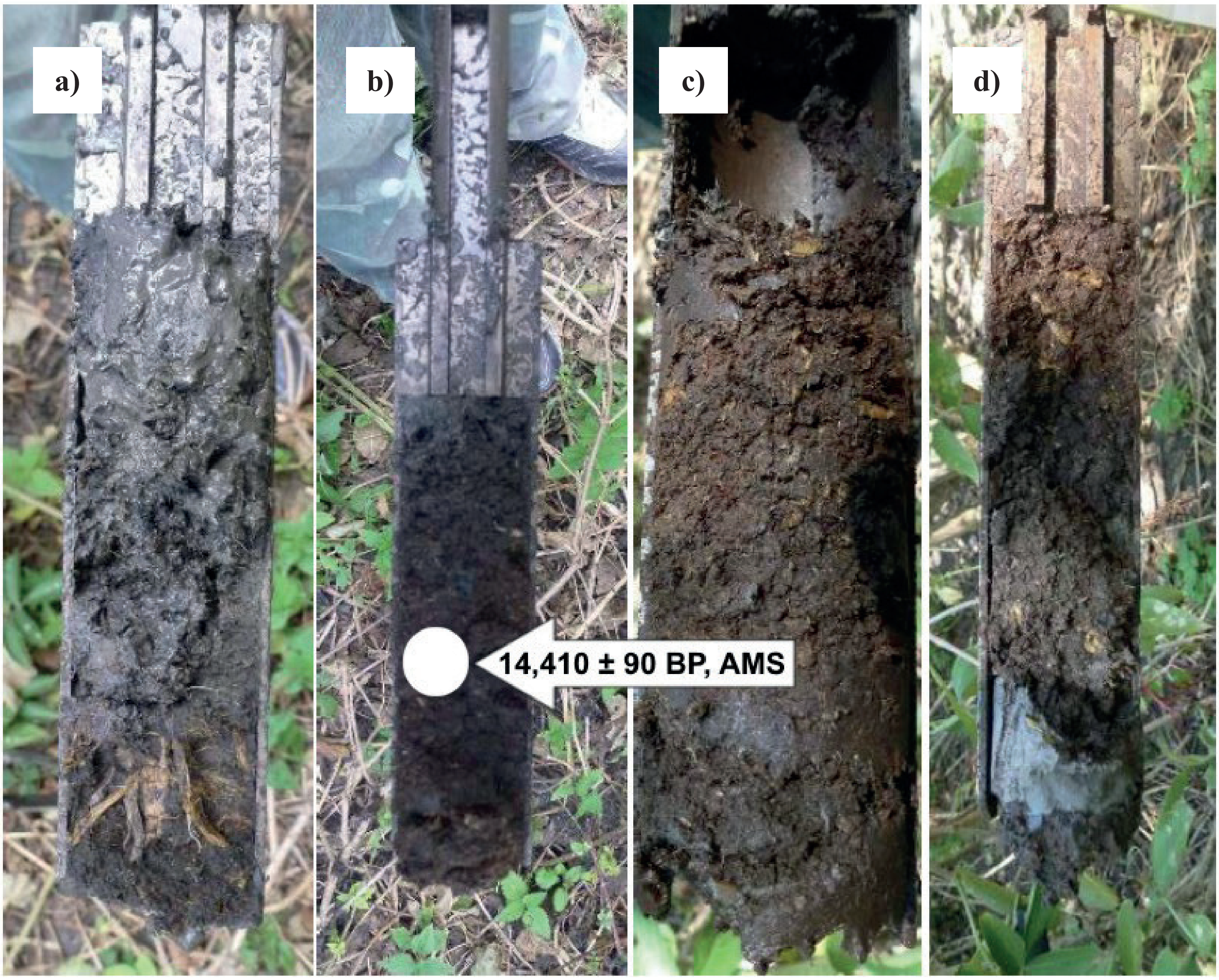


Fig. 3.9 Location Lúč na Ostrove. Plant humoliths and humus-enriched peat clays in the core of a hand drilled probe from an oxbow filling near the village of Lúč na Ostrove (width of the core is 5 cm).
a) – a surface layer of water-saturated sand-clay sediments with a rich content of recent organic matter (root systems) in thickness up to 20 cm; (b) – in the direction of the subsoil, a layer of very porous brown-black peat loams with H_2S released in pores with a total thickness of 1.8 – 2 m from which samples were taken for AMS dating. (c) – in the direction of the subsoil, more compact, sand, brown, dark brown to light brown humoliths containing a semi-decomposed plant matter with a total thickness of 30 – 40 cm; (d) – the passage of the abovementioned sediments into a subsoil consisting of medium-grained dark grey sand with organic matter, which passes into grey-blue strongly plastic clays.

Váh situated in Šoporňa until the realization of the Kráľová Waterworks.

The relatively warm period of the Late Pleniglacial optimum (GS-2b) was again followed by a period of cooler conditions, the so-called “cold” period, i.e. Old Dryas or Greenland Stadial GS-2a. This period lasted nearly 2,000 years, from about 16,900 to 14,700 cal. BP (Björck et al., 1998; Rasmussen et al., 2006). It is clear that the Central Europe at the time of the Old Dryas was already an environmentally diverse area.

Sedimentary evolution of the Late Glacial

During cold climatic conditions with lack of rainfall, loess deposition had taken place in some places of the Danube Lowland. The very frequently present sediments of the studied territory are the wind-blown sands.The youngest ones are deposited on the surface of the Late Pleistocene gravel terrace of the Danube and its tributaries. They originated from the sediments of the above-mentioned terraces at the end of the Late Glacial or in the Holocene (Pelíšek, 1963). In some wet areas and in the area above the river terraces, sapropels were formed on the basis of peat or silty alms (e.g. Jur pri Bratislave, Pusté Úľany, old Danube oxbows and Ostrov, Hrabušice; Kovanda, 1971).

Climate changes of the Late Glacial reflected in vegetation

Studying the evolution of vegetation during the Last Ice Age has an important place in order to understand the interrelationships between climate change and changes in the species assemblages of our forests and their areal representation. Moreover the course of these changes provides a comparative basis for estimating future forest community changes due to the effects of climate change in the near future (Škvarenina et al., 2013).

Since 15,000 cal. BP reforesting of the Central European region has began by expanding broad-leaved boreal forests to low mountains and foothills. The loess formation terminated in the Pannonian Basin around 13,000 cal. BP (Sümegi & Krolopp, 2002). Even in the northern part of

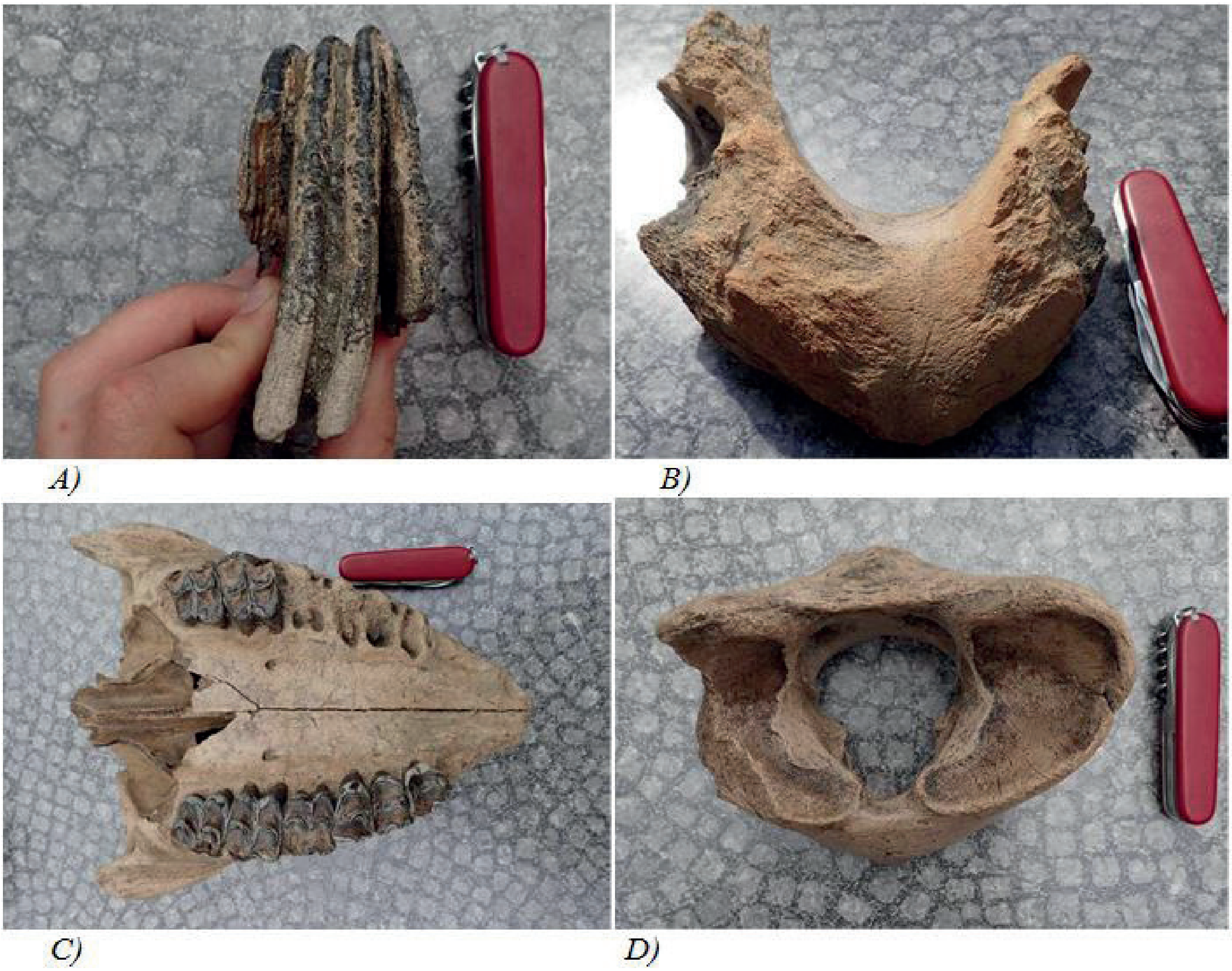


Fig. 3.10 Locality Štrkovec. Late Pleistocene fauna: A) Mammuthus primigenius – tooth fragment, B) Mammuthus primigenius – jawbone symphysis. C) Bos/Bison sp. – skull fragment, D) Bos/Bison sp. – atlas.

Hungary in the Late Glacial period, in the sediments of Lake Nagy-Mohos there were pollen-analytically found woody species such as *Larix* sp., *Pinus cembra, Picea* sp., etc. (Magyari et al., 1999). Such elements of vegetation (and fauna as well) have been mixed here with steppe elements (see also Bennet et al., 1991; Willis et al., 2000; Stewart & Lister, 2001).

13,000 years BP ago (15,854 cal. BP) across Europe significant warming and humidification of the climate occurred. Insect communities in NW Europe indicate conditions that were as warm or even warmer than today (Atkinson et al., 1987). Across the majority of Europe, changes in plant communities have begun: from dry and cold steppe-tundra to steppe, with the slow emergence of forest stands. In the European part of Russia, forests consisting of birch trees and boreal conifers very quickly followed by a warm event (Velichko, 1993), although the Western Europe and the Iberian Peninsula remained a more open steppe for several hundred years thereafter. The NW Europe remained poorly forested in the period 14,000 – 13,000 BP (17,245 – 15,854 cal. BP), with open tundra with dwarf bushes (*Juniperus* sp., *Salix* sp.; Anderson, 1977).

The NW Europe remained essentially tree-free till about 12,000 BP (13,971 cal. BP) towards the end of this period with only a very mosaic birch cover. Even dwarf bushes, which were initially present 12,000 BP, began to decline during a brief cooling of Older Dryas (around 12,000 – 11,800 BP; 13,971 – 13,697 cal. BP; Huntley & Birks, 1983; Turner & Hannon, 1988; Velichko, 1993; Anderson, 1997). Following colder conditions, tundra vegetation had been restored (Guiot & Pons, 1986).

The cold and dry period of the Younger Dryas meant the temporary disappearance of the forest cover, which had previously spread throughout Europe (northern and southern) and replacement by dry steppe and steppe tundra vegetation (Velichko, 1993; Laval et al., 1991; Starkel, 1991). According to some authors (e.g. Adams & Faure, 1997), the conditions during the Younger Dryas may not have been so harsh in the Northwest Europe. Based on their research, most of Poland and Germany were forest tundra mixed with steppe elements. The northernmost region of Poland and Germany, near the Scandinavian glacier cover, was a shrubby tundra. The conditions during most of the Younger Dryas were drier than at present, but nowhere as dry as during the Late Glacial peak.

At the end of the Younger Dryas 10,000 BP (11,482 cal. BP), forest stands returned to most of Europe. Even 9,000 years ago (10,203 cal. BP), forest cover in many parts of Europe had a rather open character comparing to present (Starkel, 1991; Huntley & Prentice, 1993; Roberts & Wright, 1993).

Over the past 15,000 years, the formability of floodplains has changed a lot. The floodplains of mainly large rivers have become refugees of climatically demanding vegetation in warmer areas in the Late Glacial. They differed significantly from their surroundings and these alluvial communities were considerably richer than the communities of the foothills (Břízová et al., 2007).

Climate change of the Late Glacial based on fauna records

The Late Glacial was formed by numerous climatic oscillations, which was also reflected in the nature of mammal fauna. During cold fluctuations (Oldest, Older and Younger Dryas), the steppe species dominated the communities. In interstadial periods (Bølling and Allerød) the species were more thermophilic, inhabiting forest and meadow environments. In many places lakes and marshes were formed, which was reflected in the continuously growing number of hygrophilous animals. Palaeontological research suggests that the communities of this period were substantially richer than during the Holocene (Musil, 1956; Klíma, 1959; Valoch, 1989; Musil, 2000; 2002a; Horáček et al., 2002; Svoboda et al., 2002).

New faunistic elements that characterize climate change began to penetrate in the territory of Slovakia. In addition to the species living on the studied area throughout the last Würm stage, animals typical of the following Holocene (e.g. *Bos primigenius, Cervus elaphus, Bison bonasus*, etc.) appeared sporadically. Similar development is evidenced by the findings of malacofauna (Svoboda et al., 2000). They are a sign of the climate change that had taken place at this time (Musil, 2002). The predominant animals were steppe species (Ložek, 1985; Horáček et al., 2002).

However, there occurred local fauna developments. Therefore, it is necessary to create and use local stratigraphic scales. Communities of this period were basically richer than those during the Holocene. Species requiring a warm climate are essentially absent. At that time, the region of Slovakia can be classified as a cold climate. Characteristic species of this period: *Rangifer tarandus, Ochotona pusilla, Lepus timidus, Lemmus lemmus, Equus* sp., *Coelodonta antiquitatis, Mammuthus primigenius, Gulo gulo, Alopex lagopus, Dicrostonyx torquatus, Alces alces, Citellus citellus, Saiga tatarica, Cricetus cricetus, Vulpes vulpes, Martes martes, Panthera leo, Bos primigenius, Cervus elaphus, Ursus arctos, Lynx lynx, Castor fiber, Canis lupus, Rupicapra rupicapra, Talpa europaea, Mustela nivalis, Sorex araneus* (Musil, 1985, 2000). In addition to this fauna, there are rare species that had diminished up in this area: mammoths, rhinos, hyenas and possibly cave bears. The composition of the findings points to their survival up to this time or, more likely, to possible sporadic migrations from the northern area than to the origin from older sediments (Musil, 2002). The findings of malacofauna, where some typical loess forms survived, show the same scenario (Ložek, 2000).

Although the structure of the communities is broadly consistent with the period of the Pleniglacial, it has been enriched by a greater number of more demanding species specialized in various open habitats, from warm steppe slopes or debris fields to marsh meadows and floodplains. So the nature of the country was obviously different from the homogeneous cold steppe with the tundra islands,which are supposed for the Pleniglacial. It apparently included not only wet habitats, but also islets of taiga and seasonal meadows (Horáček et al., 2002).

Climate change of the Late Glacial based on malacofauna records

Overall, the cold-loving elements of open formations such as *Pupilla loessica* and *Vertigo parcedentata* retreated, and the onset of thermophilic species started, particularly at warm and dry intervals (*Fruticicola fruticum* (Müll.), *Carychium tridentatum (Riss.), Discus ruderatus* (Fér.), *Pupilla triplicata. (Stud.), Helicopsis striata* (Müll.) (Kernátsová, 2001). The northern parts of the Danube Lowland could be characterized as a steppe landscape with park taiga islands based on habitats and species composition. The climate was cold with striking warmer and more humid fluctuations (Kernátsová, 1997).

First, a cold and drier climate predominated, then the climate gradually humidified. In these areas, the southern parts differed from the northern parts, which took on a steppe character with islets of park taiga.

In the Late Glacial period, changes in malacofauna communities confirm the specific position of the Pannonian region in the formation of the present Central European fauna. They demonstrate the early onset of thermophilic elements and the very late occurrence of forms of glacial fauna. During the Allerød and Younger Dryas, the climate warmed up and more demanding elements of malacofauna began to appear.

True cryophilic molluscs disappeared gradually since 15,000 cal. BP, retreating to the cold relict sites that developed in the higher altitudes of the Carpathians. It was a period of dominance of cold resistant species, followed by the boom of mesophilic species in shellfish fauna (Sümegi & Krolopp, 2002).

Climatic conditions and temperature values show a well identifiable trend in the SW and NE directions. Towards SW, higher average July palaeo-temperatures were recorded in both warm and cold seasons. Lower July palaeo-temperatures were measured in the north and south. The differences between the July palaeo-temperatures measured in the northern and southern regions were between 2 °C and 4 °C. These temperatures are consistent with the July temperatures observed today between the northern and southern regions (Sümegi & Krolopp, 2002). Modern snail species inhabiting higher Central European mountain ranges (beech and pine zones) occupied the N and E part during the Late Würm. They were either dominant species or expanded into this area along the main rivers flowing from the Carpathians during this period (Deli & Sümegi, 1999; Sümegi & Krolopp, 2000).

There is a big difference between the Late Glacial models proposed by the different approaches. According to the climate simulation model, gradual warming occurred

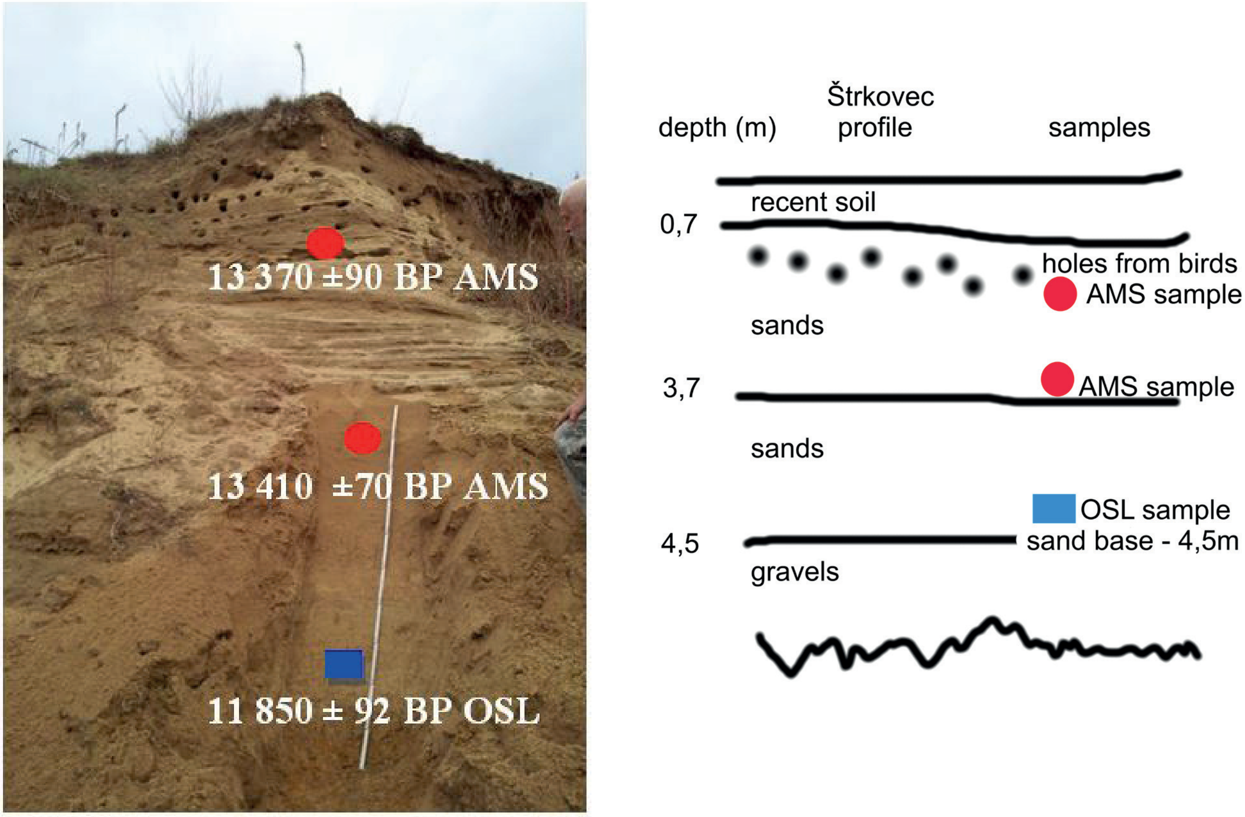


Fig. 3.11 Locality Štrkovec. Sampling sites from the thin-rhythmic-graded sands of the point bar of the Váh low terrace for dating by the ^{14}C AMS (red dots) and OSL (blue square) methods, the evaluation of which assigned the terrace to the Pleistocene period (Vlačiky, Maglay, Moravcová & Fordinál, 2017).

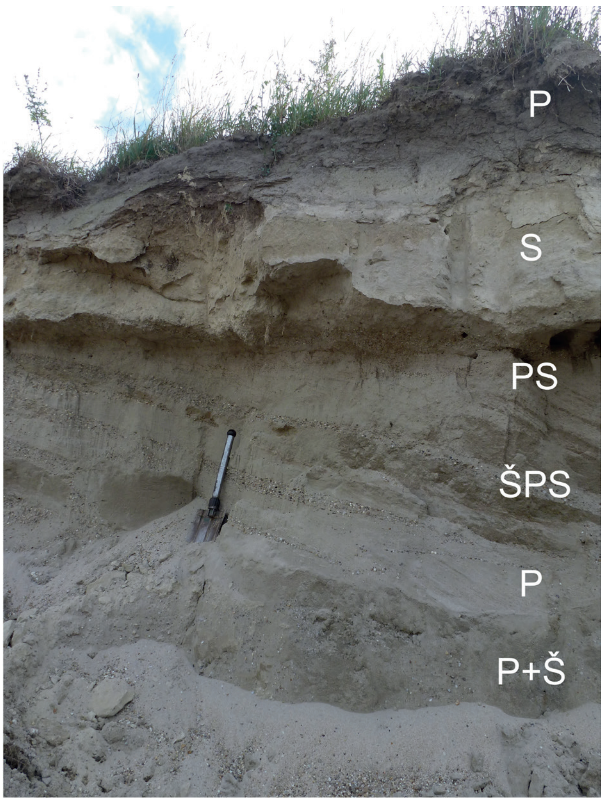


Fig. 3.12 Locality Vrakúň. Example of lithofacies: undivided silts (S), sandy silts (PS), gravel-sand silts (ŠPS), sands (P) and sand with occasional small gravel (P + Š) in the interval of 0 – 2 m in the profile at the locality Vrakúň. OSL dating of fluvial sands is 11,530 ± 84 BP.

at this time. However, changes in the composition of the malacofauna, as well as data from the dated GISP2 core recovery annual layers, indicate the presence of alternating warmer and cooler periods even during the Late Glacial. Changes in radiocarbon-dated mollusc fauna, along with palaeogeographic interpretations suggested by them, confirm the latest results obtained from radiocarbon dating and pollen analyses (Magyari et al., 1999; Sümegi et al., 1999). The results of the pollen analyses partially overlap with the malacological data confirming the expansion of the trees and vegetation during mild, humid periods and the expansion of the steppe vegetation during colder, drier periods as suggested by the composite data from malacofauna.

The Pannonian Basin can be considered as a wide fluctuation zone in the biogeographic sense, allowing expansion of the Palaeo-Illyricum, Palaeo-Carpathian, Palaeo-Balkanian, Palaeo-continental and Boreo-Alpine elements during periods with appropriate climatic conditions. However, due to the mosaic nature of environmental factors, they could occupy only a small part of this highly heterogeneous region (Sümegi & Krolopp, 2002). The Late Glacial malacofauna community is characterized by a significant change in fauna caused by higher habitat diversity, which caused an increase in the number of species and differentiation of malacocoenosis. In addition to the steppe communities, which still contained a number of loess elements, there were more frequent mesic communities, rather corresponding to meadows as well as a wide range of marshes and small aquatic environments. However, characteristic forest and thermophilic species were absent (Ložek, 1988; Ložek & Cílek, 1995).

Man and the natural environment in the Late Glacial period

In the Late Glacial (Palaeolithic) period people made their living by fishing, hunting and harvesting plants. At that time hunting was mainly focused on species such as *Rangifer tarandus*, *Equus* sp. and smaller animals (*Lepus* sp., *Aves*). *Mammuthus primigenius* had already lost its importance as a food ingredient.

The Late Glacial period is divided into three stages – Oldest, Older and Younger Dryas. Among them are shorter interstadials – Bølling and Allerød.

The INTIMATE group (INtegration of Ice-core, MArine and TErrestrial records) has proposed to standardize the terminology of Pleistocene along with a methodological guideline for Late Pleistocene proxy data (Björk et al., 1998; Walker et al, 1999).

The INTIMATE group has recognized the GRIP ss08c ice core recovery isotope record as the finest indicator of the Late Glacial climate change. As such, this Greenland iceberg record was identified as a reference stratotype. Several short-term climatic episodes are recognized in the GRIP stratotype and collectively represent the event stratigraphy. The event stratigraphy follows the isotopic nomenclature of the GRIP glacier core using the GS prefix, indicating Greenland Stadials (cold periods) versus the GI prefix, indicating Greenland Interstadials (warm periods). Denominations such as GS-2 and GS-1 further subdivide these prefixes to identify unique modes of the same kind over time. Thus, within the Stadials (GS) or Interstadials (GI), subtle events such as GS-2a and GS2c (cold episodes) versus GS-2b (warmer episodes) can be distinguished (Tab.3.2 and Fig. 3.13).

Tab. 3.2 Event stratigraphy for Last Glacial to Holocene transition based on NGRIP oxygen isotope stratigraphy presented on the GICC05 time scale (Rasmussen et al., 2006): age b2k is 2,000 AD, with maximum error (MCE) and conversion to cal. BP (before 1,950). It should be noted that the difference between the time scale given in years b2k and cal. BP is 50 years. This time difference should be taken into account when comparing results between ice core recovery and ^{14}C dated events.

	age b2k	MCE	cal BP
Holocene			
	11,703	99	11,653
GS-1			
	12,896	138	12,846
GI-1a			
	13,099	143	13,049
GI-1b			
	13,311	149	13,261
GI-1c			
	13,954	165	13,904
GI-1d			
	14,075	169	14,025
GI-1e			
	14,692	186	14,642
GS-2 .1a			
	17,480	**330**	**17,430**
GS-2.1b			
	20,900	**482**	**20,850**

3.4.2.2 Holocene (11,500 BP – present)

In the period of transition of Glacial to Interglacial, the climate changed from coldest to warmest over a few millennia (Horáček & Ložek, 1988). This transition period corresponds to the second part of the first phase of the climate cycle in the sense of Ložek (1973). After the transitional period of Late Glacial to Holocene, there was a peak and late warm period, characterized mainly by the continuous development of the forests as a consequence of high temperature and humidity. It corresponds to the second phase of the climate cycle in the sense of Ložek (1973). In the peak section, the temperature could be up to 2 – 4 °C above today's average and the precipitation could reach very high values, which in certain sections could amount to more than double the current precipitation at a given location (Smolíková, 1982; Ložek, 2002).

At this time it is necessary to begin to distinguish natural phenomena and their laws from anthropogenic interventions. The beginning of increased human activity is manifested only in the Neolithic period (in the wider area of the Central Europe, the Neolithic period is approximately the 6th-5th millennium BC) by housing development, agriculture and cattle breeding. This is the first major human intervention in the natural environment (Musil, 2014).

However, the Holocene climate was not stable in the long term. Relatively long-lasting cold periods were repeated several times (in ages of 9,200, 8,600, 5,800 cal. BP.). Rapid warming occurs at about 11,590 cal. BP, further between 8,000 to 5,800 – 4,000 cal. BP. There were also changes in the amount of rainfall. At the time of 11,160 to 10,800 cal. BP due to the severe drought, the level of European lakes was reduced on up to 5 – 7 m. Further reductions are known only from the years 9,250 to 9,340 cal. BP. Unlike the previous period, which lasted 360 years, this lasted only 90 years. Another minor reduction in precipitation was between 8,800 to 7,850, 7,000 to 6,750 cal. BP. Dry season in the years 6,200 to 5,950 cal. BP closed this period of fluctuations (Kalis et al., 2003; Litt, 2003; Zolitschka et al., 2003).

The Holocene period includes the following dating of sands, soils and organic residues:

Preboreal 10,000 – 9,000 BP; 11,734 – 10,203 cal. BP):

- O-1 Oldza – fluvial sand (9,840 ± 470 BP) OSL dating)
- BV-1 Balvany – aeolian sand (9,610 ± 470 BP), OSL dating, (Fig. 3.14)
- BV-3 Balvany – aeolian sand (9,540 ± 470 BP), OSL dating, (Fig. 3.14)

Boreal (9,000 – 8,000 BP; 10,203 – 8,900 cal. BP)

- M-1 Miloslavov – fluvial sand (8,740 ± 680 BP), OSL dating
- DS 303 Dunajská Streda – fluvial sand (8,520 ± 470 BP), OSL dating
- OKL-2 Okoličná na Ostrove – fluvial sand (8,460 ± 470 BP), OSL dating
- FS-3A Jelka – aeolian sand (8,040 ± 520 BP), OSL dating, (Fig. 3.23)

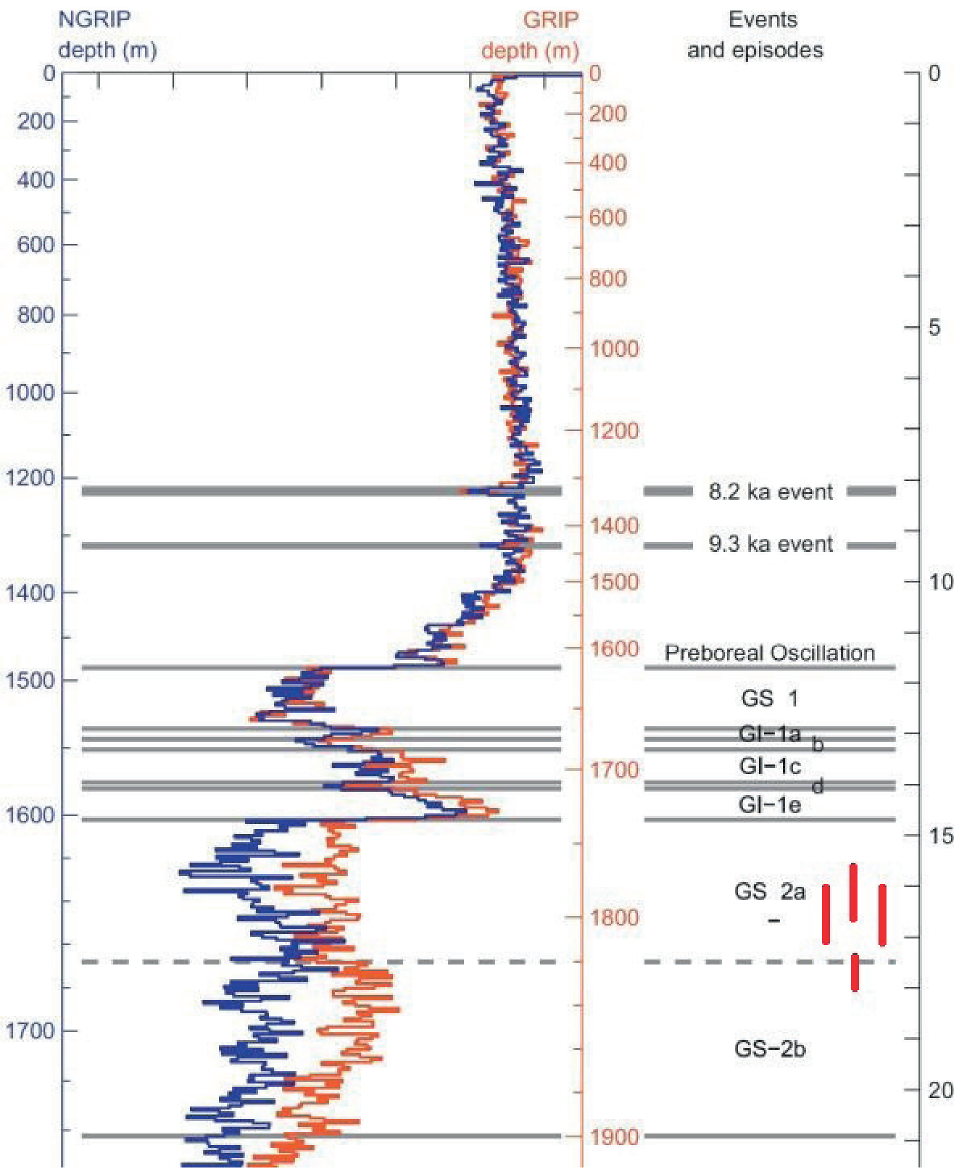


Fig. 3.13 Event stratigraphy according to INTIMATE group. The time is given in years for 2000 (b2k). NGRIP and GRIP ^{18}O profiles with determined depth, with data placed on the GICC05 time scale (Rasmussen et al., 2006; Svensson et al., 2008) and NGRIP-GRIP matches with to Rasmussen et al. (2008).
The red bars (on the left timeline) with blue rectangles show the time span in which fall the dated soils FŠ-111 Čierna Voda (Poz-78074) (13,020 ± 80 BP); 15,483 – 16,303 cal. BP and 289 F Lúč na Ostrove (Poz-78075) (14,410 ± 90 BP); 17,814 – 17,300 cal. BP and gastropods Štrkovec – shellfish – 1 m (Poz-78131) (13,370 ± 90 BP); 16,730 – 15,874 cal. BP and Štrkovec – gastropod – 3.5 m (Poz-78132) (13,410 ± 70 BP); 16,722 – 15,938 cal. BP.

Early Atlantic (7,900 – 7,050 BP)

- OKL-3 Okoličná na Ostrove – fluvial sand (7,880 ± 580), OSL dating
- NE-1 Nesvady – aeolian sand (7,170 ± 420), OSL dating
- OS-1 Opatovský Sokolec – fluvial sand (7,140 ± 530 BP), OSL dating
- 190 F Čechová – soil (Poz-78076) (7,110 ± 50 BP) 7,932 ± 48 cal. BP, ^{14}C AMS dating

Late Atlantic (7,050 – 4,950 BP)

- OKL-1 Okoličná na Ostrove – fluvial sand (6,240 ± 460 BP, OSL dating
- BT-1 Batoňa – fluvial sand (5,870 ± 400 BP), OSL dating
- BV-4 Balvany – aeolian sand (5,660 ± 460 BP), OSL dating, (Fig. 3.14)
- FS-53zk Nový Život – Šalamúnove polia – Palaeosoil (Poz-75134) (5,600 ± 40 BP), 6,377 ± 43 cal. BP, ^{14}C AMS dating
- 250A Jánošíkovo (5,155 ± 35 BP), 5,926 ± 35 cal. BP, ^{14}C AMS dating
- JM-1 Bratislava Petržalka (Poz-74923) (4,970 ± 35 BP), 5,698 ± 38 cal. BP, ^{14}C AMS dating

Subboreal (4,950 – 2,750 BP)

- 250 Jánošíkovo (2,790 ± 30 BP), 2,898 ± 36 cal. BP, ^{14}C AMS dating
- 313 Okrúhle Jazero – Moravské Kračany (Poz-78078) (4,890 ± 40 BP), 5,632 ± 26 cal. BP, ^{14}C AMS dating
- DB-3/3 soil Most pri Bratislave (Poz-75131) (4,760 ± 35 BP), 5,520 ± 48 cal. BP, ^{14}C AMS dating
- FM-49C Horné Saliby – palaeosoil (Poz-78073) (4,250 ± 40 BP), 4,791 ± 61 cal. BP, ^{14}C AMS dating
- 173 Čechová (Poz-78079) (4,010 ± 30 BP), 4,480 ± 35 cal. BP, ^{14}C AMS dating
- 877 Gabčíkovo (Poz-75132) (3,780 ± 35 BP), 4,164 ± 58 cal. BP, ^{14}C AMS dating
- S1 Štrkovec (Poz-78071) (3,750 ± 30 BP), 4,095 ± 60 cal. BP, ^{14}C AMS dating

- MV-20 Šoporňa (Poz-78072) (2,935 ± 35 BP), 3,097 ± 65 cal. BP, ^{14}C AMS dating
- FS-21op Malé Blahovo – oxbow fill (Poz-75135) (2,865 ± 30 BP), 2,995 ± 49 cal. BP, ^{14}C AMS dating
- FS-64zk Hurbanova Ves – palaeosoil (Poz-75137) (2,830 ± 30 BP), 2,936 ± 41 cal. BP, 1,083 – 906 BC, ^{14}C AMS dating

Older Subatlantic (2,750 – 920 BP)

- 250 Jánošíkovo (2,790 ± 30 BP), 2,898 ± 36 cal. BP, ^{14}C AMS dating
- 878 Gabčíkovo (Poz-75133) (2,595 ± 30 BP), 2,742 ± 13 cal. BP, ^{14}C AMS dating
- KF-24j Jelka – palaeosoil (Poz-75138) (2,340 ± 30 BP), 2,361 ± 15 cal. BP, ^{14}C AMS dating
- DB-3/2 gastropod Most (Poz-73939) (1,835 ± 30 BP), 1,775 ± 39 cal. BP, ^{14}C AMS dating
- ZE-1 Zemné – fluvial sand (1,690 ± 210 BP), OSL dating
- R-1 Rovinka – fluvial sand (1,690 ± 120 BP), OSL dating
- MO-1 Most pri Bratislave – fluvial sand (1,230 ± 120 BP) OSL dating
- FS-4j Jelka – soil (Poz-74922) (960 ± 30 BP,), 871 ± 47 cal. BP, ^{14}C AMS dating

Younger Subatlantic (920 BP – present)

- FS-3j Jelka – soil (Poz-74920) (835 ± 30 BP), 747 ± 30 cal. BP, ^{14}C AMS dating, (Fig. 3.23)
- FS-3B Jelka – aeolian sand (314 ± 28 BP), OSL dating
- DB-3/2 Most – wood (Poz-74252) (135 ± 30 BP), 139 ± 101 cal. BP, ^{14}C AMS dating

Sedimentary evolution in Holocene

Geological development in the Danubian Flat was relatively uniform during the Holocene. Climate change and hydrodynamic conditions of all major rivers have influenced the landscape structure, sedimentary and plant cover. In later periods, human activity was also associated with the impact on the natural environment. The whole territory is strongly influenced by hydromorphism. The Preboreal period in the studied area is characterized by a rather sudden and definite rise in temperatures and a decrease in precipitation. The erosive activity of the wind has been substantially reduced. The activity of the Danube also decreased. The Danube often translated its main and side channels, eroded its own deposits and resedimented them. The flood waters spilled on a wide area and also affected the higher stage of the Danube River floodplain. Fine-grained particles carried by the Danube stream settled on the riparian plain. The areas, which were not regularly flooded with water, overgrew with trees and grassland. Preboreal and Boreal periods were characterized by the greatest afforestation, followed by steppe. During the Atlantic period, the climate warmed and gradually humidified. This period was characterized by pronounced soil formation in those parts of the territory where floods did not occur frequently. In higher places, chernozems (e.g. Kuraľany, Bíňa; Šajgalík & Modlitba, 1983) and gley soils were formed. During this period, some fens began to form in abandoned meanders and oxbows. In many places aeolian sands were blown over (Pelíšek, 1963).

Holocene climate change based on vegetation records

The onset of Holocene initially shows similar conditions to the warmer phases of the Late Glacial, but the rapid rise in temperature and the consequent increase in humidity conditioned the permanent immigration of climatically more demanding species. However, the biggest changes are in living nature, especially in vegetation. Loess steppes and stony areas, or tundra formations gradually passed into the pine-birch stands of light taiga, which later penetrated more demanding deciduous trees, especially *Corylus* sp. and *Quercus* sp. In the older phase, the open formations of mesophilic meadows also played an important role. In dry and warm areas, the continental steppe on black and warm calcareous hillsides as well as the formation of hornbeams with *Cornus* sp., *Betula* sp. and *Pinus* sp. have been gradually pushed to extreme sites, such as rocky edges, sand, etc. During the Atlantic period, natural conditions (warming and humidification) prompted the emergence of enclosed damp forests (Ložek, 2002).

Holocene climate change based on malacofauna records

The elements of the glacial steppe gradually disappeared and were replaced mainly by forest species. The malacofauna community was similar to the Late Glacial in the Early Holocene. Later, thermophilic species appear more and more. There were also xerothermal species, typical of communities living in karst steppes and rocks. The occurrence of xerophilous species is also remarkable. Many species also survived from the Late Glacial. This malacofauna documents the dynamic changes in biota, which was reflected in a significant increase in the number of species and habitat diversity. The full development of forest communities occurred only in the Atlantic period (Ložek, 2002), when wet closed forests expanded. Forest species recorded in the previous period were also becoming important. Elements of continental steppe fauna and loess steppe relics were also present, but gradually diminished or moved into extreme relict environments. Due to the warming climate, the number of xerothermal populations has increased in suitable places, especially sun-exposed limestone rocks (Ložek, 1985; Ložek & Cílek, 1995).

Postglacial (Holocene) is generally a period of warmer and humid climatic development, when the July palaeo-temperature reached 18 to 20 °C. At the beginning of the Holocene there were colder climatic conditions (Kernátsová, 2001). Mollusc communities species corresponded to the recent fauna of the studied sites (Ambrož et al., 1952).

In terms of refuge theory, the relics of the Bratislava floodplain forests are among the so-called palaeo-refuges (Nekola, 1999), i.e. the fragments of the former more or less continuous and large area of historical floodplain forests,

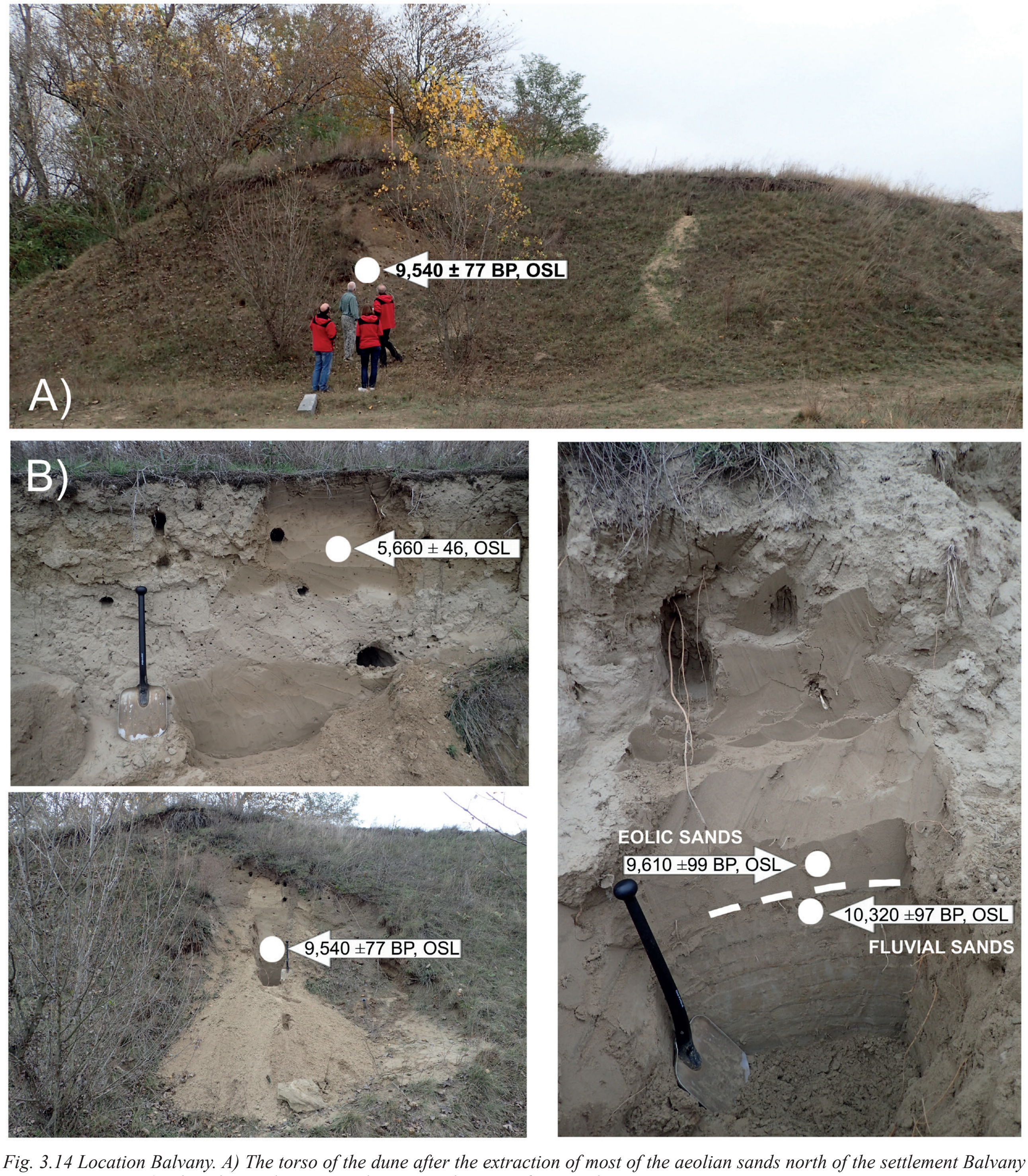


Fig. 3.14 Location Balvany. A) The torso of the dune after the extraction of most of the aeolian sands north of the settlement Balvany near Kameničná. B) White dots with arrows indicate sampling sites for OSL dating..

which occupied the territory of Bratislava at the beginning of the 19th century. Unlike today's floodplain forests, there was a much more varied mosaic of different forest types, or their successive stages. The results of the faunistic survey show that the relics of the Bratislava floodplain forests, despite their considerable fragmentation, serve as a quality refuge of the original Danube malacofauna. There are only a few species known from the Danube Lowland in the Bratislava riparian meadows, which are otherwise predominantly rare in the Danube floodplain out of Bratislava. The floodplain forest fragments provide refuge for populations of 45 terrestrial gastropods; 68% of all terrestrial species known from the Danube Lowland by 2012. Xenocene species do not penetrate into the relics of floodplain forests, the structure of most communities is semi-natural (Čejka et al., 2012).

Man and the natural environment in the Holocene period

In the Preboreal, Boreal and Early Atlantic (Mesolithic) periods, human influence on the country was not yet significant. People continued to make their living by

Fig. 3.15 Location Oldza. Layers of medium-grained sand (in places also gravel sand) in thicker layers of sand gravel in the accumulation of the core of Žitný ostrov. The white dot represents site for the OSL dating.

Fig. 3.16 Location Miloslavov. Sandy gravel at the bottom of the upper complex of fluvial accumulation of the core of Žitný ostrov without covering of sands and silts, cropping out directly to the surface. Artificial exposure with direct contact of sandy gravel and recent soil in an abandoned gravel pit north of Miloslavov. White rectangle – OSL dating.

Fig. 3.17 Location Nesvady. A) Preserved aeolian dune of loaf shape. B) Thin-rhythmic stratification of medium-grained aeolian sands in the dune. The age of the OSL (white dot) is 7,170 ± 420 BP. The sampling position is located about 6 m above the dune base, which assumes that the sands in the lower positions were deposited during the Late Pleistocene period.

fishing, their settlements were found mainly on the coasts of lakes and rivers. The settlement was still relatively scattered (Ložek, 1973). At the end of the Mesolithic period the hunters and gatherers period had terminated.

During the Neolithic period (the Late Stone Age; the end of the Atlantic and the first half of the Epiatlantic), man shifted from hunting and harvesting to agriculture. This period can be described as the beginning of anthropogenic transformation of nature (Zeman & Demek, 1984). Farmers have started to build relatively permanent settlements by cutting and burning in forest areas, preparing the land for cereal cultivation and cattle grazing.

At first they founded their settlements in the most fertile xerothermal areas, but later advanced to higher areas. They introduced new cereal crops with weed communities, but in particular they also inadvertently fostered a new secondary development of xerothermal vegetation in the area. This significantly influenced the development of vegetation and flora. In the subsequent periods of the Eneolithic, virtually nothing has changed. Farmers had increasingly sophisticated tools and advanced to higher altitudes. During the Bronze Age (including the end of Epiatlantic and Subboreal) there was an even greater development of agriculture, both ploughing and grazing. With the use of bronze (nickel-copper alloy) for the production of various tools, field machining was significantly improved and accelerated. Human settlements have expanded and interfered with ever higher altitudes (Zeman & Demek, 1984).

Preboreal (10,000 – 9,000 BP; 11,734 – 10,203 cal. BP)

This period represents the entry period of the Holocene after the last cold fluctuation of the Late Glacial. There was a continuous improvement of the climate – temperature, soil and air humidity. The climate was warming and humidifying. Temperatures rose by 4 – 8 °C. The climate was still very continental. Permafrost disappeared. The thin taiga thickened and cold steppes began to afforest due to the warming and humidification of the climate (*Pinus* sp., *Betula* sp., Svobodová et al., 2001). The landscape was gradually gaining forest character, although forests could be described only as birch-pine and birch-birch taiga with limited species diversity – pine, birch and white birch, aspen, juniper, willow, spring-tree with accompanying vegetation, which is preserved today on wetlands and peat bogs. The area of the Carpathian basins has already acquired the character of spruce taiga, unlike the light taiga. However, the steppe and tundra elements have retained a large representation of them. In dry and warm

Fig. 3.18 Location Okoličná na Ostrove. Floodplain sands. White dots represent OSL dating.

steppe areas, chernozems began to form. Archaeology recorded a breakthrough of the Late Palaeolithic and Mesolithic (Svobodová et al., 2001).

After the end of the Ice Age, the climate changed and along with it the natural conditions (Krippel, 1986; Ložek, 1980). With warming and increasing humidity, especially since the Boreal, deciduous forests began to spread and cold seasons had either extinct (mammoths) or moved north (reindeers). Instead, species of forest animals similar to today's have appeared (deer, roe deer, aurochs, bison, pig; Kaminská et al., 2014).

Reconstruction of the natural environment clearly shows that the Danube Lowland was characterized by a varied macro-, meso- and micro-level mosaic during the Pre-Prehistoric to Atlantic period (Kertész & Sümegi, 1999; 2001; Sümegi & Kertész, 1998; 2001; Sümegi et al. 2002; Sümegi, 1996). At the macro-level, this mosaic was formed by the intersection of the main climatic zones: the impact of continentality dwindling from east to west, oceanity from west to east, sub-Mediterranean from south to north, and sub-Carpathian climate in mountain areas. The mosaic pattern of climatic zones and vegetation zones resulted in a mosaic of soil types that were further influenced by the strong subsoil diversity.

In many localities of the central zone (central mound) of the "core" of Žitný ostrov, sandy gravels are exposed, where they become a significant component of recent soil cover. This is also the case at the dated Oldza site (Fig. 3.15).

Boreal (9,000 – 8,000 BP; 10,203 – 8,900 cal. BP)

Boreal is the first significant climatic period of Holocene, evolving from Early Holocene-Preboreal. The trend of climate development continues until the average temperature and ultimately the humidity slightly exceeded the present state. Mean annual temperature (MAT) was up to 2 °C higher than today. The summers were dry and the climate had a continental character. Plants with *Pinus* sp. and *Betula* sp. gave way to mixed oaks, where beside *Quercus* sp. other deciduous trees – *Ulmus* sp., *Tilia* sp., *Fraxinus* sp., *Corylus* sp. spread in the forest crossings, *Picea* sp. in mountainous locations. Man did not influence the country yet (Svobodová et al., 2001).

The precipitation conditions are less well-known, a more continental character can be assumed. However, the corresponding vegetation (e.g. Northern Italy, the Balkans) has not yet been able to penetrate into the Central Europe, as the region of its refuge was too remote. Nevertheless, fundamental changes in the forest vegetation took place. The genera were oak, elm, linden, maple and locally hazel. This is sometimes referred to as a characteristic tree, but its dominance is only regional. Foundations of floodplain forests began to form in the river valleys. In Slovakia, spruce was the dominant woody species so far; in lower areas there were more warm demanding trees, which could rise to higher elevations than today. The vegetation of the tundra, the woodland, and the cold steppes withdrew quickly, the forest dominated the whole country. This vegetation retreated to extreme sites and altitudes, allowing their refugees to rise. Significant was also the occurrence of larger lakes persisting from the Late Glacial period. It was lakes that were a significant food base of man in an otherwise forested country during the Mesolithic period.

Atlantic (7,900 – 4,920 BP)

The Atlantic period is consistent with the Holocene climate optimum. The MATs of the whole Europe at this time were 2 – 3 °C higher than today. The warming occurred very quickly and was almost stable throughout the Atlantic. Period from 9,800 to 8,500 cal. BP. represents a dry and warmer period with a peak around 9,200 cal. BP. Between 8,000 to 7,500 and between 6,000 and 5,800 cal. BP colder periods follow (Musil, 2014). The amount of precipitation also increased – up to 60 – 70% compared to the previous Boreal. The climate was humid, yet warm, with an oceanic character, which facilitated the development of forests. Soils (chernozem) formed on the surface of loess. In the lowlands, mixed forests (*Quercus* sp., *Ulmus* sp., *Tilia* sp.) were combined into continuous forests. The spread of *Fagus* sp. and *Abies* sp. began, at the same time agricultural deforestation. In cave sediments, the humid, unfavorable Atlantic climate, was expressed in sinter formation. This period was characterized by the development of Middle to Late Neolithic cultures and inhomogeneous climate (Velichko, 1989).

Since the 8,000 (8,900 cal. BP) years, the forest stands became coherent, but with more conifers than in the Eastern Europe today. Based on vegetation and lake evidence, it can be concluded that during this period more rainy conditions dominated in most of Central and Southern Europe compared to today (Harrison et al., 1996).

During the Atlantic, air temperatures culminated and, with sufficient rainfall, very favourable conditions were created for the development of forest communities. Vertical differentiation of vegetation has significantly advanced, where beeches and firs have started to become more prominent (Krippel, 1986). The fauna was typically forestry: deer, bison, aurochs, bear, marten, squirrel, fox, badger.

This climate optimum can be divided into three parts (Kalis et al., 2003):

- Early Atlantic (9,200 to 7,000 cal. BP) with low human impact and stable climatic (temperature) conditions,
- Middle Atlantic (7,000 to 6,300 cal. BP). A period of Early and Mid-Neolithic, a culture that brought increased tillage, livestock and grazing. There were noticeable changes in the vegetation cover, but the impact of human activity was still small,
- Late Atlantic (after 6,300 cal. BP). Younger Neolithic. Traces of human activity are already clearly visible on the landscape.

The accumulation of aeolian sand at the Nesvady site (NE-1 Nesvady 7,170 ± 420 BP, Fig. 3.17) was dated to the Atlantic period. These aeolian sediments represent an important genetic element of the final stage of the transitional Late Pleistocene-Holocene aeolian sedimentation, continuing into the Holocene and in many cases until recent. The aeolian sands are also a significant relief-forming element, which enriches the overall planar landscape character of the Danubian Flat. They create various irregular forms of deposition from isolated islet-like small loaves of loaf-like shape, through continuous line formations of connected loaves, to spatially more distinctive dunes of various, particularly elongated, parabolic, arched and loaf shapes. The inter-dune depressions in this area are filled with humous sandy loams and peat humoliths.

In the locality Okoličná na Ostrove, the floodplain sands were dated. They are predominantly fine-grained to silty, but in places very silty with the transition to sandy and silty loam. The age based on OSL method confirms their deposition in the Boreal to Atlantic period (Fig. 3.18).

Epiatlantic (6,000 – 3,200 BP; 6,837 – 3,423 cal. BP)

In this period, the wet and dry periods were often alternating, the summers were on average warmer than at present. MAT was 1 to 2 °C higher than today. Over time, the moisture content decreased (http://lfskripta.webpark.cz/fyto/fyto12.htm).

The term Epiatlantic was introduced by Jäger (1969) for a section corresponding to Firbas's section VII (Firbas, 1949; 1952) (Younger Atlantic) and partly also VIII (Older Subboreal section) to express periods with rapid and significant alternation of wet and dry periods. This period represents a breakthrough in the development of vegetation and the whole Central European nature, because at the beginning of the Atlantic there is a man – a farmer, who initially established settlements in the most fertile forest steppe and steppe areas. He introduces not only cereal crops with accompanying weed communities, but also inadvertently encourages the new development of xerothermal vegetation, which would otherwise have to give way to the spreading forest.

Subboreal (4,950 – 2,750 BP)

In the Subboreal period, the MAT was on average 1 to 2 °C warmer than today, but the climate was dry, rather subcontinental. At the beginning of this period there was an agricultural ecumen, i.e. continuous, populated and agriculturally exploited areas were emerging (forest grubbing – later oak in lower altitudes and later beech in middle altitudes – and ploughing of land). As a result of the permanent plowing of the soil, the removal of the continuous plant cover and the increase in the amount of rainfall, there began a strong erosion of the soil, especially in the sloping relief. This created thick layers of colluviums and in the valleys of the streams at this time large flood plains were formed. Our fluvisoils are therefore only 3,000 years old. In the lower altitudes, the hornbeam-oak forests were already spread. However, these receded in open areas, where xerothermal steppe vegetation was spreading again (http://lfskripta.webpark.cz/fyto/fyto12.htm).

Rainfall was decreasing during the Subboreal, the temperatures kept approximately the same regine. During this period, the mixed oaks gradually retreated as a result of the development of fir-beech forests, which gradually formed a separate vegetation stage, which formed between mixed oak stands and mountain coniferous forests (Krippel, 1986).

The climatic period in which the soils BD-3/3 from Most pri Bratislava (Fig. 3.19) and 313 Okrúhle Jazero – Moravské Kračany were formed represents the Subboreal period (but can be included sensu Jäger /1969/ in Epiatlantic, 6,000 – 3,200 BP). This period is characterized by a relatively rapid alternation of wetter and drier fluctuations. Local environmental problems (heavy rains, reduced water absorption, floods) should be taken into account. The whole period of the previous Atlantic and Epiatlantic was relatively calm in terms of sedimentation, but the fundamental changes in the country, which at times becomes park-like, begin to manifest themselves.

The whole stretch from 4,000 to 3,500 BC was entirely marked by a long and relatively deep precipitation minimum (3,870 to 3,640 BC), designated m-c, which undoubtedly had to have a very strong impact on the climate in a large area of Eurasia. In the whole section from 4,000 BC up to 3,500 BC there were very few noticeable increases in precipitation. Rather, it is possible to speak of a long dry period, which was probably quite cold (Svoboda, 2009). Between 3,485 and 3,400 BC it is possible to detect a marked increase in the precipitation activity, which was manifested in the maximum M-d1. This was followed by a significant precipitation minimum of m-d (Diagram 3.1).

Between 3,000 BC and 2,860 BC there was a gradual decrease in precipitation activity. The period from 2,860 – 2,833 BC represents a longer dry section of the precipitation minimum m-1 with a slight oscillation of the increase in precipitation between 2,830 – 2,820 BC. In the years 2,815 – 2,770 BC, the rapid onset of precipitation activity began to peak at M-1. During the onset of precipitation, there was a slight decrease in precipitation to sub-lows in approximately 2,815 – 2,793 BC. In the period 2,770 – 2,750 BC there was a very rapid decrease in precipitation to a minimum of m-2. Years 2,725 – 2,350 BC represent more or less normal rainfall with minor fluctuations (Svoboda, 2009).

Generally, it is possible to characterize the 3,000 – 2,500 BC section as a rather humid one. Between 2,830 and 2,730 BC, there were a few less pronounced oscillations, after which the precipitation began to decrease significantly (Svoboda, 2009).

In the period from 2,500 to 2,400 BC there was a gradual decrease of precipitation with slight fluctuations. In the years 2,400 – 2,375 BC there was a very small increase in cloudiness and precipitation, which did not even reach normal. The drought was long-lasting. Very moderate precipitation maximum M-3 is characteristic for the period from 2,375 to 2,350 BC. Its parameters correspond to rather minor oscillations (Diagram 3.2).

The beginning of the period from about 2,350 to 2,300 BC is characterized by a faster decrease in precipitation, leading to a lower m-3 minimum. This was followed by a smaller precipitation maximum of M-4 (2,245 to 2,220 BC) followed by a very long precipitation minimum of m-4 with slight fluctuations towards the increase in precipitation, but the increased values did not even reach the normal limit (2,220 to 1,935 BC; Svoboda, 2009).

Half a millennium since 1,500 BC up to 1,000 BC can be evaluated as dry, but with very significant peaks M-7 and M-8, which were quite rich in rainfall. The oscillatory period in the years of about 1,290 to 1,130 BC, which is characterized by extremely large fluctuations in precipitation activity, is significant. It is this period that can be considered one of the most powerful climatic oscillations of antiquity, during which several massive migration waves occurred throughout the Eurasian continent (Diagram 3.3).

In general, the period from 1,000 BC to 500 BC can be assessed as normal with one significant minimum of m-10 peaking around 770 BC. It can be said that in this period of time, Europe had to be extremely dry. The milder drought dominated during the next low of m-11, around 650 – 520 BC. These precipitation anomalies can be linked to the possible migration of European and non-European populations. The following oscillations were low and ranged around average values. After a very long and intensive precipitation minimum m-9 (1,235 – 1,125 BC)

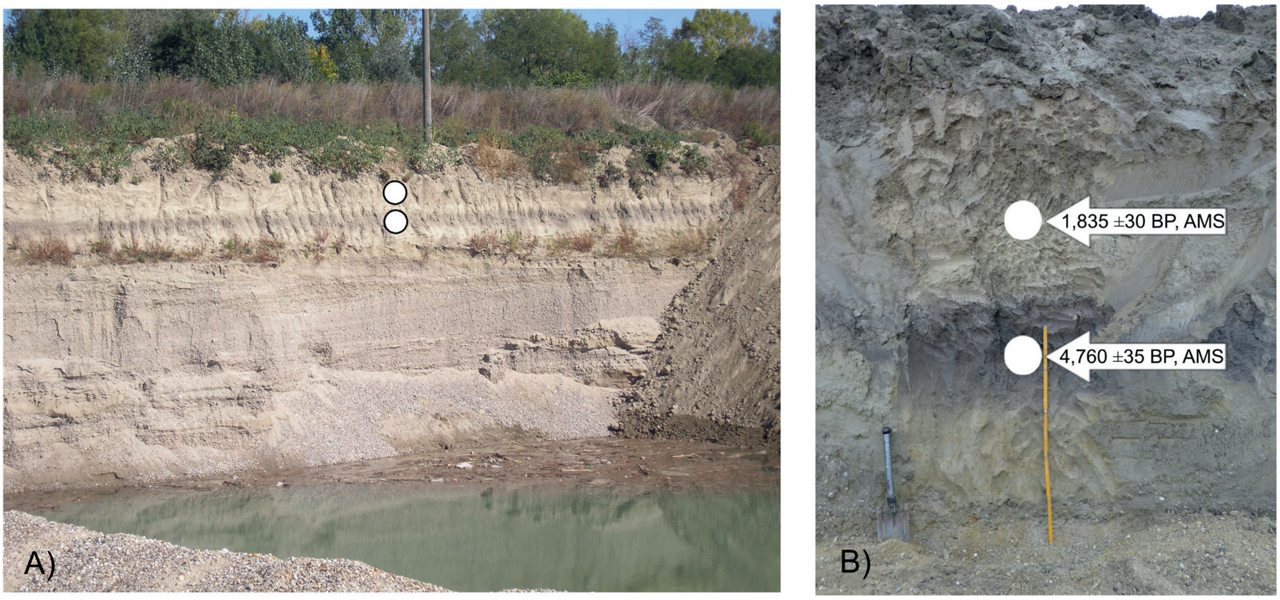


Fig. 3.19 Gravel pit Most pri Bratislave – Zelená voda

A) Panoramic view of transient Pleistocene-Holocene accumulation of the so-called "core" of Žitný ostrov in the Zelená voda gravel pit between Ivanka pri Dunaji and Most pri Bratislave. Up to 6 m thick layer of sandy gravel with apparent lateral accretion and herringbone bedding in the right part of the picture is covered by 2 m thick layer of Pleistocene-Holocene silts and Holocene loams forming a stripped overburden.

B) Fluvial fine-sand silts of the Danube alluvium in the fossil soil overburden in the gravel pitwall profile. Numerical ^{14}C AMS dating from gastropod shells taken from silts above the fossil soil (upper white point) documented the Subatlantic age of the layer and the dating of the fossil soil (lower white point) documented the Subboreal age.

with less oscillation in the years 1,205 – 1,180 followed in the years 1,125 – 1,035 BC a rapid onset of precipitation activity especially in the years 1,125 to 1,086. Then the rainfall remained at the maximum M-8 until 1,035. In the period from 1,015 to 972 BC, after a slight and minor minimum in the years 1,036 – 1,015, precipitation started to increase intensively up to the maximum of M-9. This was followed by a slight precipitation decrease between 972 and 883 (see Diagram 3.4). Dated soil from the profile FS-64zk Hurbanova Ves (1,083 – 906 BC) originated at the onset of the Late Bronze Age. All cultures in Slovakia during this period belonged to the cultures of ash fields (Diagram 3.3).

The climate during the Subboreal (1,250 – 700 BC) was supposed to be very dry and warm with heavy, storm rainfalls. The cultural steppe began to spread very quickly at the expense of the forest – especially oak and beech woods. The forest retreated by several hundred meters to higher altitudes. Exposure of large surfaces, torrential rains, and the inability to absorb water in the landscape led to repeated floods and considerable soil erosion. Slopes debris were formed. Human activities related to logging for construction, consumer and manufacturing purposes contributed to further devastation. Further destruction of the forest stand by grazing reached its peak and caused the first major changes in the composition of forest stands. Further social development takes place roughly up to the Slavic settlement of our countries in the Subatlantic climate period (700 BC – 600 BC). According to natural scientists, the climate should be less favourable than in the Subboreal. The result of the change should be soil erosion in exposed locations and their secondary sedimentation in depressions. Around amidst of this period, there was a partial decline of open areas and gradual afforestation began. This process stopped only at the end of the Subatlantic. In terms of human cultures, however, the situation seems to be slightly different. The settlement in the Early Iron Age – Hallstatt period to Early La Tène (750 – 370 BC) continuously followed the extent and forms of the previous settlement with its spatial diversification and developed further (Cílek & Kubíková, 2003; Diagram 3.3).

Subatlantic (2,750 – present)

In the Subatlantic period, the climate was humid and slightly cooler than today. However, there were fluctuations in the wet and dry phases. This is also suggested by the research of malacofauna from the pebbles in Most pri Bratislave – Zelená voda. The profile reveals Holocene flood sediments lying in the overburden of the Late Pleistocene fluvial gravel of the Danube. In floodplain sediments – calcareous silts, fossil soil was developed (age 4,760 ± 35 BP; 5,520 ± 48 cal. BP (Subboreal; Fig. 3.19). In the overburden of the humus horizon there was a rich but diversified gastropods community (Fig. 3.20). In the malacofauna community, the dominant species was *Arianta arbustorum.* The species *Fruticola fruticum* and *Trochulus striolatus* were also abundant in the community. Small amounts of *Cepaea hortensis, Ena montana, Petasina unidentata, Succinea putris* and *Oxychilus cellarius* were found.

The age of this malacofauna was dated on the basis of ^{14}C AMS dating of the snail shell *Arianta arbustorum* (from a depth of 0.75 m) to 1,835 ± 30 BP (1,775 ± 39 cal. BP, Fig. 3.19). The character of the landscape based on the analysis of this fossil community of malacofauna can be characterized as a floodplain forest. Based on isotopic oxygen analysis from shellfish shells the palaeotemperature was lower than today's temperature.

Overall, however, the climate was more oceanic in the Subatlantic period than it is at present. The upper limit of the forest descended and it can be assumed that it reached the present climatic limit of the forest by the end of this period. The Subatlantic is generally ranked in the Iron Age. At its end, nations moved in the Central Europe and our country was populated by Slavs (http://lfskripta.webpark.cz/fyto/fyto12.htm).

During this period, air temperatures gradually dropped to current levels. Differentiation of forest communities has reached its almost present form. The forests of our territory were in the middle of the Subatlantic period in terms of their composition ideal representative of today's groups of forest types sensu Zlatník (1959). During this period, human activity was already applied to the formation of forest communities (in some territories to a dominant extent) mainly in relation to deforestation of the area for agricultural production.

In the period of the Younger Subatlantic, the anthropogenic influence in the whole territory began to prevail. This represents a determining impact on the forest communities, with the exception of the most remote and extreme sites. Degradation and devastation occurred on ever larger areas, and the proportion of pioneer species (aspen, birch, pine) was growing again.Until the middle of the last century, the overall biodiversity of habitats and animal and plant species increased thanks to the introduction of new crops, animals, weed invasion, expansion of steppe and forest steppe elements. On the contrary, it was only with the beginning of industrialization that its decline have taken place due to large-scale agriculture and new trends in forestry. The overall development of forests in Central Europe and the Czech lands in particular was very short-lived and it can be assumed that it has not been fully completed. This should also have consequences in the formulation of the so-called natural composition of forests and management of protected areas, where the protection of nature and indigenous communities prevails. Frequent famines, crop failures and population fluctuations should warn us of over-romanticism in understanding human relationships and environments in recent centuries (Remeš, 2008).

Years 843 to 775 BC represent a very pronounced and deep m-10 minimum, which is most likely a dry period. The m-10 deep minimum was followed by a very rapid onset of precipitation (775 to 750 BC), but reached only normal values, so it cannot be considered a maximum (Diagram 3.4; Svoboda, 2009).

The dated soil KF-24j from Jelka (Diagram 3.5, Fig. 3.23) was formed in the period of the Early Iron Age (Hallstatt) until the beginning of the Early Iron Age (La

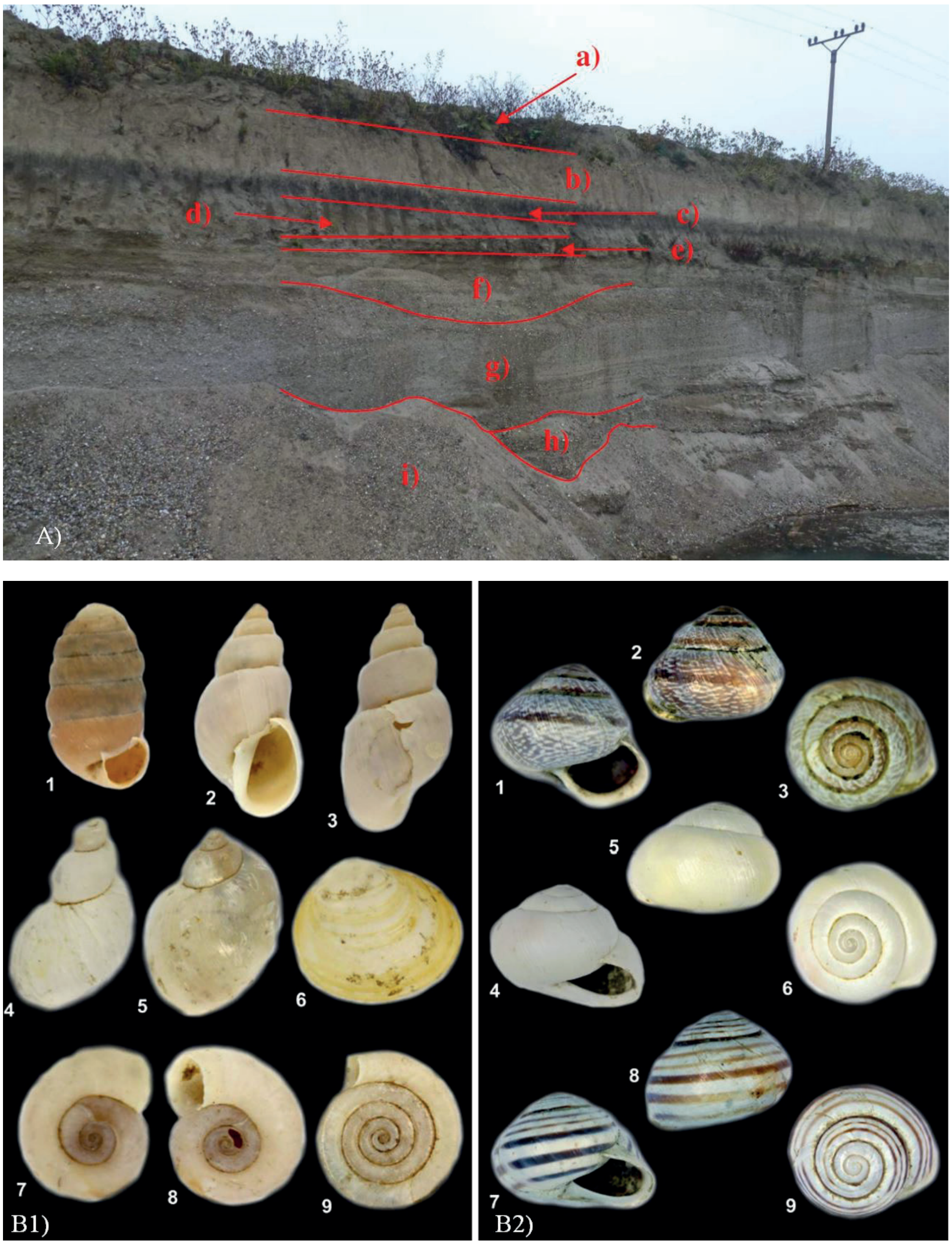


Fig. 3.20 Location Most pri Bratislave – Gravel pit Zelená voda.

A) Fine-rhythmic stratification of the transient accumulation of the "core" of Žitný ostrov in Most pri Bratislave. (a) – recent overburden; b – Holocene fluvial flood silts (loams); (c) Holocene fossil soil (Atlantic); d – silts of Early Holocene to transition period; e) – carbonate layer (calcrete); (f) – the zone of alternation of thin layers of silt, sands, sandy silts and silty fine gravels; (g) – fine-rhythmic alternation of layers, gravel, sand, sandy gravel and gravelly sands of the transitional complex; (h) – coarse layers of coarse-grained sandy gravels of the Late Pleistocene with calcrete (upper part of the Middle Complex); (i) – talus piles;

B) Shells of gastropods from the Štrkovec and Most pri Bratislave B1) Štrkovec locality – 1 Pupilla muscorum (Linné); 2, 3 Galba truncatula (O. F. Müller); 4 Succinella oblonga (Draparnaud); 5 Radix sp.; 6 Pisidium amnicum (O. F. Müller); 7, 8 Gyraulus laevis (Alder); 9 Anisus vortex (Linné); B2) Most pri Bratislave locality – 1 – 3 Arianta arbustorum (Linné); 4 – 6 Fruticola fruticum (O. F. Müller); 7 – 9 Cepaea hortensis (O. F. Müller).

Tène – Celts). This sand dune N of Jelka demonstrates the stadial development of the aeolian sediment in dependence on palaeo-climatic changes during the Holocene. The results show the stage development of the bodies, while the location of the fossil soil in the body of the dune demonstrates the interruption of the body development in the warm and humid period of the climatic optimum of the Middle Holocene, favourable for the development of soils. On the surface of fossil soil there were found fragments of ceramics, proving the settlement of such places in terms of strategy and flood defence.

The precipitation between 528 and 491 years BC was characterized by a minor low m-12. From 491 BC to 435 BC there was a gradual increase in precipitation to a very small and minor maximum. Then, in the years 435 to 400 BC, there was a decrease in precipitation, leading to a marginal minimum of m-13. This was followed by a fairly long stretch of rainfall normal with a few mild oscillations reaching the minimums (400 – 250 BC). The dry years were probably between 380 – 360, 338 – 316 and 250 – 225; Svoboda, 2009).

Generally, an interval from 1,000 BC up to 500 BC can be evaluated as normal with one significant minimum of m-10 culminating around 770 BC. It can be said that in this period of time, Europe had to be extremely dry. The milder drought dominated during the next low of m-11, around 650 – 520 BC. These precipitation anomalies can be linked to the possible migration of prehistoric European and non-European populations. The following oscillations were low and ranged around average values.

Period from 500 BC to 0 can be characterized comparable to recent conditions. Although the rainfall curve was oscillating, it was surprisingly low. Significant were two precipitation lows, m-14 and m-15, which were extremely poor in precipitation (Svoboda, 2009).

Dated gastropod from Most pri Bratislave (DB-3/2 gastropod Most (Poz-73939): (1,835 ± 30 BP) 86 AD – 246 AD) lived in a period that falls within the **Roman**

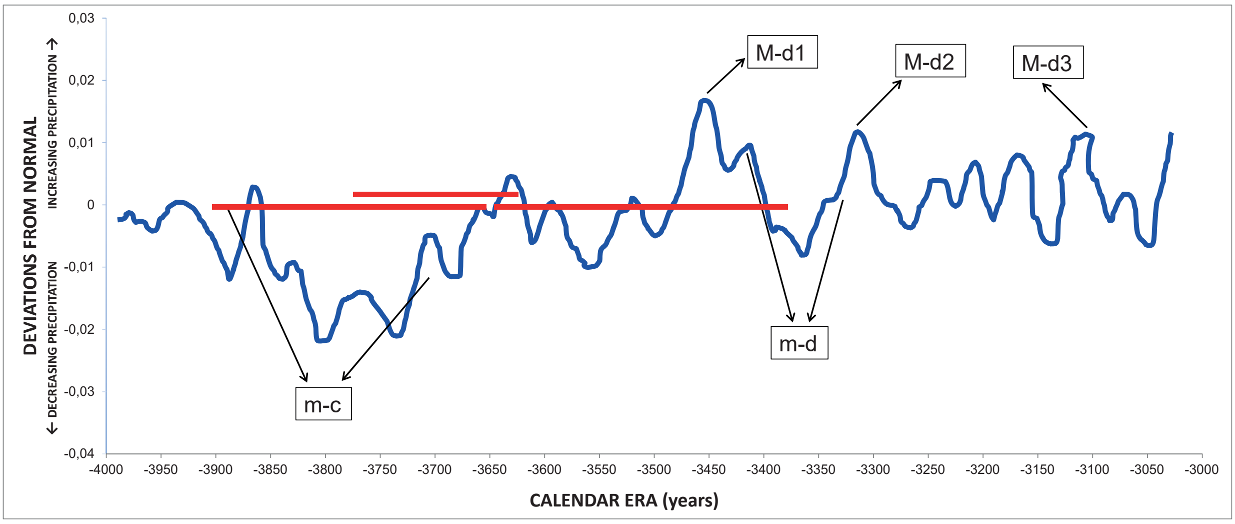


Diagram 3.1 GISP-2 Greenland – annual increases in snow in the period 4,000 – 3,000 BC (Svoboda, 2009). The red bars show the range of dated soil formation JM-1 Bratislava Petržalka (3,909 – 3,657 BC), DB-3/3 from Most pri Bratislava (3,640 BC – 3,381 BC) and 313 Okrúhle Jazero – Moravské Kračany (3,767 – 3,635 BC).

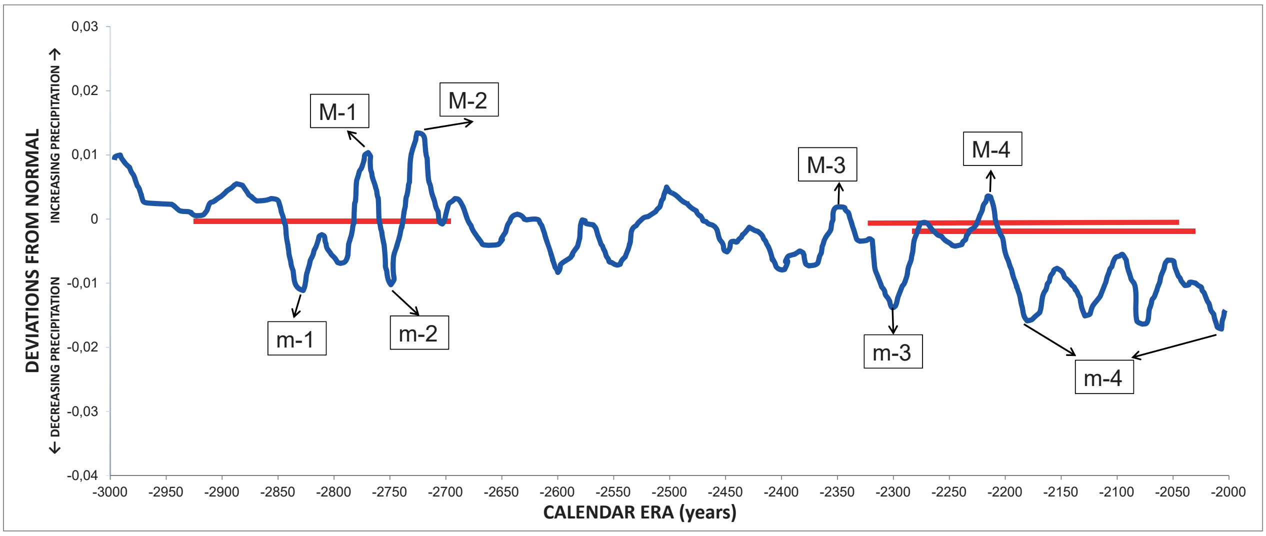


Diagram 3.2 GISP-2 Greenland – annual snow increments of 3,000 – 2,000 years BC (Svoboda, 2009). The red bars show the span of the dated soils 77 Gabčíkovo (2,336 BC – 2,047 BC), S1 Štrkovec (2,281 BC – 2,038 BC) and FM-49C Horné Saliby (Poz-78073) 2,926 – 2,680 BC.

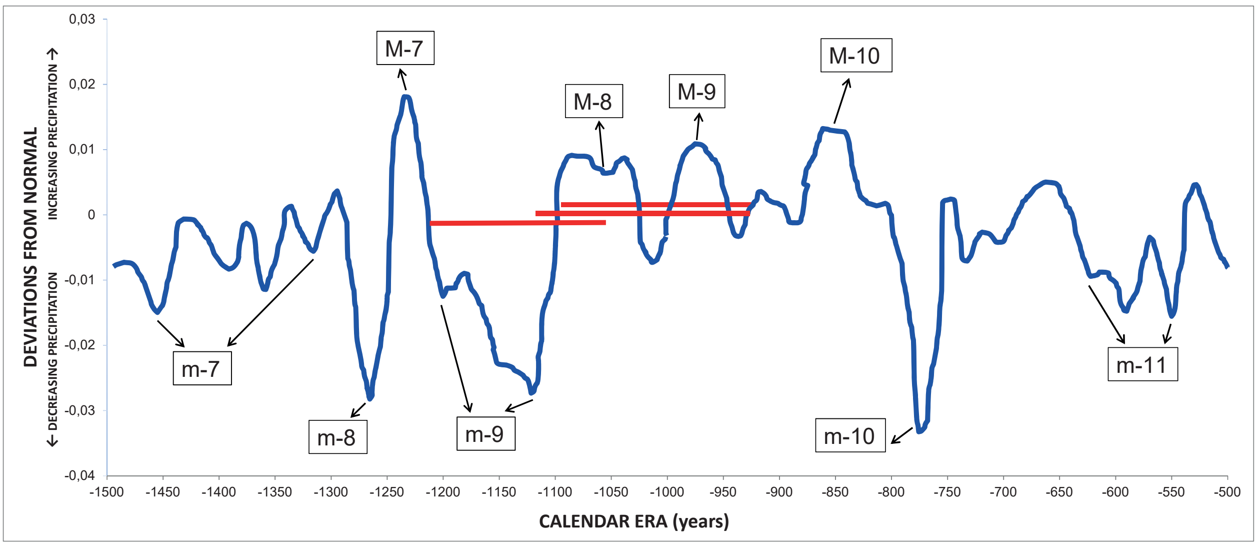


Diagram 3.3 GISP-2 Greenland – annual snow increments between 1,500 and 500 years BC (Svoboda, 2009). The red bars show the span of the dated soils FS-64zk Hurbanova Ves (Poz-75137) 1,083 – 906 BC, FS-21op Malé Blahovo (Poz-75135) 1,123 – 930 BC and MV-20 Šoporňa (Poz-78072) 1,210 – 1,060 BC.

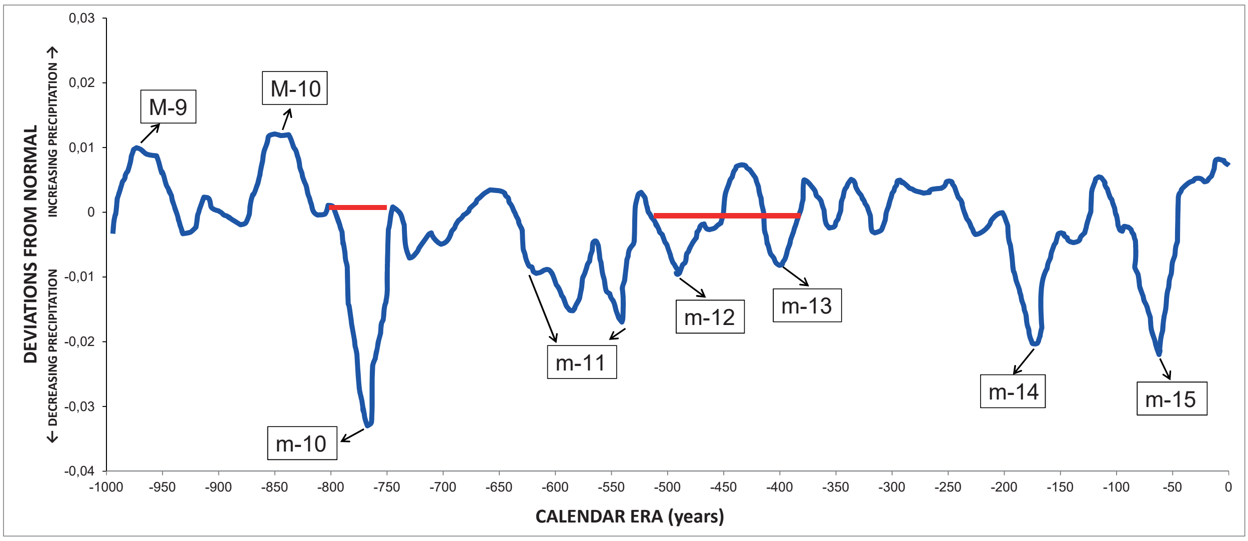


Diagram 3.4 GISP-2 Greenland – annual snow increments of 1,000 y BC – 0 years (Svoboda, 2009). The red line shows the span to which the dated KF-24j Jelka 507 – 366 BC and 878 Gabčíkovo (825 – 757 BC) fall.

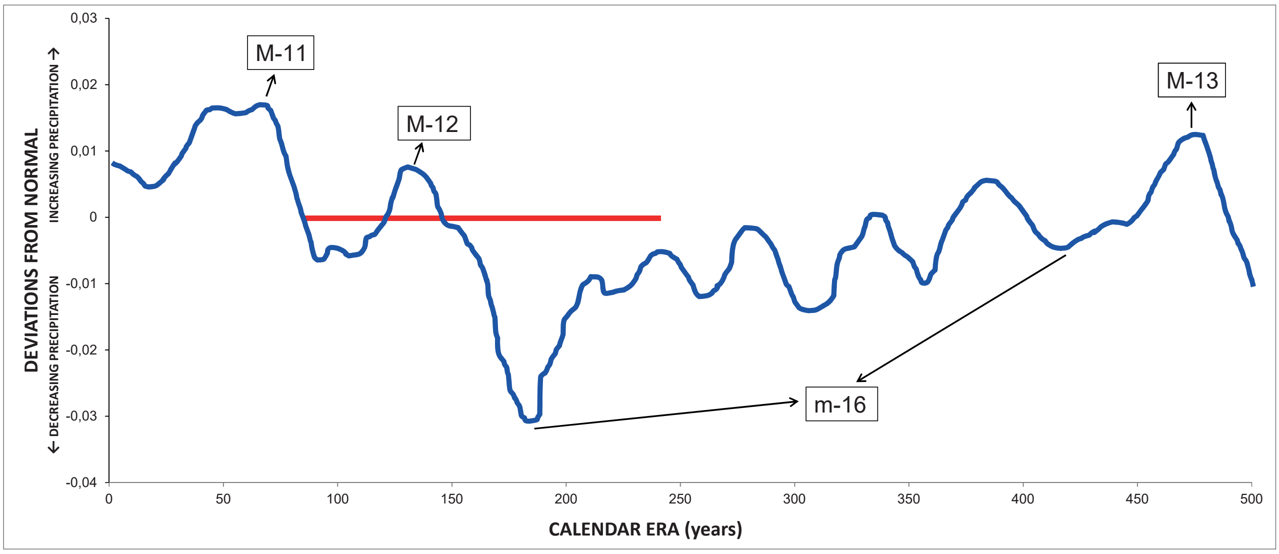


Diagram 3.5 GISP-2 Greenland – annual snow increments from 0 to 500 years AD (Svoboda, 2009). The red line shows the span of DB-3/2 from Most pri Bratislave (86 AD – 246 AD) and the blue line OSL dating of fluvial sands from ZE-1 Zemné (1,690 ± 21 BP) (= 260 AD) and R-1 Rovinka (1,690 ± 12 BP) (= 260 AD).

Climatic Optimum (about 100 BC to 200 – 250 AD). This was a relatively warm and rainfall-rich episode. At this time, the Roman Empire reached the limits of its greatest expansion (Fig. 3.24; Svoboda, 2009). Temporary warming in Central Europe is evidenced by several archaeological and palaeo-botanical findings. In the first century BC the Carpathian basin was dominated by a drier and warmer climate, similar to the one in northern Italy today. This is evidenced by densified annual rings of oak remains, findings of Mediterranean plants such as figs, apricots, peaches, plums and pears, proven by grapes growing on high cordons (Svoboda, 2009).

This is evidenced both by archaeological findings and by depictions on mosaics and paintings from that time. At the end of this period, the first signs of the impending climate catastrophe began to appear. Even in summer, strong cold inbreaks occurred (Svoboda, 2009).

Between 16 and 60 AD, there was a very sharp increase up to year 38, when the peak of M-11 was reached and remained at the same intensity until 65. Thereafter, between 60 and 100 AD, rainfall decreased with a sub-minimum of around year 100 AD. However, it can be assumed that in this case it was the start of an extraordinarily long section of a noticeable decrease in precipitation activity. Around the years 100 – 128 AD there was a slightly milder increase in precipitation to a smaller maximum of M-12. Years 130 – 418 AD are characterized by very significant and extreme precipitation minimum m-16. Generally, however, we can characterize the onset of a very long significantly rainfall-poor section. In this long period, several minor fluctuations leading to increased rainfall can be registered in the years 184 to 208, 225 to 235, 255 to 278, 310 to 333, 356 to 383 (Diagram 3.5). It was a very long period of permanently low cloudiness and probably lower temperatures. It was at this time that there had been extremely strong migratory movements throughout Europe, for which the concept of 'migration of nations' had become established. It was a time so chaotic that it

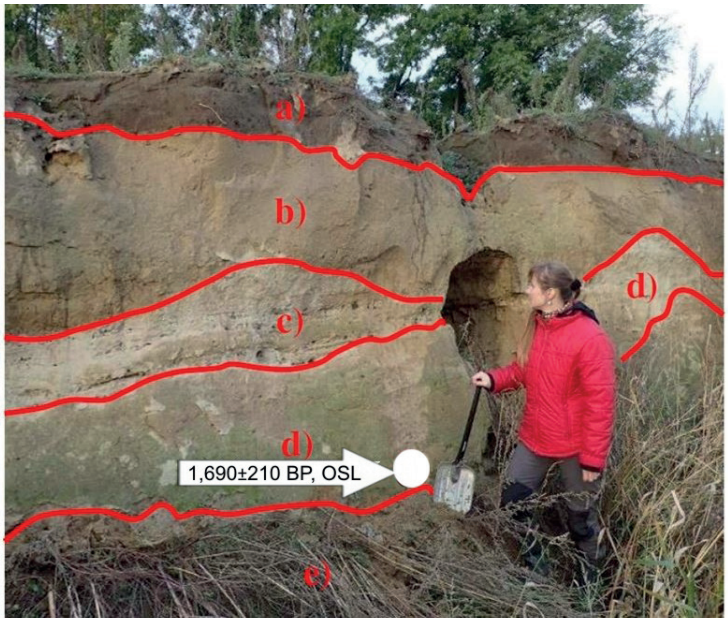


Fig. 3.21 Location Zemné. Fluvial loams (silts) of the flood facies on the fluvial sands of the riverbed facies
(a) – recent soil with anthropogenic interference; (b) – fine-sand flooding silts; (c) – calcareous silts with fine gravel; (d) – weakly calcareous fluvial sands; (e) – loamy outwash. The white point indicates the sampling point from which the sediment age was determined by the OSL method to 1,690 ± 210 BP.

Fig. 3.22 Location Rovinka. Fluvial sands. The white dot indicates the sampling point from which the sediment age was determined by the OSL method at 1,690 ± 12 BP.

Fig. 3.23 Location Jelka. White points – sampling sites and ages of individual layers of aeolian sands based on a fossil soil in the ditch of Jelka.

was enough for everything that was reached in ancient education to be completely forgotten and destroyed. A large number of people of various nationalities were moving through Europe and were constantly fighting with each other (Svoboda, 2009).

Younger Subatlantic
(920 BP – present)

Dated soil and aeolian sand (FS-3j Jelka soil (Poz-74920) (835 ± 30 BP), 747 ± 30 cal. BP, ^{14}C AMS dating and FS-3B Jelka – Aeolian sand (314 ± 28 BP), (= 1,635 AD), OSL dating, as well as wood (DB-3/2 wood Most (135 ± 30) BP), 139 ± 101 cal. BP, ^{14}C AMS dating) come from a period of Younger Subatlantic (Fig. 3.25). The soil FS-4j Jelka (Poz-74922) temporarily falls into the uppermost part of the Older Subatlantic (depending on the stratigraphy used). At this time, the climate development was optimized (from the 11th to the 13th Century). It is the period of the High Middle Ages (the High Middle Ages falls in the period from the beginning of the 11th to the 13th or 14th centuries). The climate was favourable for a long time, had warmed-up considerably and winters were mild. This climatically mild interval, so-called **Medieval Climatic Optimum** (950 – 1250 AD) ended in a generally colder so-called Little Ice Age (between the 14th and 19th centuries, with a peak in the 17th Century; Mann et al.

Fig. 3.24 The Roman Empire during the reign of Emperor Traian (117 AD). Area 6,500,000 km²(Bennet, 1997).

2009). However, as far as the Medieval Climatic Optimum and the Little Ice Age are concerned, this is not a worldwide synchronous period of heat and cold (IPCC, 2001).

Despite considerable uncertainties, especially for the period before 1,600, for which we do not have enough data, the period between 950 and 1,100 AD was the hottest period in the 2,000 years before the beginning of the 20th Century. At that time, however, temperatures were around 0.1 °C and 0.2 °C below the average of 1961 – 1990 and well below the 1980s. Proxy data records from different regions show that the hottest period of different regions took place in different years (Solomon, 2007). These regional warm periods did not occur as coherently in all areas as the warming of the late 20th Century. In some parts of the world, this period was characterized, for example, by population explosions and population expansion into previously uninhabitable areas (Mann et al., 2009).

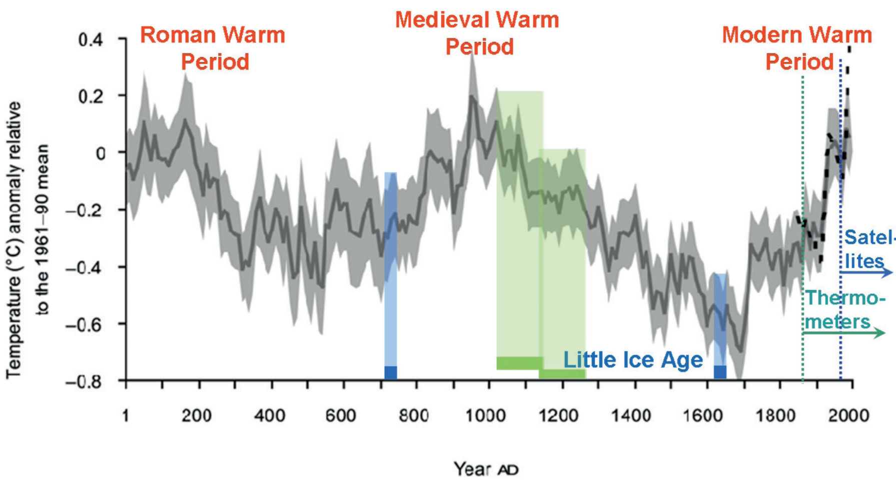


Fig. 3.25 Reconstruction of the temperature for the Northern Hemisphere in the period 1 – 2,000 AD (Ljungqvist, 2010). The green bars show the span to which the dated soils FS-3j Jelka (1,157 – 1,264 AD) and FS-4j Jelka (1,020 – 1,155 AD) fall. The blue bars show the range of OSL dating of fluvial sands from MO-1 Most pri Bratislave (1,230 ± 12 BP) (= 720 AD) and the aeolian sands from FS-3B Jelka (314 ± 28 BP) (= 1,635 AD).

Subrecent (600 BP – present)

This is the youngest period of Subatlantic, but it is strongly influenced by human settlements penetrating into previously unpopulated areas. During the subrecent, there was a clear drying-out of the landscape and the continentality increased.

The moisture difference between wooded highlands and deforested lowlands has increased. Accompanying phenomenon is again the rise of light-loving trees such as oak, hazel, alder and sometimes even pine. Spruce spreads and the pastures are occupied by juniper and a number of herbs bound to open areas. Medieval logging also affects the up-to-date forested mountain areas, leading to the drying-up of large areas and the gradual lack of water in lowland areas. The continuous forest cover is broken up into smaller units by mutually separated pastures (Wallachian colonization in the Carpathians and other types of mountain settlements). Thus, the forest stands lose their internal climate and many of the more moisture-demanding elements disappear. Recent times are characterized by the boom of artificial forest cultures of pine and spruce. In some warm areas, acacia is artificially spread. A new revival of agriculture begins with the arrival of the Slavs and continues smoothly until now (Zeidler & Banaš, 2013).

During this period, there is a large-scale deforestation of the landscape due to agriculture, a decrease in the amount of not only tree species, but also the bush floor (reduction in the amount of pine, oak, linden, elm, hazel and spruce). Wetlands with herbaceous cover are spreading. Owing to farming, nitrophilic communities (elder, nettle, marsh dock, carrot), anthropogenic indicators (juniper, heather), weeds (cornflower, knotgrass).

Later stages have witnessed retreat of the alluvial forests (beech, fir, hornbeam, shrubs) and greater development of pine forests (Remeš, 2008).

Agriculture has intensified **over the last 250 years**. There are plantings of spruce and pine monocultures, deterioration of forest soils due to clearcut logging, forest calamities (drying, frost, calamities due to pests), deterioration of water management in the country. The overall development of the Central European forests was very short-lived and it can be assumed that it has not been fully completed. This should also have consequences in the formulation of the so-called natural composition of forests and management of protected areas, where aspects of nature protection and indigenous communities prevail (Remeš, 2008).

2.4.3 Results of isotope research

As a part of the research of climate change and palaeo-environment, the shell of *Arianta arbustorum* (Linnaeus) from the locality Most pri Bratislave was studied in the Danube Lowland. We used isotopes of oxygen $\delta^{18}O$ and carbon $\delta^{13}C$. This gastropod research is a model example of an isotopic study that was measured to detect changes in the palaeo-environment based on isotopes.

Gastropod *Arianta arbustorum* inhabits damp forests in the lowlands and extends high into the mountains. It avoids only forest-free areas and steppes. Its distribution is in the Central and Northern Europe – the Carpathians, the Alps, north of the Alps, Finland, Poland, Ukraine, eastern France (Buchar et al., 1995; Juřičková et al., 2001; Ložek, 1956).

Holocene flood deposits located in the overburden of the Late Pleistocene fluvial gravel of the Danube are uncovered in the gravel pile near Most pri Bratislave, from where the analyzed gastropod originate. In flood sediments – calcareous silts, fossil soil was developed (age 4,760 ± 35 BP, Subboreal). Its overburden contained a rich but diversified malacofauna community.

In the association of gastropods, the dominant species was *Arianta arbustorum* (Linnaeus). The species *Fruticola fruticum* (O.F. Müller) and *Trochulus striolatus* (C. Pfeiffer) were also abundant in the community. Small amounts of *Cepaea hortensis* (O.F. Müller), *Ena montana* (Draparnaud), *Petasina unidentata* (Draparnaud), *Succinea putris* (Linnaeus) and *Oxychilus cellarius* (O.F. Müller) were identified, as well (Fordinál et al., 2016).

On the basis of the abovementioned malacofauna community, it can be concluded that during the Subatlantic the floodplain forest was located near Most pri Bratislave (Fordinál et al., 2016). The age of this malacofauna was dated on the basis of ^{14}C AMS dating of the snail *Arianta arbustorum* (from a depth of 0.75 m) to 1,835 ± 30 uncal. years BP (Poz-73939: 86 AD – 246 AD /95.4% probability/; Fig.3.26).

$\delta^{18}O$ and $\delta^{13}C$ have been analyzed so far from the fossil shell of land snail *Arianta arbustorum* (Linnaeus) from probe DB3/2, shell sample number DB 3/2-1 (Tab.3.3). Isotope analyses were performed in laboratories of the State Geological Institute of Dionýz Štúr in Bratislava.

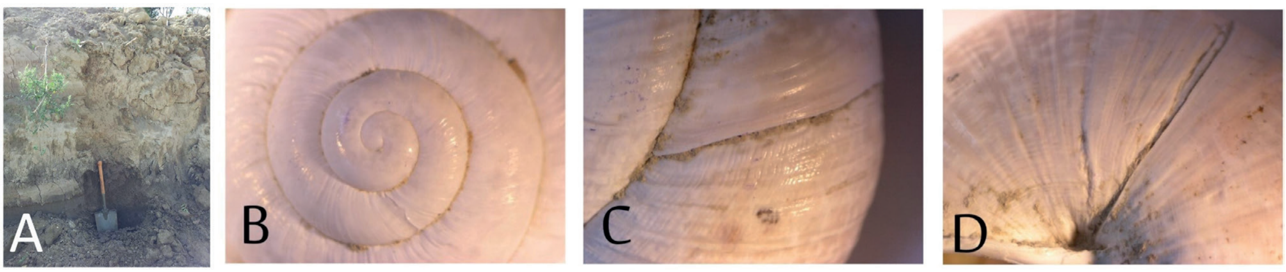


Fig. 3.26 A – location Most pri Bratislave, probe DB-3/2. B-D – gastropod sample number DB 3/2-1, which was used for isotopic analysis of carbon and oxygen. B – protoconch, the initial chamber, C – winter growth arrest line, followed by the last increment on the shell, D – winter growth arrest line and umbilicus.

Tab. 3.3 Results of isotopic ratio of carbon and oxygen from the shell of *Arianta arbustorum* from locality Most pri Bratislave, probe DB-3/2, snail sample number DB 3/2-1. The gastropod shell was divided into 5 so-called years – yearly increments, separated from each other by winter growth arrest line. 1 represents protoconch and 5 represents the last increment on the shell (stdev – standard deviation).

shell increments "years"	δ $^{13}C/^{12}C$	stdev	δ $^{18}O/^{16}O$ vs V-PDB	stdev	corr δ $^{18}O/^{16}O$ vs V-PDB	stdev	δ $^{18}O/^{16}O$ vs VSMOW
1 – protoconch	**-8.77**	xx	**-3.22**	0.36	-3.22	0.36	27.57
2	**-8.70**	0.04	**-3.07**	0.20	-3.07	0.20	27.73
3	**-9.27**	0.06	**-2.40**	1.13	-1.78	0.45	28.42
4	**-9.18**	0.06	**-3.68**	0.87	-3.28	0.56	27.10
5 – last increment	**-9.54**	0.06	**-2.88**	0.08	-2.88	0.08	27.93

	Precipitation [mm]		δ¹⁸O [‰]		δ²H [‰]		d-excess [‰]		Air Temp. [°C]	
Month	Avg	n	Avg	n	Avg	n	Avg	n	Avg	n
January	12.0	6	-11.35 ± 2.62	8	-53.6	1	9.8	1	0.7	6
February	25.6	6	-12.86 ± 2.99	7	-57.4	1	1.1	1	1.2	5
March	25.7	6	-10.33 ± 3.37	7	-	0	-	0	5.8	5
April	28.0	6	-9.05 ± 1.59	7	-	0	-	0	10.6	5
May	29.4	6	-5.84 ± 3.19	7	-	0	-	0	15.6	5
June	48.5	6	-6.13 ± 1.90	7	-	0	-	0	18.3	5
July	47.1	6	-5.89 ± 2.58	6	-	0	-	0	20.8	6
August	51.0	5	-8.46 ± 3.08	5	-	0	-	0	20.7	6
September	32.3	5	-6.53 ± 1.87	7	-	0	-	0	15.6	5
October	34.7	5	-8.49 ± 1.71	7	-	0	-	0	9.8	5
November	49.2	5	-11.16 ± 2.33	7	-	0	-	0	3.9	5

Fig. 3.27 Location Topoľníky, 133 m a.s.l.: average amount of precipitation in mm, average monthly air temperature, average δ^{18}O precipitation in ‰, average δ^{2}H precipitation in ‰, average air temperature in °C for 1988 – 1993 (IAEA/WMO, 2018).

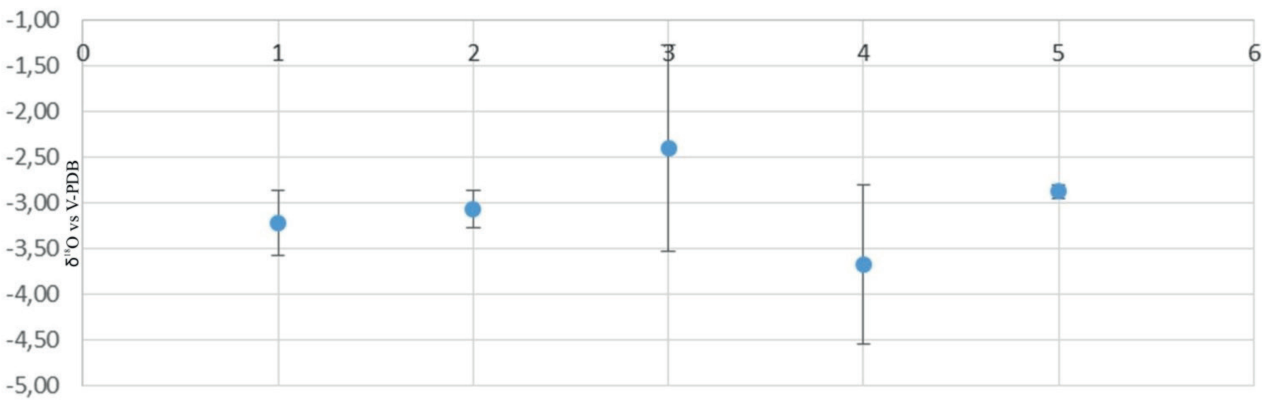


Diagram 3.6 Isotope ratio δ^{18}O from shell of Arianta arbustorum, locality Most pri Bratislave, probe DB-3/2, snail sample number DB 3/2-1. 1 represents protoconch and 5 represents the last increment on the shell (error bars represent standard deviation).

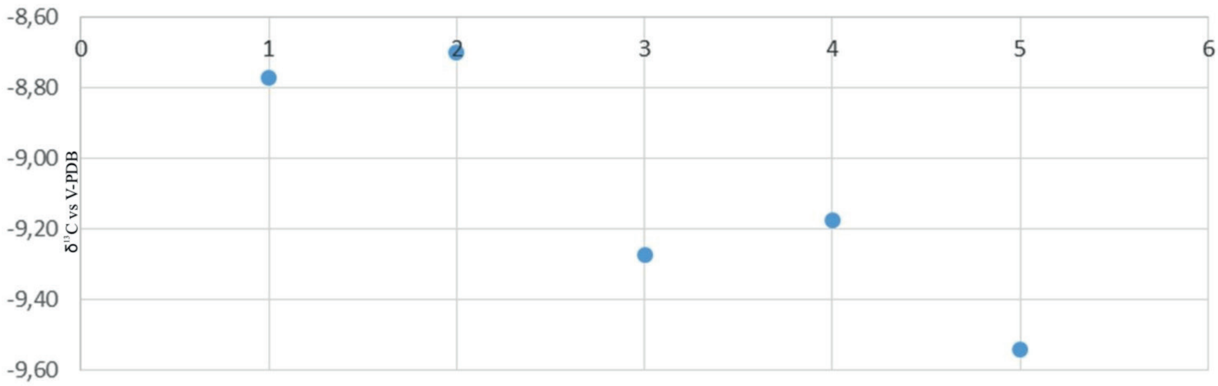


Diagram 3.7 Isotope ratio $\delta^{13}C$ from shell of Arianta arbustorum, locality Most pri Bratislave, probe DB-3/2, snail sample number DB 3/2-1. 1 represents protoconch and 5 represents the last increment on the shell (error bars represent standard deviation).

The gastropod shell was divided into individual years – increments – of winter growth arrest lines. These increments represent the period in which the individual lived actively and his shell grew (Fig. 3.26). The studied individual DB 3/2-1 survived 5 years. Each increment was isotopically analysed. The values $\delta\ ^{13}C/^{12}C$ a $\delta\ ^{18}O/^{16}O$ were determined. $\delta^{13}C$ values of *Arianta arbustorum* shellfish range from -8.77‰ to -9.25‰, $\delta^{18}O$ values from - 2.40‰ to -3.22‰ (Tab. 3.3, Diagrams 3.5, 3.6). The average value for $\delta^{13}C$ is 9.092‰, for $\delta^{18}O$ the average value is 3.05‰ (Diagram 3.7).

3.4.3.1 Palaeo-temperature derived from isotope analyses

Oxygen isotope values indicate changes in the palaeo-temperature during the life of the studied gastropod.

The $\delta^{18}O$ value of meteoric water in the study age (1,775 ± 39 cal. BP) received by the studied gastropod ranged from -7.4‰ to -8.68‰ (average -8.06‰) (assuming enrichment of $\delta^{18}O$ shells by 5‰ due to palaeo-rainwater). If we compare the average of palaeo-meteoric water values in the study period ($\delta^{18}O$ = -8.06‰) with the values of $\delta^{18}O$ rainwater from the period from 1988 to 1993 (average $\delta^{18}O_{April\text{-}September}$= -6,98‰) from Topoľníky (113 m a.s.l., southern Slovakia, approx. 46 km from Most pri Bratislave; based on data from IAEA/WMO (2018), we find that $\delta^{18}O$ palaeo-precipitation was on average -1.08‰ lower/negative than in 1988 – 1993. The average temperature in the years 1988 – 1993 in the months April-September was 17 °C (IAEA/WMO, 2018). Based on the $\delta^{18}O$ values of *the Arianta arbustorum* shell and calculations according to Goodfriend's equation (1999) (Eq. 1). we can conclude that palaeo-temperature changes during the lifetime of the subject (during the growth period of the shell) were about 5.12 °C.

$$´\Omega\ (°C) = (\delta^{18}O_{max.\ –}\ \delta^{18}O_{min./}0,5‰) \times 2°C \qquad \text{(Eq. 1)}$$

Where: Ω (°C) – relative palaeo-temperature change, $\delta^{18}O_{max.}$ – maximum value of $\delta^{18}O$ shell, $\delta^{18}O_{min.}$ – minimum value of $\delta^{18}O$ shell.

Using the recalculation according to Balakrishnan et al. (2005; Eq. 2) palaeo-temperature changes will be about 3.6 °C:

$$´\Omega\ (°C) = (\delta^{18}O_{max.\ –}\ \delta^{18}O_{min.}/0,35‰) \times 1°C \qquad \text{(Eq. 2)}$$

3.4.3.2 Palaeo-environment deduced from isotope analyses

Climate change during glacial and interglacial periods is a major cause of vegetation changes that are reflected in $\delta^{13}C$ plant values (Huang et al., 2001; Hall & Penner, 2013). If the $\delta^{13}C$ values are more negative, this is an indication that the molluscs consumed C3 plants and that the climate was cooler and humid (Goodfriend & Ellis, 2002, Yanes et al., 2008).

If the $\delta^{13}C$ values are more positive, this is an indication that molluscs consumed C4 plants, indicating a drier environment (Galy et al., 2008; Yanes et al., 2008). Variation of $\delta^{13}C$ values measured in the shell of the specimen of *Arianta arbustorum* from Most pri Bratislave ranges from **-9.54‰** to **-8.7‰** (Diagram 3.7).

C4 vegetation as a dietary source for the studied gastropod from Most pri Bratislave can be ruled out because these plants show very different $\delta^{13}C$ values ranging from **-8‰** to **-19‰** (Ambrose & Sikes, 1991), which contradicts our results, because $\delta^{13}C$ values measured in shells of fossil gastropods are enriched by 8 – 19‰ due to isotopic fractionation compared to the values of the plants they consumed (McConnaughey & Gilikin, 2008). This means that the $\delta^{13}C$ values of the molluscs from Most pri Bratislave were approximately in the range of **-17.54‰** to **16.7‰** when using at least 8‰ enrichment. This is very close to the most negative border of $\delta^{13}C$ for C4 plants. If we use the 19‰ enrichment, the plant food values consumed by the studied gastropod from Most pri Bratislave range from **-28.54‰** to **27.7‰.**

Based on these results, we can conclude that C3 plants were the main food type of vegetation for the studied gastropod. As could be observed from the variables, the gastropod's food fluctuated throughout his life. In the first years, the $\delta^{13}C$ was less negative towards the last increment on the shell, and the $\delta^{13}C$ values moved to less negative values. This provides evidence for changing food of the studied gastropod throughout his life. However, these changes in palaeo-food are not very significant.

3.5 Conclusions

The article presents the reconstruction of the palaeo-environmental development of the Danubian Flat in the period from 127,000 years BP to the present day and solving the chronostratigraphic affiliation of selected sites on the basis of dating organic material and sediments using AMS ^{14}C (radiocarbon dating) and OSL (optically stimulated luminescence).The period studied is the section of time that includes deposition of dated soils, aeolian and fluvial sands, and organic residues from the study area. The period of the Late Glacial to Holocene is discussed in more detail, because the transition of the Last Ice Age to postglacial had the greatest influence on the formation of the present natural environment, fauna and flora.

During the research, the extent of a wide spectrum of fluvial accumulations subtypes of the transient "core" of Žitný ostrov was mapped in detail, their non-coherent occurrence and precise delineations were confirmed.

There have been mapped in detail the extent and exact delimitation of sites and zones of aeolian sand (sand dunes). The post-glacial (Holocene) genesis has been assigned to majority of the aeolian deposits; to a less extent the older Late Pleistocene facies have been confirmed. The Holocene age of the vast majority of organogenic sediments (humoliths) was found, only in some cases of the fills of open oxbows within Žitný ostrov the older age has been found.

The formation of sediments in the period of the Roman Climate Optimum, the Medieval Climate Optimum and the "Little Ice Age" in our territory in the Danubian Flat area has been confirmed.

<u>Sedimentary evolution</u>

During the overall cold climatic conditions with a lack of air precipitation, loess formation took place in some places. However, the most widespread sediments in the Danube region and the lower reaches of the Váh, Nitra and Žitava rivers were the sands. In some humid places and in the area above the river terraces, sapropels were formed overlying peat or silty alms.

Geological development during the Holocene had a relatively uniform character in the Danube Lowland. Climate change and hydrodynamic conditions of larger rivers influenced the landscape structure, sedimentary and plant cover. In later periods, human activity was also associated with the impact on the natural environment. The whole territory was strongly influenced by hydromorphism. The Danube often shifted its main and side channels, eroded its own deposits and resedimented them. The flood waters spilled on a wide area and also affected the higher degree of the Danube River floodplain. Preboreal and Boreal periods were characterized by the greatest afforestation, followed by steppe intrusion. During the Atlantic period, the climate warmed and gradually humidified. This period was characterized by more pronounced soil formation in those parts of the territory where flood water was not frequently used. Chernozems and gley soils were formed at higher places (Šajgalík & Modlitba, 1983). During this period, some fens began to form in abandoned meanders and oxbows. Aeolian sands were blown over many places (Pelíšek, 1963).

<u>Holocene climate change based on vegetation</u>

The onset of Holocene initially shows similar proportions to the warmer phases of the Late Glacial, but the rapid rise in temperature and the consequent increase in humidity conditioned the permanent immigration of more climatically demanding species. However, the greatest changes occur in living nature, especially in vegetation. The loess steppes and stony areas, or tundra formations gradually passed into the pine-birch stands of light taiga, which later penetrated deciduous trees, especially *Corylus* sp. and *Quercus* sp. In the older phase, the open formations of mesophilic meadows also played an important role. In dry and warm areas, the continental steppe developed on the chernozems, and on the warm calcareous hillsides, the forest formation was gradually pushed to extreme habitats, such as rocky edges, sand, etc. In the Atlantic, natural conditions (warming and humidification) triggered the formation of enclosed damp forests (Ložek, 2002).

Dating

Using the AMS ^{14}C method, 24 samples were dated from 16 localities (Bratislava – Petržalka, Čechová, Čierna Voda, Gabčíkovo, Horné Saliby, Hurbanova Ves, Jánošíkovo, Jelka, Kolárovo, Lúč na Ostrove, Malé Blahovo, Most pri Bratislave, Nový Život – Šalamúnove polia, Okrúhle jzero – Moravské Kračany, Šoporňa, Štrkovec) from the period of the Late Glacial to the Holocene. The age of the dated samples by AMS ^{14}C ranged from 135 ± 30 years BP to 14,410 ± 90 years BP. One sample was outside the ^{14}C AMS dating method range. It came from the well VN 124-2 Kolárovo. Its age was more than 50,000 years BP.

By the OSL method in the studied profiles of the western part of the Danubian Flat 22 samples from 17 localities were dated (Aňala, Balvany, Batoňa, Bratislava, Dunajská Streda, Jelka, Miloslavov, Most pri Bratislave, Nesvady, Okoličná na Ostrove, Oldza, Opatovský Sokolec, Rovinka, Štrkovec, Tvrdošovce, Vrakúň, Zemné) from the period of the penultimate interglacial (Eemian) to Holocene. The age of the dated samples ranged from 127,000 to 314 years BP.

The age of all dated samples (both ^{14}C AMS and OSL) ranged from 127,000 ± 1000 years BP to 135 ± 30 years BP. In the dated samples, the time period from the Eemian Interglacial (i.e. the penultimate glacial period) up to the present day has been captured, thus specifying the chronostratigraphic situation in the study area.

Isotope analyses of malacofauna

The article discusses the possibilities of using isotopic analyses of oxygen and carbon in terrestrial malacofauna shells for reconstructions of climate change and natural environment in the past. Calculated relative palaeotemperature change during the life of the studied gastropod *Arianta arbustorum* from the locality Most pri Bratislave (1,835 ± 30 years BP (86 AD – 246 AD)) was 5.12 °C, or 3.6 °C, depending on which conversion formula we used.

The $\delta^{18}O$ values of the detected palaeo-precipitation were on average -1.08‰ lower/more negative than in 1988 – 1993. This suggests that the palaeo-temperature (in the months in which the gastropod was active) during the period 1,835 ± 30 uncal. BP was slightly lower than in 1988 – 1993.

Based on the analysis of $\delta^{13}C$ results from the gastropod shell. The gastropod's food fluctuated throughout his life. In the first years, the $\delta^{13}C$ was less negative towards the last increment on the shell, and the $\delta^{13}C$ values shifted to less negative values. This testifies for the changing food of the studied gastropod throughout his life. However, these changes in palaeo-food do not indicate significant differences.

Based on the results obtained by a comprehensive review from the Danube region, it can be concluded that the climate has never been stable for a long time. The alternation of climatic cycles during the Quaternary was reflected in the development of sediments, to which flora, fauna and, of course, human societies responded.

The above results show the importance of exploring climate change based on several scientific approaches. Without an interdisciplinary approach to the study of climate change, it is not possible to detect, record and explain minor climate oscillations in the past. To predict future climate change, it is necessary to know climate history and its impact on nature and human civilization.

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References

Adams, J. M. & Faure, H. (eds.), 1997: QEN members. Review and Atlas of Palaeovegetation: Preliminary land ecosystem maps of the world since the Last Glacial Maximum. Oak Ridge National Laboratory, TN, USA. http://www.esd.ornl.gov/ern/qen/adams1.html.

Alley, R., Meese, C. A., Shuman, A. J., Gow, K. C., Taylor, P. M., Grootes, J. W. C., White, M. Ram, E. D., Waddington, P., Mayewski, A. & Zielinski, G. A.: 1993: Abrupt accumulation increase at the Younger Dryas termination in the GISP2 ice core, Nature 362, p. 527 – 529.

Ambrose, S. H. & Sikes, N. E., 1991: Soil carbon isotope evidence for Holocene habitat change in the Kenya Rift Valley, Science 253, p. 1402 – 1405.

Ambrož, V., Ložek, V. & Prošek., F., 1952: Mladý pleistocén v okolí Moravan u Piešťan nad Váhom. Anthropozoikum, I, 1951, Praha, p. 53 – 142.

Anderson, D. E., 1997: Younger Dryas research and its implications for understanding abrupt climatic change. Progress in Physical Geography, p. 230 – 240.

Atkinson, T. C., Briffa, K. R. & Coope, G. R., 1987: Seasonal temperatures in Britain during the past 22,000 years, reconstructed using beetle remains. Nature 325, p. 587 – 592.

Balakrishnan, M., Yapp, C. J., Theler, J. L., Carter, B. J. & Wycoff, D. G., 2005: Environmental significance of 13C/12C and 18O/16O values of modern land–snail shells from the southern great plains of North America. Quaternary Research 63, p. 15 – 30.

Bennet, K. D., Tzedakis, P. C. & Willis, K. J., 1991: Quaternary refugia of north European trees. Journal of Biogeography, 18, p. 103 – 115.

Björck, S., Alker, M. J. C., Cwynar, L. C., Johnsen, S., Knudsen, K.–L., Lowe, J. J., Wohlfarth, B. & INTIMATE Members, 1998a: An event stratigraphy for the last termination in the North Atlantic region based on the Greenland ice–core record: a proposal by the INTIMATE group. Journal of Quaternary Science, 13, p. 283 – 292.

Björck, S., Walker, M. J., Cwynar, L. C., Johnsen, S., Knudsen, K. L., Lowe, J. J. & Wohlfarth, B., 1998b: An event stratigraphy for the Last Termination in the North Atlantic region based on the Greenland ice–core record: a proposal by the INTIMATE group. Journal of Quaternary Science, 134, p. 283 – 292.

Bortolot, V. J., 2000: A new modular high capacity OSL reader system. Radiation Measurements 32, p. 751 – 757.

Boschetti, T., Iacumin, P. & Commun, R. 2005: Mass Spectrom. 19, p. 3007.

Brock, F., Higham T., Ditchfield, P. & Bronk Ramsey, C., 2010: Current pretreatment methods for AMS radiocarbon dating at the Oxford Radiocarbon Accelerator Unit (ORAU). Radiocarbon 52, 1, p. 103 – 112.

Bronk Ramsey, C., 2001: Development of the radiocarbon calibration program OxCal. Radiocarbon 43(2A): p. 355 – 363.

Bronk Ramsey, C., 2009: Dealing with outliers and offsets in radiocarbon dating. Radiocarbon 51(3): p. 1023 – 1045.

Bronk Ramsey, C. & Lee, S., 2013: Recent and Planned Developments of the Program OxCal. Radiocarbon, 55(2–3), p. 720 – 730.

Břízová, E., Pišút, P. & Uherčíková, E., 2007: Rekonstrukce vývoje lesní vegetace na Žitném ostrově na základě pylové analýzy. In: Križová, E. & Ujházy, K: Dynamika, stabilita a diverzita lesných ekosystémov, p. 209 – 215. TU vo Zvolene. Zvolen. ISBN 978-80-228-1821-6.

Buchar J., Ducháč, V., Hůrka, K. & Lellák, K., 1995: Klíč k určování bezobratlých, Scientia, Praha, 310 p.

Cílek, V. & Kubíková, J., 2003: Střední Čechy. Příroda, člověk, krajina. Dokořán, Praha, 127 p.

Czernik, J. & Goslar, T., 2001: Preparation of graphite targets in the Gliwice Radiocarbon Laboratory for AMS ^{14}C dating. Radiocarbon 43, 1, p. 283 – 291.

Čejka, T., Čačaný, J. & Dvořák, L., 2012: Zvyšky bratislavských lužných lesov – významné refúgium podunajskej malakofauny. (Remnants of alluvial woodland in an urbanised area – important refuge for Middle Danubian land gastropods Bratislava City, Slovakia). Malacologica Bohemoslovaca, 11, p. 29 – 38.

Deli, T. & Sümegi, P., 1999: Biogeographical characterisation of Szatmár–Bereg plain based on the mollusc fauna. In: Hamar, J. & Sárkány–Kiss, A. (eds.): The Upper Tisa Valley. Tiscia Monograph Series, Szeged, p. 471 – 477.

Faško, P. & Šťastný, P., 2002: Priemerné ročné úhrny zrážok 1 : 2 000 000. In Atlas krajiny Slovenskej republiky. Ministerstvo životného prostredia Bratislava, Agentúra životného prostredia, Banská Bystrica, p. 99.

Firbas, F., 1949: Spät– und nacheiszeitliche Waldgeschichte Mitteleuropas nördlich der Alpen. I. Allgemeine Waldgeschichte. Jena.

Firbas, F., 1952: Spät– und nacheiszeitliche Waldgeschichte Mitteleuropas nördlich der Alpen. II. Waldgeschichte der einzelnen Landschaften. Jena, p. 256.

Fordinál, K., Maglay, J., Moravcová, M., Vlačiky, M., Fričovská, J. & Šefčík, P., 2017: Charakter paleoprostredia vo vrchnom pleistocéne a v holocéne na území Podunajskej roviny. Mente et Malleo, 2, 1, p. 56.

Fordinál, K., Moravcová, M., Vlačiky, M., & Maglay, J., 2016: Upper Pleistocene and Holocene molluscs fauna from Danubian Plain area (Slovak Republic). In: 17th Czech–Slovak–Polish Palaeontological Conference, Kraków, 20–21 October 2016. Abstract volume. Warsaw: Polish Geological Institute, p. 39.

Fry, B., 1991: Carbon Isotope Techniques. Academic Press: San Diego, CA.

Galbraith, R. F., Roberts, R. G., Laslett, G. M., Yoshida, H. & Olley, J. M., 1999: Optical dating of single and multiple grains of quartz from Jinminum Rock Shelter, Northern 12 Australia. Part I, experimental design and statistical models. Archaeometry 41, p. 1835 – 1857.

Galy, V., François, L., France–Lanord, C., Faure, P., Kudrass, H., Palhol, F. & Singh, S. K., 2008: C4 plants decline in the Himalayan basin since the Last Glacial Maximum. Quaternary Science Reviews 27, p. 1396 – 1409.

Gehre, M., Strauch, G. & Commun, R., 2003: Mass Spectrom. 17, p. 1497.

Goodfriend, G. A. & Ellis, G. L., 2002: Stable carbon and oxygen isotope variations in modern Rabdotus land snail shells in the southern Great Plains, USA, and their relation to environment. Geochimica et Cosmochimica Acta 66, p. 1987 – 2002.

Goodfriend, G. A., 1999: Terrestrial stable isotope records of Late Quaternary paleoclimates in the eastern Mediterranean region. Quaternary Science Reviews 18, p. 501 – 513.

Goslar, T., Czernik, J. & Goslar, E., 2004: Low–energy ^{14}C AMS in Poznan radiocarbon Laboratory, Poland. Nuclear Instruments and Methods in Physics Research B, 223 – 224, p. 5–11.

Grolmusová, Z., Rapčanová, A., Veis, P., Čech, P., Michalko, J., Šivo, A., Richtáriková, M. & Povinec, P., 2012: ^{13}C measurements of alphacellulose from tree–ring samples using the IRMS spectrometry. WDS´12: Proceedings of Contributed Papers: Part III Physics. Prague, MATFYZPRESS, p. 73 – 76.

Guerin, G., Mercier, N. & Adamiec, G., 2011: Dose–rate conversion factors: update. Ancient TL 29, p. 5 – 8.

Guiot, J. & Pons, A., 1986: Une méthode de reconstruction quantitative du climat à partir de chroniques pollenanalytiques: le climat de la France depuis 15000 ans (A method for quantitative reconstruction of climate from pollen time–series; the French climate back to 15000 years B.P.). Comptes rendus de l'Académie des sciences, 2, Mécanique, Physique, Chimie, Sciences de l'univers, Sciences de la Terre, 302, 14, p. 911 – 916.

Hall, S. A. & Penner, W. L., 2013: Stable carbon isotopes, C3–C4 vegetation, and 12 800 years of climate change in central New Mexico, USA, Palaeogeogr. Palaeocl., 369, p. 272 – 281.

Harrison, S. P., Yu, G. & Tarasov, P. E., 1996: Late Quaternary lake–level record from northern Eurasia. Quaternary Research, 45, p. 138 – 159.

Hók, J., Kahan, Š. & Aubrecht, R., 2001: Geológia Slovenska. Univerzita Komenského, Bratislava, 43 p.

Horáček, I. & Ložek, V., 1988: Paleozoology and the Midd–European Quarternary past: scope of the approach and selected results. Rozpravy ČSAV, Praha, 98, 4, p. 102.

Horáček, I., Ložek, V., Svoboda, J. & Šajnerová, A., 2002: Přírodní prostředí a osídlení krasu v pozdním palolitu a mezolitu. In: Svoboda, (ed.), Prehistorické jeskyně, Dolonověstonické studie 7, Brno. p. 313 – 343.

Horvath, F., Bada, G., Szafian, P., Tari, G., Adam, A. & Cloetingh, S., 2006: Formation and deformation of the Pannonian Basin: constraints from observational data. In: Gee, D.G., Stephenson, R.A. (Eds.), European Lithosphere Dynamics. Geological Society, London, Memoirs 32, 191 – 206 p.

Hrušecký, I., 1999: Central part of the Danube Basin in Slovakia: Geophysical and Geological Model in Regard to Hydrocarbon Prospection. Exploration Geophysics, Remote Sensing and Environment, 6.1., Praha, p. 2 – 55.

http://lfskripta.webpark.cz/fyto/fyto12.htm

http://www.iceandclimate.nbi.ku.dk/research/strat_dating/annual_layer_count/gicc05_time_scale/

http://www.sciencedirect.com/science/article/pii/S0277379114003485

Huang, Y., Street–Perrott, F. A., Metcalfe, S. E., Brenner, M., Moreland, M., & Freeman, K. H., 2001: Climate change as the dominant control on glacial/interglacial variations in C3 and C4 plant abundance. Science 293, p. 1647 – 1651.

Huntley, B. & Birks, H. J. B., 1983: An Atlas of Past and Present Pollen Maps for Europe: 0 – 13,000 years ago. Cambridge University Press, Cambridge, 667 p. + 34 overlay maps.

Huntley, B. & Prentice, I. C., 1993: Europe. Chapter 7. In: Wright, H. E. (ed.): Global Climates Since the Last Glacial Maximum. University of Minnesota Press, USA, p. 136 – 168.

IAEA/WMO, 2018: Global Network of Isotopes in Precipitation. The GNIP Database. Accessible at: https://nucleus.iaea.org/wiser.

IPCC, 2001: Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J. T., Y. Ding, D. J. Griggs, M. Noguer, P. J. van der Linden, X. Dai, K. Maskell, and C. A. Johnson (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881 p.

Jäger, K. D., 1969: Climatic character and oscillations of the Subboreal period in the dry regions of the Central European Highlands. Proc. 7th Cong. INQUA, Washington, p. 38 – 42.

Juřičková, L., Horsák, M. & Beran, L., 2001: Checklist měkkýšů České republiky, Acta Soc. Zool. Bohem., Praha

Kalis, A. J., Merkt, J. & Wunderlich, J., 2003: Environmental changes during the Holocene climatic optimum in central Europe – human impact and natural causes. Quaternary Science Reviews 22, p. 33 – 79.

Kaminská, Ľ. (ed.), Moravcová, M. & Šefčáková, A., 2014: Staré Slovensko. Paleolit a mezolit. Archeologivký ústav Slovenskej akadémie vied. Nitra, p. 350.

Kernátsová, J., 1997: Mollusc Fauna of loess complex from Mnešice locality, Danube Basin. Slovak Geological Magazine, 3, 4, Bratislava, p. 247 – 261.

Kernátsová, J., 2001: Vrchnopleistocénna a holocénna fauna mäkkýšov Slovenska v oblasti Malých Karpát, Podunajskej nížiny, Hornonitrianskej kotliny a Záhorskej nížiny. Thesis, Manuscript – archive of FNSCU, Department of Geology and Palaeontology, Bratislava. 92 p.

Kertész, R. & Sümegi, P., 1999: Az Északi–középhegység negyedidőszak végi őstörténete (Ember és környezet kapcsolata 30.000 és 5.000 BP évek között). Nógrád Megyei Múzeumok Évkönyve, 23, p. 66 – 93.

Kertész, R. & Sümegi, P., 2001: Theories, Critiques and a Model: Why Did Expansion of the Körös–Starčevo Culture Stop in the Centre of the Carpathian Basin? In: Kertész, R. and Makkay, J. (eds.): From the Mesolithic to the Neolithic. Proceedings of the International Archaeological Conference held in the Damjanich Museum of Szolnok, September 22–27, 1996. Archaeolingua, Budapest, p. 225 – 246.

Klíma, B., 1959: Archeologický výzkum jeskyně Hadí (Mokrá u Brna). Anthropozoikum, 9, NČSAV, p. 277 – 285.

Kornexl, B. E., Gehre, M., Hofling, R., Werner, R. A. & Commun, R., 1999: Mass Spectrom. 13, p. 1685.

Kováč, M., Márton, E., Oszczypko, N., Vojtko, R., Hók, J., Králiková, S., Plašienka, D., Klučiar, T., Hudáčková, N. & Oszczypko-Clowes, M., 2017: Neogene palaeogeography and basin evolution of the Western Carpathians, Northern Pannonian domain and adjoining areas. Global and Planetary Change 155, p. 133 – 154.

Kováč, M., Synak, R., Fordinál, K., Joniak, P., Tóth, C., Vojtko, R., Nagy, A., Baráth, I., Maglay, J., & Minár, J., 2011: Late Miocene and Pliocene history of the Danube Basin: inferred fromdevelopment of depositional systems and timing of sedimentary facies changes.Geologica Carpathica 62, p. 519 – 534.

Kovanda, J., 1971: Kvartérní vápence Československa. Sborník geologických věd, Antropozoikum, Praha, 7, p. 236.

Koziet, J., 1997: Mass Spectrom. 32, p. 103.

Krippel, E., 1986: Postglaciálny vývoj vegetácie Slovenska. VEDA SAV, Bratislava, 312 p.

Kukla, G. J., & 22 others, 2002: Last interglacial climates: Quaternary Research, 58, p. 2 – 13.

Lapin, M., Faško, P., Melo, M., Šťastný, P. & Tomlain, J., 2002: Klimatické oblasti. In: Atlas krajiny Slovenskej republiky. 1. vyd. Bratislava: MŽP SR; Banská Bystrica: SEA, p. 344.

Laval, H., Medus, J. & Roux, M., 1991: Palynological and sedimentological records of Holocene human impact from the Etang de Berre, southeastern France. The Holocene, 1, p. 269 – 272.

Litt, T., 2003: Environmental response to climate and human impact in Central Europe during the last 15,000 years – a German contribution to PAGES–PEPIII. Quaternary Science Reviews, 2, 1, p. 1 – 4.

Ljungqvist, F. C., 2010: A new reconstruction of temperature variability in the extra– tropical northern hemisphere during the last two millenia. Geografiska Annaler 92A, 3, p. 339 – 351.

Lowe, J. J., Rasmussen S. O. , Björck, S., Hoek, W. Z, Steffensen, Walkere, M. J. C., Yufthe, Z. C. & INTIMATE group 1, 2008: Synchronisation of palaeoenvironmental events in the North Atlantic region during the Last Termination: a revised protocol recommended by the INTIMATE group. Quaternary Science Reviews 27, p. 6 – 17.

Ložek, V., 1956: Klíč československých měkkýšů. Vydav. Slov. akad. vied SAV Bratislava, 437 p.

Ložek, V., 1973: Příroda ve čtvrtohorách. Academia, Praha, 372 p.

Ložek, V., 1980: Quaternary molluscs and stratigraphy of the Mažarná Cave. Československý Kras, 30, p. 67 – 80.

Ložek, V., 1985: The site Soutěska and its significance for Holocene climatic development. Československý kras, 36, p. 7 – 22.

Ložek, V., 1988: Slope depositions in karst environments of Central Europe. Československý kras, 39, p. 15 – 33.

Ložek, V. & Cílek, V., 1995: Klimatické změny a vývoj krasových sedimentů. Vesmír, 74, p. 16 – 24.

Ložek, V., 2000: Palaeoecology of Quaternary Mollusca. Sborník geologických věd, Antropozoikum, 24, p. 35 – 59.

Ložek, V., 2002: Vývoj přírody a podnebí. In: Svoboda, J., Havlíček, P., Ložek, V., Macoun, J., Musil, R., Přichystal, A., Svobodová H. a Vlček, E., 2002: Paleolit Moravy a Sliezska. 2. aktualizované vydanie, Dolnověstonické studie, 8, p. 38 – 47.

Maglay, J. (ed.), Fordinál, K., Nagy, A., Moravcová, M., Vlačiky, M., Kováčik, M., Šefčík, P., Šimon, L., Zlinská, A., Žecová, K., Gluch, A., Zeman, I., Kubeš, P., Liščák, P., Ondrášiková, B., Benková, K., Bottlík, F., Marcin, D., Michalko, J., Baláž, P., Baráth, I., Zlocha, M., Fričovská, J., Stupák, J & Tuček, Ľ. (in press): Vysvetlivky ku geologickej mape regiónu Podunajská nížina – Podunajská rovina v mierke 1 : 50 000. SGIDŠ Bratislava

Magyari, E., Jakab, G., Rudner, E. & Sümegi, P., 1999: Palynological and plant macrofossil data on the Late Pleistocene short–term climatic oscillations in North–Eastern Hungary. Proceedings 5th EPPC, Acta Paleobotanica, 2, p. 491 – 502.

Mangerud, J., Andersen, S. T., Berglund, B. E. & Dorner, J. J., 1974: Quaternary stratigraphy of Norden, a proposal for terminology and classification. Boreas, Vol. 3, p. 109 – 128, Oslo.

Mann, M. E., Zhang, Z., Rutherford, S., Bradley, R. S., Hughes, M. K., Shindell, D., Ammann, C., Faluvegi, G. & Ni, F., 2009: Global Signatures and Dynamical Origins of the Little Ice Age and Medieval Climate Anomaly. Science. 2009–11–26, 326, 5957, p. 1256 – 1260.

Mazúr, E. & Jakál, J., (eds.) 1980: Atlas Slovenskej socialistickej republiky. Bratislava, SAV a SÚGK. 296 p.

Mazúr, E., & Lukniš, M., 1986: Geomorfologické členenie SSR a ČSSR. Časť Slovensko. Slovenská kartografia, Bratislava.

McConnaughey, T. A. & Gilikin, D. P., 2008: Carbon isotopes in mollusc shell carbonates. Geo–Marine Letters 28, p. 287 – 299.

Murray, A. S. & Wintle, A. G., 2000: Luminescence dating of quartz using an improved single–aliquot regenerative–dose protocol. Radiation measurements 32, 1, p. 57 – 73.

Musil, R., 1956: Nové osteologické nálezy z jeskyně Axamitky. Anthropozoikum, Praha, 5, p. 47 – 60.

Musil, R., 1985: Palaeobiography of Terrestrial Communities in Europe during the Last Glacial. Sborník Národního muzea v Praze, 41 B/1–2, Praha, 84 p.

Musil, R., 2000: Natural environment. Anthropologie 38/3, Brno, p. 307 – 310.

Musil, R., 2002a: Fauna moravských jeskyní s paleolitickými nálezy. In: Svoboda, J. (ed.), Prehistorické jeskyně. Dolnověstonické studie, Brno, 7, p. 53 – 101.

Musil, R., 2002b: Prostředí jako ekonomická báze paleolitických lovců. In: Svoboda, J., Havlíček, P., Ložek, V., Macoun, J., Musil, R., Přichystal, A., Svobodová H. & Vlček, E., 2002: Paleolit Moravy a Slezska. 2. aktualizované vydanie, Dolnověstonické studie, 8, p. 52 – 66.

Musil, R., 2005: Klima v posledním glaciálu (The climate of the Last Glacial). Acta Musei moraviae, Sci. Geol. 90, Brno, p. 223 – 246.

Musil, R., 2014: Morava v době ledové – Prostředí posledního glaciálu a metody jeho poznávání. MUNIPRESS, Masarykova univerzita, Brno, 228 p.

NEEM community members, 2013: Eemian interglacial reconstructed from a Greenland folded ice core. Nature, 493, p. 489 – 494.

Nekola, J. C., 1999: Paleorefugia and neorefugia: The influence of colonization history on community pattern and process. Ecology, 80, p. 2459 – 2473.

Paul, D. & Skrzypek G., 2006: Rapid Commun. Mass Spectrom, 20, p. 2915.

Pelíšek, J., 1963: Charakteristika vátých písků Slovenska. Geologické práce, 64, Geologický ústav Dionýza Štúra, Bratislava, p. 103 – 120.

Prescott, J. R. & Stephan, L. G., 1982: The contribution of cosmic radiation to the environmental dose for TL dating. Latitude, altitude and depth dependancies. PACT 6, p. 17 – 25.

Rasmussen, S. O. (ed.), 2006: A new Greenland ice core chronology for the last glacial termination, J. Geophys. Res., p. 111.

Rasmussen, S. O., Seierstad, I. K., Andersen, K. K., Bigler, M., Dahl–Jensen, D. & Johnsen, S. J., 2008: Synchronization of the NGRIP, GRIP, and GISP2 ice cores across MIS 2 and palaeoclimatic implications. Quat. Sci. Rev., 27, p. 18 – 28.

Rassmussen, S. O., Bigler, M. & Blockley, S. P. (eds.), 2014: A stratigraphic framework for abrupt climatic changes during the Last Glacial period based on three synchronized Greenland ice–core records: refining and extending the INTIMATE event stratigraphy. Quaternary Science Reviews, Volume 106, p. 14 – 28.

Reimer, P. J., Baillie, M. G. L., Bard, E., Bayliss, A., Beck, J. W., Bertrand, C. J. H., Blackwell, P. G., Buck, C. E., Burr, G. S., Cutler, K. B., Damon, P. E., Edwards, R. L., Fairbanks, R. G., Friedrich, M., Guilderson, T. P., Hogg, A. G., Hughen, K. A., Kromer, B., McCormac, F. G., Manning, S. W., Ramsey, C. B., Reimer, R. W., Remmele, S., Southon, J. R., Stuiver, M., Talamo, S., Taylor, F. W., van der Plicht, J. & Weyhenmeyer, C. E., 2004: IntCal04 Terrestrial radiocarbon age calibration, 26 – 0 ka BP. Radiocarbon 46, p. 1029 – 1058.

Reimer, P. J., Baillie, M. G. L., Bard, E., Bayliss, A., Beck, J. W., Blackwell, P. G., Bronk Ramsey, C., Buck, C. E., Burr, G. S., Edwards, R. L., Friedrich, M., Grootes, P. M., Guilderson, T. P., Hajdas, I., Heaton, T. J., Hogg, A. G., Hughen, K. A., Kaiser, K. F., Kromer, B., McCormac, F. G., Manning, S. W., Reimer, R. W., Richards, D. A., Southon, J. R., Talamo, S., Turney, C. S. M., van der Plicht, J. & Weyhenmeyer, C. E., 2010: IntCal09 and Marine09 Radiocarbon Age Calibration Curves, 0–50,000 years cal BP. 0–26 cal kyr BP. Radiocarbon 51, p. 1111 – 1150.

Reimer, P. J., Bard, E., Bayliss, A., Beck, J. W., Blackwell, P. G., Bronk Ramsey, C., Grootes, P. M., Guilderson, T. P., Haflidason, H., Hajdas, I., Hatt, C., Heaton, T. J., Hoffmann, D. L., Hogg, A. G., Hughen, K. A., Kaiser, K. F., Kromer, B., Manning, S. W., Niu, M., Reimer, R. W., Richards, D. A., Scott, E. M., Southon, J. R., Staff, R. A., Turney, C. S. M., & van der Plicht, J., 2013: IntCal13 and Marine13 Radiocarbon Age Calibration Curves 0–50,000 Years cal BP. Radiocarbon, 55, 4, p. 1869 – 1887.

Remeš, J., 2008: Pěstování lesů II: podklady pro cvičení. Česká zemědělská univerzita, Praha, 98 p. ISBN: 9788021317871.

Renssen, H. & Isarin, R. F. B., 2001: The two major warming phases of the last deglaciation at ~14.7 and ~11.5 kyr cal BP in Europe: climate reconstructions and AGCM experiments. Global and Planetary Change, 30, p. 117 – 154.

Roberts, N. & Wright, H. E. Jr., 1993: Vegetational, lake–level and climatic history of the Near East and southwest Asia. In: Wright, H.E. (Ed.): Global climates since the last glacial maximum. University of Minnesota Press, Minneapolis, p. 194 – 220.

Severinghaus, J. P. & Brook, E. J., 1999: Abrupt climate change at the end of the last glacial period inferred from trapped air in polar ice. Science, 286, p. 930 – 934.

Smolíková, L., 1982: Pedologie I. a II. Univerzita Karlova v Praze, Fakulta přírodovědecká, Státní pedagogické nakladatelství, Praha, 129 and 284 p.

Solomon, S., 2007: Intergovernmental Panel on Climate Change. The Last 2,000 Years", Climate change 2007: the physical science basis: contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press for the Intergovernmental Panel on Climate Change.

Starkel, L., 1991: Environmental changes at the Younger Dryas – Preboreal Transition and during the early Holocene: some distinctive aspects in central Europe. The Holocene, 1, p. 234 – 242.

Stewart, J., & Lister, A., 2001: Cryptic northern refugia and the origins of the modern biota. Trends in Ecology and Evolution, 16, p. 608 – 613.

Stuiver, M. & Polach H.A., 1977: Discussion: reporting of ^{14}C data. Radiocarbon 19, 3, p. 355 – 363.

Sümegi, P., 1996: Az ÉK–magyarországi löszterületek összehasonlító paleoökológiai és sztratigráfiai értékelése. Kandidátusi értekezés, Debrecen, 120 p.

Sümegi, P. & Kertész, R., 1998: Ablak az időre. Ember és környezet kapcsolata a Kárpát–medencében az időtudományok tükrében. Szolnoki Tudományos Közlemények 1, p. 66 – 69.

Sümegi, P., Magyari, E., Daniel P., Hertelendi, E. & Rudner, E., 1999: Reconstruction of the Quaternary evolution of the Fehér–lake at Karoskút (Hungary). Földtani Közlöni 129, p. 479 – 519.

Sümegi, P. & Krolopp, E., 2000: Palaeoecological conditions of the Carpathian Basin during an climatic event of the Upper Weichselian. Part I. Soosiana, p. 25 – 49.

Sümegi, P. & Kertész, R., 2001: Palaeogeographic Characteristics of the Carpathian Basin – an Ecological Trap During the Early Neolithic? In: Kertész, R. and Makkay, J. (eds.): From the Mesolithic to the Neolithic. Proceedings of the International Archaeological Conference held in the Damjanich Museum of Szolnok, September 22–27, Budapest, Archaeolingua, p. 405 – 415.

Sümegi, P. & Krolopp, E., 2002: Quatermalacological analysis for modeling of the Upper Weichselian palaeoenvironmental changes in the Carpathian Basin. Quaternary International 91, p. 53 – 63.

Sümegi, P., Kertész, R. & Hertelendi, E., 2002: Environmental Change and Human Adaptation in the Carpathian Basin at the Late Glacial/Postglacial Transition. In: Jerem, E. and T. Biró, K. (eds.): Archaeometry 98: Proceedings of the 31st Symposium. Budapest, April 26 – May 3. 1998. BAR International Series 1043 (I) – Archaeolingua Central European Series 1, p. 171 – 177.

Svoboda, J., Horáček, I., Ložek, V., Svobodová, H., & Šilar, J., 2000: The Pekárna Cave. Magdalenian stratigraphy, environment, and the termination of the loess formation in the Moravian Karst. Sborník geologických věd, Antropozoikum, 24, p. 61 – 79.

Svoboda, J., Havlíček, P., Ložek, V., Macoun, J., Musil, R., Přichystal, A., Svobodová, H. & Vlček, E., 2002: Paleolit Moravy a Slezska. 2. aktualizované vydání, Archeologický ústav Akademie věd ČR, Brno, 303 p.

Svoboda, J., 2009: Utajené dějiny podnebí. Řídilo počasí dějiny lidstva? Praha, 263 p.

Svobodová, H., Soukupová, L. & Reille, M., 2001: Diversified development of mountain mires, Bohemian Forest, Central Europe, in the last 13,000 years. Quaternary International, 91, 1, p. 123 – 135.

Šajgalík, J. & Modlitba, I., 1983: Spraše Podunajskej nížiny a ich vlastnosti. VEDA Bratislava, 242 p.

Škvarenina, J., Hríbik, M., Škvareninová, J., & Fleischer, P., 2013: Globálne zmeny klímy a lesné ekosystémy. Technická univerzita vo Zvolene, 123 p.

Šťastný, P., Nieplová, E. & Melo, M., 2002: Priemerná ročná teplota vzduchu. Mapa 1 : 2 000 000. In Atlas krajiny Slovenskej republiky. Ministry of Environment, Bratislava, SEA, Banská Bystrica, p. 98.

Šujan, M., Braucher, R. Rybár, S. Magaly, J., Nagy, A., Fordinál, K., Šarinová, K., Sýkora, M., Józsa, Š., ASTER Team & Kováč, M., 2018: Revealing the Late Pliocene to Middle Pleistocene alluvial archive in the confluence of the Western

Carpathian and Eastern Alpine rivers: 26Al/10Be burial dating from the Danube Basin (Slovakia). Sedimentary Geology, 377 (2018), 131 – 146 p.

Taylor, K. C., Lamorey, G. W., Doyle, G. A., Alley, R. B., Grootes, P. M., Mayewski, P. A., White, J. W. C. & Barlow, L. K., 1993: The Aflickering switch of late Pleistocene climate change. Nature 361, p. 432 – 436.

Turner, C. & Hannon, G. E., 1988: Vegetational evidence for late Quaternary climate changes in SW Europe. Philosophical transactions of the Royal Society of London, p. 451 – 485.

Valoch, K., 1989: Die Erforschung der Kůlna Höhle. Anthropos, Brno, p. 24.

Velichko, A. A., 1989: Golotsen kak element obshcheplanetarnogo prirodnogo protsessa. Paleoklimaty pozdnelednikov'ya i golotsena (Holocene as an Element of the Universal Planetary Natural Process: Late Glaciation and Holocene Paleoclimates), Moscow, Nauka, p. 5 – 12.

Velichko, A. A., 1993: Evolution of Landscapes and Climates of Northern Eurasia. Late Pleistocene–Holocene elements of prognosis. Moscow Nauka, 2, p. 102.

Vlačiky, M., 2017: Kvartérne sedimenty Podunajskej nížiny – paleontologické nálezy a datovanie. Otvorený geologický kongres Slovenskej geologickej spoločnosti a České geologické společnosti, Vysoké Tatry 14. 6. – 17. 6. 2017. Zborník abstraktov a exkurzný sprievodca Otvoreného geologického kongresu Vysoké Tatry 2017. 18th Czech – Slovak – Polish Paleontological Conference, Vysoké Tatry, Slovakia 15. – 16. 6. 2017, p. 110.

Walker, M. J. C., Björk, S., Cwynar, L. C., Johnsen, S., Knudsen, K.L., Wohlfarth, B. & INTIMATE group, 1999: Isotopic „events" in the GRIP ice core: a stratotype for the Late Pleistocene. Quaternary Science Reviews, 18, p. 1143 – 1150.

Werner, R. A. & Brand, W. A., 2001: Rapid Commun. Mass Spectrom, 15, p. 501.

Willis, K. J., Rudner, E. & Sümegi, P., 2000: The full–glacial forests of central and southeastern Europe. Quaternary Research 53, p. 203 – 213.

Yanes, Y., Delgado, A., Castillo, C., Alonso, M.R., Ibánez, M., De La Nuez, J., & Kowalewski, M., 2008: Stable isotope ($\delta^{18}O$, $\delta^{13}C$ and δD) signatures of recent terrestrial communities from a low–latitude, oceanic setting: endemic land snails, plants, rain, and carbonate sediments from the eastern Canary Islands. Chemical Geology 249, p. 377 – 392.

Yin, X. & Chen, Z. J., 2014: Mass Spectrom. 49, p. 1298.

Zeidler, M. & Banaš, M., 2013: Vybrané kapitoly z ekologie horských ekosystémů. Univerzita Palackého v Olomouci, Přírodovědecká fakulta, Olomouc, 88 p.

Zeman, A. & Demek, J., 1984: Kvartér: geologie a geomorfologie. Státní pedagogické nakladatelství, Praha.

Zlatník, A., 1959: Přehled slovenských lesů podle skupin lesních typů. LF VŠZ v Brně, Brno, 195 p.

Zolitschka, B., Behre, K. E. & Schneider, J., 2003: Human and climatic impact on the environment as derived from colluvial, fluvial and lacustrine archives – examples from the Bronze Age to the Migration period, Germany. Quaternary Science Reviews, 22, 1, p. 81 – 100.

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4. Hydrogeologic Characteristic of the Podunajská Rovina Flat

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Abstract: The Podunajská rovina Flat (hereinafter Danubian Flat) represents one of the most important hydrogeological regions in Slovakia, situated in the Danube Basin. Its fill consists of alternating aquicludes (clays, claystones) and aquifers (sands, sandstones, gravels) of Neogene and Quaternary aquifers (gravel and sand), which are characteristic of intergranular permeability. The importance of the Quaternary aquifers is emphasized by the fact that they were deposited directly on the Neogene aquifers in a large part of the area of interest and often together they form a single aquiferous hydrogeological complex with ambiguous boundaries. The considerable thickness of the Neogene (max. 3,000 m) and the Quaternary (max. 600 m) sediments thus create conditions for significant accumulation of groundwater.

Key words: Groundwater, Danube, regime, level, coefficient of transmissivity, aquifer

4.1 Introduction

The favourable characterization of the Danubian Flat area from the point of view of its aquifers was of interest to local and regional hydrogeological works (about 3,000 wells), the aim of which was to obtain groundwater for a wide range of its exploitation, depending upon needs of society.

In the Žitný ostrov (Rye Island) area, the groundwater reserves, expressed in terms of the usable amount, reach approximately 20,500 $l.s^{-1}$ (Gavurník et al., 2012), which represents the largest reserves in Slovakia and the Central Europe. This part of the Danubian Flat is one of the largest protected water management areas in Slovakia. Favourable hydrogeological conditions of the area were also reflected in the implementation of six water sources, which are among the largest in Slovakia.

The groundwater circulation and regime *in the northern part of the Danubian Flat (north of the Little Danube River) and the southern part of the plain (the area between the rivers Little Danube, Danube and Váh, including the right bank of the Danube in the Slovak Republic)* differ significantly. In the northern part of the territory, the groundwater regime is mainly dependent on winter precipitation, coefficient of transmissivity and level of local rivers and groundwater transfer from neighbouring territories. In the southern part of the territory, the groundwater regime is dependent on the coefficient of transmissivity and status of the levels of the rivers Danube, Little Danube, Váh, their channels and river branch system. The operation of the Gabčíkovo and Kráľová nad Váhom water structures (Waterworks; hereinafter WW), which use the hydro-energetic, navigational and recreational potential of the two most watery surface streams (Danube and Váh) of the Danubian Flat, also affects the regime of surface- and groundwaters.

The hydrological axis of the area is formed by the Danube with a rich branch and channel system with most important branch of the Little Danube. The Váh River (with its mouth into the Danube in Komárno) with a left tributary of Nitra represents a significant water course of N-S direction. The streams of local importance are mainly represented by the left tributaries of the Little Danube, which drain the eastern slopes of the Malé Karpaty Mts. as well as the space between the mountain range and the Váh River (e.g. Čierna voda, Dudváh, Gidra).

In the Danubian Flat territory, cold mineral waters are found only in the area of Svätý Jur. On the other hand, this region is very important in terms of geothermal waters. Significant accumulations of geothermal waters are found in the sediments of the Neogene (the Danube Basin Central Depression) and the Mesozoic (the Komárno Marginal Block; article 5 of this volume). So far, the geothermal potential of the Danubian Flat has been verified through 38 geothermal wells.

In the territory of interest it is possible to distinguish hydrogeological units of Crystalline, Mesozoic, Neogene volcanics, sedimentary Neogene and Quaternary. The dominant part of the territory involves the Quaternary hydrogeological regions Q 051, Q 052 and Q 074 (Fig. 4.1).

Determination of hydraulic parameters of individual hydrogeological units was made mainly on the basis of evaluation of hydrogeological exploratory boreholes recorded in the Geofond archive of SGIDŠ.

4.2 Hydrogeologic region of the Crystalline

In the area of interest this unit is represented by a narrow stripe from Bratislava (Krasňany) to Svätý Jur and is built of granitoids, gneisses, migmatites, amphibolites, phyllites and schists. Tectonic failure determines the fissure permeability of the aquifer. More significant are transverse fissures and cracks, which are more open and therefore more permeable.

The mean value of the coefficient of transmissivity $T = 4.3 \,.\, 10^{-5}\ m^2.s^{-1}$ and the mean value of the coefficient of hydraulic conductivity $k = 4.8 \,.\, 10^{-6}\ m.s^{-1}$ (Hanzel et al., 1999) were determined for the Pezinok section of Malé Karpaty Mts. granitoids during the hydrogeological

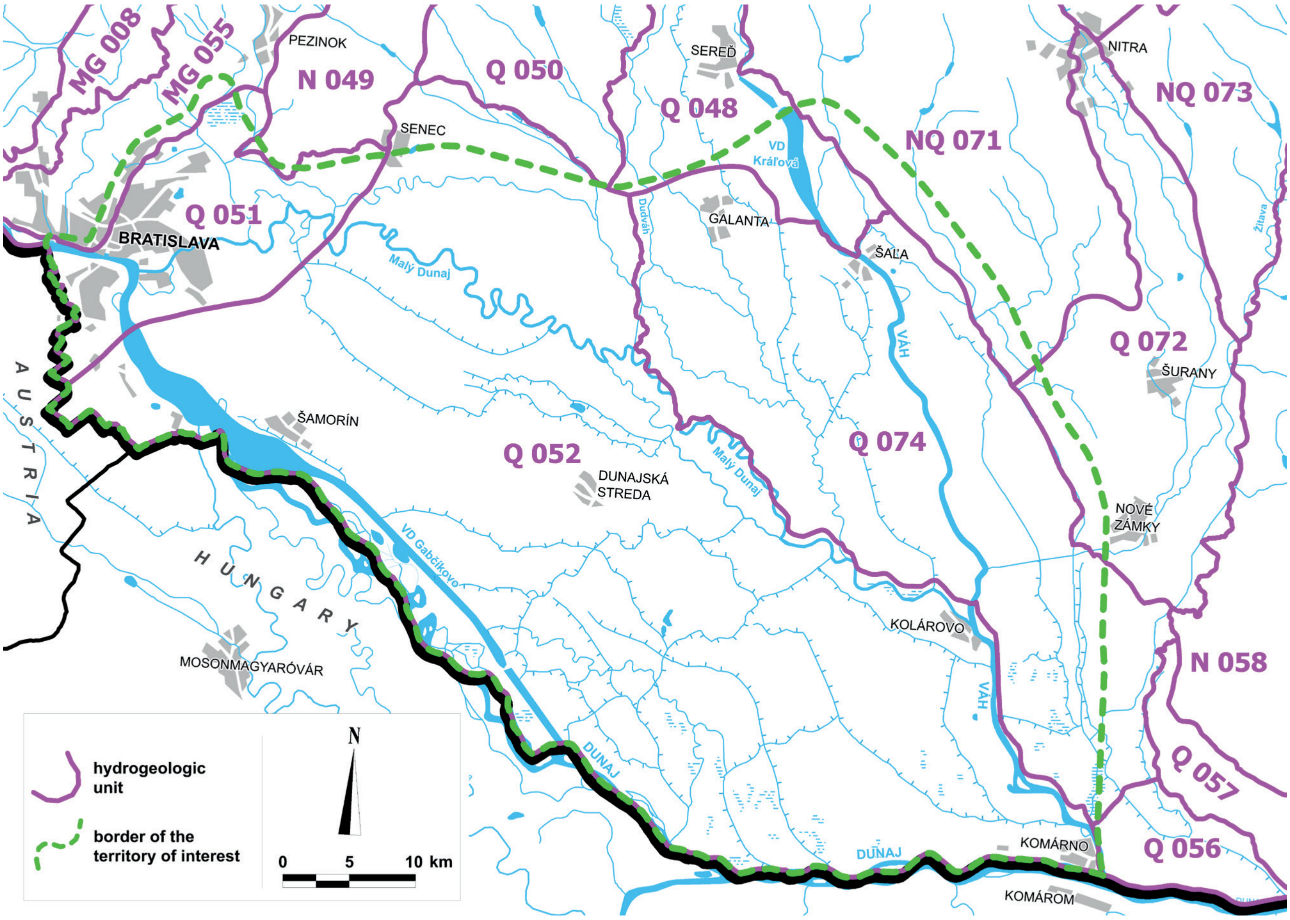

Fig. 4.1 Hydrogeological regions of the territory of interest (according to Šuba & Mihálik, 1998)

survey. The zone of weathering and near-surface loosening extends to a depth of 30 – 50 m below the ground. For crystalline schists, these values were slightly lower (T = 3.2 . 10^{-5} $m^2.s^{-1}$, k = 2.6 . 10^{-6} $m.s^{-1}$). It is obvious that these are rocks with low coefficient of transmissivity (Hanzel & Vrana, 1999).

Groundwater circulation in the granodiorite massif is limited. In particular, it is bound to the zone of weathering and near-surface disintegration of rocks, and therefore no significant accumulation of groundwater occurs. The yield of the springs is strongly influenced by atmospheric precipitation. Due to the strong influence of rainfall, the springs have a large range of yield. There are no significant springs surging from the granites of the Bratislava Massif. The yield of predominantly fissure and slope debris-fissure springs is 0.01 – 0.3 $l.s^{-1}$, sporadically 0.5 – 1.0 $l.s^{-1}$. The direct passage of groundwater from the Malé Karpaty Mts. to the sediments of the neighbouring Danube Lowland may occur at alluvial cones in places with suitable hydraulic properties.

The basic mineralization process forming the chemical composition of the groundwater of the Malé Karpaty Mts. Crystalline is the hydrolytic decomposition of the silicate minerals present. This process causes the formation of a chemical composition of A_2 type water predominantly, indistinct Ca-Mg-HCO_3 with low TDS in the range of 0.17 – 0.41 $g.l^{-1}$ with an average value of 0.25 $g.l^{-1}$ (Rapant et al., 1993). The knowledge of the isotopic composition of the groundwater of this hydrogeological unit is scarce and therefore we do not discuss it.

4.3 Hydrogeological region of the Mesozoic

Mesozoic aquifers were verified in the south-eastern part of the territory in the Komárno area by geothermal borehole M-1 (Pagáč & Čermák, 1976), geothermal borehole M-3 (Franko & Račický, 1979) and geothermal borehole FGK-1 (Remšík & Franko, 1978). The boreholes penetrated into the carbonates of the Transdanubian Mountains of the Pelsö unit from a level of about 1,100 or 1,700 m b.s. These are mainly limestones, dolomites and dolomitic limestones of the Late Triassic to Jurassic, which represent important aquifers with fissure-karst permeability. The rate of overflow on borehole collars was about 1.6 – 5.3 $l.s^{-1}$ at groundwater temperature at 42 – 64 °C. Coefficient of transmissivity fluctuates in interval T = 5.1 . 10^{-5} – 2.2 . 10^{-4} $m^2.s^{-1}$.

The geothermal water in the Komárno Marginal Block is likely to accumulate in a closed hydrogeothermal structure that does not have an infiltration and surge area. From a chemical point of view, it is a mixed type of water with a predominance of Ca-SO_4 component and an increased content of Na-Cl with mineralization of about 2.2 – 3.1 $g.l^{-1}$ (Remšík et al., 1992).

Kantor et al. (1985) states for well M-3 water $\delta^{18}O$ = -12.58‰. The water is of meteoric origin, probably infiltrated in a period of colder climate.

4.4 Hydrogeologic region of Neogene volcanics

The main fill of the whole Danube Basin, which has a bowl-shaped brachysyncline structure, consists of brackish and freshwater sediments of the Late Miocene and Pliocene; in their bedrock occur Langhian – Serravallian and Sarmatian marine and brackish sediments, or buried volcanic centres.

The oldest Neogene beds of the *Langhian* age – Šurany volcanites (andesites) were verified by geothermal borehole HGB-1 Rusovce at a depth of 1,027 – 1,259 m (Bondarenková, 1977). Pre-Cenozoic bedrock was also verified in their basement. These are Palaeozoic amphibolites of the Malé Karpaty Mts. with horizons of quartzose diorite and aplitic gneisses, drilled in the interval 1,259 – 1,493 m.

The interval of Langhian – Serravallian andesites was hydraulically tested by an open section of 1,100 – 1,124 m. By a hydrodynamic test in year 1982 the following values of yield and draw-down were found on the well: 0.5 $l.s^{-1}$/24.0 m; 0.8 $l.s^{-1}$/46.0 m; 1.08 $l.s^{-1}$/60.0 m. Since the envisaged location of the Serravallian clasts was not verified by the borehole, further hydrodynamic tests were not recommended due to low yield of a overflow (0.01 $l.s^{-1}$), low water temperature (15 – 25.4 °C), deep operating level, presence of methane and H_2S. The tested aquifer horizon was assessed as negative from the perspective of the further use of geothermal waters and the well was discarded. The coefficient of transmissivity of the Langhian – Serravallian aquifer from the HGB-1 borehole was determined T = 1.1 . 10^{-5} $m^2.s^{-1}$ and the coefficient of hydraulic conductivity k = 4.9 . 10^{-7} $m.s^{-1}$, whereby the aquifer was classified as poorly permeable.

From the chemical point of view it is fossil sea water of the Na-Cl (SO_4) type with mineralization of 17 – 23 $g.l^{-1}$. Water has a relatively high content of $SO_4/S_1(SO_4)$ (16.08%), CO_2 (206.8 $mg.l^{-1}$), H_2S (59.86 $mg.l^{-1}$), a ratio of Na : K = 33.1, SO_4 and HCO_3 as well as the presence of Br and I (Hanzel et al., 2012). No data on the isotopic composition of water are known from this hydrogeological unit.

4.5 Hydrogeologic region of the sedimentary Neogene

The thickness of the Neogene sediments in the central Gabčíkovo Depression reaches 3,500 m. These are predominantly clays and sands deposited in the lacustrine and delta environment. Groundwater of sedimentary Neogene verified by hydrogeological wells in the area of interest is bound to aquifers in the Serravallian – Pliocene range. The Neogene surface crops out in the vicinity of Bernolákovo, Chorvátsky Grob and Pezinok.

The hydraulic properties of deeper-lying sands to weakly cemented sandstones of Pliocene and Pannonian Tortonian) are known from geothermal wells (about 1,000 – 2,500 m deep) from the Central Depression of the Danube Basin. The clays act as aquicludes. The yield of overflow wells was 0.3 – 25.0 $l.s^{-1}$ (Fendek & Bodiš, 1992). Values of the coefficient of transmissivity lie in the interval T = 9 . 10^{-5} – 2.6 . 10^{-3} $m^2.s^{-1}$ with an average value of T = 5.3 . 10^{-4} $m^2.s^{-1}$, the average values of the coefficient of hydraulic conductivity were set to = 9 . 10^{-7} – 3 . 10^{-5} $m.s^{-1}$ with a mean value of 6.7 . 10^{-6} $m.s^{-1}$. The tested sections thus represent, on average, aquifers with moderate or medium coefficient of transmissivity. From a chemical point of view, it is predominantly water of the Na-HCO_3 and Na-HCO_3-Cl type with a TDS in the interval of 0.5 – 8.3 $g.l^{-1}$ (Jetel et al., 2012).

Shallower hydrogeological exploratory boreholes verified sand and gravel positions of Sarmatian (Serravallian) to Pliocene, and less frequent Zanclean.

In the shallower part of the Neogene there is documented (Bottlik et al., 2013) water coming from precipitation of the colder period ($\delta^{18}O$ from -12.19‰ to -13.90‰, δ^2H from -89.5‰ to -101.0‰). At deeper levels, $\delta^{18}O$ ranges from -13.8‰ (colder rainfall water) to -1.98‰ (sea water). The transient values of $\delta^{18}O$ are the result of mixing these two types of water (Kantor, 1985, Michalko, 1998, Franko, 2001). The residence time (^{14}C) for the water of individual wells ranges from 26,000 to 42,000 years (Franko et al., 1995, Franko, 2001).

In the northern part of the Danubian Flat, the Sarmatian (Serravallian) clay-sandy locations of the Vráble Formation were assessed by Schwartz et al. (2004). In the bedrock of the Quaternary sediments the formation forms a narrow strip following the mountains of the Pezinok Carpathians between Nižná and Pezinok. In the vicinity of the Bratislava-Vajnory suburb this complex overlies directly the crystalline bedrock. The average coefficient of transmissivity was determined T = 8.70 . 10^{-4} $m^2.s^{-1}$.

Ivanka clay-sandy Fm. of the Pannonian crops out around Pezinok. A greater number (more than 4) of sandy aquifers were found in the Vajnory – Slovenský Grob area. At the locality Chorvátsky Grob, the Fm. was verified by the structural geological borehole FGB-1 at the level of 348 – 437 m b.s. and in the borehole G-1 at the level of 240 – 480 m b.s., at the site Bratislava – Martanovičova Street in the borehole Ma-1 of 195.0 – 196.5 m b.s. The average value of the coefficient of transmissivity was determined T = 6.46 . 10^{-4} $m^2.s^{-1}$.

The *sediments of the Beladice Formation (Pannonian, Pontian)* are made up mainly of clay with layers of sand and lignite, in the marginal part they are represented by sands and sandstones. They crop out to the surface in the vicinity of Bernolákovo and Chorvátsky Grob. The sands and sandstones are cross-bedded and contain clay galls (Koutek & Zoubek, 1936 in Bottlik et al., 2013). The average number of aquifers in the Senec – Šenkvice – Chorvátsky Grob area is 2 to 4. On the basis of hydrodynamic tests, the average value of the coefficient of transmissivity was determined T = 5.986 . 10^{-4} $m^2.s^{-1}$.

The *Volkovce Formation of Zanclean* is built of colourful clays in which gravel and sand horizons are located, and sporadic lignite intercalations and lenses. South of the Galanta – Kajal – Horný Jatov line, the formation submerges below the Pliocene sediments (the Kolárovo Fm.). The complex is characterized by intergranular permeability and often confined groundwater, creating so an artesian horizon. At the top of the Zanclean the positions of sand with gravel are more and more frequent. In the central part of the depression, the data on the gravel position is absent, formed by an irregular alternation of sand and clay. Number of aquiferrous sandy horizons in the Senec area is mostly 2 – 4. In the area of Šaľa – Trnovec nad Váhom, the number of aquifers is 3 to 5. The greater number (more than 5) of aquifers was found in Nové Zámky. The regional evaluation documented the second highest average value of the coefficient of transmissivity for the sands of this layer T = 1.219 . 10^{-3} $m^2.s^{-1}$.

The *Kolárovo Formation of Pliocene* – the youngest Neogene hydrogeological unit, is the most permeable within the complex of the Neogene basinal structures. The formation consists of mica-rich sand and fine gravel alternating with strongly sandy grey, rusty and greenish clay, occasionally calcareous. The layer thickness is 100 – 150 m (Vass, Nagy & Elečko in Tkáčová et al., 1996). The Neogene hydrogeological subunit does not crop out to the surface in the area studied. The number of aquifers in the Vlčany – Komoča – Andovce – Palárikovo area is mostly 2 to 4. In the area of Sládkovičovo – Čierny Brod – Horné Saliby the number of aquiferrous sandy and sandy-gravelly horizons is 1 to 2. Greater number of aquifers (more than 4) were discovered in Galanta – Kajal. The sands and gravels of the Kolárovo formation deposited in the Latest Pliocene have an average coefficient of transmissivity T = 1.697 . 10^{-3} $m^2.s^{-1}$ (Bottlik et al., 2013).

In the southern part of the Danubian Flat the exploration boreholes in the SE parts of Žitný Ostrov (in the area between Číčov, Okoč and Kolárovo) verified permeable Neogene sandy horizons at the level of 19 – 280 m. According to the Danreg 1: 200,000 Quaternary sediment map of genetic types and thicknesses, the Quaternary overlying layer of Neogene reaches a thickness of 10 – 50 m (Pristaš, Tkáčová et al., 1998 in Scharek et al., 1998). The depth of the assessed boreholes is 19 – 280 m (113 m on average), the length of the verified sections reaches 2 – 56 m (18 m on average), which is an average of 18% of the total borehole depth. From the evaluation of the number of sandy, or gravel aquifers alternating with clay Neogene aquicludes it follows that the largest number of boreholes verified one to four permeable horizons (44 boreholes) in their profiles and 11 boreholes verified five to ten positions of aquifers.

On the territory of the Žitný Ostrov (Rye Island), the hydrogeological unit of the Neogene is characterized by the average value of the coefficient of transmissivity T = 6.1 . 10^{-3} $m^2.s^{-1}$ (2nd class of transmissivity, sensu Krásny, 1986). The average value of the coefficient of hydraulic conductivity k is 3.1 . 10^{-4} $m.s^{-1}$. The specific yield of wells q fluctuates in the range of 0.02 – 21.98 $l.s^{-1}.m^{-1}$ (average value of q is 3.0 $l.s^{-1}.m^{-1}$). Variability of the coefficient of transmissivity – the spatial inhomogeneity of the aquiferous rock environment, which is characterized by the standard deviation of the coefficient of transmissivity index Y s_Y (0.72), assigns this whole to a largely inhomogeneous hydrogeological environment with great variability.

In seven wells, the depth of which was predominantly above 100 m, artesian horizons with a positive artesian pressure were verified during the exploratory work, i.e., positive overflows were recorded on wells. These are boreholes HgK-3 Komárno (180 m), HGL-1 Veľký Lél (170 m), HG-Zl Zlatná na Ostrove (163 m), HVČ-2 Štúrová (142.5 m), HGP-2 Komárno (150 m), HP-1 Komárno (200 m) and S-1 Nová Stráž (71 m). The highest yields were verified by borehole HVČ-2 Štúrová (Šarlayová, 1986), the borehole depth was 142.5 m; filter at 92 – 138.5 m; verified maximum drilling capacity of 52.63 $l.s^{-1}$ at a drawdown of 2.29 m. Another highly productive horizon was confirmed by the HVK-1 Kameničná (Šarlayová, 1986) well, the well depth was 111.0 m with the open part of the well at a level of 54 – 110 m with yield values of 31.25 $l.s^{-1}$ at a drawdown of 2.38 m as well as in other boreholes, especially around Kolárovo, Zemianska Olča and Číčov.

In the sense of the lithological division of the Neogene, the boreholes were compared, which in their filter parts captured only sand (42 wells), sandy gravel and sand (10 wells), or only sandy gravel (3 wells). Comparing the calculated statistical parameters, the highest average coefficient of transmissivity rate for gravel (T = 2.51 . 10^{-2}.$m^2.s^{-1}$) was confirmed, lower for gravel and sand (T = 8.43 . 10^{-3} $m^2.s^{-1}$) and the lowest for sands (T=8.84 . 10^{-4} $m^2.s^{-1}$). The average specific yield q in boreholes verifying Neogene gravels was 8.10 $l.s^{-1}.m^{-1}$, in boreholes with gravel and sands 6.85 $l.s^{-1}.m^{-1}$ and in boreholes verifying only Neogene sands 1.71 $l.s^{-1}.m^{-1}$ (Benková et al., 2005).

4.5.1 Circulation and regime of groundwater in Neogene sediments

Due to lithology and tectonics, the circulation and groundwater regime in Neogene sediments are complex. In all Neogene complexes, impermeable clay positions alternate with permeable sandy or gravel horizons. Favourable conditions for the emergence of aquifers (artesian) horizons were created in the of Miocene and Pliocene facies, where the thickness of sandy horizons often reaches several meters. Their horizontal and vertical distribution is uneven, the positions of the permeable layers often wedge out and form lens-like bodies. The occurrence of aquifers is not regular and their interconnection is complicated, resulting in a significant anisotropy of the permeability properties in both the vertical and horizontal directions. The yield of wells, which have been verified by Neogene aquifers, varies considerably – from 0.1 up to several litres per second. The realization of boreholes was motivated by the need to search for groundwater at greater depths due to lack of yield or poor water quality in Quaternary sediments.

4.5.2 Hydrogeochemical properties of groundwater of Neogene sediments

From the hydrogeochemical point of view, groundwater bound to Neogene aquifers can be characterized as carbonatogenic water A_2 of a distinct type with mineralization in the range of about 306.47 – 1,059.7 $mg.l^{-1}$ with a mean value of 530 $mg.l^{-1}$. In the profile of the Neogene sediments towards the depth it is possible to observe a characteristic continuous transition of the chemical composition of water from the Ca-(Mg)-HCO_3 type to the Na-HCO_3 type. These changes are related to changes in thermodynamic, oxidation-reducing and partly hydrodynamic conditions of circulation. Apart from the increased iron content (less manganese), the groundwater with shallow circulation in the Pontian or Pannonian usually meets the criteria of the drinking water standard. The frequent increased content of ammonium ions and phosphates is mostly of primary origin (biochemical decomposition of organic substances, or dissolution of accessory apatite present in the aquifer horizons) (Bottlik et al., 2013).

The meteoric origin of groundwater of shallow sedimentary Neogene was documented on the basis of knowledge of the isotopic composition of hydrogen and oxygen. In the wider area of Galanta, Šaľa, Vlčany, Palárikovo and Nové Zámky, in the samples from boreholes with confined water the values $\delta^{18}O$ from -12.19‰ to -13.90‰ and $\delta^{2}H$ from -89.5‰ to -101.0‰ were documented (Bottlik et al., 2013). Groundwater with such an isotopic composition cannot be derived from current rainfall, it had to infiltrate during a period of colder climate at higher altitudes and should be expected to have a higher residence time. The presence of this water in the area is the result of transfer from nearby mountain ranges or is mediated by palaeo-streams. Different isotopic composition of groundwater from artesian borehole near the church in Veľký Biel – borehole no. 520 with $\delta^{18}O$ = -10.27‰ and $\delta^{2}H$ = -74.3‰ (Bottlik et al. 2013) confirms the presence of groundwater from current local precipitation.

4.6 Hydrogeologic region of Quaternary

Of the total number of genetic types of Quaternary sediments, fluvial accumulation in the stratigraphic range from the Lower Pleistocene to the Holocene dominates in the area. The highest thicknesses (up to 500 m) are reached in the central part of the Danube Basin – in the Gabčíkovo Depression, where they are deposited in superposition facies, based on locally preserved transitional fluvio-lacustrine strata (Upper Pliocene/Lower Pleistocene).

Aquicludes with low intergranular permeability include positions of Quaternary aeolian sediments (loess). Deluvial, proluvial and organic sediments are characterized by relatively low permeability. Quaternary fluvial sediments and anthropogenic sediments have a high permeability.

The average value of the coefficient of transmissivity of the main fluvial formation in the northern part of the Danubian Flat was determined to be $T = 1.55 \cdot 10^{-2}\ m^2.s^{-1}$, higher in the southern part of the plain in the Žitný ostrov area $T = 5.45 \cdot 10^{-2}\ m^2.s^{-1}$ and the highest value in the right bank of the Danube $T = 8.97 \cdot 10^{-2}\ m^2.s^{-1}$.

In the northern part of the Danubian Flat there are seven hydrogeological sub-units. These are anthropogenic, organic, deluvial, fluvial, aeolian, proluvial sediments and fluvial sediments of the middle terraces.

Anthropogenic Holocene sediments of landfill type occupy a small area in the evaluated area. These are the youngest Quaternary deposits that are the product of human activity. They are characterized by intergranular permeability of considerable variability and heterogeneity due to the diverse nature of the deposited material. Based on the processing of permeability parameters for the Integrated Landscape Management (IMK) (Malík et al., 2007), an average coefficient of transmissivity value $T = 2.62 \cdot 10^{-3}\ m^2.s^{-1}$ the anthropogenic sediments was assigned.

Organic sediments are represented in the area by peats and humus-rich peat clays, *Holocene in age*. Sediments of marsh swamps and peat bogs were formed in local marsh depressions, or older oxbows, in the overburden of low permeable to impermeable clayey and loamy flood plain sediments. The organic sediments are characterized by their own specific groundwater circulation system. They are most often bound to wetlands. From a hydrogeological point of view, these sediments have no practical use due to the low accumulation and groundwater quality. In the northern part of the Danubian Flat in the cadastral area of the municipality Svätý Jur there is a National Nature Reserve Šúr, which occupies the territory of the former Pleistocene lake. In the area of the Malé Karpaty Mts. it is the largest preserved peat bog. It is a part of several peat bogs that have been formed within Neogene depressions. The organic sediments have intergranular permeability and serve as a aquifer. There are no hydrogeological boreholes in the assessed area in the organogenic sediments, but on the basis of the results processing in the IMK project (Malík et al., 2007) the average value of the coefficient of transmissivity was determined for this whole by a qualified estimate $T = 4.52 \cdot 10^{-4}\ m^2.s^{-1}$.

Deluvial sediments – loamy-clayey and sandy slopes of the Pleistocene – Holocene age create more continuous areas in the western part of the studied area in the foothills of the Malé Karpaty Mts. They consist of lithofacies of undistinguished slope debris (mainly sandy and clay colluvial loams, outwash loams, sandy clays with fragments, fine-grained sands and loess runoffs, loamy-stony and sandy-stony sediments and deluvial re-deposited sands). The sediments are characterized by intergranular permeability. Their hydrogeological character is determined by the nature of their bedrock. Based on the results of the IMK geological task (Malík et al., 2007), the value of the coefficient of transmissivity deluvial sediments based on the evaluation of the results of hydrodynamic tests was assigned to $T = 9.71 \cdot 10^{-5}\ m^2.s^{-1}$.

Fluvial sediments of the bottom accumulation in the low terraces of the Upper Pleistocene – gravel, sandy gravel and sands mostly covered with loam occupy the most extensive and coherent area in the region. Almost all parts of the Podmalokarpatská pahorkatina Hummocks, the Trnava Table between Veľký Grob and Pusté Úľany and the Nitra Table between Močenok and Jatov cover the rest of the other areas of the Danubian Flat and the remaining table parts of the Uplands. However, due to their coverage, by younger – Holocene fluvial deposits (clays and sandy clays) of the flood-plain facies, most sediments of so-called *bottom accumulation* do not crop out to the surface. The pumping tests were mainly used to explore the bottom accumulations in the floodplains, which are a very important aquifer of groundwater and hydrogeological boreholes are situated in them quite often. The value of the coefficient of transmissivity T was determined in the range from 5.03 . 10^{-1} $m^2.s^{-1}$ to 2.12 . 10^{-4} $m^2.s^{-1}$, the mean value is T = 1.55 . 10^{-2} $m^2.s^{-1}$.

Fluvial Pleistocene sediments of middle terraces – sandy gravel and gravel through areas covered with loess and outwash deposits attain only small areas, where in the form of morphologically significant degree (edges) of the lower middle terrace they border almost the entire southern edge of the Trnava Table between Veľký Grob and Pusté Úľany and SW rim of the Nitra Table between Močenok and Jatov. Groundwater bound to gravel and sandy gravel of the middle terraces is fed by infiltration from rainfall or by hidden passages from surface streams. The groundwater table level is therefore deeper below the terrain and has a more variable oscillation than fluvial alluvia. In the monitored area the sediments of the middle terraces show about one order, i.e. 10 times lower values of hydraulic conductivity parameters compared to the parameters of fluvial the sediments. Based on the processing of the results of hydrodynamic tests, the fluvial sediments of the middle terraces was assigned a coefficient of transmissivity T = 1.104 . 10^{-3} $m^2.s^{-1}$.

Aeolian sediments – loess and loess loams of Pleistocene are the dominant cover formation in the Trnavská pahorkatina Upland. They occur in the northwest part of the area studied. Due to their granulometric characteristics, they are very poorly permeable and have the character of a regional hydrogeological aquiclude. In loess, a relatively coarse unsaturated zone is developed, and the groundwater level is often deeper. Based on the results of Schwarz et al. (2004) the sediment was assigned value T < 1 . 10^{-6} $m^2.s^{-1}$.

Proluvial sediments of alluvial cones (loamy to sandy-loamy gravels) developed in the region of the stratigraphic range of the Lower – Upper Pleistocene and preserved especially at the foothills of the Malé Karpaty Mts. in the zone of their contact with the Danubian Flat and Trnavská pahorkatina Upland from Bratislava-Rača through Svätý Jur, till Modra. They are also developed on large areas of the Podmalokarpatská pahorkatina Upland between Pezinok, Šenkvice, Chorvátsky and Slovenský Grob. They often reach the territory of the hills far from the mountains, as well as under loess in the area of contact between the Podmalokarpatská pahorkatina Upland and the Trnava Table. The edges of the largest cones are covered with aeolian loess, aeolian-deluvial loess loam and deluvial outwash. The proluvial sediments are characterized by intergranular permeability. Their important hydrogeological function is to allow direct passage of water from the mountainous areas to the lowland sediments. The surface flows on the proluvial sediments are characterized by reduced flow rates or they completely diminish. Based on a regional evaluation of hydraulic parameters, the proluvial sediments was assigned a coefficient of transmissivity T = 8.494 . 10^{-4} $m^2.s^{-1}$ (Bottlik et al., 2013).

From the hydrogeological point of view, *in the southern part of the Danubian Flat (in the Žitný ostrov and the right bank of the Danube)* we can observe almost homogeneous representation of the dominant Quaternary aquifer, the fluvial sediments of the Pleistocene – Holocene – sandy gravel.

In order to assess the depth dependence of the hydraulic parameters, the boreholes were divided into three groups according to the location of the filter within 25.0 m; in the intervals of 25.0 – 50.0 m and 50.0 – 100.0 m. As a result, it is found that in terms of hydraulic parameters in the range of 0.0 – 100.0 m b.s. there are minimal differences within the order. The mean value of the coefficient of transmissivity T is the lowest in the upper interval 0 – 25 m b.s. T = 1.93 . 10^{-2} $m^2.s^{-1}$ and the highest in the lower interval 50 – 100 m b.s. T = 2.41 . 10^{-2} $m^2.s^{-1}$. In the mean interval of 25 – 50 m the mean value of T = 2.31 . 10^{-2} $m^2.s^{-1}$.

The *spatial dependence of hydraulic parameters* in the area of interest was investigated in 4 areas – in the right bank of the Danube, in the upper part of Žitný ostrov, in the central part of Žitný ostrov and in the lower part of Žitný ostrov. The Žitný ostrov area was schematically divided according to Quaternary isolines to 100 m, i.e. in the west by the Hamuliakovo-Dunajská Lužná-Zlaté Klasy line and in the east by the Kľúčovec-Čalovo-Topoľníky line.

From the comparison of hydraulic parameters, the highest average coefficient of transmissivity was verified in the right bank of the Danube T = 8.97 . 10^{-2} $m^2.s^{-1}$, in the central part of Žitný ostrov T = 8.03 . 10^{-2} $m^2.s^{-1}$ and in the upper part of Žitný ostrov T = 7.17 . 10^{-2} $m^2.s^{-1}$. The lowest average coefficient of transmissivity value was determined in the lower part of Žitný ostrov T = 1.14 . 10^{-2} $m^2.s^{-1}$.

The highest yields of the Quaternary aquifer were verified by boreholes (with a diameter of the final borehole approx. 300 – 400 mm) at the Bratislava-Mokraď localities by the HM-1 borehole (borehole depth 64.0 m). the proportion between the pumped amount and the drawdown was Q/s – 170.0 $l.s^{-1}$/0.7 m; Dunajská Streda – borehole HDS-2 (borehole depth 80.0 m), Q/s – 209.8 $l.s^{-1}$/0.92 m; Šamorín – borehole HGŠ-1 (borehole depth 67.0 m), Q/s – 117.0 $l.s^{-1}$/0.67 m; Bratislava-Rusovce-Mokraď – borehole ST-17 (borehole depth 77.5 m), Q/s – 220.0 $l.s^{-1}$/1.95 m; Čunovo – borehole HVZ-50 (borehole depth 29.0 m) – Q/s – 117.0 $l.s^{-1}$/0.58 m, as well as at the sites Kvetoslavov, Hviezdoslavov, Baka, Gabčíkovo, Podunajské Biskupice and Eliášovce (Benková et al., 2005).

4.6.1 Groundwater circulation and regime in the Quaternary sediments

The *groundwater regime* in the Danubian Flat is monitored through the SHMI monitoring network, which consists of approximately 350 observation wells. The circulation and regime of groundwater in the northern region of the Danubian Flat is dependent on winter precipitation, coefficient of transmissivity and water level of rivers (Danube, Little Danube, Čierna voda, Dudváh and Váh) and groundwater transfer from neighbouring territories (Trnavská pahorkatina Upland, Nitrianska pahorkatina Upland, Malé Karpaty Mts.).

In the southern part of the Danubian Flat, the groundwater regime is dependent on the coefficient of transmissivity and the state of river levels (Danube, Little Danube and Váh) and their channels.

The precipitation and groundwater regime *in the northern area of the Danubian Flat* has a significant impact on groundwater replenishment, which can be observed in plain areas outside near-river zones. The meteoric water supply in these areas is evidenced by regime measurements of groundwater table levels, according to which groundwater supplies are replenished and levels rise already in the winter months, i.e. when the surface streams still have minimal levels. It is mainly due to climatic factors, the ratio of evaporation and precipitation. As a result, rainfall is substantially infiltrated in the winter months, aided by lack of plant cover, flat relief and overburden character (Bujalka et al., 1967). The course of groundwater fluctuations shows that in periods with low rainfall in the winter months there was a steady decline in groundwater levels, even though summer sums were normal or even elevated. Years with a high winter total always mean a significant rise in groundwater levels, even though the yearly total is normal (Bodiš et al., 1998).

Surface water infiltration from the Danube to gravelly sediments is already occurring in the area of Bratislava, where the general direction of groundwater flow is W-E or NW-SE. In the northern part of the Danubian Flat, the groundwater is supplied also by hidden inflows from the Trnavská pahorkatina Upland. In the Pusté Úľany and Sládkovičovo areas the direction of groundwater flow from the north to the south was found, which later turns to the NNW-SSE. According to Bujalka et al. (1967) in the area between Kráľová pri Senci, Veľké Úľany and Jelka, the groundwaters from three directions W-E, NW-SE and in direction N-S meet together.

The impact of the Little Danube on groundwater is only negligible and extends only to the riverbed area. The direction of groundwater flow in this area is along the Little Danube (Bujalka et al., 1967). The flow of Čierna voda is dependent on the state of groundwater levels. Outside the narrow belt along the Little Danube, the infiltration of the meteoric water in winter (November-March) is decisive for the groundwater replenishment of the area. In the area of Veľké Úľany – Čierny Brod there is a direction of groundwater flow from NW to SE. In the area of Kráľová pri Senci – Veľké Úľany – Jelka, the intersecting groundwaters from the Trnavská pahorkatina Upland meet the groundwater flow from the Danube, which is also reflected in the yields of individual sources.

The area around Jelka is supplied by groundwater flow of NW-SE direction at any groundwater level including extreme minimum and maximum. The extent of the territory involved in its supply is determined by groundwater levels – the lower the levels, the greater the impact of depression. Groundwater flows from the territory of the villages Kráľová pri Senci, Kostolná pri Dunaji, Hrubá Borša, Jelka, Jánovce and their surroundings; in the general direction of groundwater flow are also villages Hrubý Šúr and Hurbanova Ves (Takáčová et al., 2002).

In the northern part of the Danubian Flat, groundwater was supposed to be associated with the territory of Žitný ostrov (Takáčová et al., 1969). The evaluation of the groundwater regime in the wider surroundings of the Jelka water source for the years 1985 – 1990 (Vojtko in Takáčová et al., 2002) states that the impact of the main Danube River in the replenishment of groundwater reserves in the area of interest must be accepted, although the distance and other factors operating around the water source play their roles. The hydraulic connection of the surface flow of the Danube with groundwater in the area of the Jelka water supply was clearly demonstrated by the filling of the Gabčíkovo Waterworks, which started on 26 October 1992. The damming of the Danube and the filling of the reservoir resulted in rising groundwater levels. Since that time, groundwater levels in the Jelka water source have been higher than before the Gabčíkovo Waterworks were commissioned and put into operation (Takáčová et al., 2002).

The direction of groundwater flow in the fluvial sediments of the Váh River is parallel to the Váh River in the area and shows its infiltration effect. In the stretch of alluvia between Vinohrady nad Váhom and Galanta, the influences of Váh, rainfall and transfers from the Trnava and Nitra Uplands are overlapping (Bujalka et al., 1967).

In the northern part of the area of interest there are also wetlands where the groundwater level is close to the terrain surface. In the direction from the west there are Šúr Wetland, Úľanská mokraď Wetland, Salibská mokraď Wetland, Martovská mokraď Wetland and Novozámocké pláňavy Plains.

The Šúr *Wetland* is located near Svätý Jur in an area with a thin cover of Quaternary sediments (2 – 5 m at the edge of the structure and 5 – 10 m at its centre), in which the Neogene impermeable sediments of a bowl structure occur (Maglay et al., 2007 in Malík, et al., 2007). The circulation and regime of groundwater is dependent on precipitation totals and the yields of flows from the Malé Karpaty Mts.

The Úľanská mokraď Wetland is located between Veľký Grob and Sládkovičovo, where Quaternary fluvial sediments of the terrace gravels with a thickness of 2 – 5 m are deposited upon an impermeable bedrock built of Neogene sediments (Maglay et al., 2007 in Malík, et al., 2007). Groundwater circulation and regime are influenced by rainfall totals and groundwater inflows from terrace gravels on its northern edge.

The *Salibská mokraď Wetland* extends in a narrow stripe from Galanta to Kolárovo between the rivers Váh and Stará Čierna voda. The *Martovská mokraď Wetland* in the lane from Trnovec nad Váhom to Patince between the river Váh and Dlhý and Patinský channels. To the east of the Martovská Wetland the *Novozámocké pláňavy Plains* are situated. All three wetlands are located on the edge of the Central Depression of the Danube Basin, where the bedrock is formed by sunken Neogene blocks. In the Salibská mokraď Wetland the thickness of the Quaternary sediments ranges from 15 to 60 m, in the Martovská mokraď Wetland from 10 to 20 m and in the Novozámocké pláňavy Plains from 10 m to 30 m (Maglay et al., 2007 in Malík, et al., 2007).

The circulation and groundwater regime in the Salibská mokraď Wetland is dependent on surface water flow and from the transfer of groundwater from the territory of Šaľa – Tešedíkovo, where the depth of the Quaternary bedrock rises from 30 m to 15 m (Maglay et al., 2007 in Malík, et al., 2007). The circulation and regime in the Martovská mokraď Wetland and in the Novozámocké pláňavy Plains are dependent upon the total precipitation and the transfer of water from the terrace sediments on their eastern edge.

In 1985 in the section between Sereď and Šaľa the WW Kráľová was completed with an area of 10.9 km^2 with a backwater length of 19.7 km and a depth of accumulated water up to 15 m. The WW is a part of the system of the dams of the Váh Cascade and it was built for the purpose of energy utilization of Váh, protection of the adjacent area against floods, for water abstraction for irrigation, navigability of the Váh section, fishing, water sports, recreation. The main WW objects are a water stage containing a weir, a hydroelectric power plant and a lock and a flat-type reservoir with perimeter levees and intake objects. The power plant with two generators has a total installed capacity of 45 MW with an average annual electricity production of 117.3 GWh. The tightness of the reservoir is ensured by loose perimeter levees and clay-cement underground sealing wall.

Prior to the reservoir filling, the Quaternary groundwater regime was characterized by short-term replenishment and long-term drainage. The regime observations carried out from 1957 until the filling in 1985 at the Váhovce object show that the natural regime was characterized by a characteristic downward trend. After the water reservoir was filled in 1985, there was a steady increase in water levels, especially in the vicinity of the reservoir, for example in the village of Váhovce about 1.20 to 2.50 m. In the adjacent area, groundwater is delayed due to the sealing wall, slowing down its flow and causing it to rise (Bodiš et al., 1998).

The key factors influencing the groundwater level oscillation in the Quaternary aquifer *of the southern part of the Danubian Flat* are mainly the water level in the old Danube riverbed from Bratislava to Komárno as well as the water level in the Čunovo reservoir, regime in the river branch system, WW Gabčíkovo, handling of drainage and irrigation systems, local influence of water sources exploitation and pumping of groundwater within the hydraulic curtain near Slovnaft.

The general direction of groundwater flow is mostly parallel to the main streams in the area (Danube, Little Danube). Local deviations are around the Slovnaft hydraulic curtain where the flow direction is changed from the Danube to the centre of the artificial groundwater depression. Rainfall affects the groundwater regime in the study area, especially in the summer half, when it affects the increase in yields in the surface streams in the territory and consequently also the increase of groundwater table level with different delay interval depending on distance from surface flow. Within the areas near the Danube the groundwater level oscillation follows the fluctuations in the Danube. At greater distances from the Danube, groundwater level change depends on seasonal effects and on the relationship between precipitation, including snow melting and evaporation from the ground and vegetation. The network of irrigation channels and drainage systems has a stabilizing effect on the groundwater table level.

In the southern part of the area of interest there are wetlands (in the west direction Potônska mokraď Wetland, Čiližská mokraď Wetland, Okoličnianska mokraď Wetland), where the groundwater level is close to the terrain surface.

The area between the *Potônska mokraď Wetland* and the Klátov Oxbow of the Little Danube is drained by the Starý Klátovský Channel, the Klátovský Channel and the Klátov Oxbow.

The Klátov Oxbow is about 25 km long. It is protected along the entire length of the stream as a National Nature Reserve. It surges gradually behind the village Orechová Potôň-Lúky. The upper section of the oxbow does not have a continuous level, it consists of a series of lakes. Around the settlement Csótfa the oxbow takes on the character of a continuous flow (Figs. 4.2a, 4.2b). Its depth is mostly shallow, but in places it reaches about 5 m. Visually, the

Fig. 4.2a Klátov Oxbow – surge Bödör (photo: F. Bottlik, 2016)

Fig. 4.2b Klátov Oxbow with coherent flow near Csótfa (photo: K. Benková, 2016)

water is clear, translucent. In Dunajský Klátov, the flow is conjoined from the right side by the connected Old Klátovský Channel and the Klátovský Channel, part of the water coming from springs in the area between Lehnice and Bellova Ves. In Topoľníky, the Klátov Oxbow takes the water from the Gabčíkovo – Topoľníky Channel and soon mouths in the form of a delta into the Little Danube (Michalko in Liščák et al., 2011).

The spring water is clear, characterized by relatively low temperatures in both canals (around 13 °C to 16 °C) and increased presence of heavy O and H isotopes. The chemical type of groundwater in the Klátov Oxbow, the Old Klátovský Channel and the Klátovský Channel is $Ca\text{-}HCO_3\text{-}SO_4$ with increased specific electrical conductivity (850 $\mu S.cm^{-1}$) compared to the water of the Little Danube (390 $\mu S.cm^{-1}$), which is of the chemical type $Ca\text{-}HCO_3$. The increase in the specific electrical conductivity value is also reflected in the increase in the content of NH_4, NO_3, Ca, Mg, Fe, Mn, Al, and Zn indicators, which exceeded the limit value pursuant to drinking water (Bottlik et al., 2013).

Isotopic composition of the Potônska mokraď Wetland groundwater ($\delta^{18}O$ = -9.55 to -10.46‰, $\delta^{2}H$ = -73.65 to -77.45‰) and Klátov Oxbow water ($\delta^{18}O$ = -9.17 to -10.74‰ , $\delta^{2}H$ = -71.81 to -79.40‰) is different from the isotopic composition of the Little Danube – Hrubý Šúr water ($\delta^{18}O$ = -10.60 to -12.20‰, $\delta^{2}H$ = -77.82 to -86.24‰) and documents the presence of waters that cross the Danubian Flat from the north (Vozokany – Jahodná area). Waters of similar chemical and isotopic composition have been documented in the Dudváh River north of the Little Danube (Michalko et al., 2015) and in groundwater at Vozokany in the HV-1 borehole, 15 m deep (Némethyová, 1980), isotopically also in piezometer in Jelka (Michalko et al. 2015).

The geological structure of the area in the area of the Little Danube in the Dolné Saliby – Dunajská Streda line is of such a character that the fluvial sediments of the Quaternary fill the palaeo-valley of the Váh River. Along this line, the thickness of the Quaternary sediments varies considerably, ranging from 80 – 100 m N of Tomášikovo, from 100 to 150 m S of Tomášikovo, from 80 to 100 m in Dunajský Klátov and 150 – 200 m to the south of Dunajský Klátov (Maglay et al., 2009). The sudden change in the thickness of the Quaternary sediments is probably due to vertical bedrock differentiation, which was covered by Neogene sediments with a lower coefficient of transmissivity value than of the Quaternary sediments. The differentiation of the Quaternary bedrock in this area causes that the Quaternary groundwater stream from Dolné Saliby rises up on the Neogene sediment barrier from 150 m to 80 m. This groundwater outlet from the Quaternary sediments has the character of a barrier spring and, depending on the shape of the spring, it can be characterized as a surface spring (10 km x 5 km).

The continuous increase in the coefficient of transmissivity of the Klátov Oxbow (especially in the area below the confluence with the connected Klátovský Channel) is caused by the increase of groundwater of the Danube origin, probably coming from the Little Danube (Michalko et al., 2015). The amount of water rising to the surface in the Klátov Oxbow (according to long-term observations of SHMI about 2,000 $l.s^{-1}$) quantifies it as one of the most significant natural groundwater outlets in Slovakia (Michalko et al., 2014a, Michalko et al., 2014b).

The Čiližská *mokraď Wetland* is located in a lane between the villages of Rohovce and Trávnik near the Danube River. The thickness of the Quaternary sediments increases from east to west from 20 m to 500 m (Maglay et al., 2007 in Malík, et al., 2007). The circulation and regime in this wetland is influenced by the flow rate in the Danube River and its channel system.

The *Okoličnianska mokraď Wetland* extends in the area approximately between Okoč, Kolárovo and Komárno, where the thickness of the Quaternary sediments increases from south to north from the value of 5 m near Komárno to 150 m near Okoč. The Neogene bedrock at the edge of the Danubian Flat is considerably vertically differentiated (Maglay et al., 2007 in Malík, et al., 2007). The circulation and regime in the Okoličnianska mokraď Wetland is influenced by the flow rates in the Danube, the Little Danube, the Váh and their channel systems.

In 1992, the *Gabčíkovo Waterworks* on the Danube River was put into operation, whose construction began in 1978. Its aim is to generate electricity through 8 Kaplan turbines (which generate 720 MW and produce approximately 2.2 billion MWh per year – approximately 8% of the total energy consumption in Slovakia), protection of the area from flooding, regulation of the level of the Danube and ensuring year-round navigability of the river as well as protection of the natural environment. The WW consists of several objects. These are mainly the Čunovo reservoir (area of 40 km^2), a 17 km long supply channel (between Čunovo reservoir and Gabčíkovo), the Gabčíkovo stage with power plant and two lock chambers, a 8.2 km outlet channel (between Gabčíkovo and Sap), inundation (dam) and flood control measures (modifications to existing dams, including metering systems, seepage and drainage channels, and the construction of pumping stations for pumping internal water to reduce water in the channel network).

From the long-term assessment of the groundwater regime trends, a decrease trend of the groundwater level on all groundwater observation objects was recorded until the WW was put into operation in the given area. The largest decreases prevailed in the upper part of the area of interest along the Danube – Petržalka, Podunajské Biskupice, Kalinkovo. Downstream, the decline in trends dropped, in the vicinity of Sap and Medveďov there were only slight decreases.

After the WW commissioning (in the observed period 1993 – 2002), the character of the trends was mostly changed to ascending (Fig.4.3). The water level increased in Bratislava (blue colour), in the upper part of Žitný ostrov up to Šamorín and towards the Little Danube. Decreases occurred from the beginning of the supply channel to the mouth of the outlet channel into the Danube, with the

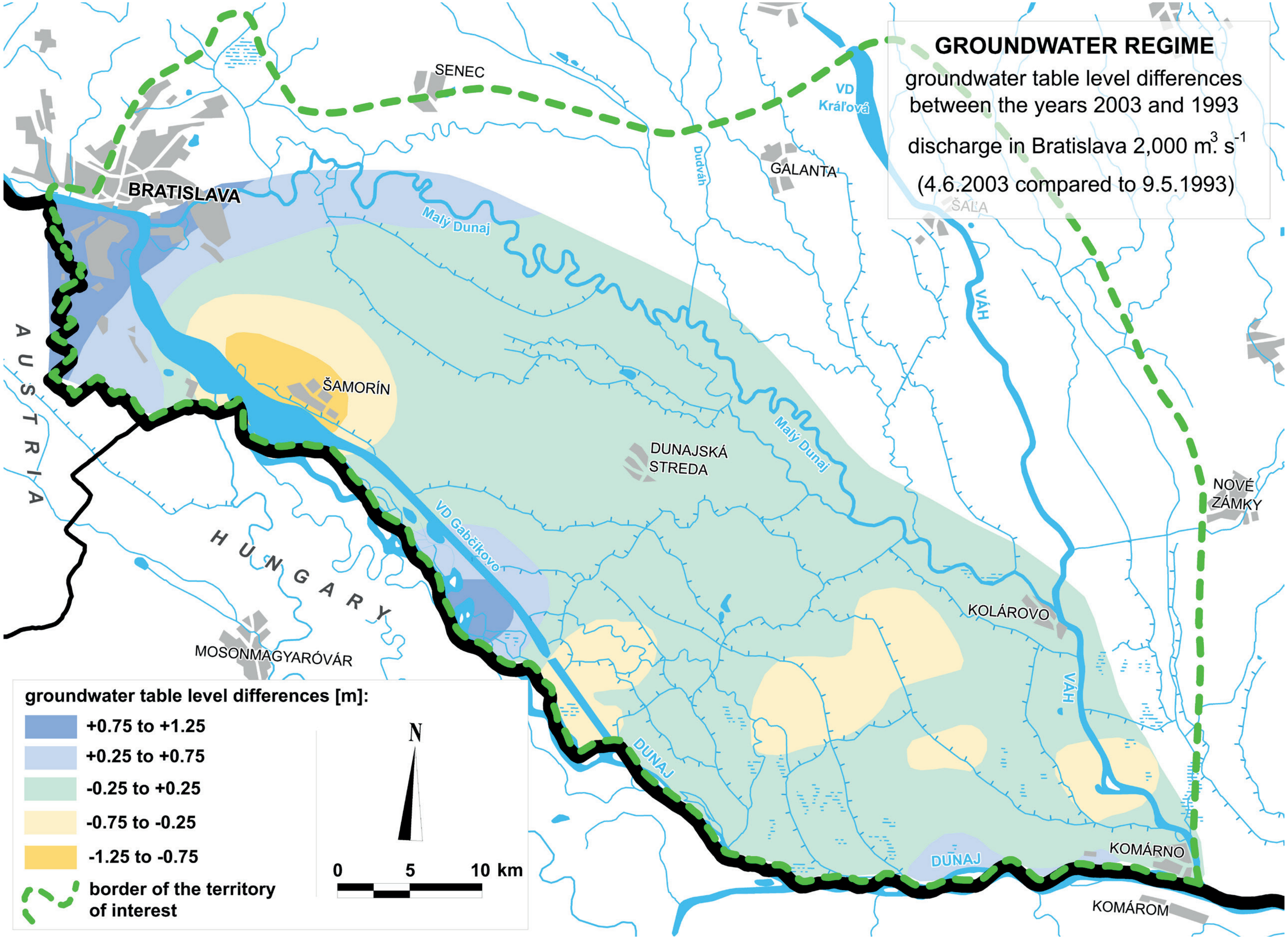

Fig. 4.3 Map of groundwater level differences between 1993 and 2003 (modified after Mucha et al., 2004)

largest decrease in Dobrohošť and Gabčíkovo – brown colour (Mucha et al., 2004).

The groundwater regime in the area of interest was evaluated in 1994 – 2003 in the right bank of the Danube in 2 profiles (AA´, BB´), in the area between the Danube and the Little Danube in 4 profiles (CC´, DD´, EE´, FF´) – Fig. 4.4. The comparison of the mean values of groundwater level and oscillation range is shown in Tab. 4.1

Tab.4.1 Average and extreme levels of groundwater level and fluctuations in longitudinal profiles of studied area in 1993 – 2002 according to SHMI data

Profile designation	Elevation (m a.s.l.)	H_{max} b.s. (m)	H_{min} b.s. (m)	H_{mean} b.s. (m)	Oscillation (m)
A-A´	136.25-132.88	2.39-6.59	2.74-6.93	2.55-6.76	0.33-0.35
B-B´	134.74-131.50	1.35-5.20	3.09-5.21	2.63-5.59	0.80-1.80
C-C´	122.98-114.94	0.52-2.63	3.09-4.26	2.57-3.73	1.20-3.70
D-D´	134.40-110.53	0.14-4.25	2.54-5.77	2.03-5.21	0.54-3.88
E-E´	131.39-108.67	0.83-3.56 (7.07 PB)	2.03-4.09 (7.52 PB)	1.52-3.85 (7.30 PB)	0.44-1.20
F-F´	134.23-108.80	0.67-6.28 (7.31 PB)	2.10-6.90 (7.92 PB)	1.70-6.60 (7.65 PB)	0.32-1.77

Legend: PB – Podunajské Biskupice

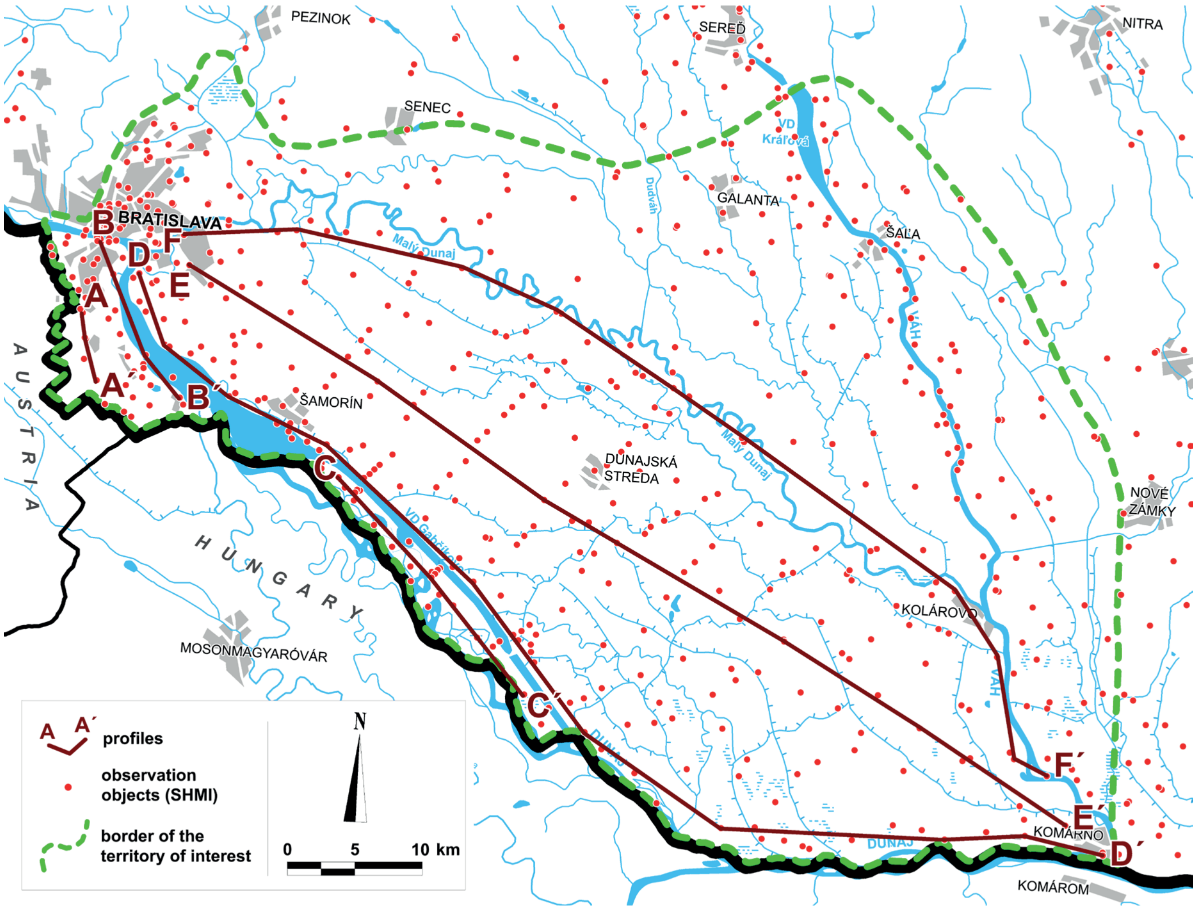

Fig. 4.4 Situation of longitudinal profiles in the area of interest – in the area of Žitný ostrov and the Danube right bank

Hydroisohypses (Fig. 4.5) were constructed on the basis of interpolation of the measured groundwater level levels in SHMI's observation objects. The respective terms for lower, average and higher levels were determined on the basis of a selection from the time series of November 1, 1995 – October 31, 2001.

From the large-scale sources from which the groundwater from the Quaternary aquifer is exploited, the water source (hereinafter WS) Jelka is located in the northern part of the territory. In the southern part of the territory – on the Žitný ostrov area there are WS Kalinkovo, Šamorín and Gabčíkovo and in the right bank of the Danube it is the water source Pečniansky les (Fig. 4.6) and Rusovce-Ostrovné Lúčky-Mokraď.

The WS Jelka from year 1969 consists of seven wells HJ-1 to HJ-7, which were realized to a depth of 44 – 65 m. An exploitable quantity of 500 $l.s^{-1}$ is approved for the water source in category A (Act 364/2004 Coll.). In 2012, from the 7 wells there were taken 399 $l.s^{-1}$.

In the WS Kalinkovo in year 1972 there were realized 10 wide-profile hydrogeological boreholes NVZ-1 to NVZ-10 to a depth of 55 – 80 m. An exploitable quantity of 660 $l.s^{-1}$ is approved for the water source in category A (Act 364/2004 Coll.). In 2012, there were taken only 48 $l.s^{-1}$ from 5 wells.

The WS Šamorín was built in years 1973 – 1981. It consists of 16 hydrogeological wells HGŠ-1 to HGŠ-16, which were built to a depth of 65 – 160 m. For the water source, the exploitable quantity in category A 600 $l.s^{-1}$ has been approved. Currently, 7 wells are being used yielding 233 $l.s^{-1}$.

The WS Gabčíkovo consists of 13 hydrogeological wells HAŠ-1 to HAŠ-13, which were realized in the period 1976 – 1984 to a depth of 85 – 90 m. An exploitable quantity of 3,000 $l.s^{-1}$ has been approved for the water source in category C_1. At present, 13 wells are used yielding 465 $l.s^{-1}$.

The WS Pečniansky les was built in the year 1976 in the right bank of the Danube. It consists of 34 wide-profile boreholes D-1 to D-34, which were realized to a depth of 10 – 13.5 m. An exploitable quantity of 350 $l.s^{-1}$ has been approved for the water source in category A. In y. 2012, the water was exploited from 17 wells yielding 174 $l.s^{-1}$.

The Rusovce-Ostrovné Lúčky-Mokraď consists of 23 wells ST-1 to ST-23, which were realized in yrs. 1978 – 1985 to a depth of 50 – 80 m. An exploitable amount of 1.828 $l.s^{-1}$ has been approved for the water source in category B. In year 2012, the water was exploited from 23 wells yielding 834 $l.s^{-1}$.

The groundwater of the Neogene sediments, which is characterized by a confined table level, is utilised from the level of about 80 – 412 m b.s. through hydrogeological wells in the northern and north-eastern part of the territory (Šaľa, Galanta, Nové Zámky, Trnovec nad Váhom, Vlčany and others) – Fig. 4.7.

4.6.2 Hydrogeochemical properties of groundwater of the Quaternary sediments

From the hydrogeochemical point of view, groundwater bound to the Quaternary aquifers can be characterized predominantly as fluviogenic with varying anthropogenic effects. Among the mineralization processes dominant are mainly hydrolysis of silicate minerals (the predominant material of the gravel-sand Quaternary sediments), dissolution of carbonates (usually present in the pebble material of gravel and loess) and oxidation of sulphides – mainly pyrite (a common accessory mineral of gravel).

As the chemical composition of groundwater in the region under consideration largely depends on the chemical composition of water in the Danube, the Tab. 4.2 shows basic statistical parameters of selected components (Bodiš 2005 in Benková et al., 2005).

In the northern part of the Danubian Flat, five chemical groundwater types were earmarked for the Quaternary. These are A_1 distinct type, Ca(Mg)-HCO_3 with an average TDS value of 746 $mg.l^{-1}$, A_2 indistinct type, Ca(Mg)-HCO_3 with an average TDS value of 940 $mg.l^{-1}$, intermediate and mixed type, predominantly components A_2 and S_2 (SO_4) with a TDS value of 173 $mg.l^{-1}$, a mixed type with a TDS value of 1,334 $mg.l^{-1}$ and hydrosilicatogenic water of the A_1 type, Na-HCO_3 with a mean TDS value 1,000 $mg.l^{-1}$.

In terms of groundwater quality classes (Tab. 4.3), there are represented classes A, B, D, F, H, with dominant class D. Groundwater of the highest class A is represented in the vicinity of Malý Jatov, the B class was verified in the wider surroundings of Jelka along the course of the Little Danube between Hrubý Šúr and Mostová and in the vicinity of Senec. In the territory of Bratislava and its close surroundings and in the area of Jelka-Komárno, groundwater is represented mainly by the quality class D. The deteriorated class F of the groundwater quality has been identified between Bratislava - Prievoz and Bernolákovo and between Kráľová pri Senci and Reca. The worst quality of the H-class was verified between Veľké Úľany and Hrubá Borša, then in the area of Vozokany, Saliby and Tešedíkovo, Jatov and Trnovec nad Váhom; in particular above-the-limit concentrations of ***chlorides, nitrates, sulphates and ammonium ions*** have been found (Bodiš, 2013 in Bottlik et al., 2013).

In the southern part of the Danubian Flat on the Žitný ostrov territory and on the right bank of the Danube, the chemical composition of groundwater due to the greater thickness of the Quaternary compared to the northern part of the Danubian Flat was characterized up to 25 m and at the level of 25 m. At the level up to 25 m, three chemical types of water were designated, namely A_2 distinct type, Ca-(Mg)-HCO_3 with an average TDS value of 462.3 $mg.l^{-1}$, A_2 indistinct type, distinct with an average TDS value of 661.8 $mg.l^{-1}$ and an intermediate and mixed type with a predominance of A_2 and S_2 (SO_4) components with an average TDS value of 911 $mg.l^{-1}$. The *first type* of groundwater is predominantly bound to the transversal zone of the Danube practically from Bratislava to Kližská Nemá. In the area below Trstená na Ostrove, the representation of this type extends below Dunajská Streda and Veľký Meder. It is represented locally between Kolárovo and Topoľníky and north of Tomášov. The first type is followed in the region by the *second type*, which is characteristic in a continuous lane from Bratislava to Kolárovo. The *third type* is bordered on the southern side by the line Podunajské Biskupice – Štvrtok na Ostrove – Horná Potôň – Malé Dvorníky – Veľký Meder – Zlatná na Ostrove – Komárno. From the northern side, this continuous lane is bounded by the flow of the Little Danube till Topoľníky and continues in the direction of Sokolce, Štúrovo to the Váh River.

At the level of 25 m, three chemical types of water were designated as A_2, Ca-(Mg)-HCO_3 type with an average TDS value of 380.6 $mg.l^{-1}$, intermediate and mixed type with predominance of A_2 a S_2(SO_4) components with an average TDS value of 680 $mg.l^{-1}$ and A_1, Na-HCO_3 type with an average TDS value of 625.9 $mg.l^{-1}$. At this level, the *first type* of groundwater is absolutely prevalent. This suggests some stabilization of the water-rock system without much anthropogenic agents. Locally, however, the values of TDS can reach 1,000 $mg.l^{-1}$. The *second type* of groundwater is bound to the Janíky – Oľdza area

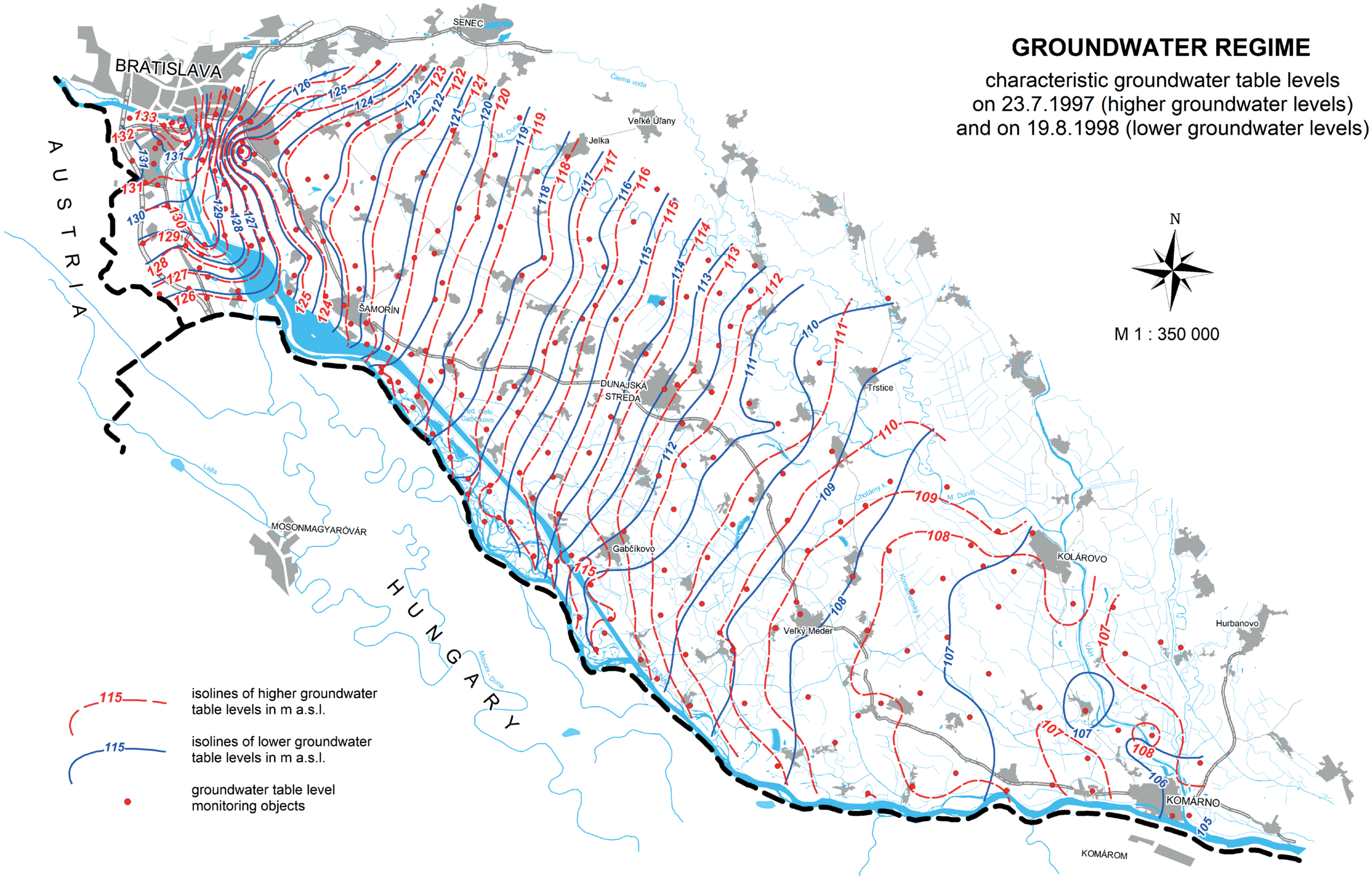

Fig. 4.5 Map of hydroisohypses at high and low water levels (Černák in Benková et al., 2005)

Fig. 4.6 Water source Pečniansky les (photo: K. Benková, 2018)

Fig. 4.7 Artesian well Šaľa-Veča (photo: F. Bottlik, 2013)

and can be justified as an upper reach. The *third type* of groundwater is located in the south-eastern part of Žitný ostrov (Kameničná – Veľký Lél – Komárno area).

At a *level of up to 25 m*, the A-class groundwater is characteristic mainly for the area of the narrower Danube zone from Bratislava to Vojka. Class B is typical for the central part of Žitný ostrov, i.e. from Bratislava till Dolný Štál. However, its homogeneity is interrupted by the cross-lane of deteriorated D-H water quality in the wider surroundings of Dunajská Streda due to the increased density of point sources of pollution (especially landfills) in this area and also the high degree of land use. For the Danube riparian zone from Vojka to Komárno and for the eastern part of Žitný ostrov, the D-class of groundwater quality is most represented. In this part is also represented the worst H class of quality in the area Kližská Nemá – Veľké Kosihy and also Zlatná na Ostrove – Komárno. Significantly deteriorated groundwater quality classes (F to H) occur in the area bounded from the southern part by the line Podunajské Biskupice – Štvrtok na Ostrove – Michal na Ostrove and from the northern part bounded by the Little Danube. In the eastern part of Žitný ostrov, the worst H quality class is represented in the transverse lane Topoľníky – Veľký Meder and locally in the area Bodza – Zemianska Olča.

The *right bank of the Danube* is characterized by the D quality class from Petržalka to Rusovce in the narrower riparian zone and further towards Čunovo in the wider area of Rusovce-Ostrovné Lúčky-Mokraď water source. The area along the state border with Austria can be characterized as an area with deteriorated F class of groundwater quality with sources of contamination probably in Austria.

A completely different qualitative picture of groundwater is at a level of 25 m. The groundwater quality at this level is significantly better than at the higher level.

Tab. 4.2 Basic statistical parameters of selected indicators of surface water of the Danube

	years 1992 – 2001					
	min.	**max.**	**mean**	**STD**	**variance**	**number**
Ca	36.07	86.40	59.53	8.71	75.97	163
Cl	0.00	35.00	18.64	5.57	31.7	166
Fe	0.023	2.470	0.34	0.37	0.139	139
HCO_3	134.00	274.00	192.77	22.90	524.79	168
Mg	10.10	26.75	14.11	2.60	6.78	165
Mn	0.002	0.180	0.033	0.031	0.001	139
Na	4.40	42.20	9.98	3.80	14.43	166
NH_4	0.025	3.37	0.273	0.284	0.081	169
NO_3	1.40	17.50	10.28	3.25	10.61	169
O_2	7.200	15.20	10.47	1.78	3.17	171
SO_4	18.00	42.30	29.18	5.72	32.73	169
Conductivity	232	518	384	61	3,731	169

Note: all the values are in mg.l^{-1}, conductivity in µS.cm^{-1}

Tab. 4.3 Groundwater quality classification scheme

GROUNDWATER QUALITY CLASS				ASSESSED INDICATORS AND THEIR LIMIT VALUES				
Class label	Class quality characterisation 1	2	3	Assessed indicators groups	Assessed indicators	Symbol	Unit	Limit values
A	+	+	+	1	**Aluminium**	Al	$mg.l^{-1}$	0.2
					Arsenic	As	$mg.l^{-1}$	0.01
					Barium	*Ba*	*$mg.l^{-1}$*	*1*
B	+	+	–		**Cadmium**	Cd	$mg.l^{-1}$	0.003
					Chromium	Cr	$mg.l^{-1}$	0.05
					Copper	Cu	$mg.l^{-1}$	0.1
C	+	-	+		**Mercury**	Hg	$mg.l^{-1}$	0.001
					Ammonium ions	NH_4	$mg.l^{-1}$	0.5
					Nitrites	NO_2	$mg.l^{-1}$	0.1
D	+	-	-		**Nitrates**	NO_3	$mg.l^{-1}$	50
					Nickel	Ni	$mg.l^{-1}$	0.02
					Antimony	Sb	$mg.l^{-1}$	0.005
E	-	+	+		**Lead**	Pb	$mg.l^{-1}$	0.01
					Selenium	Se	$mg.l^{-1}$	0.01
				2	**Chlorides**	Cl	$mg.l^{-1}$	100
F	-	+	-		**Fluorides**	F	$mg.l^{-1}$	1.5
					Iron	Fe	$mg.l^{-1}$	0.2
					Manganese	Mn	$mg.l^{-1}$	0,05
G	-	-	+		***Phosphates***	*PO_4*	*$mg.l^{-1}$*	*1*
					Sulphates	SO_4	$mg.l^{-1}$	250
					Zinc	Zn	$mg.l^{-1}$	3
H	-	-	-	3	**Calcium and magnesium (Ca + Mg)**	Ca + Mg	$mmol.l^{-1}$	1.1 až 5
					Chemical oxygen demand	$CHSK_{Mn}$	$mg.l^{-1}$	3
					Magnesium	Mg	$mg.l^{-1}$	125
+ *complies with the earmarked*					**Water saturation with oxygen**	O_2	%	>50
- *does not comply with the limit values set aside limit values*					**Water reaction**	pH		6.5 to 8.5
					TDS	*RL*	*$mg.l^{-1}$*	*1,000*

The elements in italics are not mentioned in the decree of the MH SR no. 151/2004 Coll. on requirements for drinking water and drinking water quality control

Mainly A and C quality classes dominate, while E, F and G are not represented at all. G and H classes, which appear at the higher level of the aquifer in the northern part of Žitný ostrov, are manifested only by point anomalies of classes G and H. The situation in Zemianska Oľča, Veľké Kosihy and Komárno is relatively more complicated, where the quality classes D, F, G and H are intermittently interchanged. The worst H water quality class is located only in the area of Kolárovo and Bodzianske Lúky, which is bounded by a zone with D quality class and locally east of Kostolné Kračany.

The area *of the Danube right bank* falls at the described level ***below 25 m within the A-class*** (Bodiš, 2005 in Benková et al., 2005).

In the marginal parts, local precipitation, local watercourses and Váh water should be considered as a source of groundwater. However, the Danube water plays a decisive role, either directly or indirectly through the oxbows and channels network. The isotopic composition of oxygen $\delta^{18}O$ of monthly accumulated precipitation fluctuated in the centre of the area of interest in the precipitation station Topoľníky in the period 1989 – 1998 in the interval -7.12 to -14.4‰ (the average value was -9.43‰). At the W border of the territory under study the average value of $\delta^{18}O$ = – 8.98‰ (at the station Bratislava – Koliba) and in E outskirts (in station Mochovce) -9.11‰ (Kantor et al., 1989; Michalko 1998).

The *surface water of rivers and reservoirs* originates either from local rainfall (and shorter local rivers and streams) or from rainfall from the higher altitudes of the Western Carpathians, which larger rivers (e.g. Váh) have or had brought to the area in the geological past. Their isotopic composition also corresponds to this situation.

Isotopic composition of water ine the *Váh River* in Vlčany during the period of 2013 – 2014 (12 samples) showed mean values $\delta^{18}O$ = -10,42‰, $\delta^{2}H$ = -73,87‰, *Čierna voda River* in Čierna Voda $\delta^{18}O$ = -10.56‰ and $\delta^{2}H$ = -77.51‰ and *Dudváh River* in Čierny Brod $\delta^{18}O$ = -9.47‰ and $\delta^{2}H$ = -69.10‰ (Michalko et al., 2015).

A significant amount of surface water flows into the Danube Lowland from the Alps by the Danube River. This isotopically light water (diametrically different from that of other sources) dominate the oxbows and practically also channel system, it is also present in most gravel pits (Kantor et al., 1987, 1989). The isotopic composition of the Danube in Bratislava monitored in the period 1982 – 1997 with a monthly step (346 samples) fluctuated ($\delta^{18}O$) in the interval -13.53 to -10.31‰ with an average value of $\delta^{18}O$ = -11.31‰ (Kantor et al., 1987; 1989; Michalko et al., 1997; Michalko et al., 2014a; Bodiš et al., 2015). During renewed monitoring since y. 2010 $\delta^{18}O$ = -11.23‰ and $\delta^{2}H$ = -80‰ average values were reached (Michalko et al., 2014a; Michalko et al., 2015).

The isotopic composition of the *Little Danube* follows the mother river with little influence of heavier water from the left tributaries. The average isotope values of oxygen and hydrogen in the surface water of the Little Danube in Jahodná in the period 2013 – 2014 were $\delta^{18}O$ = -11.05‰ a $\delta^{2}H$ = -80.90‰ (Michalko et al., 2015).

In the Quaternary sediments of the Danubian Plain, water of Alpine origin, which originates from the bank infiltration of the Danube, or from the streams of the river oxbow and channel system, is predominantly present. It can also be distinguished from local waters by its isotopic composition (Kantor et al., 1985; 1987; 1989; Ďurkovičová et al., 1993; Michalko et al., 1997; Michalko, 1998). The significant annual minimum of $\delta^{18}O$ in the Danube caused by snow melting at higher altitudes in the Alps is characterized by a value on 1.0 – 1.5‰ lower than the average value. The flow situation is accompanied by high flow, reduced conductivity and water temperature. Since the minimum lasts relatively shortly, this marker for bank infiltration can be tracked to a distance of several kilometres to get an idea of the flow rate. Rodák et al. (1995) in the area of Kalinkovo estimated the rate of infiltration in the preferred zone up to 2 km per year. Thereafter, the annual changes are wiped out, but the groundwater retains light "Danube" average values ($\delta^{18}O$ -10.5 to -11.0‰).

Tab. 4.4 Selected parameters of hydrogeologic units of the Danubian Flat

Hydrogeologic unit	Hydrogeologic sub-unit	Collector	Number of wells	T ($m^2.s^{-1}$)	k ($m.s^{-1}$)	TDS ($g.l^{-1}$)	Dominant chemical type of water
Crystalline	Palaeozoic of Pezinok Carpathians	granitoids	37*	$4.3.10^{-5}$	$4.8.10^{-6}$	0.17 – 0.41 (mean 0.25)	A_2 indistinct $Ca\text{-}Mg\text{-}HCO_3$
Mesozoic	Late Triassic– Jurassic of Transdanubian Mts. – GTW	limestones, dolomites, dolomitic limestones	3	$1.35.10^{-4}$		2.2 – 3.1	Mixed type with prevalent $Ca\text{-}SO_4$ with elevated Na-Cl content
Neogene volcanics	Early Badenian (Langhian) Šurany volcanics – GTW	andesites	1	$1.1.10^{-5}$	$4.9.10^{-7}$	17 – 23	fossil marine water of the type Na-Cl (SO_4)
Sedimentary Neogene below 500 m	Pannonian, (Tortonian), Pliocene of the Danubian Flat – GTW	sands, sandstones	33	$5.3.10^{-4}$	$6.7.10^{-6}$	0.5 – 8.3	$Na\text{-}HCO_3$ and $Na\text{-}HCO_3\text{-}Cl$
Sedimentary Neogene to 500 m	Pannonian (Tortonian), Pliocene, N part of the Danubian Flat	sands, sandstones	46	$6.08.10^{-4}$	$3.64.10^{-5}$	0.3 – 1.06 (mean 0.53)	A_2 distinct, with depth transition from $Ca\text{-}(Mg)\text{-}HCO_3$ to $Na\text{-}HCO_3$
	Pliocene, N part of the Danubian Flat	sands, sands with gravel	128	$1.55.10^{-3}$	$9.84.10^{-5}$		
	Pliocene, S part of the Danubian Flat	sands, sands with gravel	55	$1.84.10^{-3}$	$1.09.10^{-4}$		
Quaternary	Fluvial, N part of the Danubian Flat – bottom accumulation	sandy gravels, gravels, sands	492	$1.55.10^{-2}$	$2.5.10^{-3}$	0.27 – 0.76 (mostly 0.4 – 0.6) at anthropogenic impact above 0.8	A_2 distinct, $Ca\text{-}Mg\text{-}HCO_3$
	Fluvial, N part of the Danubian Flat – middle terraces	sandy gravels, gravels	19	$1.10.10^{-3}$	$6.0.10^{-4}$		
	Proluvial, N part of the Danubian Flat	loamy, sandy-loamy gravels	5	$8.49.10^{-4}$	$3.0.10^{-4}$		
	Fluvial of the right bank of the Danube	sandy gravels, gravels, sands	110	$5.03.10^{-2}$	$5.90.10^{-3}$		
	Fluvial of the upper part of ŽO	sandy gravels, gravels, sands	98	$3.38.10^{-2}$	$4.31.10^{-3}$		
	Fluvial of the central part of ŽO	sandy gravels, gravels, sands	406	$4.50.10^{-2}$	$3.71.10^{-3}$		
	Fluvial of the lower part of ŽO	sandy gravels, gravels, sands	198	$6.85.10^{-3}$	$8.61.10^{-4}$		

*Note: * – wells out of the territory of the Danubian Flat, GTW – geothermal water, ŽO – Žitný ostrov*

The isotopic composition of the groundwater of the Danubian Flat Quaternary has been monitored since the early 1980s (Kantor et al., 1985); the spatial isotope data are at hand since1988 (Kantor et al., 1989), monitoring of $\delta^{18}O$ in the piezometers network had been part of monitoring the impact of the WW Gabčíkovo until 1996. Virtually all groundwater in the Quaternary sediments of Žitný ostrov and the Danube right bank must be derived from the Danube. Ďurkovičová et al. (1993), Michalko et al. (1997), in relation to the isotopic composition of groundwater, delineate the area adjacent to the Danube with a rapid impact of the watercourse, the area with the Danube homogenized waters practically throughout the Žitný ostrov area and the area affected by water from local precipitation near the Little Danube (Jelka, Jánovce, Jahodná) and in piezometer Oľdza. Isotopically heavy water is also present in the piezometer Jarovce on the right bank of the Danube.

At present, isotopically lighter water (unambiguously of the Danube affiliation) occurs in the entire depth of the profile at least till the Oľdza – Dunajská Streda line. The exception is the upper horizon (level 5 – 8 m) of the aquifer verified in a piezometer in Veľký Blahov (SHMI, Final report 7293), where isotopically heavier water is present, probably altered due to evaporation (Michalko et al., 2014a; 2014b; 2015). The influence of irrigation water (Ženišová et al., 2015) can be excluded due to climatic conditions.

4.7 Conclusions

Hydrogeological units earmarked in the Danubian Flat are represented by important regional groundwater aquifers, whose overview and selected parameters are documented in Tab. 4.4. On the basis of the average value of the coefficient of transmissivity of aquifers with *fissure permeability*, it is possible to observe its increase from andesites and granitoids to carbonates. For aquifers with *intergranular permeability*, the value of the coefficient of transmissivity increases from the sands and sandstones of the Pannonian (Tortonian) to the sands of Zanclean. ***The most permeable are the fluvial sediments of the right bank of the Danube and the central part of Žitný ostrov***, as well as the fluvial sediments of the upper part of Žitný ostrov and the northern part of the Danubian Flat. The coefficient of transmissivity of the fluvial sediments of the lower part of Žitný ostrov is almost one order lower compared to the right bank of the Danube.

The TDS of groundwater of the Quaternary and shallow Neogene aquifers is not very different and reaches values mostly in the interval of approx. 0.3 – 1.0 $g.l^{-1}$.

References

Act no. 364/2004 Coll. on waters (Water Act) and on amendment of the Slovak National Council Act no.372/1990 Coll. on offenses as amended (Water Act), as amended.

Benková, K., Bodiš, D., Nagy, A., Maglay, J., Švasta, J., Černák, R., Marcin, D. & Kováčová, E., 2005: Základná hydrogeologická a hydrogeochemická mapa Podunajskej roviny – Žitný ostrov a pravobrežie Dunaja v mierke 1: 50,000. Interim final report. SGIDŠ Bratislava. Geofond archive (ID 92456), 268 p.

Bodiš, D., Čurlík, J., Liščák, P., Pristaš, J., Rapant, S., Smolárová, H. & Zakovič, M., 1998: Súbor regionálnych máp geofaktorov životného prostredia regiónu modelového územia okresu Galanta, orientačný prieskum. SGIDŠ, Bratislava. Geofond archive (ID 82900), 59 p.

Bodiš, D., Fajčíková, K., Cvečková, V., Rapant, S., Škoda, P., Slaninka, I., Michalko, J., Švasta, J., Grolmusová, Z., Mackových, D., Bystrická, G. & Antalík, M., 2015: Geochemický Atlas Slovenskej Republiky. Časť VII. Povrchové Vody 1: 1,000,000, (Geochemical Atlas of The Slovak Republic. Part VII. Surface Waters 1: 1,000,000. Bratislava: SGIDŠ, 2015, 110 p., ISBN 978-80-8174-014-5.

Bondarenková, Z., Franko, O., Hramec, J., Zbořil, Ľ. & Motlíková, H., 1977: Bratislava - Rusovce - geotermálny vrt HGB-1, vyhľadávací hydrogeologický prieskum. Účel: možnosti získať termálnu vodu v tejto oblasti Bratislava. Slovenský geologický úrad, Bratislava; IGHP, Žilina; VIKUV, Budapešť. Geofond Archive (ID 48993), 39 p.

Bottlik, F., Bodiš, D., Fordinál, K., Maglay, J., Michalko, J., Remšík, A., Lenhardtová, E. & Slaninka, I., 2013: Základná hydrogeologická a hydrogeochemická mapa severnej časti of the Danubian Flat v mierke 1: 50,000. Interim final report, SGIDŠ Bratislava, Geofond archive (ID 97192-10), 214 p.

Bujalka, P., Fatul, R., Modlitbová, O. & Urbanec, J., 1967: Hydrogeologický prieskum strednej a južnej časti Podunajskej nížiny. Geofond archive (ID18824), 147 p.

Ďurkovičová, J., Kovářová, A., Michalko, J. & Rúčka, I., 1993: Správa o výsledkoch meraní izotopového zloženia kyslíka vo vode Dunaja a pozorovacích objektoch povrchových a podzemných vôd počas rozšíreného sledovania kvality vody pri napúšťaní WW Gabčíkovo. Manuscript, GÚDŠ Bratislava. Geofond archive (AP 9427), 20 p.

Fendek, M. & Bodiš, D., 1992: Možnosti reinjektáže geotermálnych vôd v centrálnej depresii podunajskej panvy. Západné Karpaty, séria hydrogeológia a inžinierska geológia 59, GIDŠ Bratislava.

Franko, O. & Račický, M., 1979: Správa o exploatačnom geotermálnom vrte M-3 v Komárne. Manuscript. Geofond Archive Bratislava.

Franko, O., Bodiš D., Michalko, J., Remšík, A., Sivo, A. & Bálint, J., 1995: Geotermálna energia Slovenska. Bratislava, ŠGÚDŠ, Archív Geofond ID 79554, nestr. Franko, O., Michalko, J., Šivo, A. 2000: Isotopes of oxygen and ^{14}C in the geothermal waters of the Pliocene sediments of Danube basin. Sympozja i Konferencje nr. 45, IGSMiE PAN, Krakow, p. 229 – 239.

Franko, O., 2001: Pôvod a vývoj minerálnych a termálnych vôd Slovenska v priestore a čase z pohľadu veku travertínov a izotopov O, H a ^{14}C.- Podzemná voda ISSN 1335-1052, VII, 2/2001, p. 26 – 45.

Gavurník, J., Bodácz, B., Čaučík, P. & Paľušová, Z., 2012: Dunaj – zdroj dopĺňania podzemných vôd. SHMÚ Bratislava, p. 13 [Online]. Accessible on Internet.

Hanzel, V., Vrana, K., Švasta, J., Kohút, M., Nagy, A., Maglay, J. & Bujnovský, A., 1999: Hydrogeologická a hydrogeochemická mapa Pezinských Karpát v mierke 1: 50,000 a textové vysvetlivky. Geofond archive (ID 84395), 179 p., 7 annexes.

Hanzel, V., Rapant, S. & Franko, O., 2012: Vysvetlivky k základnej hydrogeologickej mape SR, list 44 Bratislava, 1: 200,000. Manuscript, SGIDŠ Bratislava, 94 p.

Kantor, J., Rybár, M., Garaj, M., Rúčka, I. & Richtarčík, J., 1985: Izotopová charakteristika vôd rôznych genetických typov. Interim final report. Manuscript. Bratislava, SGIDŠ, Geofond archive, (AP 7619), 245 p.

Kantor, J., Ďurkovičová, J., Rúčka, I., Harčová, E., Eliáš, K., Garaj, M., Richtarčík, J. & Michalko, J., 1987: Izotopový výskum hydrogenetických procesov, I. časť (vody Žitného ostrova, vody na zlomoch v neovulkanitoch, topenie snehov Chopok). Manuscript. Bratislava, SGIDŠ, Geofond archive (ID 65144), 174 p.

Kantor, J., Ďurkovičová, J., Michalko, J., Rúčka, I., Harčová, E., Kovářová, A. & Sládková, M., 1989: Izotopový výskum hydrogenetických procesov – II. časť. Manuscript. Bratislava, SGIDŠ, Geofond archive (ID 72206), 165 p.

Krásny, J., 1986: Klasifikace transmisivity a její použití. Geol. Pruzk. (Praha), 6, p. 177 – 179.

Jetel, J., Franko, O. & Fedorová, Ľ., 2012: Vysvetlivky k základnej hydrogeologickej mape SR, list 45 Nitra, 1:200 000. Manuscript, SGIDŠ Bratislava, 113 p.

Liščák, P., Kováčik, M., Németh, Z., Šimon, L., Zlinská, A., Lacenová, K., Antalík, M., Aubrecht, R., Moravcová, M., Madarás, J., Lexa, J., Martinský, L., Michalko, J., Nagy, A., Ozdín, D., Vozárová, A., Bednarik, M., Konečný, V., Vlačiky, M. & Baráth, I., 2011: Informačný systém významných geologických lokalít SR, základný geologický výskum, SGIDŠ, Geofond archive (ID 91730), 151 p.

Maglay, J., Pristaš, J., Kučera, M. & Ábelová, M., 2009: Geologická mapa kvartéru Slovenska – Hrúbka kvartérnych uložením 1 : 500 000. MŽP SR, SGIDŠ Bratislava.

Malík, P., Bačová, N., Hronček, S., Ivanič, B., Káčer, Š., Kočický, D., Maglay, J., Marsina, K., Ondrášik, M., Šefčík, P., Černák, R., Švasta, J. & Lexa, J., 2007: Zostavovanie geologických máp v mierke 1 : 50,000 pre potreby integrovaného manažmentu krajiny, regionálny geologický výskum, zodpovedný riešiteľ: Malík Peter Bratislava: MŽP SR; Bratislava: SGIDŠ, Geofond archive (ID 88158), 554 p., 7 annexes (Annex 1: Maglay, J., Pristaš, J., Kučera, M. & Ábelová, M., 2007: Digitálna mapa hrúbok kvartéru Slovenska v mierke 1: 500,000. ME SR, SGIDŠ).

Michalko, J., Ďurkovičová, J., Ferenčíková, E., Kovářová, A. & Rúčka, I., 1997: Správa o výsledkoch meraní izotopového zloženia kyslíka povrchových a podzemných vôd v oblasti Vodného diela Gabčíkovo a Žitného ostrova v roku 1996. SGIDŠ Bratislava, Geofond archive (AP 9499), 15 p.

Michalko, J., 1998: Izotopová charakteristika podzemných vôd Slovenska. Kandidátska dizertačná práca, SAV, Bratislava, 94 p.

Michalko, J., Bodiš, D., Černák, R., Grolmusová, Z., Pažická, A. & Veis P., 2014a: Izotopy kyslíka a vodíka vo vode Dunaja a Moravy v Bratislave, Zborník 17. Slovenská hydrogeologická konferencia, Slovenská asociácia hydrogeológov, Bratislava 2014, p. 14, ISBN 978-80-971126-5-3.

Michalko, J., Bodiš, D., Ženišová, Z., Malík, P., Kordík, J., Čech, P., Grolmusová, Z., Luptáková, A., Bottlík, F., Švasta, J. & Káša, Š., 2014b: Pôvod vody v Klátovskom ramene, Zborník 17. Slovenská hydrogeologická konferencia, Slovenská asociácia hydrogeológov, Bratislava 2014, p. 90, ISBN 978-80-971126-5-3.

Michalko, J., Bodiš, D., Ženišová, Z., Malík, P., Kordík, J., Čech, P., Grolmusová, Z., Luptáková, A., Bottlik, F., Švasta, J. & Káša, Š., 2015: Groundwater and surface water interactions in the Podunajská nížina lowland and Trnavská pahorkatina hills. In: Podzemná voda. – ISSN 1335-1052. – Roč.21, č.1 (2015), p. 24 – 39.

Mucha, I., Kocinger, D., Hlavatý, Z., Rodák, D., Banský, Ľ., Lakatosová, E. & Kučárová, K., 2004: Vodné dielo Gabčíkovo a prírodné prostredie. Súhrnné spracovanie výsledkov slovenského a maďarského monitoringu v oblasti vplyvu WW Gabčíkovo. Konzultačná skupina Podzemná voda, s.r.o., Bratislava.

Némethyová, M., 1980: Čierna Voda III. – Vozokany, HGP, účel: overenie možnosti získania vodného zdroja pre závlahovú čerpaciu stanicu Bratislava: Vodné zdroje n. p. Bratislava, Geofond archive (ID 49475), 6 p.

Pagáč, I. & Čermák, D., 1976: Záverečná správa z termálneho vrtu Komárno 1. Manuscript, Geofondu Bratislava.

Rapant, S., Vrana, K., Lánczos, T. & Girman, J., 1993: Hydrogeochémia územia − Mapa kvality prírodných vôd. In: Bratislava − Životné prostredie, Abiotická zložka. Bratislava, ME SR.

Remšík, A. & Franko, O., 1978: Správa o výskumnom geotermálnom vrte FGK-1 v Komárne, čiastková záverečná správa. Úloha v perspektívnom pláne: Základný výskum rozloženia zemského tepla a geotermálnych zdrojov Západných Karpát. Názov čiastkovej úlohy: Základný výskum geotermálnych zdrojov podunajskej panvy. Doba riešenia: 1974-1978. GÚDŠ, Bratislava. Archív Geofondu (ID 45011), 51 p.

Remšík, A., Franko, O. & Bodiš, D., 1992: Geotermálne zdroje komárňanskej kryhy. Záp. Karpaty, sér. hydrogeológia a inž. geológia, 10, Geol.úst. D. Štúra, Bratislava, p. 159 – 199.

Rodák, D., Ďurkovičová, J. & Michalko, J., 1995: The use of stable oxygen isotopes as a conservative tracer in the infiltrated Danube river water. Gabčíkovo part of the hydroeletric power project, environmental impact rewiev, Faculty of Natural sciences, Comenius University, Bratislava, Slovakia, p. 79 – 81, ISBN 80-85401-50-9

Scharek, P. (ed.), Herrmann, P., Kaiser, M., Pristaš, J. & Tkáčová, H., 1998: Danube region Vienna – Bratislava – Budapest. Map of genetic types and thickness of Quaternary sediments 1 : 200,000. DANREG (Danube region Environmental Geology Programme). Magyar Állami Földtani Intézet (Geological Institute of Hungary), Budapest.

Schwarz, J., Kováč, M., Tupý, P., Malík, P., Benková, K., Jasovská, A., Hrnčárová, M., Pitoňák, P., Čurlík, J., Šefčík, P., Hricko, J., Kandrík, M., Hojnoš, M., Lučivjanský, L., Ilkanič, A., Vasiľko, T., Oroszlány, J., Zlocha, M. & Antal, B., 2004: Súbor regionálnych máp geofaktorov životného prostredia regiónu Trnavská pahorkatina. SGIDŠ, Bratislava. Geofond archive (ID 85743), 139 p.

Šarlayová, M., 1986: Kameničná – Čalovec – hydrogeologický prieskum. Manuscript. Bratislava, Archív Geofondu (ID 63586), 33 p.

Šuba, J. & Mihálik, F., 1998: Hydrogeologická rajonizácia Slovenska. SHMI Bratislava.

Takáčová, J., Pospišil, P., Hálek, V., Kocinger, D., Adamus, V., Jendraššák, E., Bukovská, E., Števušková, V., Makrányiová, Z. & Ferková, O., 1969: Jelka – hydrogeologický prieskum. Vodné zdroje. Bratislava. Geofond archive (ID 23367), 97 p.

Takáčová, J., Vojtko, A. & Skřeková, E., 2002: Vodný zdroj Jelka – Zhodnotenie monitoringu podzemných vôd za obdobie rokov 1991 – 2000. Západoslovenské vodárne a kanalizácie š. p. SGIDŠ, Bratislava. Geofond archive (ID 84020), 32 p.

Tkáčová, H., Kováčik, M., Caudt, Ľ., Elečko, M., Halouzka, R., Hušták, J., Kubeš, P., Malík, P., Nagy, A., Petro, Ľ., Piovarči, M., Pristaš, J., Rapant, S., Remšík, A., Šefara, J. & Vozár, J., 1996: Podunajsko – DANREG. Manuscript SGIDŠ, Bratislava. Geofond archive (ID 84334), 114 p.

Ženišová, Z., Povinec, P., Šivo, A., Breier, R., Richtáriková, M., Ďuríčková, A. & Ľuptáková, D., 2015: Hydrogeochemical and isotopic characterization of groundwater at Žitný Island (SW Slovakia). Hydrology Research 2015 Dec, 46 (6) p. 929 – 942; DOI: 10.2166/nh.2015.187.

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5. Mineral and Geothermal Waters of the Podunajská Rovina Flat

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Abstract: In the Podunajská rovina Flat (Danubian Flat) there are mineral water sources on its western edge in Svätý Jur. These sources contain water of chemical type Na-Cl-HCO_3 with mineralization of 867.9 mg.l^{-1} and H_2S content of 2.82 mg.l^{-1}, which was used in the past for spa treatment. Geothermal waters of the Danubian Flat are widespread mainly in the area of the Central Depression of the Danube Basin and the Dubník Depression, where the sediments of the Neogene with predominant intergranular permeability above the fissure are found. In the Central Depression of the Danube Basin, the geothermal water reaches in the depth range of 1,050 – 2,500 m a temperature of 42 – 91 °C, a mineralization of 1.5 – 8.3 g.l^{-1} and a chemical type of water is Na-HCO_3, Na-HCO_3-Cl to Na-Cl-HCO_3. In the eastern part of the Danubian Flat, the geothermal water of the Dubník Depression has a temperature of 50 °C, a mineralization of 5.3 g.l^{-1} and a chemical type of Na-Cl at a depth of 975 – 1,321 m. Geothermal water is found in the Mesozoic aquifers with karst-fissure permeability in the Komárno Marginal Block. In the area of Komárno the geothermal water in the depth interval of 1,140 – 1,900 m reaches a temperature of 42 – 64 °C, a mineralization of 2.2 – 3.1 g.l^{-1} and a chemical type ranges from Na-Ca-Mg-SO_4-HCO_3-Cl, Ca-Na-Mg-SO_4-Cl-HCO_3 to Ca-Na-Mg-SO_4-Cl. The vast majority of geothermal wells in the Danubian Flat are used for recreation and in agriculture and, to a lesser extent, for heating.

Key words: porous aquifers, karst-fissure aquifers, chemical and isotopic composition of waters, installed capacity of boreholes

5.1 Introduction

The Danubian Flat is not rich in the occurrence of natural groundwater outlets. However, its potential due to the nature of the geological setting of the area is hidden in depth, where there are significant aquifers of geothermal water verified by drilling.

In the Danubian Flat, mineral water sources are found only in Svätý Jur (St. George), which began to be used in local spas since the beginning of the 17th century. The mineral water of the Svätý Jur Spa has the character of cold sulphur water (12.8 °C) of chemical type Na-Cl-HCO_3 with total mineralization (TDS) of 867.9 mg.l^{-1} and H_2S content of 2.82 mg.l^{-1}. This water has been used to treat rheumatism, gout, female diseases and nerve inflammation (Krahulec et al., 1978). According to Hensel (1941), mineral water taken from four captured springs was used for drinking treatment and two sources were used for balneologic treatment. According to the registration of mineral resources of Slovakia (Vandrová et al., 2015), two springs with registration numbers BA-001 (U troch pilotov – At three pilots) and BA-002 (Kúpeľný prameň – Spa Spring) are currently known. The spring BA-001 has disappeared, the spring BA-002 is located on the southern outskirts of Svätý Jur in the former Svätý Jur Spa between the railway and the Šúrsky kanál (Šúr Channel). The facility later served as the Institute for Disabled Youth. The initial yield of the Spa Spring was 0.21 l.s^{-1}. Mineral water is captured by a well with a diameter of 2.5 m and a depth of 2.0 m. The well is walled into a dome shape to a height of 1.4 m above the terrain. At present, the spa area and the mineral water spring are in a devastated state.

There are three geothermal groundwater bodies in the Danubian Flat – the Central Depression of the Danube Basin (SK300240PF), the Dubník Depression (SK300250PF) and the Komárno Marginal Block (SK300020PF) – (Fig. 5.1). The first work on hydrocarbon exploration of the Danubian Flat documented the presence of geothermal waters in Bernolákovo (Be-1, Homola, 1956), Diakovce (Di-1, Homola, 1960), Kráľová nad Váhom (Kr-1, Gaža, 1966e) and Kolárovo (Kolárovo-2, Gaža, 1966a; Kolárovo-3, Gaža, 1967; Kolárovo-4, Gaža, 1970). The Di-1 well was later converted to a geothermal well. Within the framework of the research and exploration of geothermal waters, 38 geothermal boreholes were realized in the area of the Danubian Flat in the period 1966 – 2010 (Figs. 5.1, 5.2, 5.3 and Tab. 5.1).

5.2 Central Depression of the Danube Basin

The Central Depression of the Danube Basin is the largest geothermal water body in Slovakia. This body of geothermal water, as a hydrogeothermal structure, has a bowl-like brachysyncline structure and is filled with Pannonian to Quaternary sediments (clays, sandstones, sands, gravel). The geothermal water reservoir is spatially delimited between Bratislava and Komárno so that it is bounded from above by a plane at a depth of 1,000 m, with a relatively impermeable subsoil – an bowl-shaped aquiclude from the sides and from below till 3,400 m depth – Gabčíkovo area (Franko et al., 1984a).

There are geothermal waters with a temperature of 42 – 92 °C, which are mainly bound to Tortonian to Zanclean sandstone and sand to a large extent. Hydrogeologically, it is a structure with interlayer flow, intergranular permeability and a regime with a confined water level. From a structural point of view, it is a semi-open structure of mineral waters with a natural infiltration and accumulation area, but without an outflow area. Water supply is provided both through a reservoir of ordinary groundwater in Quaternary – Piacenzian sediments and also through Neogene sediments emerging at its northern edge (Senec – Sereď – Šurany).

A characteristic feature of the structure pattern is the alternation of aquifers (sands, sandstones) and aquicludes (clays) in the vertical direction and their mutual lateral wedging-out. Spatially, the aquifers are distributed in such a manner that the highest percentage (40 – 50%) is in the marginal part.

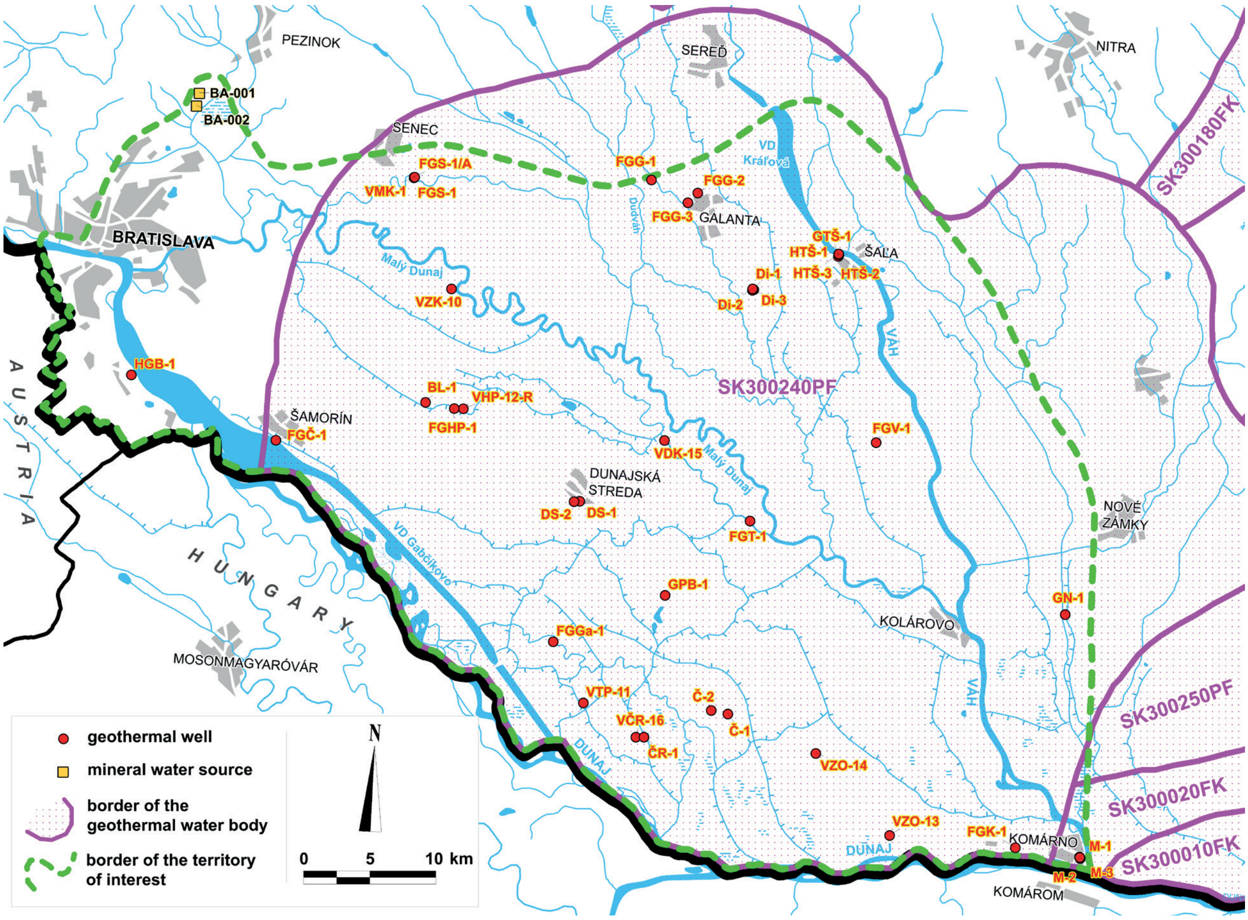

Fig. 5.1 Geothermal water bodies of the Danube Flat

In the centre of the depression, the proportion of the aquifers decreases to 20 – 30%, which is related to the disappearance of the aquifers with increasing depth. According to lithology, there are 6 hydrogeological units in the reservoir and in its overburden, which form certain complexes with different proportion of aquifers and aquicludes (e.g. complex with approximately equal representation of aquifers and aquicludes, complex of aquicludes, complex with aquicludes predominating over aquifers, etc.). Hydrogeological units do not respect the stratigraphy of the Neogene stages due to the vertical alternation and horizontal wedging out of aquifers and aquicludes.

In the temperature field of the depression to the depth of 1,000 – 1,500 m, two positive anomalies occur at the NW and SE edge of the depression caused by elevation of subsoil. In the middle part of the depression, a decrease in the temperature caused by the infiltration of water can be observed. The geothermal gradient in depression in the depth range of 0 – 2,500 m ranges from 34.1 to 43.7 °C.km^{-1} with an average of 39 °C.km^{-1}. The average temperature at 1,000 m is 48 °C, at 2,000 m at 87 °C and at 3,000 m at 125 °C. The density of the Earth's heat flux is in the range of 67.7 – 87.0 mW.m^{-2} with an average value 76 mW.m^{-2} (Franko et al., 1995).

The chemical composition of the geothermal waters of the Central Depression of the Danube Basin is closely related to lithostratigraphy and paleosalinity of the environment. Its regular depth changes are reflected in the increase in the mineralization and Na-Cl proportion of the S_1 component (Cl) and in the decrease in the Na-HCO_3 component (A_1) and the HCO_3/Cl ratio with depth.

Geothermal waters according to chemical type and mineralization belong to five hydrogeochemical types of waters (Bodiš in Fendek & Bodiš, 1992):

1. Type Na-HCO_3 with mineralization up to 1 g.l^{-1}; Component A_1 above 60 eq.%, HCO_3/Cl – ratio above 10 (characteristic of Zanclean and Messinian aquifers).
2. Type Na-HCO_3 with mineralization 1 – 5 g.l^{-1}; Component A_1 above 60 eq.%, HCO_3 Cl 3 – 10 ratio (characteristic of the aquifers of the Zanclean and Messinian, or well-washed Tortonian aquifers).
3. Type Na-Cl with the presence of component A_1 above 30 eq.% Na-HCO_3 or type with the

presence of a component S_1(Cl) above 30 eq.% with a mineralization of 3 – 8 g.l^{-1}; HCO_3/Cl ratio predominantly 1 – 2 (typical especially for Messinian aquifers).

4. Distinct type Na-Cl with mineralization 5 – 8 g.l^{-1}; HCO_3/Cl ratio max. 0.3 (typical for Messinian and Tortonian aquifers).
5. Significant Na-Cl type with mineralization above 10 g.l^{-1} (10 – 36 g.l^{-1}); HCO_3/Cl ratio very low, below 0.3 (typical for Tortonian to Langhian aquifers).

Fig. 5.2 Collar of one of the most valuable geothermal wells of the Central Depression of the Danube Basin – well FGT-1 in Topoľníky (photo: D. Marcin, 2010)

The isotopic composition of the geothermal waters of the Central Depression of the Danube Basin is characterized by $\delta^{18}O$ values from -13.8‰ (Di-1 Diakovce) to -9.8‰ (Č-1 Veľký Meder) and $\delta^{2}H$ values from -96‰ (Di-1 Diakovce) to -68.2‰ (Č-1 Veľký Meder), which represent waters of meteoric origin. The value of $\delta^{18}O$ and $\delta^{2}H$ increases with the depth of the built-in sections of Di-1 Diakovce (open section 720 – 810 m) and Č-1 Veľký Meder (open section 2,284 – 2,389 m). In the Danubian Flat in the Kolárovo K-3 structural borehole in the cadastral area of the village Nesvady with water of chemical type Na-Cl and in the geothermal DS-1 borehole Dunajská Streda with water of chemical type Na-Cl-HCO_3 typical for marine (to a certain degree a desalinised) water, namely $\delta^{18}O$ = -1,98‰, or $\delta^{18}O$ = -7.31‰). The $\delta^{18}O$ values in other documented geothermal waters are within this range and document the evolution of infiltration degradation of seawater and its progressive replacement with meteoric water (Kantor et al.,1985; Michalko, 1998; Franko et al., 2000; Franko, 2001).

Fig. 5.3 Geothermal borehole M-3 Komárno in the Komárno Marginal Block (photo: K. Benková, 2017)

Based on ^{14}C dating the residence time of geothermal waters in the Neogene sediments of the Danubian Flat (Franko et al., 1994b; 2000; Franko, 2001) ranges from 26,000 years (Di-1 Diakovce, Č-1 Veľký Meder) to 42,000 years (FGHP-1 Horná Potôň, FGS-1/A Kráľová pri Senci, FGG-1 Sládkovičovo – Vincov Les).

Until 2017, geothermal boreholes to a depth of 290 – 2,800 m were implemented in the area, of which one well (GBP-1 Boheľov) served for geothermal observation. Geothermal waters were captured by boreholes at depths of 73 – 2,482 m, the yield was 0.1 – 25.0 l.s^{-1}, with a water temperature of 18.0 – 92.9 °C, water mineralization of 0.5 – 18.6 g.l^{-1} and with a borehole installed capacity of 0.01 – 6.8 MW_t. The verified total yield of wells in the formation is 488.3 l.s^{-1}, which corresponds to a installed capacity of 101.96 MW_t.

The total exploitable amount of geothermal water from the Galanta Depression substructure was determined by a mathematical model (Fendek in Franko et al., 1984b). The total abstraction of geothermal water from the area in question together with the geothermal wells realized so far represents 176.0 l.s^{-1}, which corresponds to 39.77 MW_t of thermal energy. Comparing the results of the mathematical model and the geothermal balance documented a very good match of results (Remšík et al., 2011).

Currently 30 geothermal wells are used with a total annual consumption of approx. 2.8 mil. m^3.year^{-1} (approx. 100 l.s^{-1}). Most used are geothermal boreholes Č-2 Veľký

Tab. 5.1 Geothermal wells in the territory of Danubian Flat

Designation	Cadaster/Site	Year of implementation	Well depth (m)	Active section (m)	Aquifer age and lithology	T ($m^2.s^{-1}$)	Q ($l.s^{-1}$)	T_{water} at collar (°C)	Installed capacity (MW)	TDS ($g.l^{-1}$)	Chemical type of water	Utilisation	Data source
SK300240PF Danube Basin Central Depression													
GPB-1	Boheľov	1982	2,800.0									GT	1
Č-1	Veľký Meder (Čalovo)	1972	2,502.0	1,573 – 1,791	Messinian; sands	$1.1.10^{-4}$	4.5	79	2.59	1.1	$Na-HCO_3$	R, V	2
Č-2	Veľký Meder (Čalovo)	1983	1,503.0	1,037 – 1,439	Messinian; sands	$6.9.10^{-3}$	10.50	57	3.2	0.9	$Na-HCO_3$	R, V	3
FGČ-1	Čilistov	1979	2,500.0	1,195 – 1,549	Tortonian; sandstones	$4.1.10^{-3}$	15.0	52	2.32	6.9	$Na-HCO_3-Cl$	N	4
ČR-1	Čiližská Radvaň	1986	2,513.0	1,614 – 2,430	Messinian – Tortonian; sands	$1.4.10^{-4}$	6.0	82	3.3	1.6	$Na-HCO_3-Cl$	P	5
VTP-11	Čiližská Radvaň / Ňárad (Topoľovec)	1988	2,500.0	1,533 – 2,482	Messinian – Tortonian; sands	$7.2.10^{-4}$	14.6	74	3.6	1.2	$Na-HCO_3-Cl$	P	6
VČR-16	Čiližská Radvaň	1990	1,800.0	1,390 – 1,745	Messinian; sands	$1.5.10^{-3}$	14.5	65	2.93	0.8	$Na-HCO_3$	N	7
Di-1	Diakovce	1962	3,303.0	720 – 810	Zanclean; sands		4.0	38	0.39	0.5	$Na-HCO_3$	R	8
Di-2	Horné Saliby/ Diakovce	1982	1,551.0	1,416 – 1,536	Messinian – Tortonian; sands	$1.2.10^{-3}$	6.7	68	2.66	2.1	$Na-HCO_3-Cl$	R, V	9
Di-3	Horné Saliby/ Diakovce	1983	306.0	215 – 275	Zanclean; sands	$5.7.10^{-3}$	7.0	19	0.25	0.6	$Ca-Na-HCO_3$	R	10
DS-1	Dunajská Streda	1971	2,500.0	2,183 – 2,432	Messinian; sands	$3.9.10^{-4}$	15.2	91	5.82	6.9	$Na-Cl-HCO_3$	P	11
DS-2	Dunajská Streda	1986	1,600.0	1,190 – 1,549	Zanclean – Messinian; sands	$2.3.10^{-3}$	23.0	55	3.85	1.6	$Na-HCO_3$	R	12
VDK-15	Dunajský Klátov	1991	2,240.0	1,425 – 2,222	Messinian – Tortonian; sands	$5.8.10^{-4}$	15.4	74	3.75	2.4	$Na-HCO_3-Cl$	N	13
VZK-10	Eliášovce/ Zlaté Klasy	1987	1,800.0	1,331 – 1,457	Messinian; sands	$3.2.10^{-4}$	12.5	65	2.6	8.3	$Na-Cl-HCO_3$	N	14
FGGa-1	Gabčíkovo	1982	2,582.0	1,122 – 1,926	Messinian; sands	$1.4.10^{-3}$	10.0	52	1.64	1.1	$Na-HCO_3$	N	15
FGG-1	Sládkovičovo (Vincov les)	1975	1,990.0	1,212 – 1,670	Messinian; sands	$7.1.10^{-4}$	10.8	62	2.13	3.2	$Na-HCO_3-Cl$	R	16
FGG-2	Galanta	1983	2,101.0	1,706 – 2,032	Tortonian; sands	$2.6.10^{-3}$	25.0	80	6.8	4.9	$Na-HCO_3-Cl$	V	17
FGG-3	Galanta	1984	2,102.0	1,731 – 1,999	Tortonian; sands	$4.9.10^{-4}$	25.0	77	6.49	5.9	$Na-HCO_3-Cl$	V	18
FGHP-1	Horná Potôň	1980	2,500.0	1,394 – 1,804	Messinian; sands	$1.2.10^{-3}$	20.0	68	4.43	4.7	$Na-Cl-HCO_3$	P	19
VHP-12-R	Horná Potôň	1987	2,100.0	1,380 – 1,832	Messinian; sands	$1.7.10^{-3}$	22.3	68	4.94	4.3	$Na-HCO_3-Cl$	P	20
M-2	Komárno	1971	1,060.0	771 – 1,025	Messinian – Tortonian; sands		4.5*	42	0.51	3.9	$Na-HCO_3-Cl$	R	21
FGK-1	Komárno (Nová Stráž)	1976	1,970.0	904 – 1,082	Messinian – Tortonian; sands	$9.2.10^{-5}$	4.0	45	0.5	2	$Na-HCO_3-Cl$	P	22

Tab. 5.1 – continue

Designation	Cadaster/Site	Year of implementation	Well depth (m)	Active section (m)	Aquifer age and lithology	T ($m^2.s^{-1}$)	Q ($l.s^{-1}$)	T_{water} at collar (°C)	Installed capacity (MW)	TDS ($g.l^{-1}$)	Chemical type of water	Utilisation	Data source
FGS-1	Kráľová pri Senci	1974	810.0	430 – 570	Messinian; sands	$1.0.10^{-4}$	0.3	23	0.01	3.6	Na-Mg-HCO_3	N	23
FGS-1/A	Kráľová pri Senci	1974	1,500.0	910 – 1,370	Messinian – Tortonian; sands	$7.4.10^{-4}$	13.0	52	2.01	7.7	Na-HCO_3-Cl	N	24
VMK-1	Kráľová pri Senci	1992	804.5	439 – 572.5 601 – 784	Messinian; sands	$1.5.10^{-4}$	1.2	30	0.07	2.8	Na-Mg-HCO_3	N	25
BL-1	Lehnice	1985	1,500.0	1,031 – 1,455	Zanclean – Messinian; sands	$2.1.10^{-3}$	12.0	54	3.78	2.2	Na-HCO_3	N	26
GN-1	Nesvady	2008	1,505.0	1,283 – 1,494	Messinian; sands, sandstones	$1.3.10^{-4}$	2.7	60	0.5	2.9	Na-HCO_3	N	27
HGB-1	Rusovce	1975	1,493.0	1,067 – 1,493	Langhian – Serravalian; andesites		0.1	28		18.6	Na-Cl	L	28
HTŠ-1	Šaľa	1982					0.2*	22				L	29
HTŠ-2	Šaľa	1983	1,200.5	880 – 1,169	Messinian; sands	$3.0.10^{-4}$	3.1	42	0.36	1.5	Na-HCO_3	L	30
HTŠ-3	Šaľa	1983	290.0	73 – 282	Zanclean; sands	$5.5.10^{-4}$	3.0	18	0.06	0.5	Na-HCO_3	L	31
GTŠ-1	Šaľa	2010	1,800.0	1,481 – 1,786	Tortonian; sands, sandstones		15*	69	3.39	4.9	Na-HCO_3-Cl	V	32
FGT-1	Topoľníky	1975	2,503.0	1,394 – 2,487	Messinian; sands	$1.6.10^{-3}$	23.0	74	5.68	2.2	Na-HCO_3-Cl	P, R	33
FGV-1	Vlčany	1982	2,500.0	1,244 – 1,852	Messinian; sands	$1.8.10^{-4}$	10.0	68	2.22	2.1	Na-HCO_3	P	34
VZO-13	Zlatná na Ostrove (Ontopa)	1990	1,780.0	1,089 – 1,625	Messinian - Tortonian; sands	$2.8.10^{-4}$	7.5	51	1.25	7.5	Na-Cl	P	35
VZO-14	Zlatná na Ostrove/Zemianska Oľča	1990	1,908.0	1,555 – 1,839	Messinian; sands	$3.2.10^{-4}$	10.0	74	2.51	2.7	Na-HCO_3-Cl	P	36
SK300020FK Komárno Marginal Block													
M-1	Komárno	1966	1,224.0	1,140 – 1,221	Mesozoic; limestones, dolomites		1.6	42	0.18	2.2	Na-Ca-Mg-SO_4-HCO_3-Cl	R	37
M-3	Komárno	1979	1,184.0	1,139 – 1,184	Jurassic – Triassic; dolomitic limestones	$1.4.10^{-4}$	5.0	51	0.75	3.1	Ca-Na-Mg-SO_4-Cl-HCO_3	R	38
FGK-1	Komárno (Nová Stráž)	1976	1,970.0	1,710 – 1,900	Triassic; limestones, dolomites	$1.5.10^{-4}$	3.3	64	0.67	2.9	Ca-Na-Mg-SO_4-Cl	N	22

Notes: GT – observation of geothermal parameters over time; P – agriculture; N – out of operation; V – heating; R – recreation; L – well discarded; T – coefficient of transmissivity; Q – well yield; TDS – total dissolved solids, 0,2 * – yield at pumping

Data source: 1 – Fendek et al., 1984; 2 – Čermák & Gaža, 1972; Franko, 1976; 3 – Šindlář et al., 1985; 4 – Franko et al., 1981; 5 – Bondarenková et al., 1986a; 6 – Bondarenková et al., 1991b; 7 – Bondarenková et al., 1991b; 8 – Homola, 1960; 9 – Šindlář et al., 1982; 10 – Valíček et al., 1983; 11 – Bondarenková, et al., 1984a; 12 – Bondarenková et al., 1986a; 13 – Bondarenková et al., 1991c; 14 – Bondarenková et al., 1988 ; 15 – Franko et al., 1984a; 16 – Franko & Mateovič, 1977; 17 – Franko et al., 1985; 18 – Bondarenková et al., 1985a; 19 – Franko et al., 1980; 20 – Bondarenková et al., 1991b; 21 – Trávniček, 1971; 22 – Remšík & Franko, 1978; 23 – Bondarenková et al., 1980; 24 – Bondarenková et al., 1980; 25 – Dzúrik et al., 1992; 26 – Bondarenková et al., 1985; 27 – Hlavatý, 2008; 28 – Bondarenková et al., 1977; 29 – Bondarenková et al., 1984 ; 30 – Bondarenková et al., 1984; 31 – Bondarenková et al., 1984; 32 – Halás et al., 2010; 33 – Franko & Mateovič, 1978; 34 – Remšík et al., 1984; 35 – Dzúrik et al., 1991; 36 – Dzúrik et al., 1991; 37 – Pagáč & Čermák, 1976; 38 – Franko & Račický, 1979.

Meder, FGG-2 and FGG-3 Galanta, GTŠ-1 Šaľa, Di-2 Horné Saliby and BS-1 Senec.

5.3 Dubník Depression

The geothermal water body termed as Dubník Depression reaches only marginally in the area of the Danubian Flat in the east. The depression is filled with Neogene sedimentary rocks, which reach the thickness of more than 3,000 m in the central and western part of the depression. The geological structure of the pre-Tertiary underlayer consists of Palaeozoic granitoids and Palaeozoic and older rocks of Veporicum (crystalline schists, phyllites, mica, gneiss, migmatites). Geothermal activity of the area is slightly increased to increased. The image of the heat and thermal fields has a similar pattern. The temperature at a depth of 1,000 m ranges from 45 to 70 °C, at a depth of 2,000 m to 80 to 100 °C, at a depth of 3,000 m to about 105 to 125 °C and rises in the direction from south to north. The temperature on the pre-Tertiary underlayer ranges between 50 – 100 °C and increases in the west and also towards the centre of the depression, which is related to the depth of the pre-Tertiary underlayer. The heat flux density ranges from 70.0 – 90.0 $mW.m^{-2}$ and rises from south to north.

Geothermal waters in the Dubník Depression are bound to Neogene sands, sandstones and basal conglomerates, or breccia. In the Dubník Depression, 4 boreholes to a depth of 350 – 1,927 m were located outside the Danubian Flat. The closest to the Danubian Flat at a distance of about 4 km is the borehole PGT-11 Svätý Peter, which reached a depth of 1,856 m. The borehole documented the presence of geothermal water with a temperature at the mouth of the well 50 °C and a mineralization of 5.3 $g.l^{-1}$ in the depth interval 972 – 1,321 m (Neogene sediments – sands). The well yield during the pumping test was 6 $l.s^{-1}$ and the water was Na-Cl chemical type. The installed capacity of the well is 0.88 MW_t (Franko et al., 1995).

5.4 Komárno Marginal Block

The Komárno Marginal Block extends into the area of the Danubian Flat near Komárno. In this area, the sediments of the Mesozoic (Triassic limestones and dolomites) of the Transdanubian Mountains descend from the Gerecse Mountains below the sedimentary fill of the Danube Basin. The Komárno Marginal Block is bordered by the Komárno fault system in the west and the Hurbanovo fault in the north.

The geothermal waters bound to the Komárno Marginal Block are accumulated as static reserves, probably in a closed hydrogeothermal structure (without infiltration and outflow area).

The water temperature in the Komárno Marginal Block reaches a value from 40 °C to 68 °C, which was documented in 4 geothermal wells with a depth of 1,184 – 1,970 m (Tab. 5.1). The geothermal gradient is in the range of 32.2 – 35.8 $°C.km^{-1}$ for a depth interval of 0 – 2,000 m. The coefficient of absolute transmissivity (T_p) of carbonates at depths of 700 – 2,000 m is $1.9.10^{-12} – 2.1.10^{-11}$ m^3 and decreases with depth.

From the chemical point of view, it is a mixed type of geothermal water with a predominance of Ca-SO_4 component and an increased content of Na-Cl with a mineralization of 2.7 – 5.9 $g.l^{-1}$ and an HCO_3/Cl ratio of less than 1. It is a mixture the sulphato-carbonatogenic waters of the Mesozoic and the infiltration of significantly degraded marinogenic waters of the overlying Miocene, which seeped into the carbonate complexes mainly in the early phase of its marine transgression. The higher presence of sulphates in waters in the Komárno region indicates their contact with gypsum (Remšík et al., 1992).

The isotopic composition of the geothermal waters of the Komárno Marginal Block carbonates occurring in the Danubian Flat (Kantor et al., 1985; Michalko, 1998; Franko, 2001) is characterized by $\delta^{18}O$ -12.58‰ (M-3 Komárno) and $\delta^{18}O$ -12.0‰ (M-1 Komárno). The results document a significant degradation of seawater, with infiltrating water coming from precipitation in a colder period.

5.5 Conclusion

In the Danubian Flat, mineral water sources are located only on its western edge in Svätý Jur. Geothermal waters of the Danubian Flat are located in three bodies of geothermal waters – the Central Depression of the Danube Basin (SK300240PF), the Dubník Depression (SK300250PF) and the Komárno Marginal Block (SK300020PF).

The aquifers of mineral and geothermal waters of the Danubian Flat are Neogene sediments (sands, gravel, sandstones, conglomerates) with prevailing intergranular permeability over the fissure one, which occur in the Central Depression of the Danube Basin and in the western part of the Dubník Depression. Mesozoic sediments (Triassic limestones and dolomites) with karst-fissure permeability form the geothemal water reservoir in the Komárno Marginal Block.

Coefficient of transmissivity of the Neogene sediments of the Central Depression of the Danube Basin reaches parameters from $9.2.10^{-5}$ to 1.10^{-4} $m^2.s^{-1}$. For the Mesozoic sediments of the Komárno Marginal Block in the Komárno region, its value is around the value $1.5.10^{-4}$ $m^2.s^{-1}$.

Mineral water in Svätý Jur has the character of sulphuric and cold water of chemical type Na-Cl-HCO_3 with TDS 867.9 $mg.l^{-1}$ and H_2S content 2.82 $mg.l^{-1}$. In the Central Depression of the Danube Basin, the geothermal water reaches in the depth range of 1,050 – 2,500 m a temperature of 42 – 91 °C, a TDS of 1.5 – 8.3 $g.l^{-1}$ and a chemical type of water is Na-HCO_3, Na-HCO_3-Cl to Na-Cl-HCO_3. In the eastern part of the Danubian Flat, the geothermal water of the Dubník Depression has a temperature of 50 °C, a TDS of 5.3 $g.l^{-1}$ and a chemical type of Na-Cl at a depth of 975 – 1,321 m. Geothermal water reaches 42 – 64 °C in the western part of the Komárno Marginal Block at a depth of 1,140 – 1,900 m, TDS of 2.2 – 3.1 $g.l^{-1}$ and the chemical type ranges from Na-Ca-Mg-SO_4-HCO_3-Cl, Ca-Na-Mg-SO_4-Cl-HCO_3 to Ca-Na-Mg-SO_4-Cl.

The isotopic composition of the geothermal waters of the Central Depression of the Danube Basin documents its precipitation origin, whereas in its deeper parts (1,500 – 2,000 m below the ground) it is possible to observe the degradation of marine origin by infiltrating rainwater in the colder period.

The largest quantities of geothermal water are exploited from the Central Depression of the Danube Basin, where the most abundant geothermal wells are located in Galanta (FGG-2, FGG-3), Topoľníky (FGT-1), Dunajská Streda (DS-1) and Horná Potôň (FGHP-1, VHP-12-R).

Geothermal water of the Danubian Flat is taken through geothermal boreholes and used mainly for recreation (aqua parks, thermal pools), agricultural activities (greenhouses) and, to a lesser extent, for heating purposes.

References

Bondarenková, Z., Franko, O., Hramec, J., Zbořil, Ľ. & Motlíková, H., 1977: Bratislava – Rusovce – geotermálny vrt HGB-1, vyhľadávací hydrogeologický prieskum. Účel: možnosti získať termálnu vodu v tejto oblasti Bratislava. Slovenský geologický úrad, Bratislava; IGHP, Žilina; VIKUV, Budapešť. Geofond archive (ID 48993), 39 p. In Slovak.

Bondarenková, Z., Franko, O., Hramec, J. & Haluška, M., 1980: Senec a Streda nad Bodrogom – geotermálne vrty FGS-1, FGS-1A, TGS-1, záverečná správa z vyhľadávacieho hydrogeologického prieskumu, časti: I. – VI. Slovenský geologický úrad, Bratislava; IGHP, Žilina; VIKUV, Budapešť. Geofond archive (ID 48994), 23 p., 4 text annexes. In Slovak.

Bondarenková, Z., Klaučo, S. & Drahoš, M., 1984a: Dunajská Streda – hydrodynamické merania, podrobný hydrogeologický prieskum. IGHP, Bratislava. Geofond archive (ID 58144), 45 p. In Slovak.

Bondarenková, Z., Roháčiková, A., Repiský, I. & Šulc, E., 1984b: Šaľa – termálny vrt (HTŠ-1, HTŠ-2 a HTŠ-3), vyhľadávací hydrogeologický prieskum. Účel: Overenie možnosti zabezpečiť zdroj termálnej vody pre kúpalisko. IGHP, Bratislava. Geofond archive (ID 58587), 58 p. In Slovak.

Bondarenková, Z., Drahoš, M., Kovařík, K., Roháčiková, A., Motlíková, H. & Klaučo, S., 1985a: Galanta – podrobný hydrogeologický a geotermálny prieskum (vrt FGG-3). IGHP, Žilina. Geofond archive (ID 67198), 79 p. In Slovak.

Bondarenková, Z., Motlíková, H. & Drahoš, M., 1985b: Lehnice – termálny vrt (BL-1), vyhľadávací hydrogeologický prieskum. Cieľ: Získať termálnu vodu pre plánované využitie pre liečebné účely v rámci poskytovania liečebnej starostlivosti v odbornom liečebnom ústave. IGHP, Bratislava. Geofond archive (ID 67842), 44 p. In Slovak.

Bondarenková, Z., Motlíková, H. & Drahoš, M., 1986a: Dunajská Streda – termálny vrt DS-2, vyhľadávací geologický prieskum, Cieľ: Vypracovanie projektovej dokumentácie a realizácie termálneho vrtu s hĺbkou 1600 m v priestoroch kúpeľno-rekreačného areálu. IGHP, Žilina. Geofond archive (ID 67200), 37 p. In Slovak.

Bondarenková, Z., Michalič, J. & Vika, K., 1986b: Čiližská Radvaň – termálny vrt ČR-1, vyhľadávací hydrogeologický prieskum. IGHP, Žilina. Geofond archive (ID 73876), 49 p. In Slovak.

Bondarenková, Z., Kertész, A., Michalič, J., Pelikán, V., Sokola, K., Vika, K., Král, M. & Jančí, J., 1988: Zlaté Klasy - Trnávka - výpočet zásob termálnej vody, stav k 31.12.1988. Vyhľadávací hydrogeologický prieskum. IGHP, Bratislava. Geofond archive (ID 87692), 107 p. In Slovak.

Bondarenková, Z., Drahoš, M., Motlíková, H., Sokola, J., Štěpanková, K., Vika, K., Drozd, V., Král, M. & Jančí, J., 1991a: Topoľovec – Čiližská Radvaň – CDPN – VP /centrálna depresia Podunajskej nížiny/ – termálne vody (vrt VTP-11, VČR-1), vyhľadávací hydrogeologický prieskum. IGHP, Žilina. Geofond archive (ID 80444), 81 p. In Slovak.

Bondarenková, Z., Michalič, J., Roháčiková, H., Štěpánková, K., Sokola, K., Škollová, Z., Vika, K., Fendek, M., Gallas, A., Zachar, M., Tuba, Ľ. & Král, M., 1991b: Horná Potôň – reinjektáž, vyhľadávací hydrogeologický prieskum. IGHP, Žilina. Geofond archive (ID 79542), 121 p. In Slovak.

Bondarenková, Z., Motlíková, H., Michalič, J., Fendek, M., Štěpánková, Škollová, Z., Vika, K. & Drozd, V., 1991c: Dunajský Klátov – vyhľadávací prieskum termálnych vôd, hydrogeologický prieskum. IGHP, Žilina. Geofond archive (ID 79543), 62 p. In Slovak.

Čermák, D. & Gaža, B., 1972: Čalovo – prieskumný termálny vrt Čalovo-1, hydrogeologický prieskum. Účel: Získanie termálnej vody zo spodného panónu centrálnej pliocénnej depresie Podunajskej panvy vo vzťahu k výdatnosti, teplote a chemizmu vrstevných vôd. Nafta, Gbely. Geofond archive (ID 28486), 13 p. In Slovak.

Dzúrik, J., Bondarenková, Z., Roháčiková, A., Babíková, M., Čellár, S., Král, M. & Jančí, J., 1991: Zlatná na Ostrove – Ontopa (vrt VZO-13, VZO-14), hydrogeologický prieskum. IGHP, Bratislava. Slovenský geologický úrad, Bratislava. Geofond archive (ID 87967), 88 p., 8 text annexes. In Slovak.

Dzúrik, J., Roháčiková, A., Král, M., Jančí, J., Fendek, M., Pecov, I., Michalíček, M., Procházková, V., Řehák, Z. & Čellár, S., 1992: Kráľová pri Senci – hydrogeologický prieskum zdrojov minerálnej vody. GEOS, Bratislava. Geofond archive (ID 80563), 91 p. In Slovak.

Fendek, M., Franko, O., Brestenská, E., Král, M., Priechodská, Z. & Vass, D., 1984: Správa o výskumnom geotermálnom pozorovacom vrte GPB-1 Boheľov, čiastková záverečná správa. Názov štátnej úlohy: Geologický výskum vybraných oblastí SSR z hľadiska využitia geotermálnej energie. Názov čiastkovej úlohy: Hydrogeotermálny výskum vybraných oblastí SSR, doba riešenia: 1981-1984. GIDŠ, Bratislava. Geofond archive (ID 64149), 41 p. In Slovak.

Fendek, M. & Bodiš, D., 1992: Možnosti reinjektáže geotermálnych vôd v centrálnej depresii podunajskej panvy. Západné Karpaty, séria hydrogeológia a inžinierska geológia 59, GIDŠ Bratislava. In Slovak.

Franko, O., 1976: Hydrodynamický výskum geotermálneho vrtu Č-1 Čalovo, čiastková záverečná správa, doba riešenia: 1975-1976. Názov úlohy: Základný výskum geotermálnych zdrojov podunajskej panvy. GIDŠ, Bratislava. Geofond archive (ID 36702), 10 p. In Slovak.

Franko, O. & Mateovič, Ľ., 1977: Správa o výskumnom geotermálnom vrte FGG-1 v Galante – čiastková záverečná správa. Čiastková úloha: Základný výskum geotermálnych zdrojov Podunajskej panvy. GIDŠ, Bratislava. Geofond archive (ID 43641), 33 p. In Slovak.

Franko, O. & Mateovič, Ľ., 1978: Správa o výskumnom geotermálnom vrte FGT-1 Topoľníky, čiastková záverečná správa za roky 1974-1978. Základný výskum geotermálnych zdrojov Podunajskej panvy. Názov úlohy: Základný výskum zemského tepla a geotermálnych zdrojov v Západných Karpatoch. GIDŠ, Bratislava. Geofond archive (ID 42313), 32 p. In Slovak.

Franko, O. & Račický, M., 1979: Správa o exploatačnom geotermálnom vrte M-3 v Komárne. Manuscript. Geofond Bratislava.

Franko, O., Bodiš, D., Brestenská, E., Priechodská, Z. & Remšík, A., 1980: Správa o výskumnom geotermálnom vrte FGHP-1 Horná Pôtoň, čiastková záverečná správa. Názov úlohy v perspektívnom pláne: Základný výskum priestorového rozloženia zemského tepla a geotermálnych zdrojov v Západných Karpatoch (SSR). Základný výskum geotermálnych zdrojov Podunajskej panvy. Doba riešenia: 1977-1980. GIDŠ, Bratislava. Geofond archive (ID 51990), 33 p. In Slovak.

Franko, O., Bodiš, D., Brestenská, E., Harča, V., Ondrejičková, A., Priechodská, Z., Remšík, A. & Vass, D., 1981: Správa o výskumnom geotermálnom vrte FGČ-1 v Čilistove, čiastková záverečná správa. Názov štátnej úlohy: Geologický výskum vybraných oblastí SSR z hľadiska využitia geotermálnej energie. Názov čiastkovej úlohy: Hydrogeotermálny výskum vybraných oblastí SSR, 1971-1981. GIDŠ, Bratislava. Geofond archive (ID 56132), 74 p. In Slovak.

Franko, O., Remšík, A., Bodiš, D., Brestenská, E., Priechodská, Z. & Vass, D., 1984a: Správa o výskumnom geotermálnom vrte FGGa-1 Gabčíkovo. Čiastková záverečná správa. Názov štátnej úlohy: Geologický výskum vybraných oblastí SSR z hľadiska využitia geotermálnej energie. Hydrogeotermálny výskum vybraných oblastí SSR, 1979-1984 . GIDŠ, Bratislava. Geofond archive (ID 63874), 58 p. In Slovak.

Franko, O., Remšík, A., Fendek, M., Bodiš, D., Priechodská, Z., Vass, D., Král, M. & Jančí, J., 1984b: Geotermálna energia centrálnej depresie podunajskej panvy – prognózne zásoby. Čiastková záverečná správa. Názov štátnej úlohy: Geologický výskum vybraných oblastí SSR z hľadiska využitia geotermálnej energie; Názov čiastkovej úlohy: Hydrogeotermálny výskum vybraných oblastí SSR, doba riešenia: 1981-1984. GIDŠ, Bratislava. Geofond archive (ID 60255), 116 p. In Slovak.

Franko, O., Fendek, M., Bodiš, D., Brestenská, E., Priechodská, Z. & Vass, D., 1985: Správa o výskumnom geotermálnom vrte FGG-2 Galanta, čiastková záverečná správa. Názov štátnej úlohy: Geologický výskum vybraných oblastí SSR z hľadiska využitia geotermálnej energie; Názov čiastkovej úlohy: Hydrogeotermálny výskum vybraných oblastí SSR, doba riešenia: 1982-1985. GIDŠ, Bratislava. Geofond archive (ID 64323), 54 p. In Slovak.

Franko, O., Fusán, O., Král, M., Remšík, A., Fendek, M., Bodiš, D., Drozd, V., Vika, K., Elečko, M., Franko, J., Gross, P., Hrušecký, I., Jančí, J., Kaličiak, M., Konečný, V., Lexa, J., Marcin, D., Maťo, J., Pereszlényi, M., Pašeková, P., Pôbiš, J., Roháč, J., Slávik, M., Vass, D. & Zvara, I., 1995: Atlas geotermálnej energie Slovenska. GIDŠ, Bratislava, ISBN 80 – 85314 – 38 – X, 268 p. In Slovak & English.

Franko, O., Michalko, J. & Šivo, A., 2000: Isotopes of oxygen and ^{14}C in the geothermal waters of the Pliocene sediments of Danube basin. Sympozja i Konferencje nr. 45, IGSMiE PAN, Krakow, p. 229 – 239.

Franko, O., 2001: Pôvod a vývoj minerálnych a termálnych vôd Slovenska v priestore a čase z pohľadu veku travertínov a izotopov O, H a ^{14}C. Podzemná voda ISSN 1335-1052, VII, 2/2001, p. 26 – 45. In Slovak with English summary.

Gaža, B., 1966a: Závěrečná vrtně-geologická zpráva o pionýrské vrtbě Kolárovo-2. Geofond archive (ID 16898), 70 p. In Czech.

Gaža, B., 1966b: Geologické zhodnotenie štruktúrno-stratigrafického vrtu Kráľová – 1. Prieskumno-ťažobný závod ČND, Gbely. Geofond archive (ID 16971), 17 p. In Slovak.

Gaža, B., 1967: Závěrečná vrtně-geologická zpráva o pionýrské vrtbě Kolárovo-3. Geofond archive (ID 18514), 20 p. In Czech.

Gaža, B., 1970: Závěrečná vrtně-geologická zpráva o pionýrské vrtbě Kolárovo-4. Geofond archive (ID 52999), 21 p. In Czech.

Halás, O., Bondarenková, Z., Drozd, V. & Hlavatý, Z., 2010: Šaľa – vyhľadávací a podrobný hydrogeologický prieskum na termálne vody. Slovgeoterm, Bratislava. Geofond archive (ID 90836), 60 p. In Slovak.

Hensel, J., 1941: Slovenské kúpele. Štátny zdravotne-sociálny ústav, Bratislava, 179 p. In Slovak.

Hlavatý, Z., 2008: Nesvady – geotermálny vrt GN-1, podrobný hydrogeologický prieskum. RNDr. Zoltán Hlavatý-Zdroje vody, Šamorín. Geofond archive (ID 89105), 78 p. In Slovak.

Homola, V., 1956: Závěrečná vrtně-geologická zpráva o pionýrské vrtbě Bernolákovo-1. Geofond archive (ID 3162), 4 p. In Czech.

Homola, V., 1960: Oporná vrtba Diakovce-1 v Malej dunajskej nížine (česky): Výzkumný ústav Československých naftových dolů, Brno. Geofond archive (ID 8226), 52 p. In Czech.

Kantor, J., Rybár, M., Garaj, M., Rúčka, I. & Richtarčík, J., 1985: Izotopová charakteristika vôd rôznych genetických typov. Partial interim report. Manuscript. Bratislava, SGIDŠ, Geofond archive, 245 p.

Krahulec, P., Rebro, A., Uhliarik, J. & Zeman, J., 1978: Minerálne vody Slovenska. Krenografia. 2. Martin, Osveta, 1,040 p. In Slovak.

Michalko, J., 1998: Izotopová charakteristika podzemných vôd Slovenska. PhD. Thesis, Slovak Academy of Sciences, Bratislava, 94 p. In Slovak with English summary.

Pagáč, I. & Čermák, D., 1976: Záverečná správa z termálneho vrtu Komárno 1. Manuscript, Geofond archive, Bratislava. In Slovak.

Remšík, A. & Franko, O., 1978: Správa o výskumnom geotermálnom vrte FGK-1 v Komárne, čiastková záverečná správa. Úloha v perspektívnom pláne: Základný výskum rozloženia zemského tepla a geotermálnych zdrojov Západných Karpát. Názov čiastkovej úlohy: Základný výskum geotermálnych zdrojov podunajskej panvy. Doba riešenia: 1974-1978. GIDŠ, Bratislava. Geofond archive (ID 45011), 51 p. In Slovak.

Remšík, A., Franko, O., Bodiš, D., Brestenská, E., Priechodská, Z. & Vass, D., 1984: Správa o výskumnom geotermálnom vrte FGV-1 Vlčany, čiastková záverečná správa. Názov štátnej úlohy: Geologický výskum vybraných oblastí SSR z hľadiska využitia geotermálnej energie. Názov čiastkovej úlohy: Hydrogeotermálny výskum vybraných oblastí SSR, doba riešenia: 1979-1984. GIDŠ, Bratislava. Geofond archive (ID 61681), 61 p. In Slovak.

Remšík, A., Franko, O. & Bodiš, D., 1992: Geotermálne zdroje komárňanskej kryhy. Záp. Karpaty, sér. hydrogeológia a inž. geológia, 10, GIDŠ, Bratislava, p. 159 – 199. In Slovak.

Remšík, A., Švasta, J., Marcin, D., Benková, K., Černák, R., Mikita, S., Bottlik, F., Kováčová, E., Bahnová, B., Jurčák, S., Pažická, A., Gregor, M., Tóthová, K., Fajčíková, K., Cvečková, V., Kováčik, M., Siráňová, Z., Buček, S., Bačová, N., Záhorová, Ľ. & Lenhardtová, E., 2011: Hodnotenie útvarov geotermálnych vôd. Final report. Geofond archive (ID 92025). 108 p., 10 annexes. In Slovak.

Šindlář, V., Fialová, Z., Krajčí, P., Musil, M., Pauková, V. & Hradilová, M., 1981: Diakovce – termálne kúpalisko (vrt Di-2), surovina: termálna voda, geologicko prieskumné práce: Geologický prieskum, Ostrava. Geofond archive (ID 53459), 29 p. In Slovak.

Šindlář, V., Mukařovský, J., Panková, V., Musil, M., Mikolajková, I., Holuša, J., Slivková, A., Rozehnal, T., Polášková, D. & Šmít, R., 1985: Čalovo – jímací vrt Č-2. Final report. Geologický průzkum, Ostrava. Geofond archive (ID 60220), 51 p. In Czech.

Trávniček, I., 1971: Záverečná geologická správa o vrte Komárno M-2. Manuscript. GIDŠ archive, Bratislava. In Slovak.

Valíček, S., Šindlář, V., Pauková, V., Musil, H. & Mukařovský, J., 1983: Diakovce – Di-3, surovina: voda. Final report. Geologický průzkum, Ostrava. Geofond archive (ID 56135), 12 p. In Czech.

Vandrová, G. & Štefanka, P., 2015: Revízia registrácie minerálnych zdrojov na území žilinského a bratislavského kraja. Final report. Aquamin, s.r.o. Žilina. Geofond archive (ID 95273), 52 p. In Slovak.

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Manuscript

Radvanský, F., Slivka, B., Viktor, J. & Srnka, T., 1985: Vein deposits of the Jedľovec nappe of Gemericum. Final report from the project SGR-geophysics. Manuscript-archive ŠGÚDŠ Spišská Nová Ves, 28 p.

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