Stratigraphy of Pannonian deposits in southern Transdanubia

NKFI 116618

2016-2021

Final report

The primary objective of the research was to create a chronostratigraphic system for the Pannonian Stage by investigating surface outcrops and drill cores in southern Transdanubia, Hungary, and in adjacent areas of the Pannonian basin. We met this objective and fulfilled our commitment. The results of our research were continuously published in 30 scientific papers (including eleven Q1 and three Q2 ranked) with a cumulated impact factor of 50+, 52 conference abstracts, 2 MSc theses, and one popular paper; two more scientific papers are submitted and are under review, and several more are in preparation.

In this final report, first the progress of the research is presented, with changes in the staff, program and budget, all justified. This is followed by the list of stratigraphic results according to geological age, and with references to the published papers (listed separately). We briefly report on the ongoing subprojects, give a summary about the significance of our completed research, and describe the broader impacts of the project.

Progress of the research

Research staff

The staff included I. Magyar as principal investigator, O. Sztanó, Zs. Ruszkiczay-Rüdiger, G. Csillag as senior team members, and L.T. Katona, A. Szuromi-Korecz, L. Tőkés, M. Bosnakoff, K. Sebe and V. Baranyi as associated researchers.

Our research program has aroused great interest among students, and five of them joined the staff subsequently:

- Vivien Csoma, Eötvös University, Budapest, with investigations of ostracods, in 2016 (Csoma 2017, 2018; Magyar et al. 2019; Botka et al. 2019; Csoma et al. 2021; Bartha et al. 2021; Szuromi-Korecz et al. 2021);
- Dániel Bálint Botka, Eötvös University, Budapest, with investigations of molluscs, in 2016 (Botka 2016; Botka et al. 2017, 2019a, 2019b, 2021; Baranyi et al. 2021a; Bartha et al. 2021; Szuromi-Korecz et al 2021);
- Nóra Rofrics, Szent István University, Gödöllő-Budapest, with investigations of molluscs, in 2016 (Botka et al. 2021; Rofrics 2021);

- Ádám Kovács, University of Pécs and Eötvös University, Budapest, with investigations of surface outcrops and 3D stratigraphic forward modeling, in 2016 (Kovács et al. 2018, 2021; Sebe et al. 2020; Baranyi et al. 2020, 2021b);
- István Róbert Bartha, Eötvös University, Budapest, with sedimentological investigations of outcrops, in 2018 (Botka et al. 2019a; Bartha et al. 2021; Tőkés et al. 2021).

Each member of the staff, either named originally or joined subsequently, provided significant contribution to the final results of the project.

Program

The original work plan contained the biostratigraphic investigation of Pannonian mollusc and ostracod faunas from more than 250 scattered localities (outcrops and drill cores) across southern Transdanubia, and the complex stratigraphic investigation of a ca. 600 m long fresh core drilled by Paks II Ltd. In 2016, however, we unexpectedly got the chance to investigate not only one but all the 6 Paks-II drillings, in a total length of 2700 m. This development offered an unparalleled opportunity to create 1) a biochronostratigraphy for a certain part of the Pannonian Stage with very high temporal resolution, and 2) a paleoenvironmental study with very high spatial resolution. At this point we re-arranged our priorities and focussed our research on localities where long sections were available and complex research methods could be applied. The selected focus areas were located in southern Transdaubia (see 1-3 below) and in adjacent areas (3, 4), or in regions where coeval sediments are better exposed (4, 5). These were as follows:

1. Paks and surroundings: 6 cores (sedimentological description, mollusc, ostracod, dinoflagellate biostratigraphy, isotope geochemistry, magnetostratigraphy, authigenic $^{10}Be/^{9}Be$ dating) (Csoma 2017; Kelder et al. 2018; Magyar et al. 2019; Sztanó et al. 2019; and yet unpublished).
2. Mecsek Mts and surroundings: Pécs-Danitzpuszta outcrop (sedimentological description, structural analysis, mollusc-, ostracod-, foraminifer-, dinoflagellate-, calcareous nannoplankton-, vertebrate biostratigraphy) (Sebe et al. 2021a, 2021b; Ćorić 2021; Krizmanić et al. 2021; Szuromi-Korecz et al. 2021; Csoma et al. 2021; Dulai et al. 2021; Botka et al. 2021; Szabó et al. 2021; Sebe 2021); Nagymányok (sedimentological description, structural analysis, mollusc-, ostracod biostratigraphy) (Kovács et al. 2018); Hímesháza (sedimentological description, structural analysis, mollusc biostratigraphy) (Budai et al. 2019); Pécsvárad (mollusc biostratigraphy) (Sebe et al. 2017).
3. Drava basin (seismic and lithostratigraphy, dinoflagellate biostratigraphy, 3D stratigraphic forward modeling); Našice outcrop in Slavonia (mollusc, ostracod, dinflagellate biostratigraphy, authigenic $^{10}Be/^{9}Be$ dating) (Botka et al. 2019b; Sebe et al. 2020; Kovács et al. 2021; Baranyi et al. 2020, 2021b).
4. Northern Pannonian basin: Gerecse Mts (sedimentological description, mollusc biostratigraphy of 12 surface outcrops) (Magyar et al. 2017a; Sztanó et al. 2020), Bükk Mts (Magyar et al. 2016a); Szilágyság (Şimleu basin) and surroundings (sedimentological description, mollusc-, ostracod-, mammal biostratigraphy) (Magyar et al. 2016a; Bartha et al. 2021).

5. Transylvanian Basin, southern part: Nagyszeben-Szenterzsébet (Sibiu-Guşteriţa) outcrop and surroundings (sedimentological description, mollusc-, ostracod-, dinoflagellate-, calcareous nannoplankton biostratigraphy, magnetostratigraphy, authigenic $^{10}Be/^{9}Be$ dating) (Kovács et al. 2016; Botka et al. 2017, 2019a; Tőkés et al. 2021; Baranyi et al. 2021a).

In parallel with investigations in the focus areas, studies of wider (Pannonian Basin or Paratethys) focus were also conducted, which put the Pannonian stratigraphy into a broader context (van Baak et al. 2017; Balázs et al. 2018; Magyar et al. 2020; Magyar 2021).

Budget

The budget plan of the proposal contained the purchase of an electric earth drill (2,560,000 Ft) and various software (590,000 Ft). Eventually we waived the purchase of the drill because we focussed on the investigation of the Paks cores instead of shorter cores drilled by ourselves in the field, and we did not buy the software either as we had access to the necessary software in our home institutions. The financial resources saved this way were spent on authigenic $^{10}Be/^{9}Be$ dating measurements and on optical instruments used for photographing cores and fossils.

Stratigraphic results

1)

The Sarmatian/Pannonian boundary with the oldest part of the Pannonian Stage was studied in Pécs-Danitzpuszta and a correlative succession in Guşteriţa. Study of the same stratigraphic interval in core PAET-35 is in progress.

In Pécs-Danitzpuszta, we had a trench excavated that uncovered the lowermost part of the Pannonian Stage as well as the underlying Sarmatian and Badenian Stages. A composite sedimentary log, representing 220 m of stratigraphic thickness across the Badenian, Sarmatian and Pannonian Stages, was measured and sampled for biostratigraphic studies (Sebe et al. 2021a). In the lower part of the succession, Badenian and Sarmatian units were identified by Szuromi-Korecz et al. (2021), Dulai et al. (2021) and Coric (2021). In the Pannonian, the *Lymnocardium praeponticum – Radix croatica*, *Congeria banatica*, *Lymnocardium schedelianum* and *L. conjungens* Zones of mollusc biostratigraphy were correlated with the *Hemicytheria lorenthey*, *H. tenuistriata*, *Propontoniella candeo* and *Amplocypris abscissa* Zones of ostracod biostratigraphy and the *Pontiadinium pecsvaradensis* Zone of dinoflagellate stratigraphy (Botka et al. 2021; Csoma et al. 2021; Krizmanic et al. 2021). The largely endemic calcareous nanoplankton flora of the same interval was also characterized (Coric 2021). The time interval represented by the Pannonian part of the succession was estimated as 11.6-10 Ma. Geochronological studies based on authigenic $^{10}Be/^{9}Be$ dating and radiometric dating of an intercalated volcanic ash layer is in progress (Sebe et al. 2016). With all these investigations, Pécs-Danitzpuszta qualifies as one of the best-studied Pannonian successions.

The 55 m thick Guşteriţa section, the largest and most fossiliferous outcrop in the Transylvanian Basin, proved to cover the ~11.0–10.5 Ma interval, corresponding to the middle part of the Pécs-Danitzpuszta section. In this deep-water succession we identified and correlated the *Congeria banatica* Zone (molluscs), *Hemicytheria tenuistriata* and *Propontoniella candeo* Zones (ostracods), the *Spiniferites oblongus*, *Pontiadinium pecsvaradense* and *Spiniferites hennersdorfensis* Zones (organic-walled microplankton), and the *Noelaerhabdus bozinovicae* Zone (calcareous nannoplankton). The Guşteriţa section thus became the best-investigated Pannonian outcrop of the Transylvanian basin (Botka et al. 2019a; Tőkés et al. 2021; Baranyi et al. 2021b).

2)

The time interval of 10.2 – 9.6 Ma is represented by *Lymnocardium soproniense* in the sublittoral and *L. schedelianum* in the littoral deposits (Magyar et al. 2016a). The sublittoral mollusc fauna of the *Lymnocardium soproniense* Zone was studied and described in the surroundings of Sopron, Mályi (Bükk Mts), Nagyvárad (Oradea), and in the Şimleu basin (Magyar et al. 2016a). The coeval littoral deposits, i.e. the younger part of the *Lymnocardium conjungens* Zone, was identified and described from the Şimleu Basin (Bartha et al. 2021). The typical species of these zones are not known from southern Transdanubia.

3)

The uppermost part of the *Congeria czjzeki* Zone in the sublittoral deposits and the coeval littoral deposits (*L. ponticum* Zone) were investigated in 14 outcrops of the Gerecse Mts. Here they form a single transgressive-regressive cycle, which can be dated to 9.4 – 8.7 Ma (Magyar et al. 2017a; Sztanó et al. 2020). Mollusc faunas in the SE Banat, as part of a similarly short transgressive-regressive cycle, largely overlap in age with this cycle (9.6 –9.1 Ma; Radivojević et al. under review).

4)

The complexity of the stratigraphic and sedimentological investigations on the Paks cores is unprecedented in the Pannonian Stage. The lowermost, condensed part of cores PAET-29P and PAET-34P did not allow high-resolution stratigraphy. Five cores, however, represent the 9.1-6.5 Ma interval with a rich and sometimes exceptionally well-preserved fossil record. In the sublittoral to profundal deposits, the *Congeria praerhomboidea* and *C. rhomboidea* Zones were identified. In the overlying littoral deposits, the base of the *Prosodacnomya carbonifera* Zone was dated to 8.15 Ma, the *P. dainellii* Zone to 7.6 Ma, and the *P. vutskitsi* Zone to 7.1 Ma. These zones correlate with the *Spiniferites validus* and *Galeacysta etrusca* Zones (dinoflagellates) and with the *Sinegubiella sublabiata – Amplocypris nonreticulata* and *Bakunella dorsoarcuata – Thaminocypris pontica* Zones (ostracods) (Csoma 2017; Kelder et al. 2018; Magyar et al. 2019; Sztanó et al. 2019; and yet unpublished).

Pannonian successions outcropping at Nagymányok and Himesháza (Mecsek Mts) and SE of Vršac in SE Banat belong to the *P. dainellii* Zone and thus have an age of 7.6-7.1 Ma (Kovács et al. 2018; Budai et al. 2019; Radivojević et al. under review).

5)

The Pannonian succession is truncated by an unconformity in the Paks cores. The age of the youngest beds below the unconformity is 6.5 Ma (early Messinian), and the overlying layers belong to the Quaternary. The unconformity corresponds to the regional surface that is apparently the same as the „Miocene-Pliocene unconformity" in the Alföld area (van Baak et al. 2017). This unconformity was observed in the Drava basin and in the Našice outcrop as well, where the youngest beds below the unconformity belong to the younger part of the *Galeacysta etrusca* Zone (benchmarked by the presence of *Spiniferites cruciformis*) and have an age of younger than ca. 7.5 Ma (Sebe et al. 2020; Kovács et al. 2021; Baranyi et al. 2021b, 2021). As a consequence of erosion, upper Messinian deposits, coeval with the Messinian Salinity Crisis of the Mediterranean, cannot be studied in surface outcrops in the Pannonian basin.

6)

Deposits of Lake Pannon are present above the unconformity in the Našice section (*Prosodacnomya vodopici* Zone). We assessed the age of this succession by authigenic $^{10}Be/^{9}Be$ dating method. The preliminary results suggest a Pliocene age (yet unpublished). The spatial and temporal relationship between this succession and the so-called „Paludina beds" remains unclear; the latter might have formed either on the shelf of Lake Pannon or in the fluvial plain that formed after the infilling of the lake's bed (Sebe et al. 2020; Radivojević et al. in review).

7)

In most of the above cases, we applied thorough sedimentological investigations in order to assess the changes of the sedimentary environment and to distinguish diachronous environmental changes from biochronostratigraphically important first appearances of certain fossils. In the Paks cores we demonstrated lateral and vertical variability of stacked deltaic successions and highlighted the pitfalls of high-resolution correlation. Both lateral and vertical facies changes from prodelta via delta front to lower and upper delta plains could be reconstructed. Vertical changes defined parasequences, i.e. shallowing-upwards successions with 21 m average thickness. The recognized short- and long-term cyclicity in the succession, combined with the available high-resolution age model, leads to the recognition of cycle duration, an important argument in the debates on climatically-induced lake-level variations. Parasequence stacking pattern was mostly progradational in the lower part of the deltaic succession, but aggradational, progradational and even retrogradational stacking occurred in coeval deposits of the upper part. This phenomenon points to a great lateral variability of sediment supply rates and shifts of sediment entry points. Our high-resolution example demonstrated the risk and challenge of model-driven, log-based correlation of deltaic deposits even within short distances (Sztanó et al. 2019). The role of laterally changing sediment supply was also highlighted by means of numerical stratigraphic forward modelling, demonstrating

that transgression and regression may occur coevally within a few kilometers' distance (Kovács et al 2021).

8)

In addition to the strictly stratigraphic results, we 1) obtained an published a wealth of new information on the leaf flora, fish and amphibian fossils of the Pécs-Danitzpuszta section, holding important implications on paleogeographic conditions and evolution history (Hably et al. 2019; Szentesi et al. 2020; Szabó et al. 2021), 2) revised the taxonomy of many endemic Lake Pannon forms (Magyar et al. 2016a, 2016b, 2017b; Botka 2016; Katona et al. 2017; Botka et al. 2021; Szabó et al. 2021; Baranyi et al. 2021b), and 3) used the biochronostratigraphic data for dating tectonic and sedimentary events (Kovács et al. 2018; Sztanó et al. 2020; Sebe and Magyar 2019; Sebe 2021).

Work in progress

Presently we are working on several additional publications. The Paks cores, their detailed sedimentology, fossils and stratigraphy will be presented soon in a volume with more than 100 photoplates of fossils. We are completing papers on the stable isotope study of ostracods from the Paks cores (Csoma et al. in prep.), radiometric isotope dating of the Pécs-Danitzpuszta outcrop (Sebe et al. in prep.), and on the taxonomic revision of the endemic subgenus *Budmania* (Lymnocardiinae) (Magyar and Katona in prep.). Two papers on the large-scale tectonic evolution of the Mecsek-Villány area (Sebe and Magyar) and on the Pannoniain evolution of the southeastern Banat (Radivojević et al.) have been submitted and are under revision.

Significance of the research

We were the first to apply mollusc-, ostracod-, dinoflagellate-biostratigraphy, seismic stratigraphy, authigenic $^{10}Be/^{9}Be$ dating, magnetostratigraphy, lithostratigraphy and detailed sedimentological analysis together on long Pannonian drill cores. We applied a similarly complex stratigraphic tool kit for the study of some large surface outcrops. As a result, we could correlate the various Pannonian biostratigraphic systems and, in some cases, provided high-resolution dating of biozone boundaries. Our results will serve as firm chronostratigraphic and biostratigraphic reference for any exploration activities in the Pannonian basin that have a stratigraphic relevance, such as hydrocarbon exploration, water prospecting, etc.

We revealed common and generalizable pitfalls in 1) magnetostratigraphic interpretation of greigite-bearing strata, 2) application of the authigenic $^{10}Be/^{9}Be$ dating in late Neogene sedimentary basins, 3) log-based correlation of deltaic deposits, and 4) chronostratigraphic

interpretation of clinothem-bearing successions. The lessons learnt from our studies can be useful in the exploration of many sedimentary basins worldwide.

Broader impacts

The results of the project are incorporated into courses held at the Eötvös University (O. Sztanó, I. Magyar) and the University of Pécs (K. Sebe). Students from both universities and secondary school students from Pécs were involved into the research through joint fossil collecting in outcrops. We installed an exhibition of the Pécs-Danitzpuszta fossils at the University of Pécs, and published a popular paper on their significance (Sebe et al. 2021b).

We persuaded Paks II Ltd to donate the invaluable fossil material from the Paks cores to the Hungarian Natural History Museum. Together with the specimens that we collected in the course of the project, thousands of fossils and rock samples were thus reposited in the museum where their digitalization, in line with the Hungarian museological directives and strategy, is in progress. We also donated specimens collected in Našice to the Croatian Natural History Museum, Zagreb, and provided expertise to the Komló Natural History Collection, where we participated in the sorting and ordering of the fossils collected from the Pannonian layers of the Mecsek Mts.

31st January 2022

Imre Magyar

Principal Investigator