Final report of the OTKA research K113013: Correlation of tectonic units, deformation events and facies belts in the Pannonian-Alpine-Dinaridic domain: first step towards quantitative tectonic reconstruction

In this final report, letters of the original plan are indicated at the beginning of the paragraph, while references are cited as paper (P). abstract (A) and MSc or doctoral theses (D).

Aggtelek and Rudabánya Hills

A1: In this area we studied the depositional setting of Middle and Upper Triassic carbonate rocks, formed after the disruption of the Steinalm carbonate platform using field observations, borehole data, and revision of archive and new thin sections. Recognition of microbial activity during the formation of Bódvalenke Limestone Formation suggests a shallower deposition depth than values supposed by earlier studies (P24, A34–36). This is in agreement with studies in the Dinarides which suggests deep shelf environment (Gawlick & Missoni 2015). We revised and clarified the ages of basinal formations in the Rudabánya Hills, ranging from Anisian to Norian based on Conodonts (A39; D8, unpublished report). All these data suggests that the Bódva and Szőlősardó units were not close to the Neotethyan oceanic crust, rather formed part of the proximal passive margin. Coherent publications have not yet prepared (partly because Horváth left his scientific career without finishing his PhD research).

A4: We made the first attempt to find out the source area of the Triassic rhyolite and andesite volcanic clasts occurring in different Middle Jurassic mélange nappes (Telekesoldal, Mónosbél). The geochemical characteristics of the clasts show great similarities to several possible Middle Triassic volcanic horizons (both in the paraautochtonous sequence of the Bükk and the Transdanubian Range). However, there is significant difference within the radiometric age of the clasts and the possible source rocks (P30; A45–46). The calculated age groups (222.6±6.7 and 209.0±9 Ma) do not fit into the Late Anisian – Ladinian (~242- 238 Ma) magmatism, which was a wide-spread event on the south-western passive margin of the opening Neotethys Ocean. However, both REE and trace element pattern and U/Pb zircon age show positive correlation between the clasts and in situ Late Triassic rhyolitic rocks from the Slovenian Trough. Trace element and REE pattern suggest subduction-unrelated, most probably rift/continental margin-type volcanism as plate tectonic setting. Due to the large (~20 Ma) time gap, we prefer connecting this magmatism rather to the early, continental thinning of the Penninic rifting, than to the renewal of the Neotethyan extension.

Concerning the deformation of the Aggtelek-Rudabánya Hills (B1), and the nappe emplacement of the Silica nappe (B2), we mainly focused on the basal tectonic carbonate breccia (rauwacke) and to the internal deformation of the Silica nappe, both to infer its transport direction. We also obtained few thermochronological and metamorphic petrological data. A master thesis and additional studies were completed about the petrographic characterization of the rauhwacke samples (D5). The textural pattern, clast composition show that most of the samples are chaotic breccias. Both matrix (a fine-grained version of the clasts) and cement were found amongst the clasts. The most common cement phase is calcite, locally enclosing authigenic quartz and feldspar crystals.

Hannah Pomella (Innsbruck University) and Sz. Kövér successfully applied for additional support for studying carbonate fault rocks (UNI-0404/1764 Tiroler Wissenschaftsfond). Most of the investigated fault rocks are considered as meso- and ultracataclasite with mostly sandstone and carbonate clasts, and carbonate matrix that shows different degree of recrystallization. We studied anisotropy of magnetic susceptibility (AMS) supposing that AMS texture, not visible by other methods, record the nappe emplacement direction. Samples were collected both from Hungary and from Slovakia, from the base of the Silica, Torna and Muráň nappes. Paleomagnetic samples for AMS was measured at the Innsbruck University and at AGICO (Brno). The data from below the Muráň nappe show consistent results; they have deformed texture, also corroborated by the presence of macroscopic foliation. ARM measurements demonstrated that the magnetic texture is connected to mica, while occasional magnetite content did not show oriented pattern. The obtained AMS axes can be correlated to known deformation features below the Muráň nappe. The determined nappe emplacement direction is top-to-N. Samples from the Hungarian part of the Silica nappe were not successful (were not in situ or do not show oriented texture), so the nappe emplacement direction cannot be directly determined. The results were presented at several conferences (A41, 47–48; 62–63) while a methodological paper is close to be completed (P41 in preparation).

B1: We tried to separate authigenic K-feldspar from the basal rauwacke to find out the age of the nappe movements, but unfortunately we failed. We were more successful with fission track thermochronology (FT). Zircon FT ages are clearly different in the Rudabánya and Szendrő Hills (~118 versus 90-88 Ma) demonstrating that the opposite vergency of folding was associated to different deformation phases; and old one in Rudabánya and younger one in Szendrő (A20–21; A69–70, 72). The former can be connected to the deformation in the Bükk Mts., and potentially also to the early folding of the northern TR, while the younger phase is the typical folding in the entire TR, and nappe stacking in the Austroalpine units. The new FT data perfectly corroborate with K/Ar ages of Kövér et al. (2009).

In the Rudabánya Hills a few metamorphic petrological data were obtained by Raman spectroscopy in 2019 from the very-low grade Telekesoldal nappe (A51); the calculated temperature values are very homogenous (280°C±15).

After a failed MSc thesis (Márky left his studies) and a preliminary student field trip (2016) new student and master works have been carried out to investigate nappe transport direction of the Silica nappe. The main target was to study the complex deformation of Lower Triassic rocks. These works served with surprises; Oravecz (A58–59, D10–11) demonstrated that most of the folds are related to salt tectonics and not to contractional deformation. The age of deformation was equally surprising, while it was most probably Triassic and not Cretaceous. Although salt diapirs were already postulated in earlier works (Less et al. 1988), but this is the first systematic study on the subject. The present of salt deformation can explain the inconsistent displacement directions of the Silica nappe postulated in earlier studies (both to NW and SE). While some of the Triassic normal faults were reactivated in the Cretaceous contractional deformation, a slight top-to-SE displacement could be verified.

BÜKK Mts., Darnó Zone, Recsk area

We made considerable progress in the Bükk Mts., within the Jurassic sedimentary and magmatic successions, concerning the age, sedimentation environment, metamorphic degree, style and age of deformation. Variable field work campaigns included MSc students, 2 PhD students, one student from India and post-docs and researchers from other institutions (ATOMKI, Geol. Bundesanstalt Wien, Univ. Göttingen, Technische Univ. Ilmenau, Germany and Univ. of Belgrade). Two student works and two MSc works have been completed, two PhD studies are under way.

We obtained new paleontological ages from the Jurassic rocks of the Mónosbél unit despite poor preservation of dinoflagellate cists. The obtained Aalenian (?) to Bajocian age of the basal Mónosbél shale is in agreement with earlier foundings of Haas et al. (2013) but are the first fossils in shaly rock type.

A4: We revised the origin of clasts of the Jurassic formations of the Bükk sequence. Considerable part of the limestone clasts were derived from the Adriatic carbonate platform. The age of the disruption of the platform seems to be Bajocian in the Slovenian trough (Rozic et al. 2018) and the age of the platform limestone clasts have the same age in the Bükk as well. The origin of the Late Triassic magmatic clasts could also be originated from the passive Adriatic margin or from the Slovenian trough (P30). Other clasts, mainly sandstone lenses can partly be interpreted as stretched layers (boudins) and not olistoliths. Sandstone channels or thick intercalations are present at all levels of the Mónosbél unit. This analysis shows that the Mónosbél unit once formed part of the passive margin of the Neotethys, and only the Darnó Complex is related to the obducted ophiolite unit.

We carried out sedimentological and paleontological analysis of core materials from dozens of boreholes of the Recsk and Darnó areas, on both sides of the Darnó Zone. New core materials and archive thin sections were analysed. This re-evaluation demonstrate strong paleogeographic connection with the Jurassic Dinaridic carbonate platform; several boreholes contain platform-derived bioclasts and lithoclasts whereas the westernmost borehole (Rm-109) indicate a paleogeographic setting close to the platform foreslope. These data, together with sedimentological data from Slovenia, could permit a more precise paleogeographic reconstruction. These new aspects suggest that the Bükk area (the Mónosbél unit at least) may have been located in the neighbourhood of the Dinaridic Carbonate platform and also to the Slovenian Trough (Haas et al. 2019). On the other hand, rock sequences show similarities to Dinaridic units in both sides of the Darnó Zone thus the boundary with the Transdanubian Range should be located further to the west.

B1, C: Concerning the structural observations, a student work demonstrated early, soft-sediment deformation structures (slump folds and faults) in the Bükkzsérc Limestone (D9; A51–53; P38 submitted). The determined NW-SE extensional direction agree with the postulated direction of the Dinaridic passive margin fault-system if one applies the ca. 70–90° CCW rotation. We tried to constraint the early deformation by paleomagnetism; the AMS signal is clearly pre-dated the tilt of the layers, but seems to be related to another deformation phase than registered by early deformation features.

B1: One of our most interesting results is that we were able to determine shortening direction within the Mónosbél sequence; all data, including pre-tilt thrust faults, asymmetric boudins, shear planes gave coherent SE-ward tectonic transport direction (D14; A20–21; A69–70, 72;). Our data demonstrate a structural break between fold-axial planar and layer-parallel foliation; this is within or at the top of Lökvölgy Formation. It is thus highly probable that a shear zone or detachment developed at the top of this formation (the former top of the Bükk “paraautochtonous unit”). Structural cross section suggest multiple imbrications of units and the occurrence of Szarvaskő not only at the top but sometimes below other units.

In a co-operation with ATOMKI-Debrecen, with Raman spectroscopy we determined the temperature range of metamorphism of Jurassic clastics (the work started by Molnár and continued by G. Obbágy). Results fall between 240–270±10°C all for Lökvölgy slate, Mónosbél and Szarvaskő samples (A51). There is a weak tendency toward lower temperature westward. The values are at the lower limit of calcite plasticity and corroborate to the observation that sedimentary structures have not been overprinted during very low grade metamorphism.

To constraint the age of deformation, we carried out fission track analysis from different units of the Bükk Mts. The work was started by the post-doc researcher Bertrand and, after her early return to France, was finished by Martin Reiser (Innsbruck Univ.) and Fodor with the partial support of the AÖU-OMAA (Stiftung Aktion Österreich-Ungarn) scholarship. The zircon samples indicate 3 main period of cooling, which could be connected to structural phases (A20–21). Some samples record cooling around 140-135 Ma, which is similar to deformation ages of the Driva-Ivanjica unit (P33). This cooling age can indicate deformation (nappe emplacement?) related to Neotethyan obduction. Other samples record mid-Cretaceous ages (113-123 Ma), which can be correlated to Austroalpine deformations.

A3: We determined the age of the plagiogranite dykes of the Tardos Gabbro of the Szarvaskő unit using Sm-Nd method on garnet. The 164.7±1.6 Ma age refined the former results (A40) and is coeval or younger than that has been suggested on the basis of biostratigraphic studies of the Jurassic successions of the Bükk area. This makes possible that the basaltic suite is the stratigraphically highest unit and not a nappe. Additionally to the project plan, we executed geochemical analysis of the Szarvaskő magmatic suite. The new and revised geochemical data indicate MORB or back-arc basin setting (A41–42).

A4: Heavy mineral separation was executed on 5 samples from Jurassic clastic sequences of the Mónosbél and Szarvaskő units. New U-Pb zircon ages were measured in order to further analyse their provenance of the clastics. The age spectra mostly show Variscan, Middle Triassic and Jurassic ages and the postulated two nappe units show exactly the same age distribution (A43). Final interpretation needs additional work and will be provided in the PhD. thesis of Kovács in 2020.

One overview presentation marks the preliminary step for a planned summary paper (A21) which integrated the new structural, geochemical and geochronological data. Our results question the original concepts of nappes around Szarvaskő. Opposing to the former ideas, the deeper Mónosbél unit has older ZFT ages, than the higher Szarvaskő unit.

C: We tried to get new paleomagnetic samples from the Bükk Mts. to constraint the rotation. We used the same samples already analysed for AMS from the less deformed Jurassic limestone of the Mónosbél unit. Declination-inclination data point to counterclockwise rotation, but the age of magnetisation could be Cretaceous. After this failed trial, we started to re-evaluate older data in the Szarvaskő unit.

D2: Structural research on the Nekézseny boundary fault of the Bükk and Uppony units was carried out by a student work (A54–57). Results verify thrust deformation, overturned folds in the Senonian, and suggest nearly syn-sedimentary onset of deformation. Thermochronological research is still ongoing, mineral separation has been terminated but planned U/Th measurements is to be done.

E: Detailed structural works were carried out to characterise the Cenozoic structural evolution of NE Hungary, south and mostly west from the Bükk Mts. Understanding the Cenozoic structural evolution is a key issue in going back to previous Mesozoic deformations, and also for future balancing. We combined field-based fault-slip data, seismic reflection profiles, deformation band analysis and structural diagenesis and established connection with the University of Strathclyde, Glasgow, Scotland. Two PhD studies have been prepared and defended (D1; Petrik 2017) while several conference presentations and two journal papers have been published (P31; A4–6; A17–19).

The complete data sets permitted a very fine temporal calibration of deformation events, and separation of 10 deformation phases. Using these data we determined the fault kinematics and detailed Cenozoic deformation history in N Hungary, including the Darnó Zone. This latter had reverse kinematics from ca. 30 to 18.5 Ma, while sinistral slip could occur between ca 17 and 15 Ma. Presence of deformation band suggests that sinistral slip already occurred during the Eggenburgian (21.5-20 Ma) in agreement with inferences from the sediment pattern.

We published a paper, which describes the effect of burial and lithology on the type and mechanism of deformation (P6). The reconstruction of burial history permitted the determination of the depth-time-temperature range of the successive deformation events. On the other hand, results on structural diagenesis, namely O and C isotope values measured in calcite generations of host rock and deformation structures clearly show that deformation and fluid flow were coupled and all influenced by the burial history of the host rock and the regional fluid-flow system. In addition to several conference papers (A4–6; A17–19; A76), the compilation of a manuscript is almost complete (P39 in prep).

One MSc work has been completed on the structure of the Zagyva Graben between the Buda and Bükk Mts. (D15; A75) in order to analyse one segment of the planned trans-Pannonian section. After carrying out field work Soós (2017, D15) reinterpreted the available seismic reflection profiles and compiled a structural map. Two depth-converted sections were balanced using the Move software. Results show increasing extension southward, thus rotational deformation played important role in the opening of the graben. The estimated rate of extension remained modest (8–15%), but the dip of the main fault is not well constrained. While Soós did not continue his career in the research, the section was not extended, as it was planned.

Dinarides in Serbia and Slovenia

A1: We started to study the stratigraphy and deformation of the Dinarides because we followed earlier assumptions suggesting similarities between units in the Rudabánya Hills and some internal Dinaridic units. From 2017 we realised that we should focus our efforts to the Slovenian trough because the stronger relationship of this area and the Bükk Mts. In Slovenia we executed field works and started a PhD project.

We made progress in our correlative research of Northern Hungarian and Dinaridic formations. A continuous Upper Triassic to Middle Jurassic key-section of toe-slope- and hemipelagic basin deposits were investigated in the Dinaridic Ophiolite Belt in the Zlatar Mt. The succession records the depositional history of the Bosnian Basin during a cc. 50 My period and contribute to the understanding of the evolution of the Adriatic margin of the Neotethys Ocean in the transitional interval from passive to active margin stages (Görög 2018, Haas et al. 2019). We carried out two field trips in south-western Serbia (Tara Gorge region, a Drina-Ivanjica unit). Our primary aim was to understand the Mesozoic sequence, the structural position and stratigraphy, all of which seem to be similar to the Hungarian equivalent units. We executed a combined research on the Drina-Ivanjica unit including field mapping, structural measurements, sedimentological, petrological and geochronological investigations. During these works we cooperated with Serbian colleagues, who visited north Hungarian sites. The results demonstrate that this unit has a metamorphic Mesozoic cover, but was thrust by a non-metamorphosed unit, erroneously also attributed to the Drina-Ivanjica unit (D3; D13; P33; A64–66). The unit suffered earliest Cretaceous metamorphism at ca. 140 Ma, similar to some north Hungarian units.

All these data permitted the construction of a new structural map of SW Serbia (A50). We suggested an important backthrusting of formerly juxtaposed Dinaridic units toward the north-east.

We prepared new paleomagnetic data in the Inner Dinaridic units to constraint rotation of these units and to compare the structural directions to the Bükk Mts. The age of the sampled rocks vary from Triassic to Late Cretaceous. The collected 127 samples, representing 12 localities were elaborated in the laboratory. Unfortunately, most samples were remagnetised thus this plan failed. They documented the moderate post-Turonian CCW rotation which fits to the Cenozoic deformation of the externa Dinaridic units (A50). These data constraint the boundary of the oppositely rotating internal and external Dinaridic units into a narrow belt.

From 2017 we made several field trips to central Slovenia, in the so-called Slovenian trough, and in the Sava fold region. We carried out promising observation of Triassic normal faults which can be compared to structures in the TR in the future. New recognitions in the Bükk Mts. strongly suggest their spatial relationship with the Slovenian trough (see in the chapter about the Bükk). To exploit more this suggested relationship, a new PhD research project started to study the structure and stratigraphy of the Sava fold region. Several fold sets were identified, their age should be analysed in the future (A71, 73).

TRANSDANUBIAN RANGE

Buda Hills

A2: We published new results on Triassic carbonate formations of the northern Transdanubian Range (TR); their distribution, sedimentary and diagenetic characteristics have serious tectonic consequences. A previous research project yielded these results, but we will exploit the tectonic inferences in this study. Detailed stratigraphic results of the Buda Hills comprised comprehensive studies of Conodonts, palynomorphes and algae. One PhD theses have been completed (D8), 3 papers published, and 2 conference papers presented.

Conodonts derived from the Upper Triassic basin successions (Mátyáshegy Fm) demonstrate that this formation is the time equivalent of the Csővár Fm (P26). Conodont-based age data revealed that the middle Carnian carbonates from the NW Buda Hills cannot be assigned to the Mátyáshegy Fm., they are rather similar to the Pilis area; while this age is absent in the Buda Hills, resulting a huge gap between the Ladinian and the uppermost Carnian, just like in the Csővár area (D8; P25–27; A37–38).

Biostratigraphic and sedimentological revision of the Budaörs-1 borehole (P18) confirmed the stratigraphic assignment of the upper dolomite unit to the Budaörs Fm and the alga flora proved its Late Anisian to Ladinian age. Palynostratigraphic studies prooved the Late Carnian–Early Norian age of the the lower unit (belonging to the Mátyáshegy Fm).

B3: Based on new biostratigraphic data, several folds and strike-slip faults were postulated; all of them have Cretaceous age (D8). In the Budaörs-1 borehole a tectonic repetition has been demonstrated. The causative structure could be a Cenozoic(?) transpressive strike-slip or a Cretaceous reverse fault (P18).

A2: U-Pb age of zircon crystals of an andesite dike in Budaörs-1 borehole revealed Carnian age (~233 Ma) and support a larger data set on Carnian volcanics of the entire TR (Dunkl et al. 2019). This volcanic rocks were eroded and redistributed during the Late Eocene. Newly developed application for combined Cluster and Discriminant Analysis permitted the separation of various sedimentological environments: fan, intermittent stream or shallow marine (P13).

Gerecse

A4: In the Gerecse Hills, we studied the stratigraphy and deformations of the Early Cretaceous clastic sediments, which are thought to be related to Neotethyan obducted nappes (Császár & Árgyelán 1994; Tari 1994). We mapped the westernmost boundary of the lower fine-grained clastics of this foreland basin; the successive Barremian westward shift has been clearly documented (P36). At this western part the Aptian sandstone contains siltstone intercalations proving the easterly source of the sand component (unfortunately Csengődi did not finish her MSc studies on this subject). New biostratigraphic data (nannoplankton+ammonites) clarified the stratigraphic extent of the Lábatlan Fm. including its higher member (Köszörűkőbánya Mb.). No younger fossils than late Aptian has been found (P35). On the other hand, preliminary nannoplankton data suggest latest Berriasian to earliest Valanginian for the base of the clastic sequence (Felsővadács Mb.).

B3: We described in detail the structural evolution from the Jurassic to present, partly based on previous results (Fodor et al. 2013). The results are published on a 1:50000 scale map, in chapters of the explanatory booklet and a paper. (P9; P8, 16; 36; P35). We correlated the sedimentation and deformation phases with more regional events; (1) bending of the subducting plate, including the TR, from latest Bajocian (~169 Ma), (2) drowning of carbonates in the latest Berriasian (~140 Ma), (3) Valanginian–Hautrivian (140–129 Ma) fine-grained clastic sedimentation of a foreland basin, related to reactivation of the obducted Neotethyan nappe stack, (4) westward shift of sedimentation and coarsening, due to the advancing Neotethyan nappe stack from the Barremian (128 Ma), and (5) arrival of deformation front (gentle folding) in the late Aptian (116-113 Ma). A gradual but fast and considerable change from NNE–SSW to NW–SE compression occurred in the earliest Albian (ca. 113 Ma) and the latter deformations were already related to “Austroalpine” folding and nappe stacking of the entire TR (P16, 35).

E: We also made methodological advance, using Agisoft software for visualisation of a cross section showing Jurassic deformation; a first step in balancing the deformation (A74).

Additional to the main targeted Mesozoic deformation, we documented the Cenozoic phases (P16), including Late Miocene deformations and related tsunami in the western margin of the Gerecse (Budai et al., in preparation). With new geochronological ages (supported by other projects) the Plio-Quaternary tectonics, particularly uplift rates of the Gerecse has been clarified. The lack of young structures strongly argue for deep lithospheric process controlling the slow deformation (A67–68; P42 in preparation). On the other hand, only modest horizontal deformation could occur after ca. 5 Ma, probably less than the actual 1mm/a displacement rate.

Bakony, Keszthely Hills

B3: We carried out more extensive structural work in the southern TR than previously planned. Studies included field structural measurements, mapping, and seismic data analysis in the central TR (Bakony) and in the southern TR (Keszthely Hills and Zala Basin). These results are embedded in 2 MSc thesis (D2; D6), one PhD thesis (D7) and several publications (P15; P22–23) and conference abstracts (A9; A14–15; A25-33). Results were also presented at two conferences organised by our group; during the Central European Tectonic Studies Group Meeting (CETeG) in 2017 (P15; A30) and during the International Lithosphere Program Meeting in 2019 (Fodor et al. 2019). The students presented their results in conferences, and they won 3 prizes.

These works demonstrated widespread presence of Triassic faults in the TR; some of these faults were reactivated during the Cretaceous orogeny but others remained intact (P23). On the other hand, the Cretaceous deformation pattern was strongly controlled by Triassic extensional deformation, a feature not recognised so far in the TR (P23, P40). The presence of Triassic faults distorted the folds from their general directions, resulted in variable local contractional directions (P14; P40). The pre-existing Triassic folds determined the segmentation of the Cretaceous thrust faults; possibly the most important one is the segmentation of the major Litér thrust (P15). The change in fold strike can be interpreted as a large salient (A33). All these data and interpretations suggest that the central and southern TR was affected only by Austroalpine deformation, and no trace of earlier folding was found. The folding could start in the Albian (ca. 113 Ma) and ended before Santonian (86 Ma).

Héja et al. (P40 in preparation) clarified that rather folding than thrusting characterised the deformation style of the SW TR; this style seems to decrease the amount of shortening. On the other hand, new thrust was recognised in the central TR (A7–8) and the role of transfer faults was emphasized (following Tari & Linzer 2012). These transfer faults had Cretaceous ages and are not part of the Miocene dextral fault system (A8; P15). Preliminary tectonic connections between Cretaceous structures of the TR and NE Slovenia (Pohorje) was prepared (A14). On the other hand, Héja et al. (A33) connected the large salient to the Cretaceous activity of the paleo-Giudicarie line.

E: Cross sections, and particularly their balancing permitted the estimation of the amount of deformation. This work was mostly executed in the frame of the PhD project of Héja, supported by the University of Innsbruck and UNKP project. Csicsek (D2) obtained 2.8km shortening/thrusting along the easternmost segment of the Litér thrust. Héja (D7) estimated 15% shortening along an E–W transect of the Zala basin–Keszthely Hills, while a less refined estimates suggests similar value in NW-SE direction. The Miocene deformation of the E–W section was also calculated (15%). So the SW TR is the area where the quantification of deformation became the best and more detailed.

Connection of the Transdanubian Range and deeper Alpine nappes

D: A master work of Lőrincz started to study of the south-western and western boundary of the TR, along its major basal Rechnitz and Baján-Pohorje detachments. Core materials from two boreholes were studied and sampled for both structural and geochronological analyses. Cores show evidence of important extensional deformation including a 30m thick tectonic breccia, quartz veins, and deformation bands in the hanging wall sediments. Unfortunately, the planned geochronological work and estimation of the amount of extension were not completed because Lőrincz did not finish her geological studies. The same contact was investigated on 3D seismic block by a master diploma work (Nyíri 2017). He demonstrated the Baján detachment zone and suggested folding of the fault zone itself by ~N–S shortening. This latter deformation constraints the main extensional slip before ca. 15 Ma.

Further to the west, we carried out structural and paleomagnetic studies in the Pohorje Mts. The studied magmatic rocks intruded the footwall of the TR nappe, below the Baján detachment. The combined AMS and structural data confirm that the Miocene Pohorje intrusion was deformed by extension oriented between NE-SW and ESE–WNW. Deformation started in metamorphic settings and continued in brittle style. All these deformations occurred in connection of rifting of the Pannonian Basin, potentially connected to motions along the Baján detachment (A12–14; P37 under review).

Mid-Hungarian Zone (MHZ)

A3, D1: The original plan was to classify the Mesozoic rocks encountered in the boreholes of the wide shear zone, and to study its structure. Unfortunately, the early leaving of Palotai prevented the completion of the structural analyses although we reached local results (see below). So this is the area where our study is behind the schedule the most.

We studied the Mesozoic successions of the Medvednica–Kalnik region in the frame of a CEEPUS-supported field work. However, detailed analyses were not carried out. Recently, we were able to start a revision of Mesozoic borehole material in the Zala region, but this research is still ongoing.

We progressed with the structural analysis of Mid-Hungarian Shear Zone and adjacent areas south of the Bükk Mts. and Polgár basin. Petrik et al. (2016: P31) demonstrated that the Vatta-Maklár trough might have had dextral character just before and at the onset of the Pannonian rifting, but before that time it was mostly characterised by Oligo-Miocene compression. On the other hand, Mid-Miocene sinistral transtension was the most remarkable deformation lasting up to ca. 9.7 Ma. Similar deformation was documented in the Polgár basin (Petrik 2017, P32; A60–61). In this basin we demonstrated that the increasing sedimentation rate at the turn of middle and Late Miocene, possibly associated with slight change in fault kinematics, changed the style of magmatism, from surface volcanism to subsurface magma intrusion (P32; A61). All these deformations could be part of an important sinistral displacement along the MHZ, which can be connected to similar displacement along the Dragos-Voda fault system in northern Romania (Tischler et al. 2007; P32).

Near the southern segment of the MHZ, southwest from the TR Héja (2019: D7) analysed the Cenozoic deformation along the Balaton Zone. The demonstrated dextral slip of the Balaton Zone was combined with thrusting during the early Miocene deformation phase. This makes the correlation across the dextral zone more complicated than previously anticipated.

Pannonian basin, Miocene and pre-Cenozoic deformations

E: A large dataset containing 2D, 3D seismic and well data covering the Pannonian basin was interpreted and the overall temporal and spatial evolution of the main tectonic and stratigraphic processes was revised. Our study demonstrated that extensional deformation migrated from the basin margins towards its centre (P2). Our analysis infers a much larger amount of extension in the Pannonian Basin than previously thought, reaching values up to 270 km (P1). This estimate takes into account the eroded footwalls of the low angle structures during extensional exhumation, the thicker initial crustal thickness (ca. 45 km) and the large amount of asymmetric extension along the Dinaridic margin. Extension was still active in the eastern part of the Pannonian Basin (Szeged, Makó, and Derecske sub-basins), when the onset of contractional deformation took place near the Dinarides. Therefore, the last stage of inversion also migrated in space and time from the south and SW margin of the Dinarides northeastward (i.e., from the Adriatic indenter) toward the central Pannonian Basin (P1).

Our stratigraphic analysis was supported by a backstripping methodology facilitated by well lithology and porosity data (P4). The thick Late Miocene sediment overburden effects were gradually removed. This approach has resulted in a morphological reconstruction of the former depositional surfaces. Our calculations show that the water depth of Lake Pannon was more than 1000 m in the deepest sub-basins. The significant compaction associated with lateral variations of Neogene sediment thicknesses has created non-tectonic normal fault offsets and folds. We furthermore compare the geometries and effects of such non-tectonic features with the activity of larger offset sinistral strike-slip zones using 3D seismic attributes. This scenario and our syn-rift and post-rift tectono-stratigraphic scenario was also analysed by the means of 3D stratigraphic numerical forward modelling (P3).

Seismic and well data interpretation was complemented by a series of 2D and 3D thermo-mechanical numerical modelling quantifying the role of inherited orogenic structures, brittle and ductile deformation and the role of elasticity and surface processes. We quantified the tectonic subsidence history of the half-grabens. Furthermore, our model results infer that the initial lithospheric mantle asymmetry is attenuated by the lateral heat conduction and further dynamic evolution of the asthenosphere during the “post-rift” phase, resulting in the neotectonic kilometre-scale differential vertical movements. 3D thermo-mechanical numerical modelling (P5) deciphered crustal and mantle thinning factors during asymmetric extension. Furthermore, modelling yields new constraints on the kinematics of the Mid-Hungarian Fault Zone.

All these new results contributed to the knowledge on and understanding of the lithospheric scale and asthenospheric process in the Pannonian basin. The new modelling techniques can lead in the future to a high resolution 3D forward model of extension, subsequent basin inversion and can be compared with high resolution reconstructions.

New Tectonic map of the Carpathian–Pannonian area

During the compilation of our map data base, we prepared a new tectonic map of the entire Carpathian-Pannonian-East-Alpine-Dinaridic domain (P29). This map is a part of a new map series of the Hungarian Academy of Sciences (P19–20), but our work covers larger area. We used published maps of different authors, mainly of Schmid et al. (2008), but we analysed the individual units more in detail and separated the bounding structural elements in time.

Plate tectonic modelling

F: We collected and revised great number of existing paleomagnetic data sets, which were used in the plate tectonic reconstructions. Data were put in data bases, one for the Western Carpathians and another for the Adriatic autochthon in addition to the palaeomagnetic information (palaeomagnetic directions with statistical parameters, palaeomagnetic poles with statistical parameters, field test to constrain the age of the magnetization) other important information, like the co-ordinates of the study area, the stratigraphic or isotope ages of the studied rocks were also tabulated. The former data set were revised, when recently accepted stratigraphic ages differed from the originally published ages.

Using the paleomagnetic database we carried out preliminary tests preparing plate tectonic modelling for Adria. As the software requires paleomagnetic directions which are free from the influence of the secular variation of the Earth magnetic field, and other biasing factors, like inclination flattening due to compaction, the paleomagnetic data need careful checking. This long-lasting process somewhat slowed down in 2018, but was taken up by a new research project, led by E. Márton from 2019.

In the beginning of the research project, we progressed with plate tectonic reconstruction more than predicted in our plan. Due to a successful application to the DAAD foundation, Kövér spent one month in Berlin (Freie Universität) to study the GPlates software. She was able to set our preliminary reconstruction for the Alcapa unit for the last 20 Ma. After she returned, we also set up a series of displacement markers, to prepare our next step and went back to situation at 23 Ma, before main displacement along the Mid-Hungarian–Balaton–Periadriatic strike-slip fault.

We applied a new technique for incorporation of the amount of deformation of a given unit into the reconstruction; this part was involved in the original package, which used fix size. We applied this technique for preliminary models using qualitative estimates for extension, but not exact quantitative data. We also started building the first version of rotation poles into our model.

The modelling can benefit some of our recognitions (suggestions) about former paleogeographic position of units; one of these is the new suggested position of the Bükk Mts. close to the Slovenian trough and the Dinaridic platform. We also learnt much from prof. Gawlick (Leoben Univ. Austria), during a short course of Mesozoic paleogeographic reconstructions. The course and discussions largely improved our understanding of the related problems. All these aspects could be tested in the next future.

During November 2016 we organised an international conference in Budapest. Our project could benefit this occasion involving a short course on GPlates software what we use in our reconstruction work. Our preliminary plate tectonic model for the Miocene was presented (Kövér et al. 2017).

Although we started well this aspect of the project, the intensity declined in the second part of the project. Despite this, the plate tectonic modelling system has been established and the first results are promising while they show consistency but also discrepancy between quantitative data and qualitative paleogeographic estimates. Modelling should continue in the future.

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Bold= project participants (including foreign long-term partners)

Paper, book, book chapter, conference excursion guide, map / 24/1/8/1/2

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P37. **Fodor, L., Márton, E.,** Vrabec, M., Koroknai, B:, Trajanova, M., Vrabec, M. Relationship between magnetic fabrics and deformation of the Miocene Pohorje intrusions and surrounding sediments (Eastern Alps). — Submitted to *International Journal of Earth Sciences*

P 38. **Oravecz É., Fodor L., Kövér Sz., Héja G. (submitted):** Syn-sediment and early deformation structures as proxies for Jurassic passive margin deformation in the SW Bükk Mts. — submitted to *Geologica Carpathica*.

Manuscript in preparation (4)

P39. **Beke, B.,** Szőcs, E., K., Schubert, F., Petrik, A., **Fodor, L.** Interconnection of diagenesis /cementation and deformation band formation: structural-diagenetic study in pre-rift siliciclastics of the Pannonian Basin. — to be submitted to *Marine and Petroleum Geology*

P40. **Héja G., Ortner H., Kövér Sz.,** Németh A. & **Fodor L. (2020):** Cretaceous oblique inversion of a Late Triassic upper crustal normal fault system in the western Transdanubian Range. — to be submitted to *Tectonics*.

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D4. Fialowski M. (2018): Deformation and kinematics of the Mónosbél Nappe, Bátor area, SW Bükk. — MSc thesis, Eötvös L. Univ. Budapest, 84 p.
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D7. Héja G. (2019): Mesozoic deformations of the southwestern Transdanubian Range: the role of Triassic-Jurassic inherited normal faults in the development of Cretaceous folding and thrusting. — PhD thesis, Eötvös L. Univ. Budapest.
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D10. Oravecz É. (2019): Jósvafő környékének szerkezetföldtani vizsgálata — Student work (OTDK Eger), 60 p.
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Oragnisation of conferences

Mediterranean Geodynamics MedMeet, Budapest, 2016. 11.
15th Meeting of the Central European Tectonic Studies Group – 2017. április 5-8, Zánka.
14th Workshop of the International Lithosphere Program Task Force Sedimentary Basins – 2019. 10. 15-19, Hévíz.

Prizes, scholarships won by project participants

AGU Tectonics publication, **AGU – EOS Research Spotlight award,** 2016, Balázs Attila
International Lithosphere Program workshop *Limassol, Cyprus 2017,* **1st Poster Presentation**– Balázs Attila
CETEG Meeting 2017, **3rd Best Student Presentation** – Oravecz Éva
CETEG Meeting 2018, **1st Best Student Poster Presentation** – Oravecz Éva
ESSEWECA Conference 2018, **2nd Best Student Poster Award** – Oravecz Éva
ESSEWECA Conference 2018, **3rd Best Student Poster Award** – Héja Gábor
Ifjú Szakemberek Ankétja 2017, Elméleti kategória, **3. helyezés** – Oravecz Éva
Ifjú Szakemberek Ankétja 2017, **Magyarhoni Földtani Társulat Ifjúsági Bizottságának Különdíja** – Oravecz Éva
Ifjú Szakemberek Ankétja 2018, Poszter kategória, **1. helyezés** – Oravecz Éva
Ifjú Szakemberek Ankétja 2019, Poszter kategória, **1. helyezés** – Scherman Benjámin
Ifjú Szakemberek Ankétja 2019, Elméleti kategória, **1. helyezés** – Oravecz Éva

Kőzettani és Geokémiai Vándorgyűlés, 2017, Poszter kategória, **1. helyezés** – Kovács Zoltán
Országos Tudományos Diákköri Konferencia 2017, **1. helyezés** – Oravecz Éva
Országos Tudományos Diákköri Konferencia 2019, **1. helyezés** – Oravecz Éva
Új Nemzeti Kiválósági Program 2016/17, **10 hónapos ösztöndíj** – Oravecz Éva
Új Nemzeti Kiválósági Program 2017/18, **10 hónapos ösztöndíj** – Oravecz Éva
Új Nemzeti Kiválósági Program 2018/19, **5 hónapos ösztöndíj** – Héja Gábor
Új Nemzeti Kiválósági Program 2018/19, **10 hónapos ösztöndíj** – Oravecz Éva
International Lithosphere Program workshop *Hévíz, Hungary 2019,* **1st Poster Presentation**– Gábor Héja
The Vol. in which the map of Kövér et al. (2018) and the associated text (Haas et al. (2018) were published won the **1st prize** at the Word Cartographic Conference.