Field Excursion Guide - TOPO-EUROPE Workshop 2024, Sopron

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1. Introduction

The NW Pannonian Basin, as the transitional zone between the Eastern Alps and the Western Carpathians, is one of the classical regions of European geology. In this area, which belongs to Austria, Hungary and Slovakia, the magnificent nappes of the Alps project below the Styrian and Danube subbasins. In fact, about 90% of the pre-Tertiary "basement" and about 60% of the pre-middle Miocene strata are covered by the sedimentary fill of the Pannonian Basin. This clearly shows the importance of subsurface geology. Many of the "classical" geological problems in the Pannonian Basin, debated for almost a century, may be resolved only by the systematic evaluation of all subsurface geologic information, most importantly from the interpretation of seismic data combined with well information.

Our fieldtrip intends to give a brief introduction to the complex problems of Alpine geology in NW Hungary. Six outcrops were chosen to show examples of the major tectonostratigraphic units, from the metamorphic basement and the uppermost, poorly consolidated post-rift basin fill in the junction area between the Alps, Carpathians and the Pannonian Basin.

This decidedly short field trip guidebook builds on a long and detailed one which was put together for a longer field trip that was run after the AAPG International Conference in Nice, France, in September 1995 (Horvath et al., 1995). In that guidebook ten contributions addressed a very wide range of geological problems in the NW Pannonian Basin. To make the short version a little more "unconventional", we have added some additional information which may not have much to do with geoscience, but it is something certainly worthwhile to know about Hungarian culture and Hungarian people. Hopefully these minor additions made this work a little bit more colourful and enjoyable!

Sopron/Vienna, October 2024

2. Geological background: from nappe stacking to extension in the Alpine-Pannonian transition area

The Pannonian basin is a large extensional basin system surrounded by the orogenic arcs of the Eastern Alps, Carpathians, and Dinarides (Figure 1). The formation of the basin system initiated during the extensional collapse of the Eastern Alps and active subduction in the Eastern Carpathians during the Early Miocene, with subsidence lasting until the end of Miocene in many sub-basins (e.g. Tari, 1996; Balázs et al., 2016). With respect to the Eastern Carpathian subduction zone and volcanic arc, the Pannonian basin is considered a major back-arc basin system, which formed in response to slab roll-back (e.g. Horváth et al., 2006).

The extension fabric in the basin was overprinted by strike-slip and contractional structures since the late Miocene, resulting in the inversion of extensional structures and the regional-scale uplift of the basin margins so typical in many segments of the basin complex (Horváth, 1995; Horváth and Cloetingh 1996; Tari et al., 2020). The region of Sopron is one of the key areas for the understanding of initial syn-rift basin formation processes, as it is located at the transition zone between the Eastern Alps and the Pannonian basin (Figure 1).

2.1 Tectonic setting and nappe structure of the Eastern Alps

The subject of the field excursion is the relation between the extensional collapse of the Eastern Alps and the formation of the NW-Pannonian basin, where the Cretaceous-Paleogene nappe

stack becomes increasingly buried below Middle Miocene synrift and Upper Miocene-Quaternary post-rift basin fill towards the East (Figures 1, 2). The basin fill is 1-2 km thick in the Eisenstadt-Sopron sub-basin, but reaches 6–8 km in the deepest parts of the Danube basin (Figure 1), attesting to significant extension and subsidence (e.g. Kilényi and Šefara, 1989). The basins are underlain by a complex Cretaceous-Paleogene Alpine nappe stack consisting from top to bottom of 1) Adria-derived thrust sheets (Austroalpine nappes of the AlCaPa megaunit in the sense of Schmid et al., 2008); 2) remnants of the Alpine Tethys ocean ("Penninic" units); and 3) the basement and Mesozoic cover units of the European foreland (Figure 1). The Adria-derived Austroalpine units were stacked on top of each other from Early-to Late Cretaceous times ("Eoalpine orogeny"), followed by their Paleogene emplacement over the oceanic rocks of the Alpine Tethys and subsequently the European continental foreland.

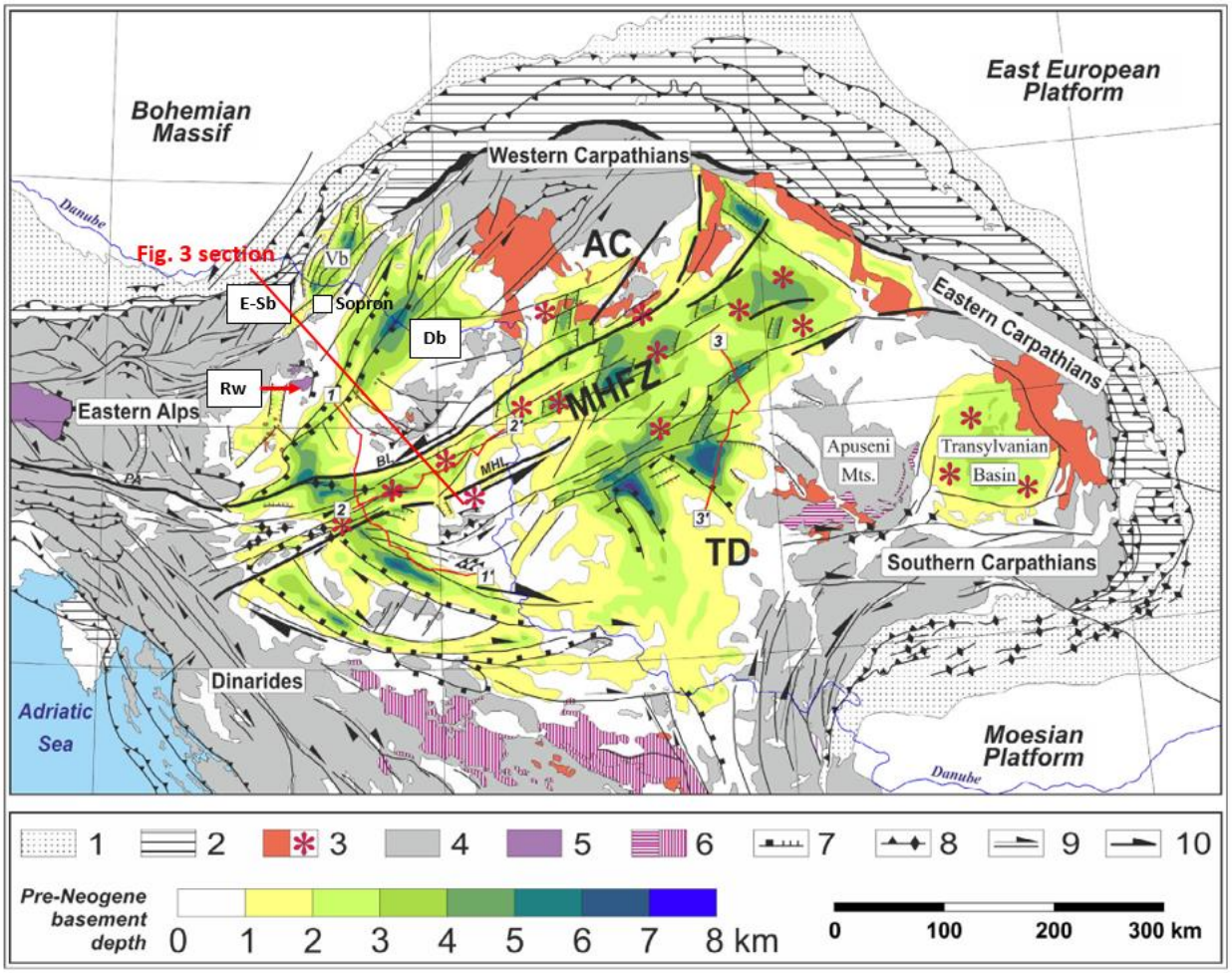


Fig. 1. Map showing the basement depth of the Pannonian basin and the main faults controlling the basin formation (Horváth et al., 2015). 1 = Foredeeps; 2 = Flysch belt; 3 = Miocene volcanoes and approximate position of explosive centres erupting rhyolitic volcanoclasts; 4 = Inner Alpine, Carpathian and Dinaric mountains; 5 = Penninic windows; 6 = West- and East-Vardar ophiolites; 7 = Detachment and normal faults; 8 = Thrusts and folded anticlines; 9 = Strike-slip faults; 10 = First order strike-slip faults; E-Sb = Eisenstadt-Sopron sub-basin; Db = Danube basin Vb = Vienna basin; Rw = Rechnitz-window; AC = Alcapa terrane; MHFZ = Mid-Hungarian Fault Zone; TD = Tisza-Dacia terrane

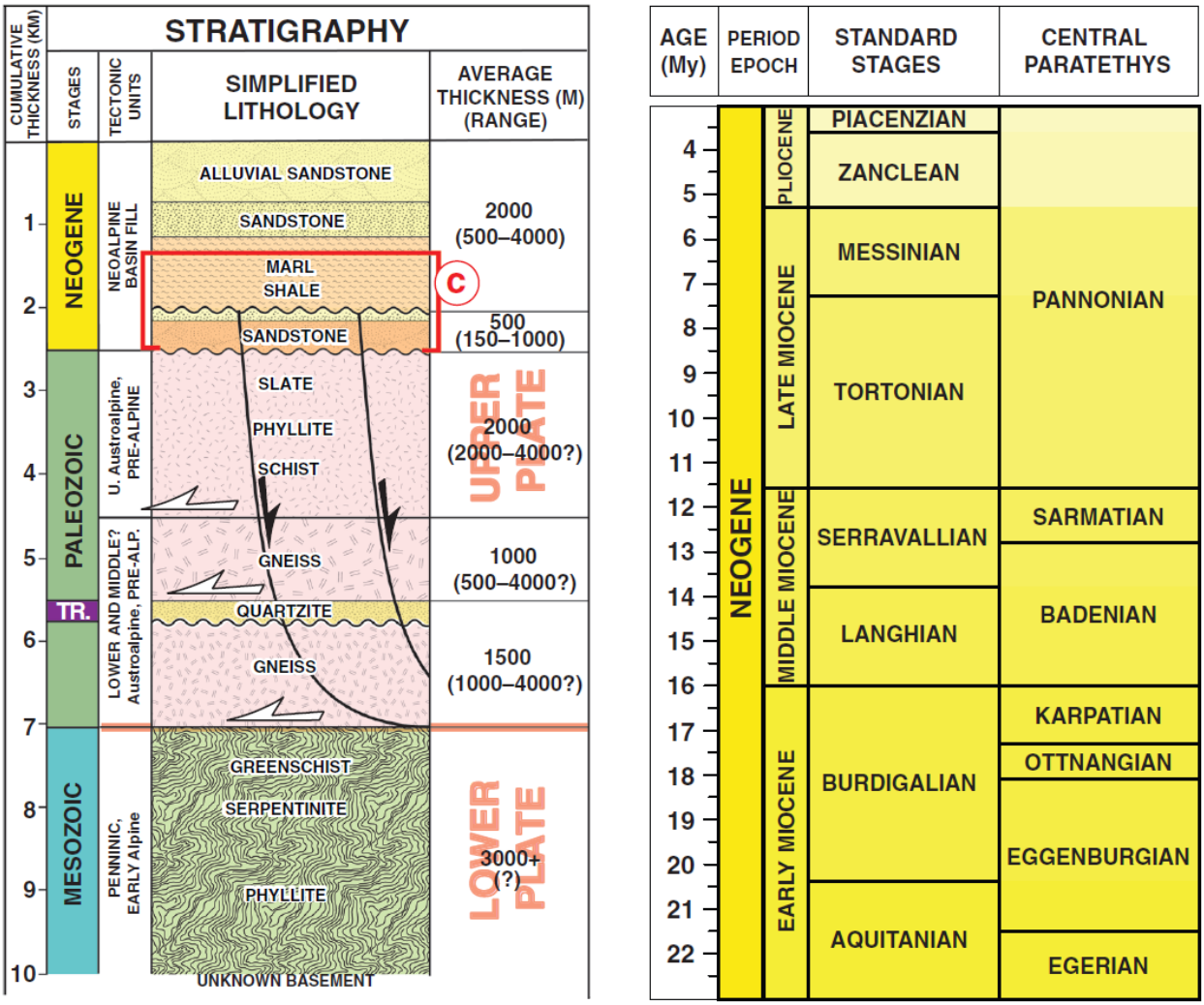


Fig. 2. Simplified lithostratigraphy of various Alpine units of the Alpine-Pannonian transition area (left), adapted from Tari et al. (2020). Correlation of the standard global Neogene geologic stages with the local Paratethys stages (right), redrafted from Magyar et al. (2020). For a very detailed treatment of the entire Phanerozoic stratigraphy in the NW Pannonian Basin, see Tari (1995).

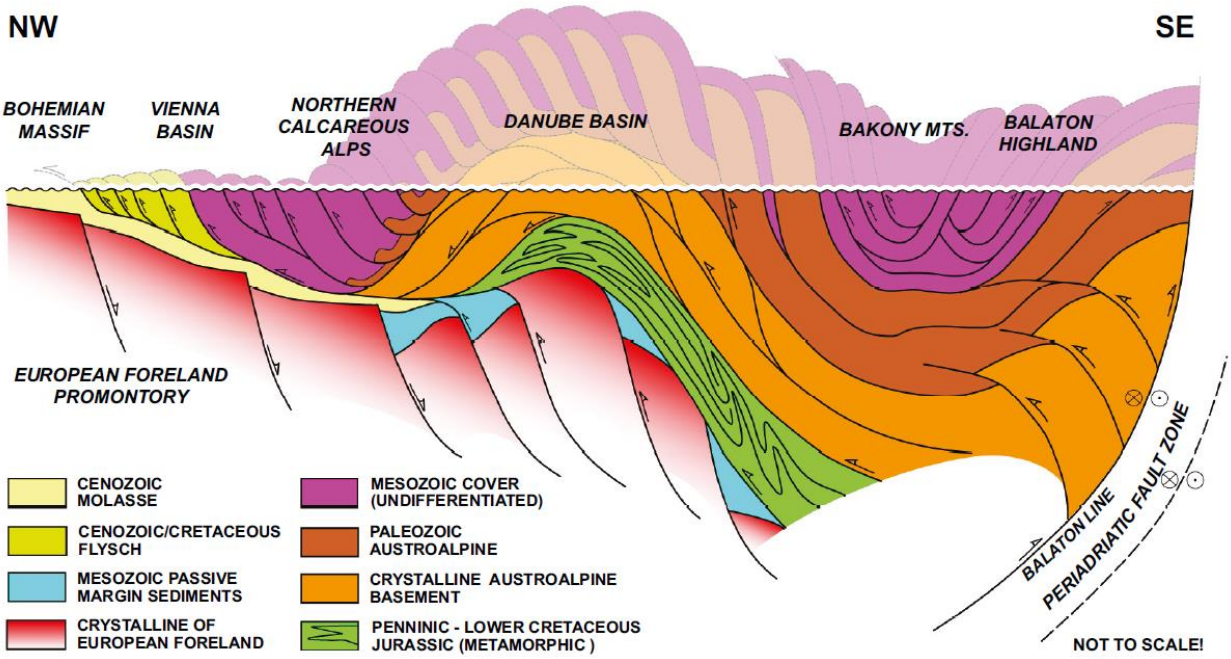


Fig. 3. Cartoonish cross section of the Alpine-Pannonian transition area (for the trace of the section see Fig. 1), flattened at the erosional surface of the combined Upper Cretaceous-Cenozoic basin fill (Tari and Horváth, 2006). By the "removal" of the Neogene Pannonian Basin, the presence of the underlying, mostly Cretaceous, Alpine folded belt becomes obvious.

The Austroalpine nappes include an ultra-high-pressure (UHP) unit, which experienced deep intracontinental subduction and subsequent exhumation during the Eoalpine orogeny (with peak metamorphism around 90 Ma; Janák et al., 2004, Thöny et al., 2008). In the interpretation of Schmid et al. (2008) this UHP unit is sandwiched between the Northern and Southern continental margin units of the former Meliata oceanic branch (the western branch of the Neotethys), and these three nappe units together were emplaced on the Lower Austroalpine unit by 80 Ma (van Hinsbergen et al., 2020 and references therein).

The metamorphic basement rocks of the Lower Austroalpine nappe are exposed in the Sopron Mountains (Stops 1 and 2 of the excursion), and show a multiphase metamorphic evolution that includes both Variscan and Alpine phases. Fission track data implies that the Lower Austroalpine rocks in the Sopron Mountains were exhumed to the surface relatively late from a shallow crustal position, during Pliocene-Pleistocene times (Balogh and Dunkl, 2005). The Lower Austroalpine nappe overlies the ocean-derived Penninic units, which are exposed in the Rechnitz tectonic window (Rechnitz Window Group), representing the deepest exposed part of the Alpine nappe stack in the area. The formation of this tectonic window is related to the Miocene extension of the Eastern Alps.

2.2. Extensional collapse of the Eastern Alps

Extension was induced by the orogenic thickening of the Alpine crust, while the space for the eastward escape of the overthickened lithosphere was provided by the retreating subduction zone of the Eastern Carpathians (e.g. Ratschbacher et al., 1989; Frisch et al., 2000; van Gelder et al., 2017). The southern boundary of the extruding Alpine wedge was the Periadriatic fault (e.g. Schmid et al., 1989), and its continuation in the Pannonian basin, the Mid-Hungarian Shear Zone (Figure 1, latter also represents the southern boundary of the AlCaPa megaunit). Extensional deformation was at first accommodated by major, low-angle, normal-sense shear zones (i.e. extensional detachments), for example, at the Rechnitz (Rohonc) windows group (Figure 4) from earliest Miocene times in a classic metamorphic core complex style high-strain manner (Tari and Bally, 1990; Tari et al., 1992).

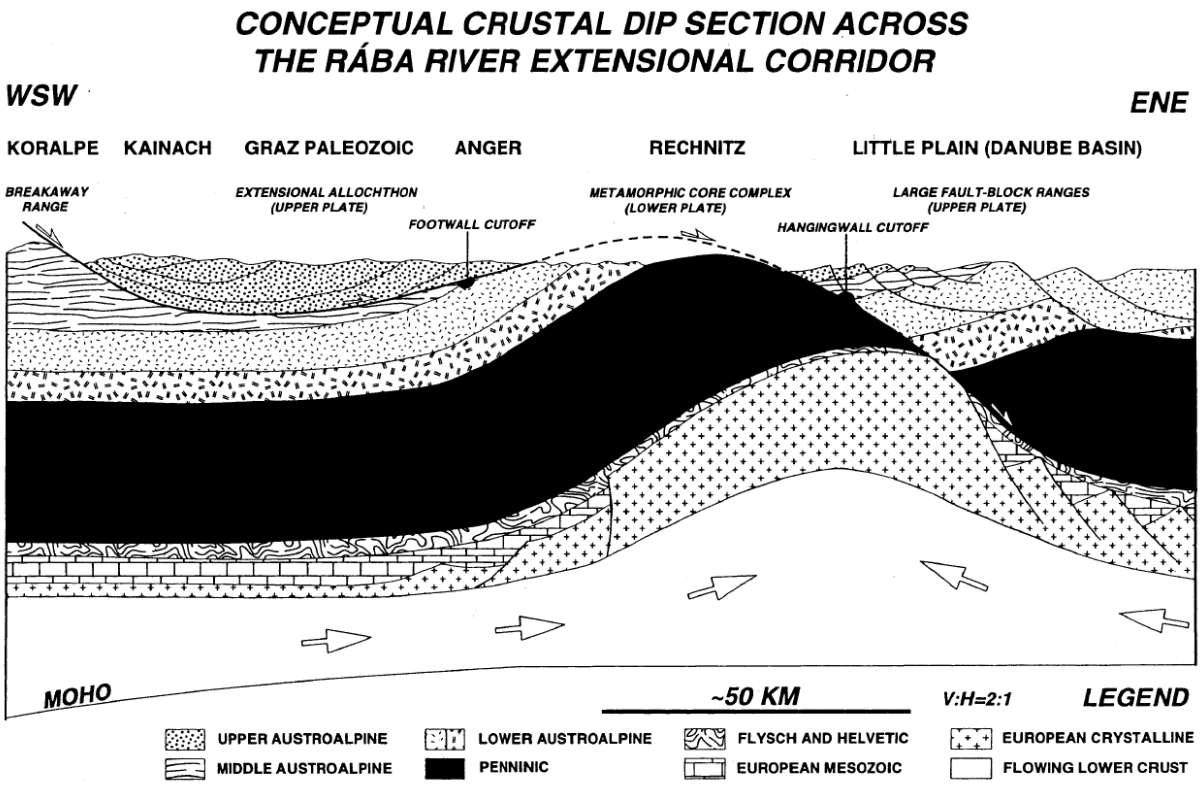


Fig. 4. Conceptual crustal section across the Rechnitz-window, from the Eastern Alps to the Danube basin (Tari, 1994). Vertical exaggeration is about twofold. Stops 7 and 8 will show the greenschist metamorphosed lower plate of this Miocene metamorphic core complex.

These detachment faults progressively unroofed the mid-or deep-crustal portions of the Alpine nappe stack and resulted in the Miocene surface exhumation of the Penninic units in the tectonic windows (e.g. Dunkl et al, 1998; Cao et al., 2013). The lower plate of these windows contains a meta-mafic and meta-sedimentary succession that formed in the Alpine Tethys ocean during Late Jurassic-Early Cretaceous times (Koller, 1985), and was metamorphosed (buried and exhumed) during the Alpine orogeny. A mixed mafic-sedimentary succession, that reached blueschist facies metamorphism with greenschist facies overprint during subduction and subsequent exhumation, is exposed in the Kőszeg mountains.

Strain localization during low-angle detachment faulting in these tectonic windows was influenced by pre-existing orogenic structures, such as Cretaceous thrust planes. Most commonly, steep Miocene normal faults merged with Cretaceous thrusts between 4-8 km depth, hence reactivating the intra-basement decoupling levels as normal-sense shear zones (Tari, 1996; Tari et al., 2021). Subordinately, some thrust planes were also reactivated more extensively, along most of their length. On a larger scale, inherited suture zones from the orogenic phase appear to play an important role in the initial localization of extensional deformation (Balázs et al., 2017, Fodor et al., 2021). Thermo-mechanical models predict that a thick and hot orogenic lithosphere with inherited weakness zones is prone for the initial development of extensional detachment systems (core-complex type extension), which is followed by the migration of extension and basin development away from the orogenic suture zone (in this case, towards the inside of the Pannonian basin, Fodor et al., 2021).

2.3 Formation of the NW-Pannonian basin (Danube basin)

The extensional deformation within the Alpine nappe stack in the broader Danube basin region occurred in the Early and Middle Miocene, initiating the syn-rift phase.



Fig. 5. Geologic map of the pre-Tertiary basement around Sopron, showing the outcrops and the depth of the basement around (Fülöp, 1990). We highlighted the 5 field trip stops located in this area with red circles.

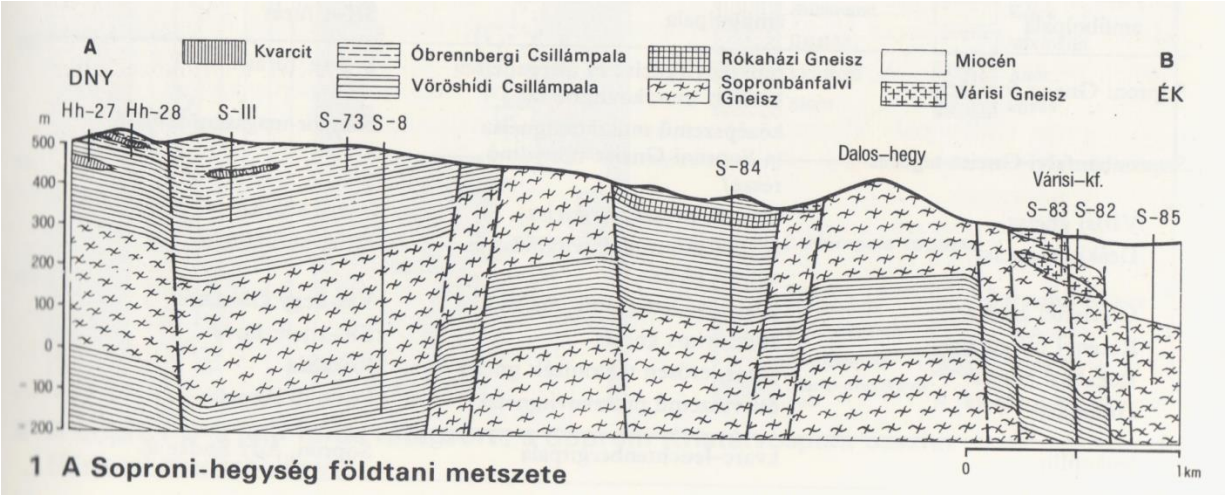


Fig. 6. SW (left) to NW (right) oriented geologic section through the Sopron Mountains, showing the Neogene extensional faults and the various outcropping metamorphic basement units (Fülöp, 1990). Note the 2x vertical exaggeration. Some of the major lithological boundaries within the Austroalpine basement might be Eo-Alpine (Cretaceous) overthrust planes.

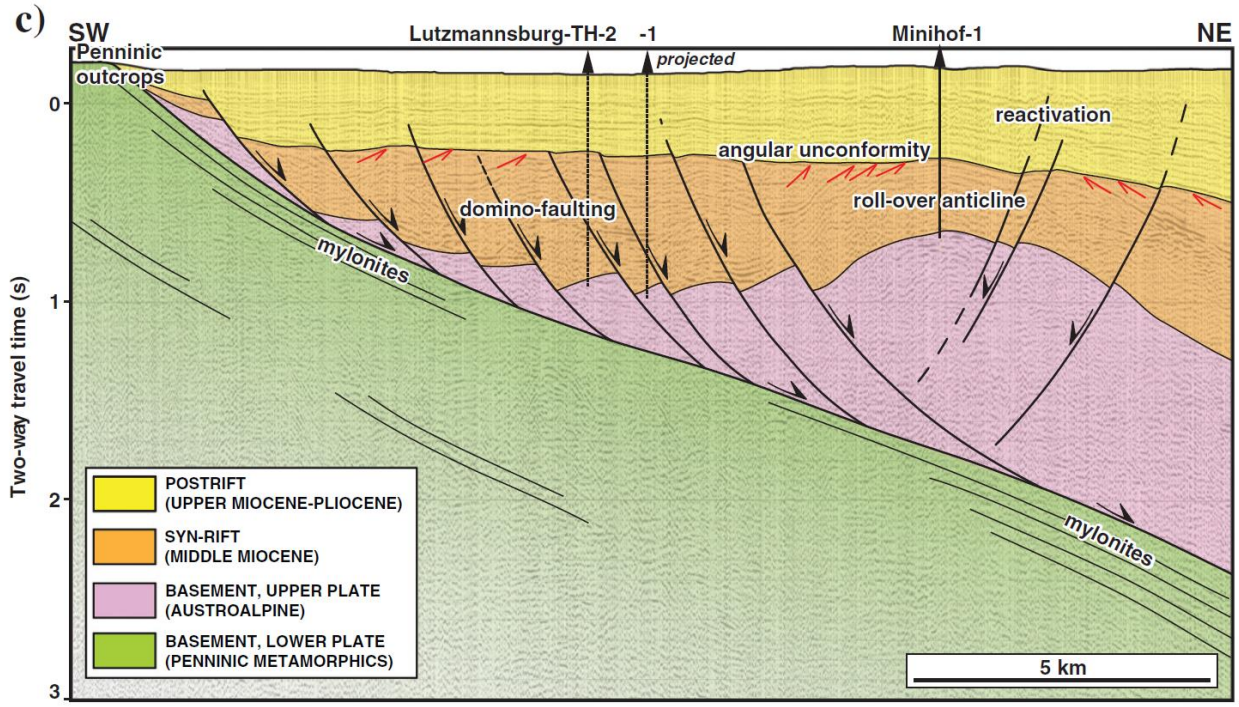


Fig. 7. Vintage 2D seismic section through the Oberpullendorf subbasin, located just south of the Sopron Mts. in Austria, showing high-strain Neogene extensional faults associated with the syn-rift period in this part of the Pannonian Basin (Tari et al., 2020). Note the seismic expression of the low-angle Rechnitz detachment fault separating the lower plate Penninic units from Austroalpine units in the upper plate. Beneath the prominent angular unconformity Middle Miocene coarse clastics were penetrated in all three wells shown, similar to the ones seen at Stop 3. Also, we consider the faulted-up roll-over anticline tested by the Minihof-1 well as a useful structural analogue for the outcropping basement of the Sopron Mts. which was exposed by uplift and erosion at the basin margin during the Pliocene.

The syn-rift extension had an early high-strain period manifested by a number of low-angle normal faults and the formation of the Rechnitz metamorphic core complex. MCC, (e.g. Tari et al., 2020). This was followed by a more distributed, lower-strain extensional period which could be also described as wide-rifting leading to the formation of several subbasins in the overall Danube Basin area (e.g. Horvath et al., 2006; Sztano et al., 2016; Šujan et al., 2021).

The syn-rift subsidence during the Karpatian and Badenian (see Figure 2) driven by normal faulting (partly reactivating Alpine thrusts) created accommodation space for the deposition of basal alluvial to fluvial very coarse conglomerates and overlying clastics that can reach the total thickness of 800 meters (Stop 3), overlain by shallow marine limestones (Stop 4 of the excursion) in the surroundings of Sopron.

The syn-rift extensional fault fabric around the Sopron area is depicted on Figure 5, whereas several prominent syn-rift grabens are shown, with a depth of circa 2000 m. The isometric and circular shape of the presently outcropping basement in the Sopron area (Figure 5) and block-faulted nature of it in a cross-sectional sense (Figure 6) suggests that it is possibly an exposed hangingwall anticline. A good subsurface structural analogue is shown in Figure 7 located in the adjacent Oberpullendorf subbasin, located just south of the Sopron Mts (Tari et al., 2021). The map-view dimensions and circular shape of the Minihof High, interpreted as a roll-over anticline by Tari et al. (2020) serves as a structural template which has not been uplifted and exhumed due to the regional basin margin inversion, like in the case of the Sopron Mountains, but maintained its relatively thin post-rift basin fill cover.

Whereas there is thermochronological data available for the Sopron Mts., such as AFT analysis (e.g. Balogh and Dunkl, 2005; Tari et al., 2021), what is missing at present is the direct dating of the inversion-related exhumation during the Pliocene. For the dating of this important episode in the evolution of the area, low-temperature geochronological work is needed (e.g. U-He geochronology).

During the Late Miocene, the rising Carpathian and Alpine chains lead to the isolation of the Pannonian basin from the Central Paratethys Sea, hence creating Lake Pannon (e.g. Magyar et al., 2013, 2020). This isolation process was reflected in the decreasing salinity of the water and lead to the development of a diverse endemic fauna. The basin was filled during the Late Miocene and Pliocene, from the surrounding mountain chains in the WNW and NE towards the South, primarily by the gradual progradation of deltaic depositional systems (Figures 9 and 10, Sztano et al., 2016). The paleo-Danube deltaic system entered the present-day Danube basin from the Eastern Alps around 10.5 Ma. The deltaic deposition system was gradually replaced by alluvial, which was interrupted by early Pliocene basin inversion. Subsequently, late Pliocene-Pleistocene deposition took place via braided river systems (e.g. Sztano et al., 2016 and references therein). Sediments of the Middle and Late Miocene basin fill are visited at Stops 4, 5 and 6 of our excursion.

Finally, we would like to emphasize the regional importance of the late-stage inversion of the Pannonian Basin (e.g. Horváth and Cloetingh, 1996). This primarily structural phenomenon, not being fully appreciated before the early 1990s, manifests itself at different scales and in various geological and geophysical data sets. The example we chose to include here is based on shallow (50-200 m deep, on average) "counter-flush" wells drilled in the Austrian side of the area shortly after the WWII (Tauber, 1959). The close spacing and exceptionally detailed documentation of these wells allowed a superb lithostratigraphic correlation between them (Figure 11). At the dramatic 20x vertical exaggeration, the truncation of the Pannonian (Upper Miocene to Pliocene, Figure 2) strata at the basin margin is very pronounced and it is attributed to the intra-Pliocene (circa 4-5 Ma) period of inversion, triggering regional uplift and erosion of the Pannonian basin fill in many segments of the basin (e.g. Šujan et al., 2021). Basin inversion is still active in the Pannonian region, as demonstrated by the analysis of present-day stress field and strain rate field (Bada et al., 2007; Békési et al., 2023; Porkoláb et al., 2023; Porkoláb et al., 2024). GPS velocities furthermore confirm that the relative uplift of basin margins and subsidence of deep sub-basins is an ongoing process (Porkoláb et al., 2023).

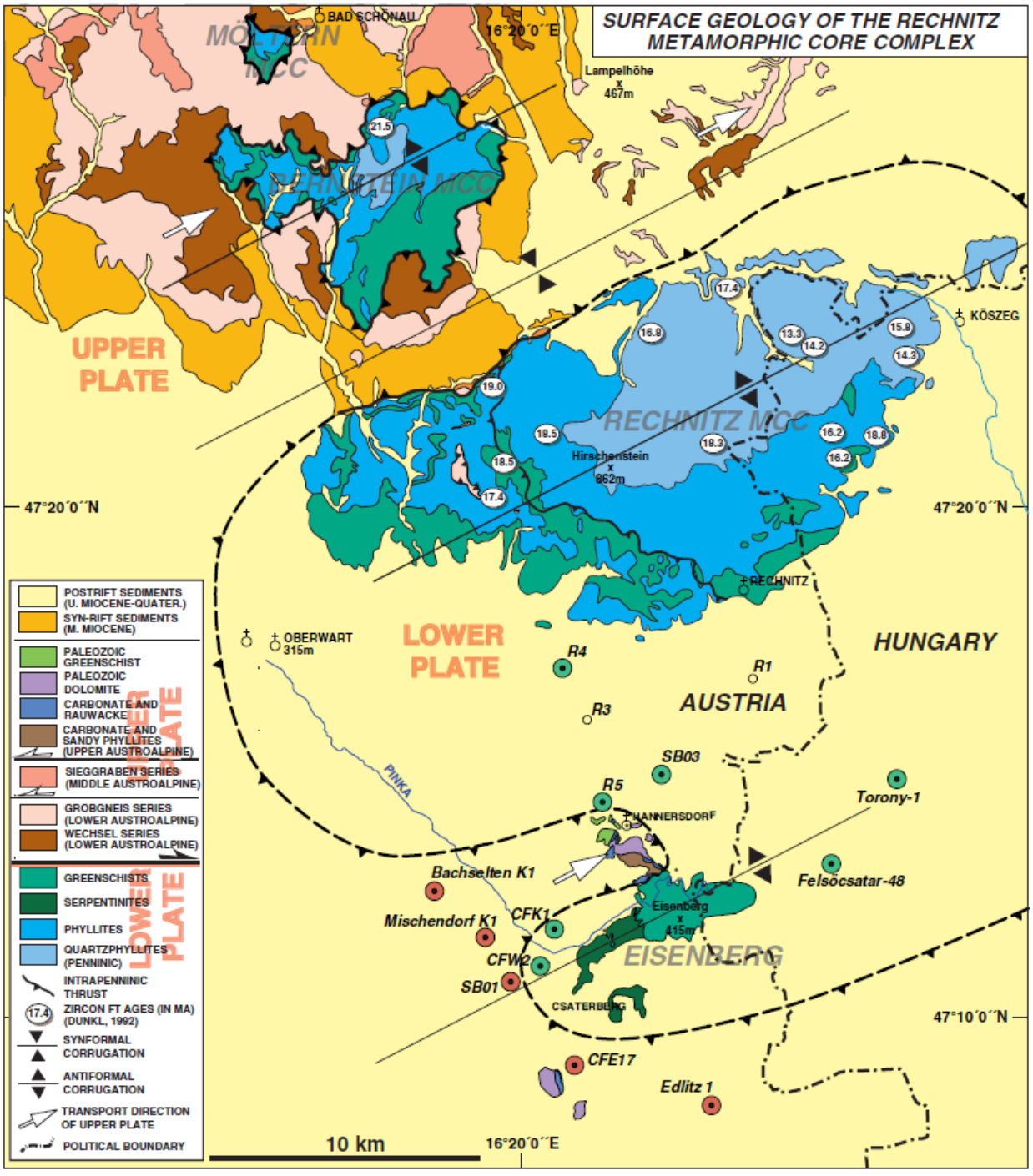


Fig. 8. Simplified surface geology of the Rechnitz metamorphic core complex compiled from various sources by Tari et al. (2020). Stops 7 and 8 are located on the SE flank of the Rechnitz-Kőszeg Mts., on the Hungarian side. Note the subdivision of the pre-Cenozoic basement into an upper and lower plate separated by the regional extensive Rechnitz detachment fault responsible for at least 80 km extension (Tari, 1996). Also note the prominent corrugations that formed during the dominant east–northeast transport direction of the upper plate in the Early Miocene, quite typical for MMCs in other parts of the world. Other authors consider these features as

the manifestation of neotectonic shortening (F. Neubauer, personal communication, 2020), however, it does not fit the orientation of the present-day stress field in the region (e.g. Bada et al., 2007).

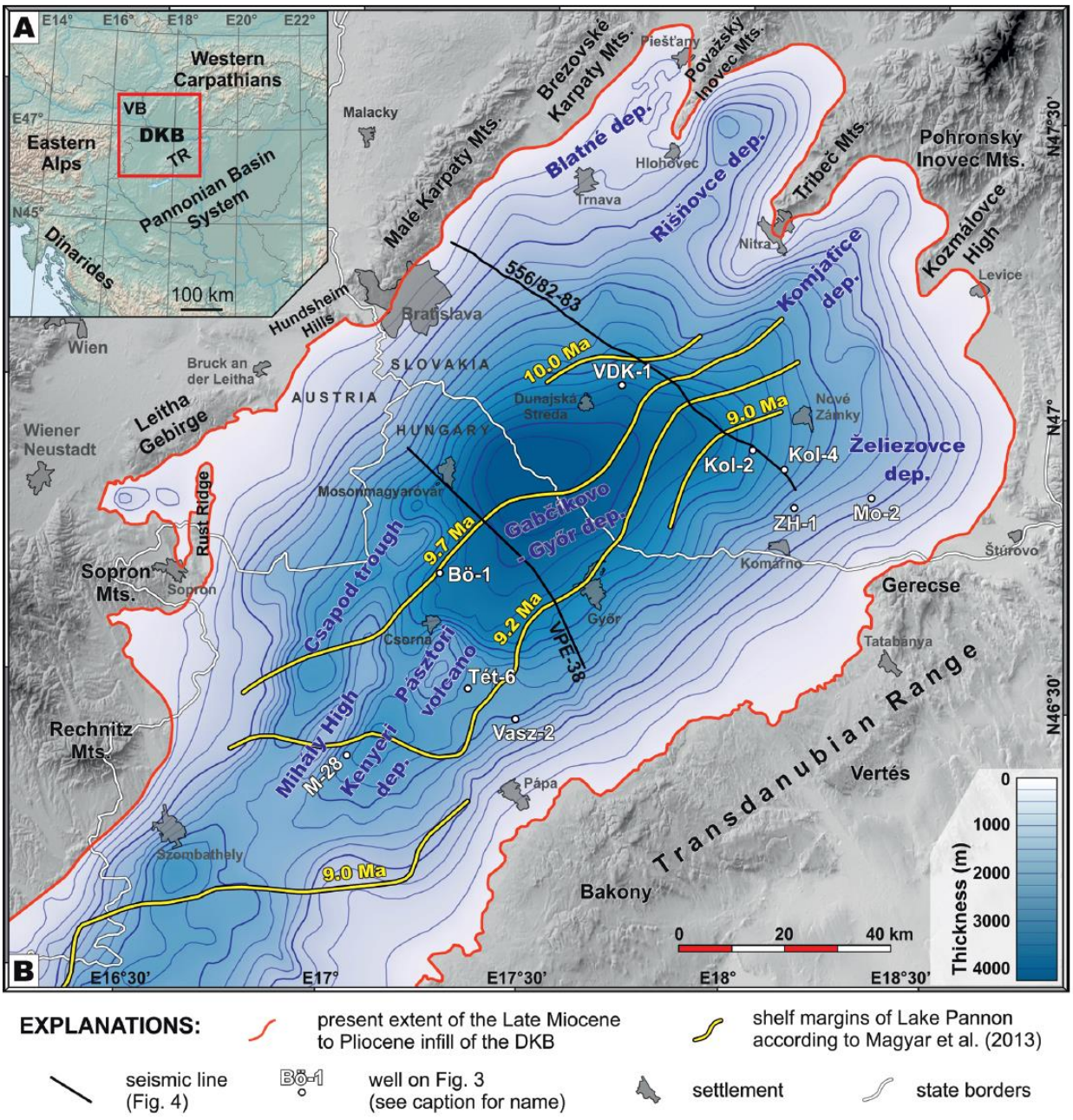


Fig. 9. a) Location of the Danube/Kisalföld Basin (DKB) in the Eastern Alps–Western Carpathians–Pannonian Basin junction area (TR: Transdanubian Range, VB: Vienna Basin). b) Map of the DKB with thickness of the Late Miocene to Quaternary succession, adapted from Sztano et al. (2016). The prograding shelf edge trajectories are displayed after Magyar et al. (2013). Location of wells and seismic sections shown on Figure 10 are indicated.

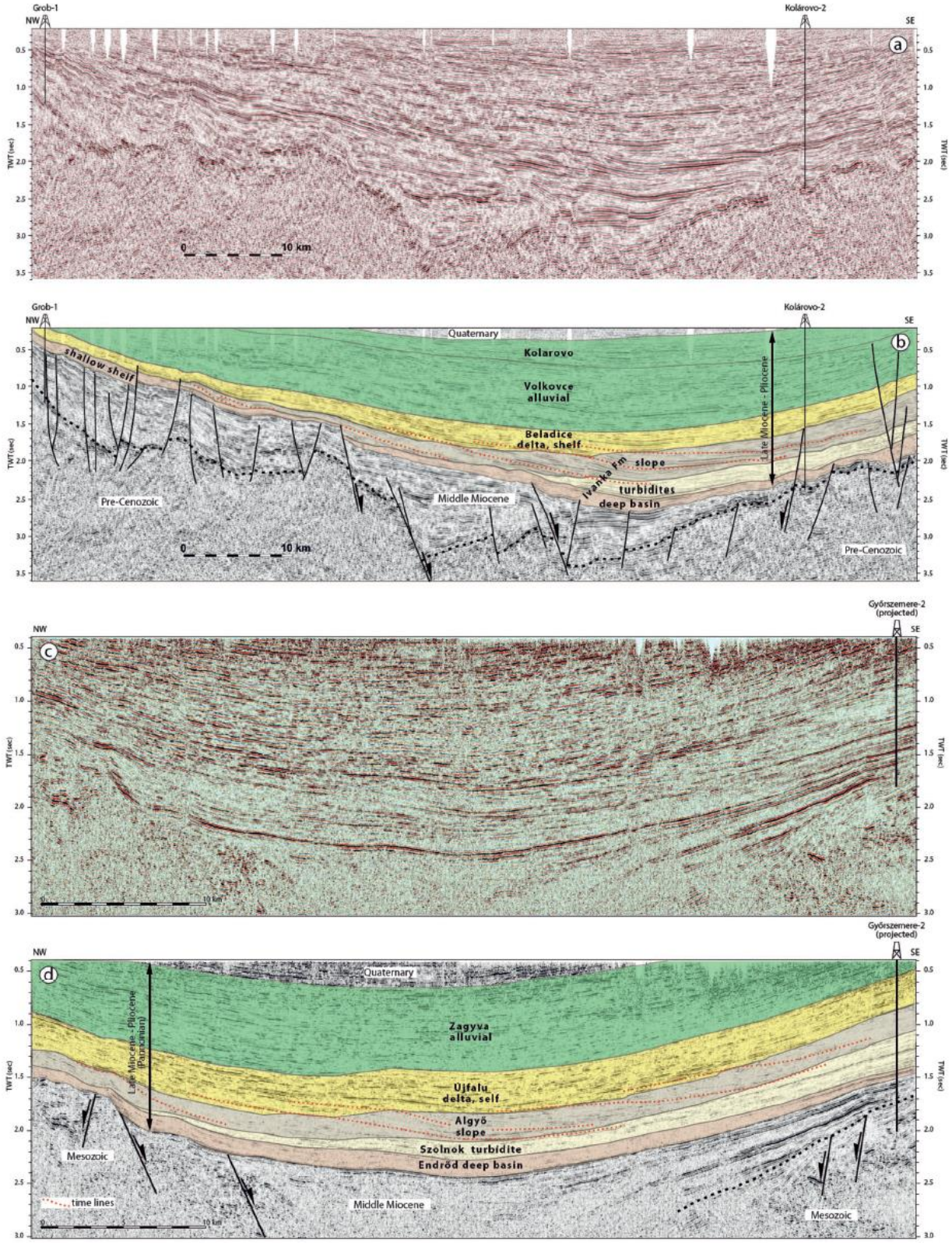


Fig. 10. Regional seismic sections 556/82-83 in Slovakia (**a**, **b**) and VPE-38 (**c**, **d**) in Hungary are oriented in a dip direction (NW-SE) in relation to the Pannonian delta progradation (Sztano et al., 2016). For location of these profiles, see Figure 9.

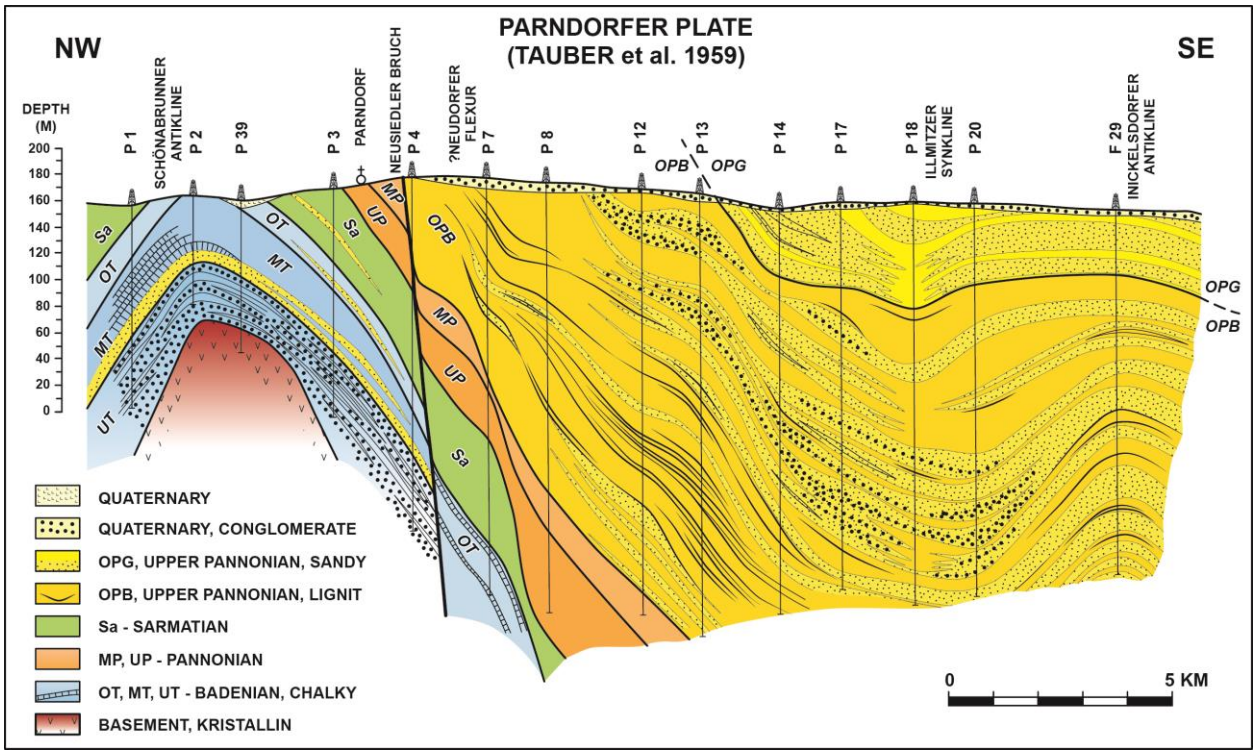


Fig. 11. Detailed geologic cross-sections based on shallow drilling to the north of the Neusiedlersee in Austria, redrafted after Tauber (1959). Note that the section is 20x overexaggerated. At this scale the dramatic truncation of the Upper Miocene to Pliocene strata at the basin margin is obvious and it is attributed to an intra-Pliocene (circa 4-5 million years ago?) period of uplift and erosion of the Pannonian basin fill (e.g. Šujan et al., 2021). The isopachous and thin (just a few m thick) Quaternary in this area clearly postdates the regional inversional period.

Description of excursion stops

Stop 1

Sopron(bánfalva), NW Nándor Hill

Lower Austroalpine basement

Location: On the western side of Sopron, at the intersection of the Ady and Szikla streets

Coordinates: 47.682385, 16.556327

Lithology:

A special rock type, leucophyllite, outcrops here in a small road-cut with dimensions of about 16 m length and about 6 m height. The leucophyllite belongs to the Sopronbánfalva Gneiss Member of the Sopron Gneiss Formation. As shown by the analytical results, the rock is almost uniformly leuchtenbergite-muscovite-quartz schist (leucophyllite) affected in varying measure by fracturing and foliation.



Location of field excursion stops.

The snow-white, excellently foliated rock easily falls apart along the cleavage planes. Accessory components: apatite, opaque ore, zircon, epidote and rutile. Quartz segregate is frequent in the leucophyllite which is locally brecciated, too. These segregates are ordinarily present in form of lenses, lying parallel to the schistosity. Along the zones of faults and fractures a slight limonitic impregnation is observed to occur in patches.

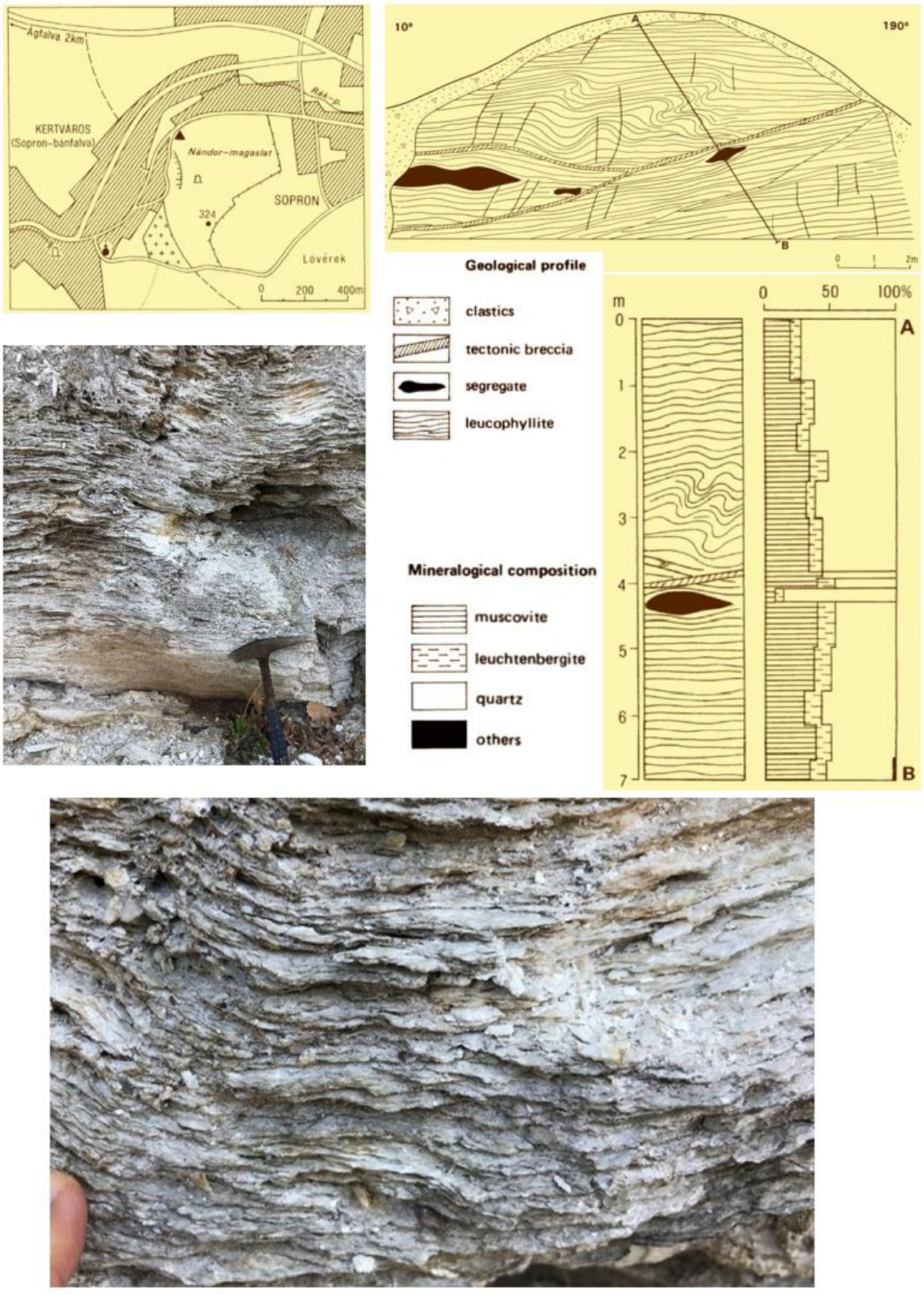
The leucophyllites, like the kyanite-quartzites to which they are related to some extent, are rocks of extraordinary origin, having been formed at considerable depth, in places most affected by tectonic deformation and fluid flow. The kyanite-quartzites seem to have been formed at a greater depth and also accompanied by a considerable increase in volatile pressure during the Alpine thrust movements. In both rock types, intensive chemical exchange of substances is inferred: essential elements, such as iron and alkalis tended to migrate out, while magnesium got enriched by in-migration. As a result of a decrease in the amount of iron, these rocks are of very light colour. Another feature they have in common is the appearance of colourless chlorite (sheridanite- or clinochlore-like leuchtenbergite) which is the principal carrier of magnesium.

The leucophyllites most frequently occur at the

contacts of the Eoalpine gneiss- and michaschist nappes. However, leucophyllite is known to have been generated along secondary thrust planes within gneiss and micaschist units, too.
Zoned transitions from the leucophyllite to the country rock beds are recognizable. The first zone represented by a gneiss of normal appearance; the microcline was converted by N-metasomatism into checkerboard-albite (muscovite-plagioclase gneiss). In the second zone, albite was altered by K-metasomatism into sericite and, in some places, phlogopite appears as well (phlogopitic muscovite-quartz schist). In the innermost zone, true leucophyllite has resulted from the appearance of leuchtenbergite at the expense of muscovite. The transition to micaschists is marked by the formation of green chlorites.
It may be guessed from the rather steep slope that the rather thick leucophyllite mass at the foot of the steep hillside is not completely autochthonous, having perhaps slipped to its present-day position partly from higher uphill (see Stop 2). Manifestations of a slight folding can be observed in several places in the outcrop.

Further reading:

Kisházi (1977); Fülöp (1990); Demény et al. (1997)



Stop 1. Leucophyllite in Sopron

Stop 2

Sopron(bánfalva), W Nándor Hill, Lower Austroalpine basement, gneiss

Location:

On the western slope of the Nandor Hill, a fairly large, abandoned quarry with an observation station of the Institute of Earth Physics and Space Science of Sopron.

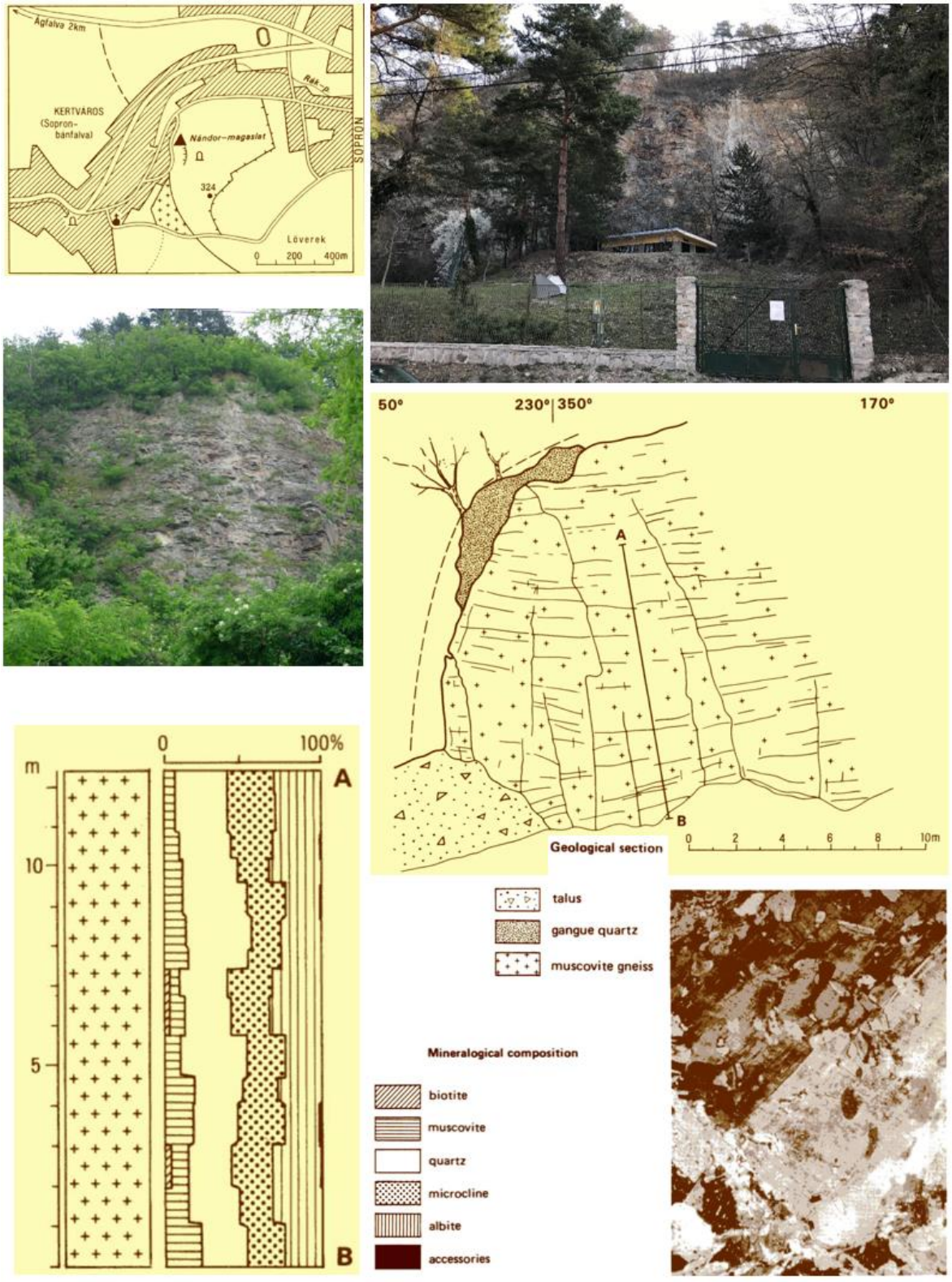
Coordinates: 47.680722, 16.556504

Lithology:

One of the finest and most typical exposures of muscovite gneiss in the Sopron Mountains is in the abandoned quarry on the W side of Nándor Hill at Sopronbánfalva. The medium-grained rock of medium-grade metamorphism is a typical representative of the Sopronbánfalva Gneiss Member of the Sopron Micaschist Formation. The quarry in the Szikla Street is a closed property owned by the Institute of Earth Physics and Space Science, and hosts a geodynamic observatory that includes a seismological station, an extensometer and a tiltmeter.
The quarry has exposed the gneiss in a length of about 150 m and a height of about 50 m, with a thin leucophyllite cap at its top. The gneiss is typically coarse-grained and scarcely schistose, however, mica-rich layers show well-developed and closely spaced foliation. Quartz veins are frequent and are emplaced along schistosity, varying from a few mm up to a few cm in thickness. The gneiss has very few mafic constituents (biotite, ore minerals), hence may be called a leucogneiss. Given the predominant mica-mineral, it may be called *muscovite gneiss.* The rock is rather acidic in composition from which the conclusion can be drawn that the plagioclase of the parent rock (granite) must have been very acidic (close to albite in composition), too. During the Variscan orogeny - probably in its later stage - granite magma of anatectic origin intruded a micaschist sequence that had already been affected by progressive metamorphism of amphibolite facies and it consolidated there as a rather acidic leucogranite. Deformation and metamorphism during the *Alpine orogeny* affected these granites together with the micaschists, resulting in the formation of a moderately schistose gneiss.
The main mineralogical components are feldspars (microcline and albite) and *quartz.* The microcline grains largely vary in size. Anyway, the largest grains in the rock are represented by microcline which often contain inclusions (plagioclase, quartz, sericite). Xenoblastic, often twinned, they are often affected by active metasomatism towards the adjacent grains (mainly albites). The albites are represented by two generations: an older and more developed one which is often twinned and dotted with inclusions (sericite, quartz, lower quantity of albite) and a younger and small-grained one with no manifestation of twinning and inclusions. Of the micas, *muscovite* is much more frequent than *biotite* and the former increases, the latter decreases in amount as the grade of metasomatism (schistosity) increases. Accessory components: *apatite, garnet, opaque mineral, rutile* and *zircon.*

Further reading:

Kisházi (1977); Fülöp (1990)



Stop 2. Muscovite gneiss in Sopron

"The wines of the Sopron area, one of the oldest wine regions of the country, were the first

Hungarian wines to achieve European fame. Celtic peasants probably cultivated vines here even before the vine-planting campaign of the Roman Emperor Probus. Sopron was most favorably sited, transport costs to Western European countries being minimal from this westerly point of the country.

The Sopron wine region comprises the vineyards in the immediate vicinity of the town also the villages of Balf, Fertörákos, Kópháza, and Magyarfalva. Red wine, made from the Kékfrankos grape, accounts for three-quarters of the produce of the whole region. The Kékfrankos is a prolific variety yielding rich crops. The must is fermented together with the crushed grape skins, which give to the must, and therefore to the wine, a beautiful, deep red colour. The pleasant tanginess of the dark, ruby-coloured Soproni Kék-frankos is due to a favorable ratio of acid and tannin. It is a harmonious and velvety wine, the alcohol content being lower than that of other Hungarian hill wines, but perhaps this is precisely why it is so popular in western Europe where wines with a low alcohol content are more common."

Kettle gulyás (Bográcsgulyás), 8 servings

2 medium-sized onions 2 tablespoons "Noble Rose" paprika

2 tablespoons lard 2 1/2 pounds beef chuck or round, cut to 3/4-inch cubes

2 green frying

1/2 pound beef heart (optional) or Italian peppers

cut to 3/4-inch cubes 1 pound potatoes 1 medium-sized tomato

1 garlic clove little Dumplings

pinch of caraway seeds salt

1. Peel onions and chop into coarse pieces. Melt lard in a heavy 6- to 8-quart Dutch oven. Saute onions in lard. Heat should be low in order not to brown the onions.

2. When onions become glossy, add beef and beef heart. Stir so that during this part of the process, which should last for about 10 minutes, the meat will be sauteed with the onions.

3. Meanwhile, chop and crush the garlic with the caraway seeds and a little salt; use the flat side of a heavy knife.

4. Take kettle from heat. Stir in paprika and the garlic mixture. Stir rapidly with a wooden spoon. Immediately after paprika is absorbed, add 2 I/2 quarts warm water. (Cold water toughens meat if you add it while the meat is frying)

5. Replace covered kettle over low heat and cook for about 1 hour.

6. While the braising is going on, peel the tomato, then cut into 1-inch pieces. Core green peppers and slice into rings. Peel potatoes and cut into 3/4-inch dice.

7. After meat has been braised for about 1 hour (the time depends on the cut of the meat), add the cut-up tomato and green peppers and enough water to give a soup consistency. Add a little salt. Simmer slowly for another 30 minutes.

8. Add potatoes and cook the gulyas till done. Adjust salt. Add hot cherry pepper pods if you want to make the stew spicy hot.

9. Cook the dumplings in the stew.

10. Serve the gulyas steaming hot in large extra-deep bowls. The meat should be tender, but not falling apart.

As far as the spicing is concerned, some cooks add a small amount of black pepper in addition to paprika; others add marjoram or bay leaf; some use a little more onion and no garlic at all. Particularly in the southern section of Hungary, fresh or dried cherry peppers are added, which puts the crown on this glorious soup for the Hungarians. For a non-Hungarian, in this case, the crown is white-hot.

Stop 3

Sopron, Brennbergbánya, Tödl, old railroad-cut, Middle Miocene clastics, syn-rift

Location:

To the W of Sopron, on the road to Brennbergbánya and about 2.5 km from Brennbergbánya is the railway-cut of Felső-Tödl.

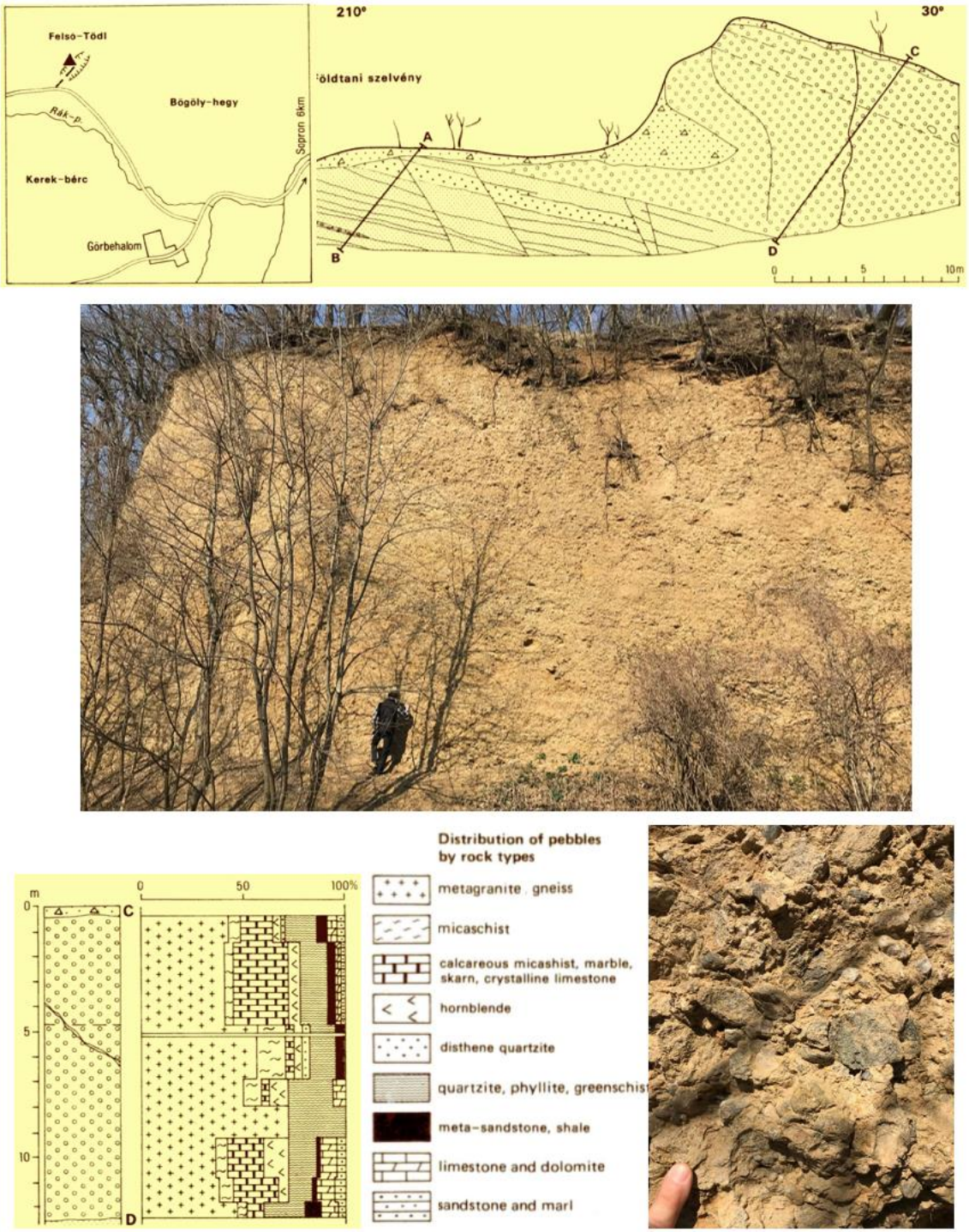
Coordinates: 47.677136, 16.490453

Lithology:

This outcrop represents the best exposure of the Middle Miocene Brennberg Gravel and the overlying Magasbérc (Hochriegel) Sand formations in the Sopron area. The finer-grained, silty-sandy deposits cropping out at the base of the gravel represent the so-called "Magasbérc Beds" that are also of Karpatian age. Thus, the exposure includes two formations: the Brennberg Block Gravel Formation and the Magasbérc Sand Formation. Both terms were proposed, at an earlier date, by Austrian geologists: the name "Brennberger Blockschotter" derives from R. Janoscheck (1931), the name "Magasbérc Beds" (Hochriegel-schichten) was proposed by A. F. Tauber (1952).

The underlying fine-grained unit has a NNE dip. The dip values measured on the cleavage planes are: 10°/15°, 22°/20°, 24°/15° and 8°/10°. Vertically, hardly any dislocation is observable. The system of minor faults or rather just cleavage planes dip at 138°/85°, 144°/65° and 160°/75°. The overlying gravel-conglomerate sequence also dips NNE, but with a slightly steeper slope.
Earlier referred to also as "underlying marl", the lower sequence is constituted mainly by fine-grained silty sandstone with varying amounts of lime segregations of infiltration and concretionary type. In some beds, even a coarsening of the grain size in form of coarse sandy or, less frequently, small-sandy layers can be observed. Each sample contains varying quantities of clay fraction, too. As far as the genetic circumstances of these finer-grained formations are concerned, a limnic or brackish-water deposition may be considered.
The coarser-grained clastic sequence of the higher horizons overlies, with some angular unconformity, the slightly undulate surface of the lower horizon which is particularly accentuated by the sudden and marked coarsening of the grain size. The pebbles are unsorted, but mostly less than 5 cm in diameter, huge blocks (sometimes even 1 m^3 in size), typical of the block-gravel horizon elsewhere, are totally absent here. The pebbles are heavily rounded for the most part, being markedly to fairly affected by tear and wear. Their distribution in terms of grain shape is as follows: squat or massive (round) 65%, elongate (cylindrical) 20% and lamellar 15%. Interestingly, a rather great percentage of the pebbles, about 40-50%, is in a heavily weathered state, falling apart quite easily into pieces when struck with a hammer. For the most part, they are quite loosely bound to one another: what holds them together is for the most part the finer interstitial clastic material in the matrix. There are, however, conglomerate-like parts too which are slightly more strongly cemented by some calcareous and limonitic cement. The stratification is almost missing, the NE dip of some of the elongated pebbles has resulted in a kind of stratification.
The pebbles are rather varied in lithology. 92% (326 pebbles) of the pebbles studied with more scrutiny are of metamorphic origin and only 8% are sedimentary. The gravel-conglomerate beds of the exposure belong, as already mentioned, to the block-gravel horizon, even if they do not represent its typical facies (true blocks are absent and the roundness of the pebbles is better than would be expected). The exact origin of this sequence is debatable, our preferred explanation is that it represents fanglomerates and braided river deposits in a syn-rift setting.

Further reading: Janoschek (1931), Tauber (1952), Tari et al. (2020)



Stop 3. Middle Miocene (Karpatian) syn-rift coarse clastics, west of Sopron

Stop 4

Piusz puszta, Sarmatian and Pannonian clastics, very close to the Austrian/Hungarian border

Location:

To the N of Sopron, on the road towards the Austrian border

Coordinates: 47.752749, 16.621753

Tectonic context:

The effect of the underlying Kőhida-fault zone on the Sarmatian-Pannonian (Miocene) sedimentation was studied in this area by Rosta (1993). The N-S directed Kőhida-fault zone is the eastern boundary of the Sopron-Eisenstadt/Kismarton Basin (NW Hungary and nearby Austria), which is bordered by crystalline basement rocks and is filled by Neogene sediments. In the enclosed, brackish basin two types of sedimentary environments were recognized. The first one is a steeply dipping, coarse grained Gilbert-type delta with two delta-cycles. The older cycle is Late Sarmatian in age and is built up by prodelta, delta front and delta plain deposits.

The younger, Early Pannonian cycle is not complete, the deltafront deposits appear only. The other sedimentary environment was recognized south of the Gilbert-delta. It is a N-S directed steep coastline with sand and pebble deposits. The older part is Upper Sarmatian and it consists of a shallowing-coarsening upward sequence. The younger, upward deepening part is Lower Pannonian and is built up by sandy formations which were deposited partly by gravity flows in a steep, coastal environment.

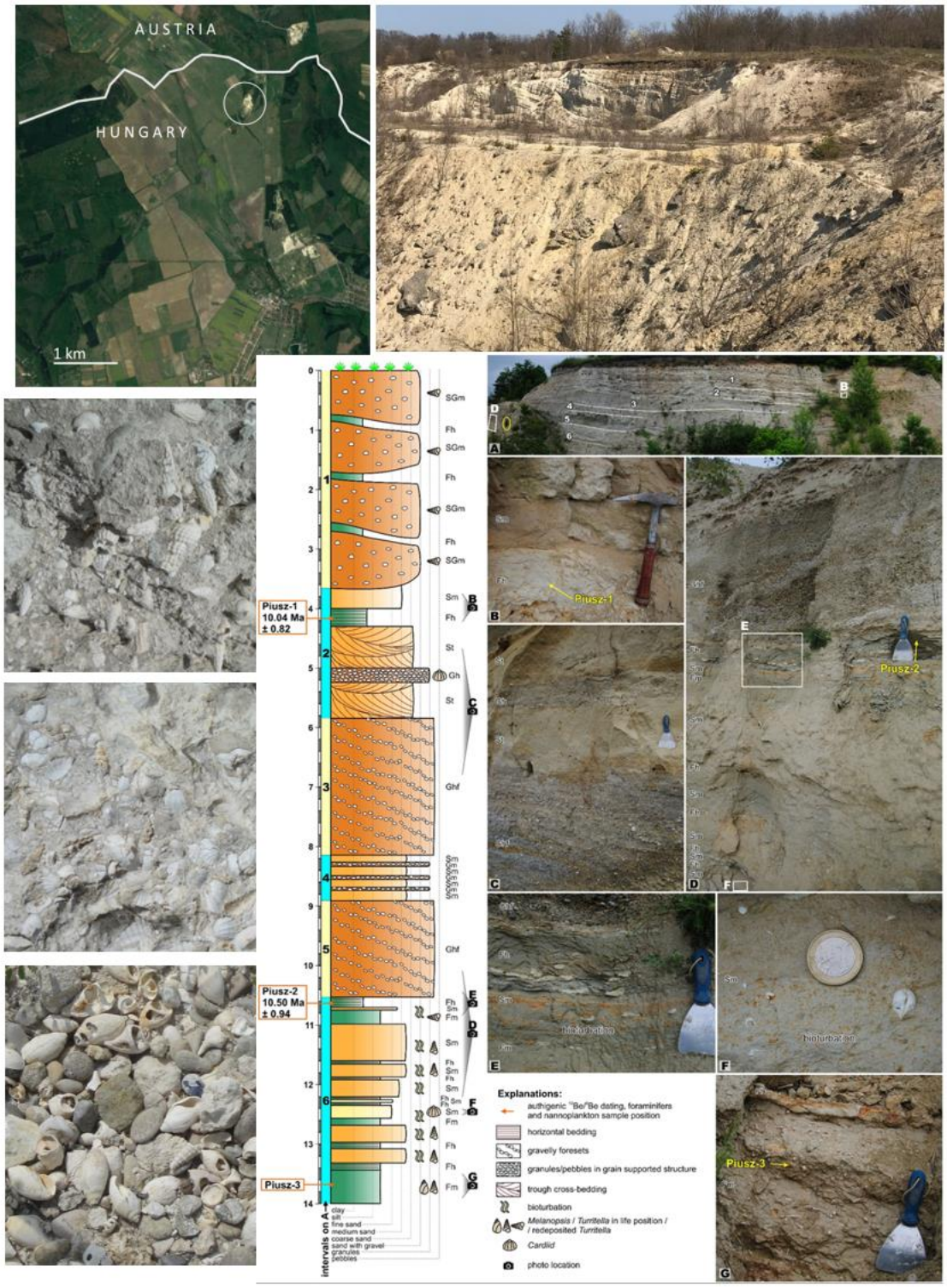
The steep morphology was developed by the N—S directed Kőhida-fault zone. During the Sarmatian normal faulting with dextral strike-slip component forced NW progradation of the deltafront, then in the Lower Pannonian NNE directed progradation occurred as a result of the modified stress direction. At the Sarmatian-Pannonian boundary the accommodation space decreased in both environments. It might have been caused by break or decrease in the activity of the fault zone, and/or by eustatic sea level fall.

Lithology:

The outcrop exposes gravel and sand of a Gilbert-type delta in its lower part. Frequently found marine molluscs indicate marine conditions. The gravel pass into foreshore and shoreface sand towards the top of the lower section. The mollusc fauna is indicative for the late Sarmatian *Sarmatimactra* Zone. The upper level of the outcrop is predominated by pinkish peloidal carbonates intercalated by gravel layers. During minor transgressions of the Paratethys Sea, the delta plain was flooded and intertidal carbonates formed, settled by potamidid gastropods. Caliche formation is frequent and traces of roots indicate emersion.

An exceptional feature are serpulid-microbial buildups. In the uppermost part of the upper section, gravel and reworked Sarmatian carbonate sand yield shells of the gastropod *Melanopsis*, which dwelled in Lake Pannon. Thus, after a hiatus of about 200 kyr, Lake Pannon flooded the area during the late Miocene and intensively reworked Sarmatian deposits. Therefore, the Sarmatian/Pannonian boundary is difficult to define on lithological criteria alone.

Further reading: Rosta (1993), Harzhauser and Kowalke (2002), Harzhauser and Mandic (2019), Sujan et al. (2018)



Stop 4. Upper Miocene (Sarmatian-Pannonian) post-rift clastics to north of Sopron

Stop 5

St. Georgen sand quarry, deformed succession of Middle Miocene calcareous sandstone, limestone, arkosic sandstone. Spectacular deformation bands.

Location:

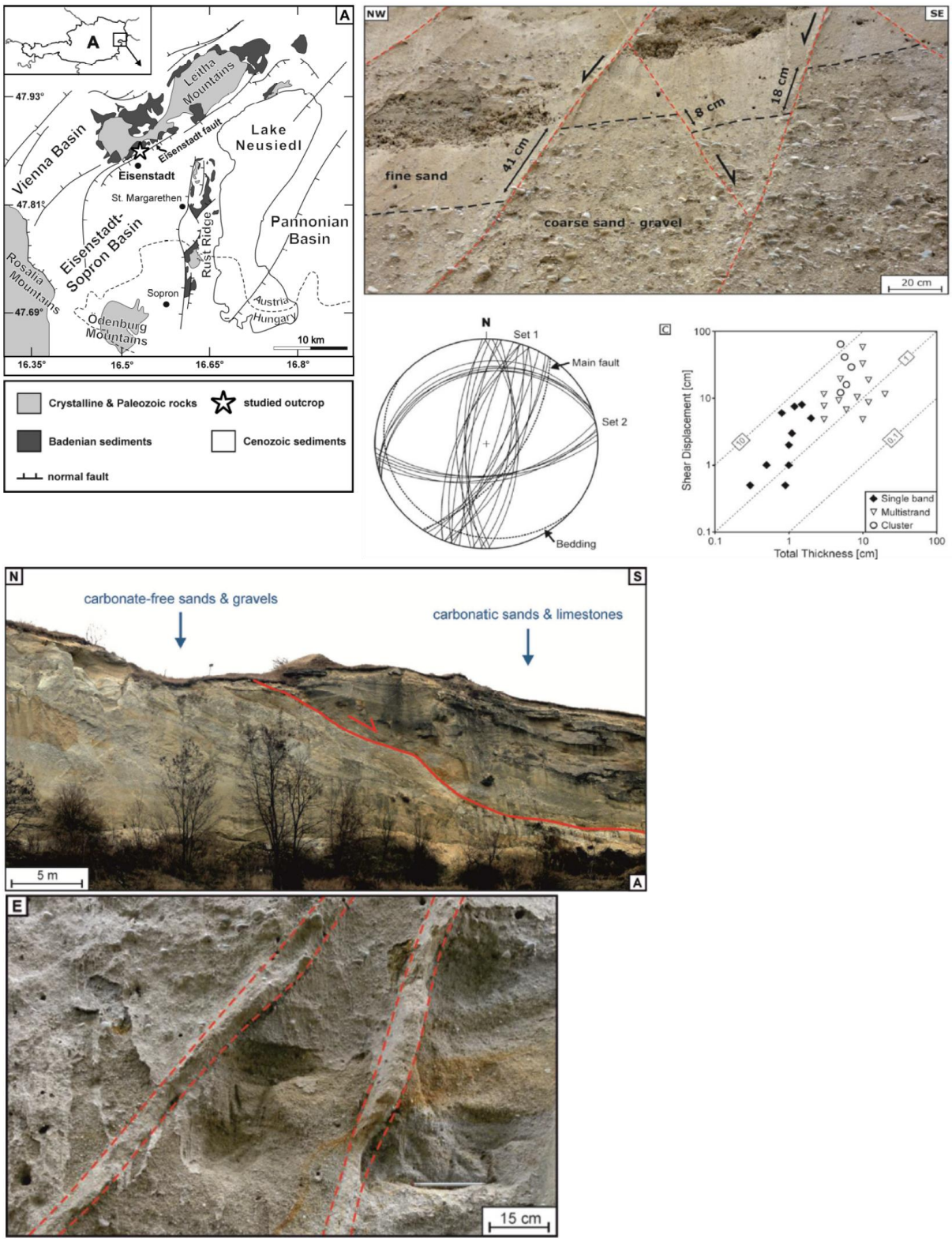
Abandoned sandpit near Eisenstadt, located at the northern margin of the Eisenstadt-Sopron Basin.

Coordinates: 47°51’29.94’’N; 16°32’25.84’’E
Lithology: Middle Miocene calcareous sandstone, limestone, arkosic sandstone

The outcrop is an abandoned sand pit and located at the south-eastern margin of the Leitha Mountains (see Figure Stop 5). The Leitha Mountains represent a NE–SW trending horst with locally exposed metamorphic rocks and a sedimentary cover, stretching along the south-eastern margin of the Vienna Basin. The Leitha Mountains is bounded towards the SE by the Eisenstadt Fault, a significant normal fault that was active until Pliocene times, thus postdating the deposition of the exposed Miocene lithologies in the quarry. The lithologies in the quarry are also cut by a normal fault, which is subparallel with the larger Eisenstadt Fault (see Figure Stop 5). The exposed normal fault separates carbonate-rich beds (calcareous sands intercalated with limestones) in the hanging wall and carbonate-free fluvial sediments in the footwall. The exposed units have experienced only shallow (< 1 km) burial.

The outcrop and especially the footwall unit exhibit a spectacular array of deformation bands, a typical structural feature of poorly consolidated sedimentary formations. Deformation bands form in highly porous sediments, where the pore space facilitates grain reorganization and grain fracturing (cataclasis) along tabular zones of deformation. The deformation bands in this particular case are characterized by a porosity and permeability reduction caused by grain fracturing and cementation. Deformation bands formed in extension, mimicking the larger scale Eisenstadt fault system. The deformation bands formed via dilation (negative compaction), which resulted in an initial 4-6 % porosity increase in the centre of the bands. Dilatant shear bands generally form at low confining pressures whereas compactional shear bands form at higher confining pressures. The new pore space localized fluid flow and was largely filled by carbonate cement, creating low-porosity bands eventually (around -8% porosity with respect to the original). Cementation was syn-kinematic and caused the hardening of the deformation bands, probably contributing to the migration of deformation. Understanding and possibly predicting porosity and permeability changes due to deformation band evolution is a key aspect of fluid flow patterns in siliciclastic reservoirs.

Further reading: Lommatzsch et al. (2015); Fossen et al. (2017)



Stop 5. St. Georgen sand quarry exhibiting a deformed Upper Miocene (Badenian) sedimentary sequence (illustrations from Lommatzsch et al., 2015).

Paprika chicken (Paprikás csirke), 4 servings

2 medium-sized onions, peeled

1 heaping tablespoon and minced "Noble Rose" paprika

2 tablespoons lard

1 teaspoon salt

1 plump chicken, about 3 pounds, disjointed, washed and cut into pieces

2 tablespoons sour cream

1 green pepper sliced

1 tablespoon flour

1 large ripe tomato, peeled

2 tbls heavy cream

Egg Dumplings

1. Use a 4- or 5-quart heavy casserole with a tight-fitting lid. Cook the onions in the lard, covered, over low heat for about 5 minutes. They should become almost pasty, but definitely not browned.

2. Add chicken and tomato and cook, covered, for 10 minutes.

3. Stir in paprika. Add l/2 cup water and the salt. Cook, covered, over very low heat for 30 minutes. In the beginning, the small amount of water will create a steam-cooking action. Toward the end of the 30-minute period, take off lid and let the liquid evaporate. Finally let the chicken cook in its own juices and fat, taking care that it does not burn. (If the chicken is tough, you may have to add a few more tablespoons of water).

4. Remove chicken pieces. Mix the sour cream, flour and 1 teaspoon cold water, and stir in with the sauce till it is very smooth and of an even color. Add green pepper, replace chicken parts, adjust salt. Put lid back on casserole and over very low heat cook until done.

5. Just before serving whip in the heavy cream. Serve with egg dumplings.

NOTE: The combination of sour cream and heavy cream is the almost forgotten, but ideal way to prepare this dish. These days typically the heavy cream is omitted. ln Hungary, the lily is gilded by spreading several tablespoons of additional sour cream on top of the chicken in the serving platter.

Stop 6

Fertőboz, Pannonian outcrop close to the main road

Location:

At the western end of the village of Fertőboz, abandoned quarry on the southern side of the main road around the lake.

Coordinates: 47.637509, 16.692368

Lithology and tectonic significance:

The outcrop portrays the typical expression of the Pannonian sequence assigned to the Újfalu Formation. Cross-bedded loose sands dominate the outcrop with some intercalations of marls and clays. The deposition of this sequence occurred in very shallow water, near-coastal or even delta-plain, fluvial environments. A detailed sedimentological description of this particular Pannonian outcrop is missing at this point.

Note the presence of numerous Liesegang bands across the entire outcrop which is quite typical for almost any Pannonian outcrop in the broader region. These developed in a very "picturesque" manner in brown bands of iron oxide that entirely 'ignore' the original bedding of the sands and seemingly precipitated in consecutive "waves" moving across the very permeable Pannonian strata.

In general, Liesegang bands are poorly understood chemical structures often seen in rocks, especially sandstones. They were discovered more than a hundred years ago by the German chemist Raphael E. Liesegang, when he accidentally dropped a drop of silver nitrate solution on a layer of gel containing potassium dichromate, and concentric

rings of silver dichromate started to form. In sedimentary rocks, Liesegang bands appear well after the sediment has become a rock (that is, it got compacted and cemented). Stratification and lamination within the sandstone are typically crosscut by the Liesegang bands while fractures usually have a more obvious effect on the distribution and orientation of them.

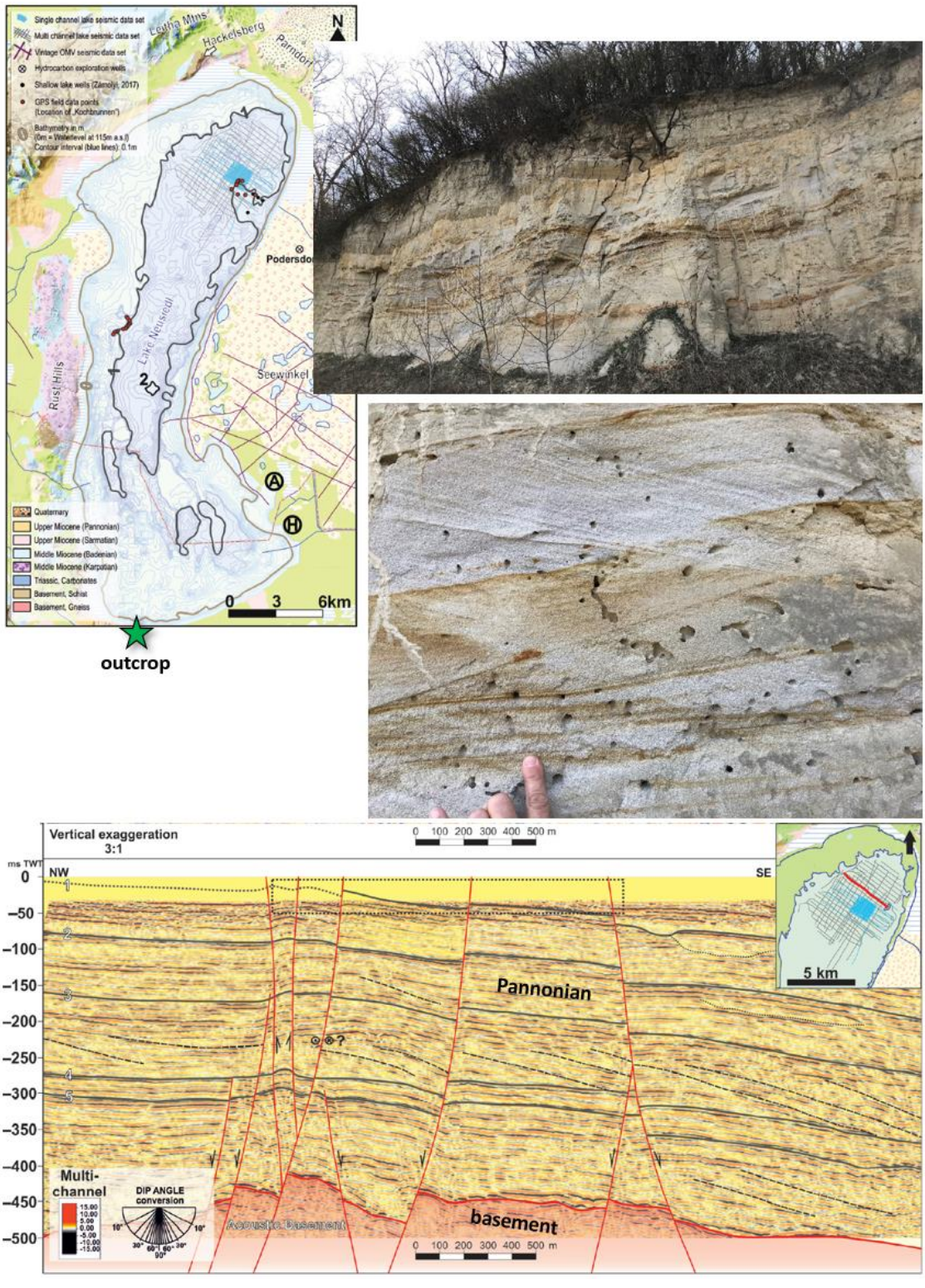
Lake Neusiedl (Hungarian: Fertő-tó), straddling the border between Austria and Hungary in the northwest Pannonian Basin, covers an area of approximately 320 km2, including the extensive reed areas along its margin. The lake is the second largest lake in the Pannonian Basin located in the transition zone between the Eastern Alps, Carpathians, and the Pannonian Basin, which forms a complex deformation zone that has been active since the Early Miocene (Cloething et al., 2002). For the geodynamic setting, formation, age, and evolution of Lake Neusiedl, the reader is referred to the recent summaries by Zámolyi et al. (2017) and Loisl et al. (2018).

The lowland around the lake is very poor in outcrops; therefore, the geologic investigation of the sediments and deformation structures is limited. With an average water depth of approximately 1.4 m, Lake Neusiedl is an exceptionally shallow lake, and therefore it is an ideal testing site for seismic acquisition in the so-called transition zones, representing in this context an area of shallow water between onshore and offshore environments.

A combination of single- and multichannel seismic reflection data of approximately 400+ km was collected on Lake Neusiedl in May 2013 (Loisl et al., 2018). The one-week-long geophysical campaign was a multinational academic effort among the Universities of Vienna, Budapest, Bremen, and Southampton. The project was funded by OMV as a pilot study to test the latest technology in the "transition zone" between onshore and offshore. The multichannel lake seismic section shown in TWT, vertically exaggerated 3:1. Tectonic and sedimentary features down to a major nonconformity at the base (pre-Cenozoic basement) can be observed. Reflector terminations and vertically offset reflector packages indicate normal faults, often affecting the entire seismic section. The fault zone in the northwest indicates a minor reverse displacement interpreted as a slightly transpressive structure (positive flower structure?).

Reflectors dipping at higher angles than the overall regional dip are interpreted as clinoforms of a southeastward prograding system (dashed lines). Above the key horizon, two paleoriverbeds and channel incisions can be mapped indicating basin inversion, regional uplift and truncation of the Pannonian sequence as early as the Pleistocene.

Further reading: Cloething et al. (2002), Zámolyi et al. (2017), Loisl et al. (2018), Sujan et al. (2018)



Stop 6. Uppermost Miocene to Pliocene (Pannonian) sand outcrop near Fertőboz. The high-resolution 2D seismic illustration of age equivalent rocks imaged beneath the nearby Neusiedlersee/Fertő Lake in the Austrian side is adopted from Loisl et al. (2018). Assuming a 2000 m/s average velocity the two-way travel time scale translates directly to depth in meters. Please note that V:H=3.

References

Bada, G., Horváth, F., Dövényi, P., Szafián, P., Windhoffer, G., & Cloetingh, S. (2007). Present-day stress field and tectonic inversion in the Pannonian basin. *Global and Planetary Change*, *58*(1-4), 165-180.
Balázs, A., L. Matenco, I. Magyar, F. Horváth, and S. Cloetingh (2016), The link between tectonics and sedimentation in back- arc basins: New genetic constraints from the analysis of the Pannonian Basin. *Tectonics*, *35*(6), 1526-1559.
Balogh, K. & I. Dunkl (2005), Argon and fission track dating of Alpine metamorphism and basement exhumation in the Sopron Mts. (Eastern Alps, Hungary): thermochronology or mineral growth? *Mineralogy and Petrology*, *83*(3), 191-218.
Békési, E., K. Porkoláb, V. Wesztergom, and Z. Wéber (2023), Updated stress dataset of the Circum-Pannonian region: Implications for regional tectonics and geo-energy applications. *Tectonophysics*, *856*, 229860.
Cao, S., F. Neubauer, M. Bernroider, J. Liu, and J. Genser (2013), Structures, microfabrics and textures of the Cordilleran-type Rechnitz metamorphic core complex, Eastern Alps. *Tectonophysics*, *608*, 1201-1225.
Cloethingh, A. P. L., F. Horvath, G. Bada, and A. C. Lankreijer, 2002, Neotectonics and surface processes: The Pannonian Basin and Alpine/Carpathian system, EGU Stephan Mueller Special Publication Series
Dunkl, I., B. Grasemann, and W. Frisch (1998), Thermal effects of exhumation of a metamorphic core complex on hanging wall syn-rift sediments: an example from the Rechnitz Window, Eastern Alps. *Tectonophysics*, *297*(1-4), 31-50.
Fülöp, J., 1990. Geology of Hungary, Paleozoic I. In Hungarian. Hung. Geol. Inst., Budapest, 326 p.
Fossen, H., R. Soliva, G. Ballas, B. Trzaskos, C. Cavalcante, and R. A. Schultz (2018), A review of deformation bands in reservoir sandstones: geometries, mechanisms and distribution.
Gundel, K., 1994. Gundel's Hungarian Cookbook, Corvina, Budapest, 136 p.
Halász, Z., 1981. The Book of Hungarian Wines. Corvina, 212 p.
Harzhauser, M. and Kowalke, T. 2002. Sarmatian (Late Middle Miocene) Gastropod assemblages of the Central Paratethys. Facies, 46, 57-82.
Harzhauser, M. and Mandic, O., 2019. AAPG Vienna field trip guide book
Horváth, G. Tari, and Bokor, Cs. (1995), Extensional Collapse of the Alpine Orogene and Hydrocarbon Prospects in the Basement and Basement Fill of the Western Pannonian Basin. AAPG International Conference and Exhibition, Nice, France, Guidebook to Fieldtrip No. 6, Hungary
Horváth, F. (1995), Phases of compression during the evolution of the Pannonian Basin and its bearing on hydrocarbon exploration. *Marine and Petroleum Geology*, *12*(8), 837-844.
Horváth, F. & S. Cloetingh (1996), Stress-induced late-stage subsidence anomalies in the Pannonian basin. *Tectonophysics*, *266*(1-4), 287-300.
Horváth, F., G. Bada, P. Szafián, G. Tari, A. Ádám, and S. Cloetingh (2006), Formation and deformation of the Pannonian Basin: constraints from observational data. *Geological Society, London, Memoirs*, *32*(1), 191-206.
Janoschek, R., 1931. Die Geschichte des Nordrandes der Landseer Bucht im Jungtertiär (mittleres Burgenland). Mitt. Geol. Ges. Wien, 24: 38-133.
Kisházi, P., 1977. Contributions to the knowledge of metamorphic rocks of Sopron Hills (Western Hungary). Verh. Geol. B.-A., 35-43.
Koller, F., 1985. Petrologie und Geochemie der Ophiolite des Penninikums am Alpenostrand. Jb. Geol. B.-A., 128: 83-150.
Kubovics, I. 1983. Petrological characteristics and genetic features of crossitite from western Hungary. In Hungarian with English abstract. Földt. Közl., 113: 207-224.
Lang, G., 1994. Cuisine of Hungary. Random House, New York, 495 p.
Loisl, J., Tari, G., Draganits, E., Zámolyi, A., and Gjerazi, I. (2018). High-resolution seismic reflection data acquisition and interpretation, Lake Neusiedl, Austria, northwest Pannonian Basin. Interpretation, 6(1), SB77-SB97.
Lommatzsch, M., U. Exner, S. Gier, and B. Grasemann (2015), Dilatant shear band formation and diagenesis in calcareous, arkosic sandstones, Vienna Basin (Austria). *Marine and petroleum geology*, *62*, 144-160.
Magyar, I., Radivojević, D., Sztanó, O., Synak, R., Ujszászi, K., & Pócsik, M. (2013). Progradation of the paleo-Danube shelf margin across the Pannonian Basin during the Late Miocene and Early Pliocene. *Global and Planetary Change*, *103*, 168-173.
Magyar, I., C. Krezsek, and G. Tari, 2020, Clinoforms as paleogeographic tools: Development of the Danube catchment above the deep Paratethyan basins in Central and Southeast Europe. *Basin Research*, 32, 320–331.

Oravecz, J., 1979. Geologische Untersuchung des Cáker Konglomerates. In Hungarian with German abstract. Földt. Közl., 109: 14-45.
Porkoláb, K., T. Broerse, A. Kenyeres, E. Békési, S. Tóth, B. Magyar, and V. Wesztergom (2023), Active tectonics of the Circum-Pannonian region in the light of updated GNSS network data. *Acta Geodaetica et Geophysica*, 1-25.
Porkoláb, K., E. Békési, E. Győri, T. Broerse, B. Czecze, A. Kenyeres, G. Tari, and Z. Wéber (2024), Present-day stress field, strain rate field and seismicity of the Pannonian region: overview and integrated analysis. *Geological Society, London, Special Publications, 554*(1), SP554-2023-2219.
Ratschbacher, L., J. H. Behrmann, and A. Pahr, 1990, Penninic windows at the eastern end of the Alps and their relation to the intra-Carpathian basins: *Tectonophysics,* 172, 91–105.
Rosta, E., 1993. Gilbert-type delta in the Sarmatian/Pannonian sediments, Sopron, NW Hungary. Földt. Közl., 123: 167-193.
Schmid, S. M., D. Bernoulli, B. Fügenschuh, L. Matenco, S. Schefer, R. Schuster, M. Tischler, and K. Ustaszewski (2008), The Alpine-Carpathian-Dinaridic orogenic system: correlation and evolution of tectonic units. *Swiss Journal of Geosciences, 101*(1), 139-183.
Šujan, M., Braucher, R., Rybár, S., Maglay, J., Nagy, A., Fordinál, K., ... & ASTER Team. (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, 131-146.
Sztanó, O., Kovac, M., Magyar, I., Sujan, M., Fodor, L., Uhrin, A., ... & Tőkés, L. (2016). Late Miocene sedimentary record of the Danube/Kisalföld Basin: interregional correlation of depositional systems, stratigraphy and structural evolution. *Geologica Carpathica*, *67*(6), 525-542.
Šujan, M., Rybár, S., Kováč, M., Bielik, M., Majcin, D., Minár, J., ... & Kotulová, J. (2021). The polyphase rifting and inversion of the Danube Basin revised. *Global and Planetary Change*, *196*, 103375.
Tari, G., and A. W. Bally, 1990, Metamorphic core complexes at the boundary of the Eastern Alps and the Pannonian basin. Geological Society of America Abstracts with Programs, 22, 97–98.
Tari, G. C. (1994), Alpine tectonics of the Pannonian Basin, PhD Thesis, Rice University, 501 p.
Tari, G. (1996a). Extreme crustal extension in the Rába River extensional corridor (Austria/Hungary). Mitt. Ges. Geol. Bergbaustud. Österr., 41: 1-17.
Tari, G. and Horváth, F., (2006). Alpine evolution and hydrocarbon geology of the Pannonian Basin: an overview. In: Jan Golonka and Frank Picha (Editors), The Carpathians and their Foreland: Geology and Hydrocarbon Resources. *AAPG Memoir*, 84: 605-618.
Tari, G. C., Gjerazi, I., & Grasemann, B. (2020). Interpretation of vintage 2D seismic reflection data along the Austrian-Hungarian border: Subsurface expression of the Rechnitz metamorphic core complex. *Interpretation*, *8*(4), SQ73-SQ91.
Tari, G., Bada, G., Beidinger, A., Csizmeg, J., Danišik, M., Gjerazi, I., ... & Szafián, P. (2021). The connection between the Alps and the Carpathians beneath the Pannonian Basin: Selective reactivation of Alpine nappe contacts during Miocene extension. *Global and Planetary Change*, *197*, 103401.
Tauber, A. F., 1959, Grundzüge der Tektonik des Neusiedlerseegebietes, *Wissenschaftliche Arbeiten aus dem Burgenland*, 23, 26–31.
Zámolyi, A., B. Salcher, E. Draganits, U. Exner, M. Wagreich, S. Gier, M. Fiebig, J. Lomax, G. Surányi, M. Diel, and F. Zámolyi, 2017, Latest Pannonian and quaternary evolution at the transition between Eastern Alps and Pannonian Basin: New insights from geophysical, sedimentological and geochronological data. International Journal of Earth Science, 106, 1695–1721.