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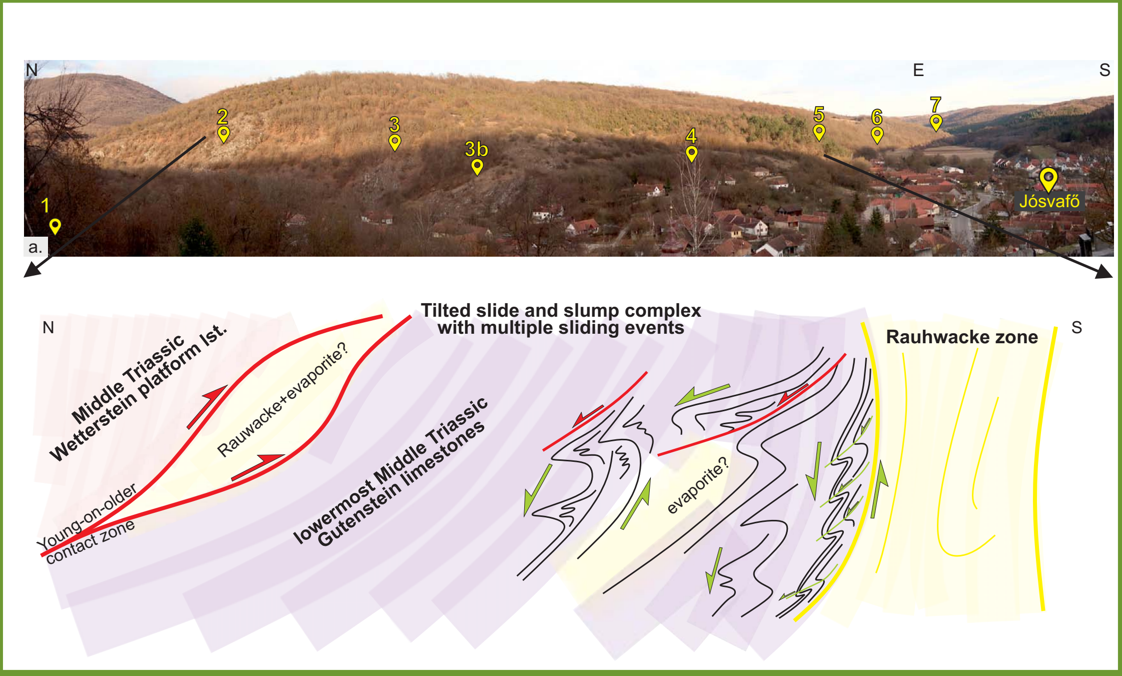
László FODOR, Éva ORAVECZ, György LESS, Szilvia KÖVÉR:

Pre-conference excursion: From rifted margin to nappe stacking: Permo-Mesozoic structural evolution of the Aggtelek and Northern Rudabánya Hills. (spotlight on salt tectonics and nappe stacking)

Post-conference excurstion: From Triassic rifted margin sequences to Jurassic deep marine sediments: nappe stacking in the Southern Rudabánya Hills and Aggtelek margins

CETEG 2023 PRE- AND POST-CONFERENCE FIELD TRIP GUIDE



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On the cover: Panoramic view and interpretation of the evaporite-related structures near Jósvafő
On the back: Two cross-sections from the central part of the Rudabánya Hills

19^{th} Meeting of the Central European Tectonic Studies Group (CETeG)

$12\text{-}15^{th}$ April, 2023

Kazincbarcika, NE Hungary

Pre- and post-conferece field trip guide book

Structure and evolution of the Aggtelek and Rudabánya Hills, NE Hungary

Guidebook for pre- and post-conference excursions related to the CETEG 2023 Meeting, Kazincbarcika, Hungary

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1. General introduction to the pre- and post-conference excursions

NE Hungary does not offer large and spectacular outcrops. However, decade-long thorough geological research revealed a very complex Mesozoic stratigraphy and structure of the area. One of the main results was the recognition of the nappe structure of the area (Grill et al. 1984, Less et al. 1988, 2006) which makes the connection to the inner units of the Western Carpathians.

Our knowledge on rifted and passive margins have changed considerably during the last decades due to geophysical data from present-day margins, but also from field works on fossil margins of the Alps (Manatschal & Müntener, 2009; Mohn et al., 2011, 2014), combined with the better understanding of subduction, metamorphism and exhumation of rifted margin blocks. This multidisciplinary approach is particularly useful and necessary when considering the Alpine-Carpathian-Dinaridic realm as a whole and lessons can be taken from better studied or outcropping orogens/mountains. One of the results was the model of Schmid et al. (2008) and the implementation (albeit with slightly different results) of their logic in interpretations of tectonic processes. Many attempts were made to apply their findings and interpretations to the poorly outcropped Aggtelek-Rudabánya area, which led to some modifications of former (tectonic) models. In this volume, and during the conference, you will see some of the results we have obtained and directions to be followed in near future.

The newest developments are connected to the analysis of halokinetic structures. The models presented in this volume are working model styles, and definitely draw analogies from the Northern Calcareous Alps (Granado et al., 2018; Strauss et al., 2020; Fernandez et al., 2022). We are our way to better understand the role of salt tectonics in the Triassic facies distribution and its control on the latest Jurassic to Cretaceous orogenic structure. This early step explains our enthusiasm, and also the non-matured character of our conclusions and models. Let us hope that the field trip and conference will also contribute to mature concepts.

Research does not stop at boundaries, and knowledge is often larger on the other sides. The intention of this volume is equally to reheat our former cooperation between scientists for the Carpathian and Alpine community, because our understanding alone is limited and will remain so without open-minded cooperation.

This guidebook contains relevant information about the geologic structure of the Aggtelek–Rudabánya Hills compiling some older concepts and new ideas. Purposely we present these different solutions, (referring sometimes as “concept of Less”, and “and concept of Fodor-Kövér”) just to clarify that (1) there is no unique solution, and (2) views, models explain some, but not all aspects of the geological observations. This dichotomy of interpretation will be kept in the entire text. After a long introductory part (Chapters 2-4) the stops of the excursions are described later in Chapter 5, referring back to the previous parts. Consume this volume according to your interest and geological appetite

.

2. Introduction

2.1. Rifted margins in some recent publications

As the first element of the Wilson cycle, continental rifting is one of the most important processes on Earth (Wilson, 1966), yet many aspects of it are still poorly understood. Early pure shear (McKenzie, 1978) and simple shear (Wernicke, 1985) models provided good approximations to how symmetric and asymmetric rift can form, they were, however, unable to explain natural observations like exhumation of sub-continental mantle rocks, far-travelled extensional allochtonous units and drastic thinning of the lithosphere within a narrow zone. The pure shear and simple shear models are now considered to be the two end members of the rifting process, and the latest rifting models interpret the continental rifting as a polyphase process that alternately applies both of mechanisms (Lavier & Manatschal, 2006; Peron-Pinvidic & Manatschal, 2010; Huismans & Beaumont, 2011; Haupert et al., 2016). In this chapter, we give a brief introduction to the internal structure of passive margins and temporal evolution of continental rifts and ocean-continent transition zones.

Based on the enormous seismic data acquired in hydrocarbon producing passive margins during the last decades, Peron-Pinvidic et al. (2013) subdivided continental rifts into proximal, necking, distal and outer domains (Figure 1). There is no sharp boundary between these domains, but they generally represent different spatial and temporal segments of the rifting process.

Closest to the undeformed part of the continental crust, the proximal domain shows the least amount of thinning and represents the earliest phase of rifting. The predominant structures of this zone asymmetric half grabens and symmetric horst-and-graben structures with wedging syn-rift sedimentary fills, bounded by relatively low-offset high-angle normal faults (Figure 2). The resulting deformation geometry is the closest to the pure-shear rifting model (McKenzie, 1978) and it affects the whole width of the rifted margin, however, the subsequent rifting processes overprint these early extensional structures in other more extended domains. In contrast, the continental crust undergoes drastic thinning and the MOHO rapidly emerges to shallow depth in the narrow zone (usually not wider than a few 10 km) of the necking domain. Hyperextension occurs when the crust thins below 10 km, also marked by the taper break point (Osmundsen & Redfield, 2011; Peron-Pinvidic et al., 2013). This drastic thinning is achieved by low-angle detachment faults, also called thinning faults, which often show more than 10 km displacement and can cut through the whole crust (Figure 2, Sutra et al., 2013; Peron-Pinvidic & Manatschal, 2010).

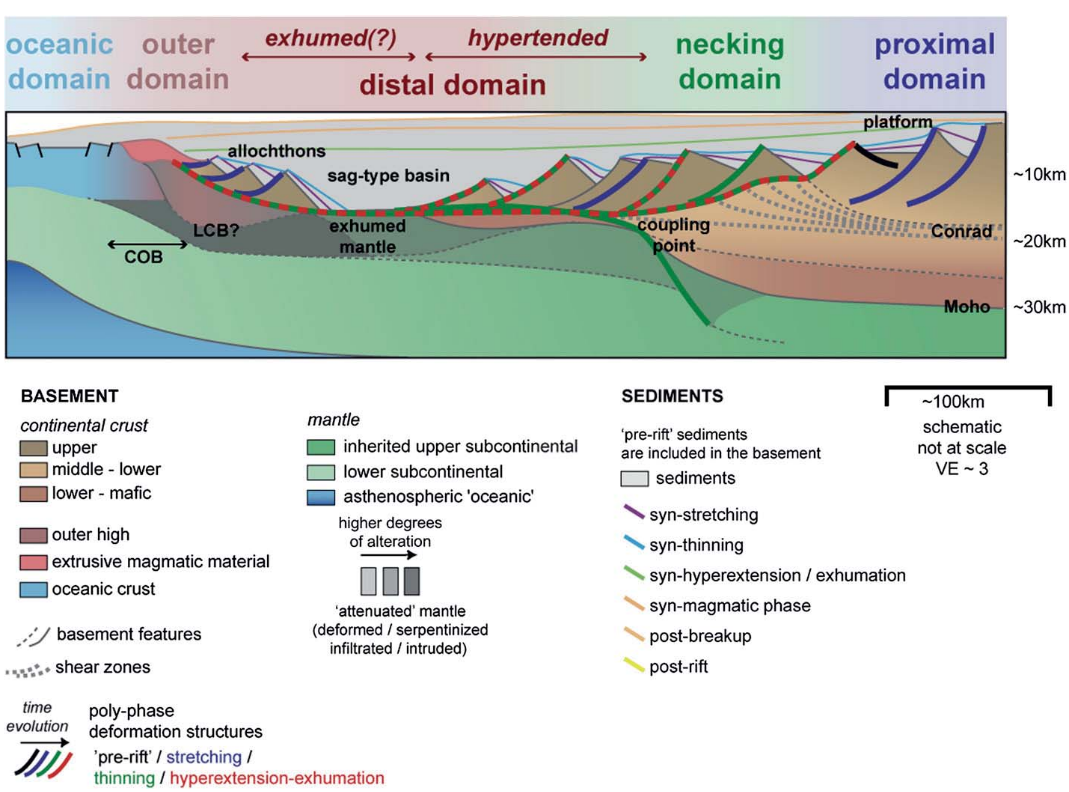

Figure 1. Schematic cross section through a passive margin (Péron-Pinvidic et al., 2013). COB=Continent-ocean boundary; LCB=Lower crustal bodies.

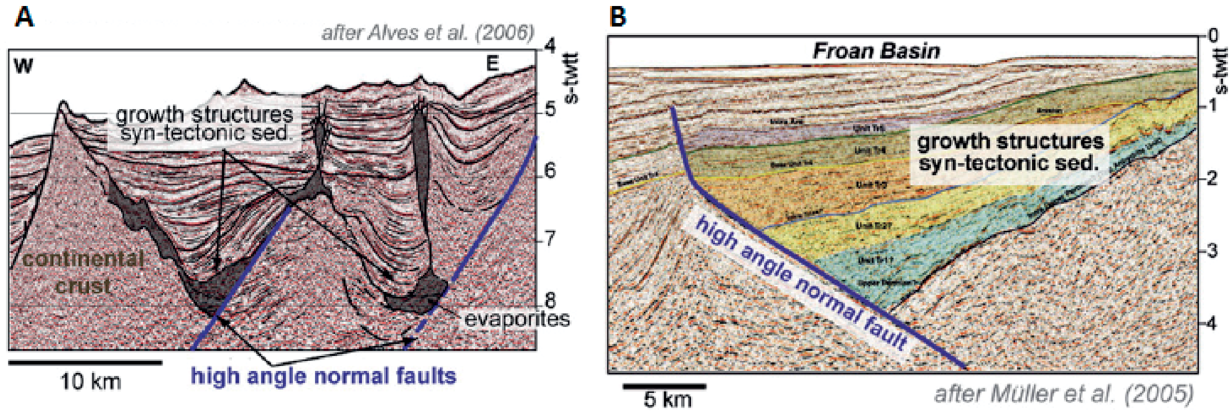

Figure 2. Characteristic structures in the proximal and necking domains of rifted margins. Up) Low-offset high-angle normal fault in the proximal domain, with wedging syn-rift sedimentary infill in the related half graben. Down) High-offset listric normal faults in the necking domain, cross-cutting the entire crust

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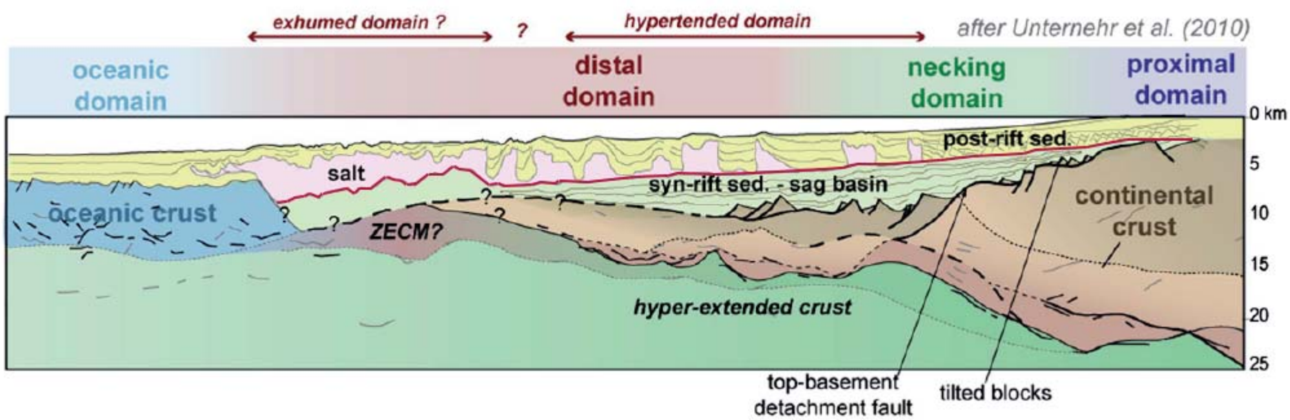

Figure 3. Seismic section from the Norwegian margin, showing rapid crustal thinning and exhumation of mantle rocks in the distal domain (Peron-Pinvidic et al., 2013). ZECM=Zone of Exhumed Continental Mantle

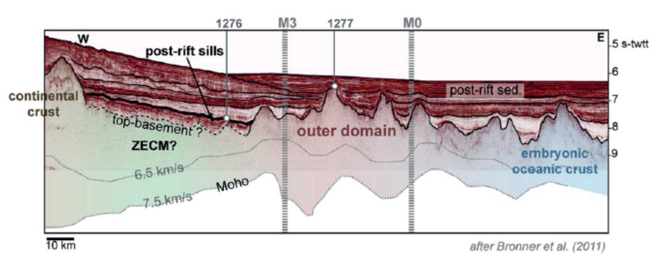

Figure 4. Outer and oceanic domains on a seismic section from the Newfoundland margin (Péron-Pinvidic et al., 2013). ZECM=Zone of Exhumed Continental Mantle

The distal domains, also called as exhumed mantle domains and/or hyperextension domains, are the transitional zones between the continents and oceans, and represent a mature phase of the rifting process (Péron-Pinvidic et al., 2013). Accordingly, most of the deformation is accommodated by shear zones crossing through the deeper parts of the crust, while the upper crustal deformation is very limited. The characteristic structures are very large-offset detachment faults that exhume lower crustal and mantle rocks in their footwalls (metamorphic core complexes, Figure 3, Lavier & Manatschal, 2006). One of the most interesting structures of the distal domains are the so-called extensional allocthons, i.e. far-travelled hanging wall blocks and crustal fragments that were completely torn off and separated from the continental crust by exhumed mantle domains during extreme extension (Buck, 1988; Davis & Lister, 1988).

The outer domain is a poorly constrained zone of the rifted margins that contains the continent-ocean boundary (Figure 4, Péron-Pindivic et al., 2013). Its role lies in the classification of volcanic and non-volcanic passive margins: in magma-poor margins, generally controlled by slow drifting and spreading rates and characterized by oceanic crust and exhumed mantle domains along strike, the change from extension to drifting and spreading is a long-lasting process, whereas magma-rich margins are characterized by the extensive underplating of large magmatic bodies, a rapid transition and discrete timing for the continental break-up (Manatschal et al., 2015).

2.2. Introduction to salt tectonics

Whenever evaporites are present in the sedimentary record, we should count on its deformation. Evaporite rocks are mechanically weaker than any other sedimentary rock (except for the extremely weak unconsolidated shales), therefore they are particularly prone to mobilize and localize deformation (Urai et al., 1987; Jackson & Vendeville, 1994). The deformation related to the remobilization of the weak evaporite media is called salt tectonics or halokinesis. As evaporite deformation will be an essential part of our interpretation, we give a general overview in this chapter on the most prominent salt tectonic features and processes.

2.2.1. Diapir formation in extensional basins

Salt diapirs form by vertical flow of salt rocks. By definition, the geometry of diapirs clearly reflects the weak mechanical properties of the evaporites, and they have discordant boundaries towards the surrounding rocks and their (Warren, 2016). For diapirs to form, two factors should be considered: the appropriate thickness of the sedimentary (or tectonic) cover and the regional

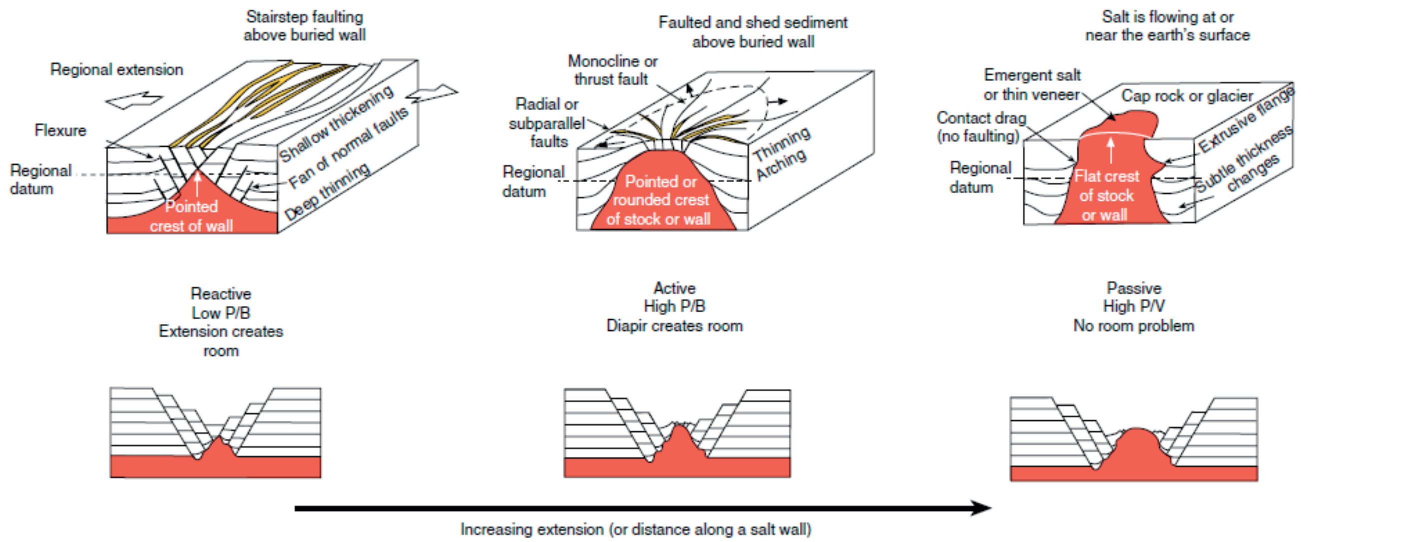

Figure 5. Three types of diapir formation in extensional stress regimes (Warren, 2016). Reactive diapirs are closely linked to actively deforming extensional faults, while active diapirs use pre-existing faults as gateways to actively uplift and pierce their sedimentary cover. When the diapir reaches the surface, it evolves into a free flowing passive diapir

tectonic setting. Differential loading on the evaporites drives the salt migration and outflow from the primary salt body, whereas a too thick cover may hamper the salt from its piercement and upward movement. Sufficient amount of loading can initiate diapirism by itself, but pre-existing fracture and fault zones can make the vertical growth of diapirs substantially easier. Diapirs that actively uplift and pierce through their sedimentary covers are called active diapirs (Figure 5, Vendeville & Jackson, 1992; Hudec & Jackson, 2007). Oppositely, reactive diapirs initiate at actively deforming normal faults, which have already extended, thinned and weakened the sedimentary cover. In this case, the evaporites do not pierce their cover, they only use the already weakened fault zones as gateways. Finally, free flowing diapirs that reached the surface, are called passive diapirs. Depending on the boundary encountered conditions, a single diapir may change its type several times during its lifetime, for instance from reactive diapir to active diapir and finally to passive diapir).

2.2.2. Diapir geometry and related structures

Diapirs and salt structures show a great variety in geometry. There are concentric structures like salt pillows, salt stocks and mushroom-shaped diapirs, and linear structures like salt rollers, walls and anticlines (Figure 6), that still have connection to the primary salt body situated in its original stratigraphical position (autochtonous salt structures). Later, as salt structures mature, their upper part may separate from the primary body and migrate into stratigraphically younger formations (allochtonous salt structures). Salt sheets, canopies and “teardrop” structures are good examples for these detached and pinched salt structures.

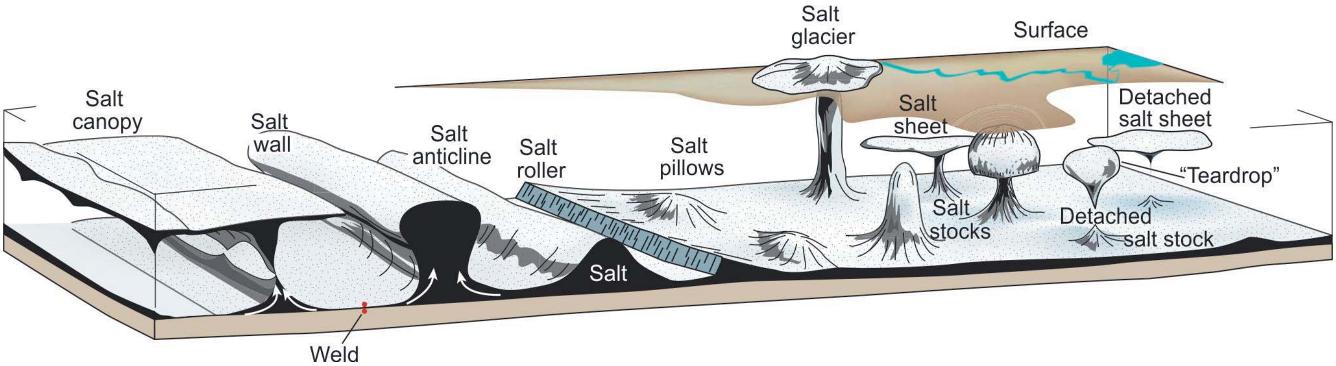

Figure 6. Geometrical classification of salt diapirs (Fossen, 2010). Young salt structures are drawn in the middle, while the diapirs and linear salt structures get progressively more mature towards the right and left sides, respectively

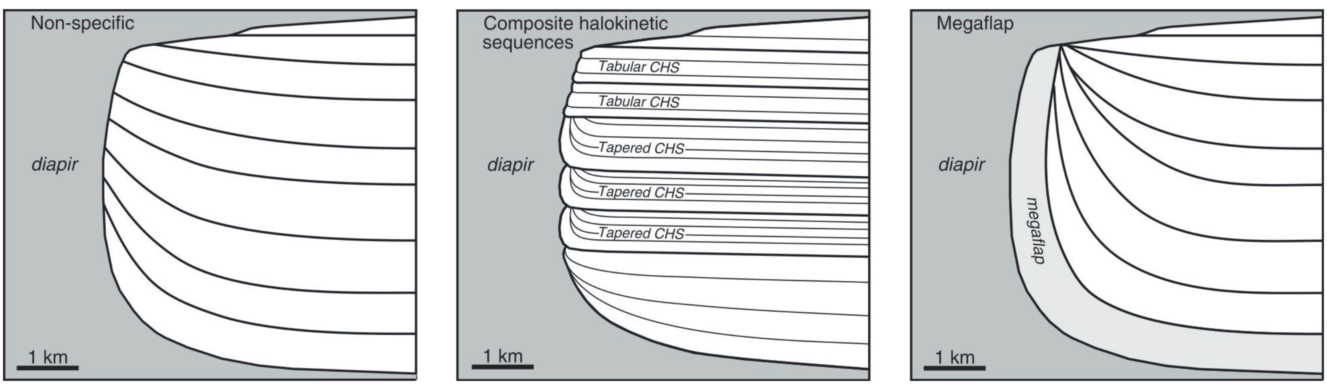

Figure 7. Examples for different types of drag folding along the diapir flanks (Rowan et al., 2016). A) Simple drag folding. B) Composite halokinetic sequence with multiple unfornformity horizons and near-vertical dragged strata. C) Extreme drag folding with sub-vertical or even overturned strata (megaflap).

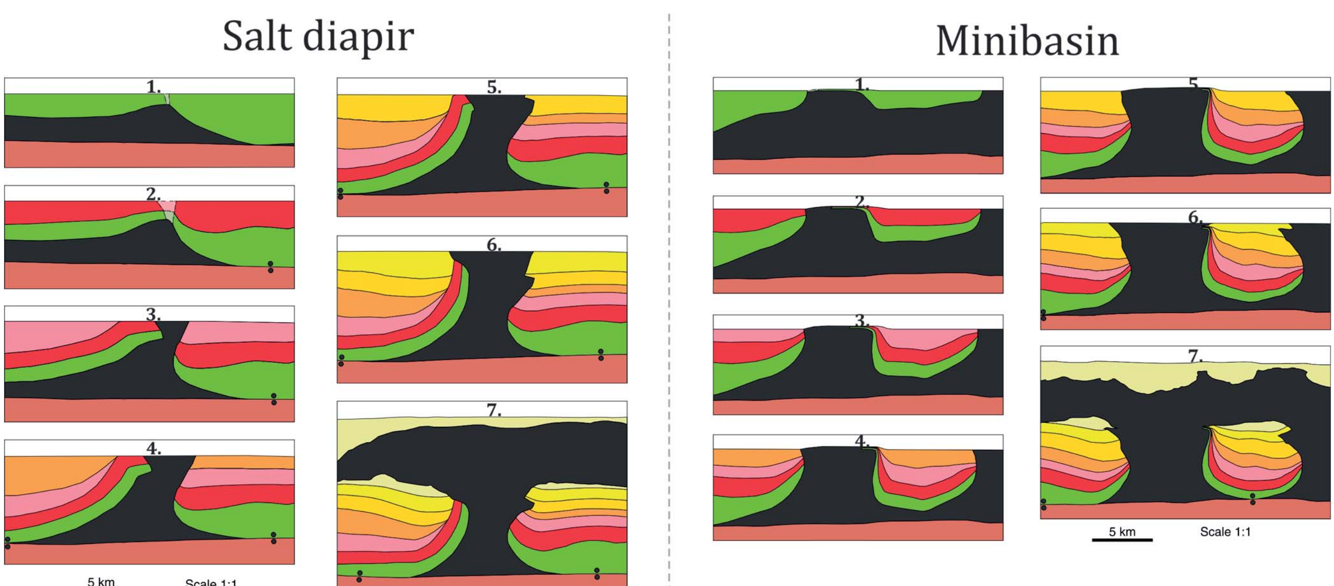

Figure 8. Schematic sections showing the syn-sedimentary growth of a salt diapir and a minibasins (Rowan et al., 2016). The thickness changes and unconformities are clear signs of syn-sedimentary activity of salt tectonics. The two black circles on the two sides of stratigraphy contacts mark the primary salt welds, i.e. segments where the evaporites were squeezed from their original sedimentary positions.

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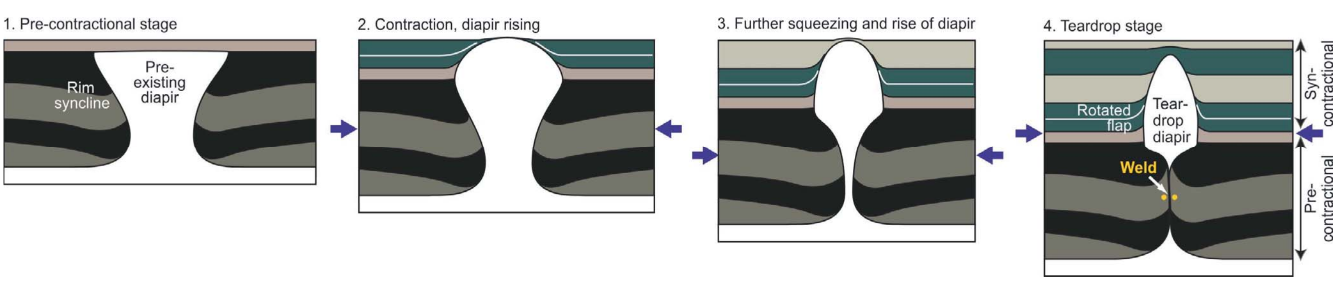
When a salt structure starts to grow vertically and pierces through its sedimentary cover, the flanking formations are dragged along the structure. The degree and geometry of drag folding vary, but in mature salt structures, the flanks can steepen to sub-vertical or even overturned positions (megaflap, Rowan et al., 2016), often with more than 1 km displacement (Figure 7). The growth of the salt structure requires continuous supply of salt from the primary evaporite body. This and if the diapirism is contemporaneous with the sedimentation, the loading effect of the accumulating sediments will lead to subsidence of the sedimentary cover into the thinning primary evaporite body, which further drives the evaporitic outflow into the diapir (Figure 8). This dynamic system is maintained until the primary evaporite body runs out of salt. When this happens, the base and top of the primary evaporite body comes into direct contact along the so-called primary salt weld (Wagner & Jackson, 2016). As a result of subsidence, small asymmetric basins called rim synclines may form near the flanks, and in case a part of the sedimentary cover gets separated and surrounded by evaporites, minibasins form, whose geometry and subsidence evolution is controlled by the growth of salt structures (Worrall & Snelson, 1989; Jackson & Talbot, 1991; Hudec et al., 2009; Callot et al., 2016). Syn-salt tectonic minibasins sequences (halokinetic sequences) frequently show thickness changes and contain pinch-outs and onlap surfaces (Giles & Lawton, 2002; Rowan et al., 2003).

2.2.3. Contractional salt tectonics

In compressional stress regime, the evaporites mobilize (again) and move towards the smallest resistance, which is often a pre-existing fault zone. If the evaporites are squeezed completely from the diapir, the two opposite salt flanks will come into direct contact along the so-called secondary salt weld (Figure 9, Wagner & Jackson, 2016). Internally, the welds are built up by narrow zones of leeched evaporite rocks, strongly altered host rock fragments and breccias (rauhwackes, Milovsky et al. 1999). If the two sides of the squeezed salt wall subsided unevenly, the formations on the sides of the weld will show vertical displacement. Once the secondary salt welds formed, further contraction can reactive the welds as (oblique) thrust welds (Wagner & Jackson, 2016). If the reverse displacement is less than the early salt-related normal slip, the total throw remains normal, leading to the development of young-on-older-type thrust contacts.

Figure 9. Schematic model of the formation of secondary salt welds (Hudec & Jackson, 2007; Fossen, 2010). As the salt gets squeezed out, the two opposite side of the diapir come into direct contact along the surface of the secondary salt weld.



3. Geological build-up and structural evolution of the Aggtelek-Rudabánya Hills (NE Hungary) – concepts from the end of the past millennium

3.1. Introduction

The investigated area is part of the ALCAPA composite unit which is a large nape emplacement during the latest Jurassic to Cretaceous (Fig. 10). The Late Paleozoic to Mesozoic sedimentary and igneous rocks of this unit derived from the margin and more internal parts of the Neotethys exactly from the area where the original margin changed its strike (Haas et al. 1995). The Cretaceous nappe emplacement gradually progresses northward and involved more and more proximal marginal units from the Gemer to the Pieniny Klippen Belt (Fig. 10C) (Lexa et al. 2003; Plašienka et al. 1999; Jerabek et al. 2015; Plasienka 1997, 2018). One of the investigated units, the Silica nappe system occupies the highest tectonic position, has large areal extent and a very small thickness (Fig. 10C).

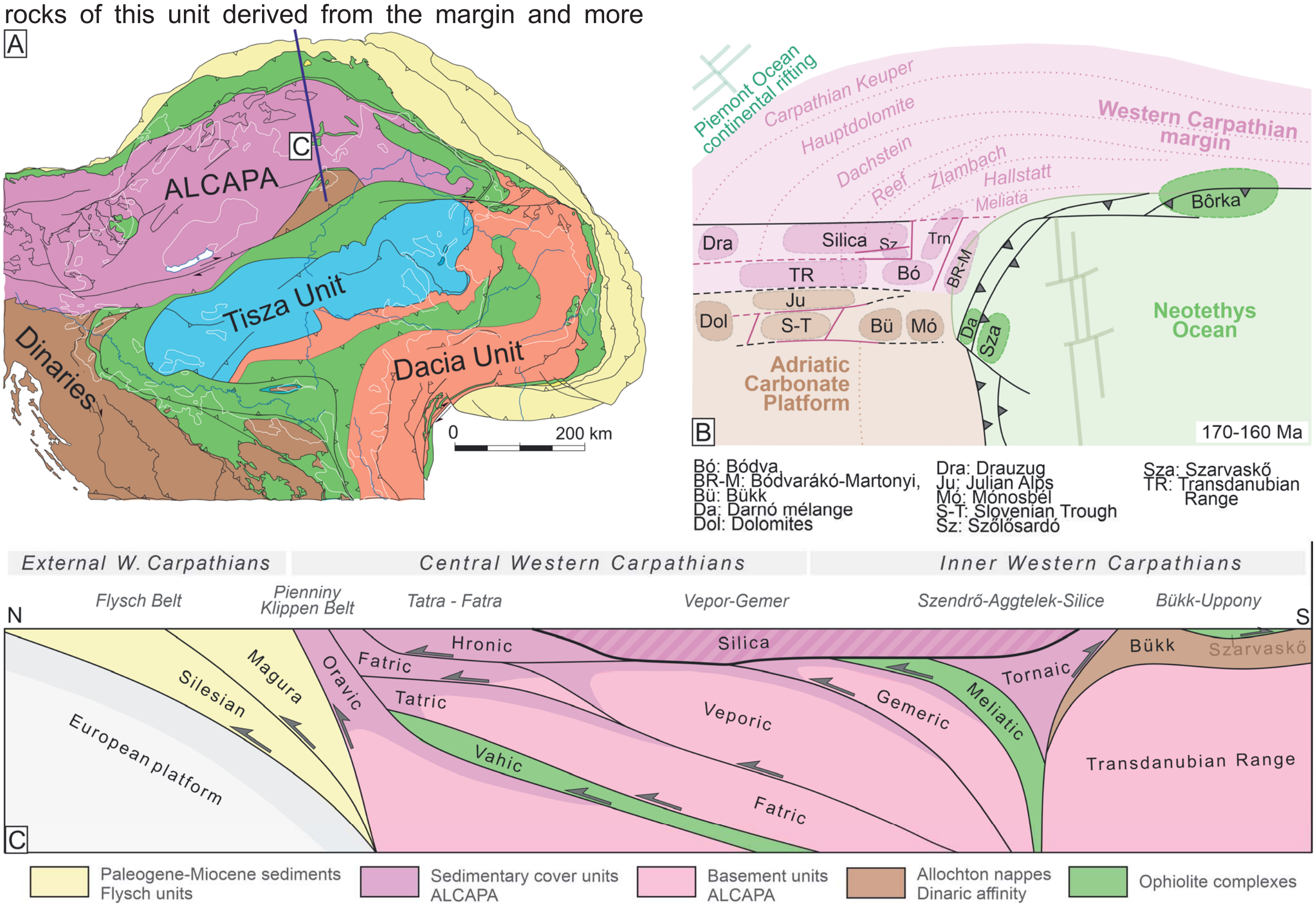


Fig. 10. Tectonic setting of the Western Carpathians. A) Tectonic units of the area including the ALPACA unit (Schmid et al. 2008). B) Paleogeographic reconstruction, after Kövér et al. (2018, modified). C) Cross section of the ALCAPA unit (Plasienka 2018).

The underlying Turňa-Torna, Meliata units are very weakly metamorphosed and their geometrical relationship is disputed (see this and later chapters). The south-eastern boundary of the IWC with the Bükk unit having Dinaric affinity can be traced along the ~5 km wide, SW-NE striking Darnó Zone interpreted as a sinistral strike slip fault (Fig. 10, 11); the fault zone could have Cretaceous (this volume) and Miocene ages (Szentpétery 1988, 1997; Less 2000; Less et al. 2006).

The Inner Western Carpathians (IWC; geographically the Gömör-Torna/Gemer-Turňa Karst and the Rudabánya Hills) is separated from the Central Western Carpathians (including the Gemericum, Veporicum and other more northern units) to the north by the Rožňava suture that was later moved into the Rožňava zone. This

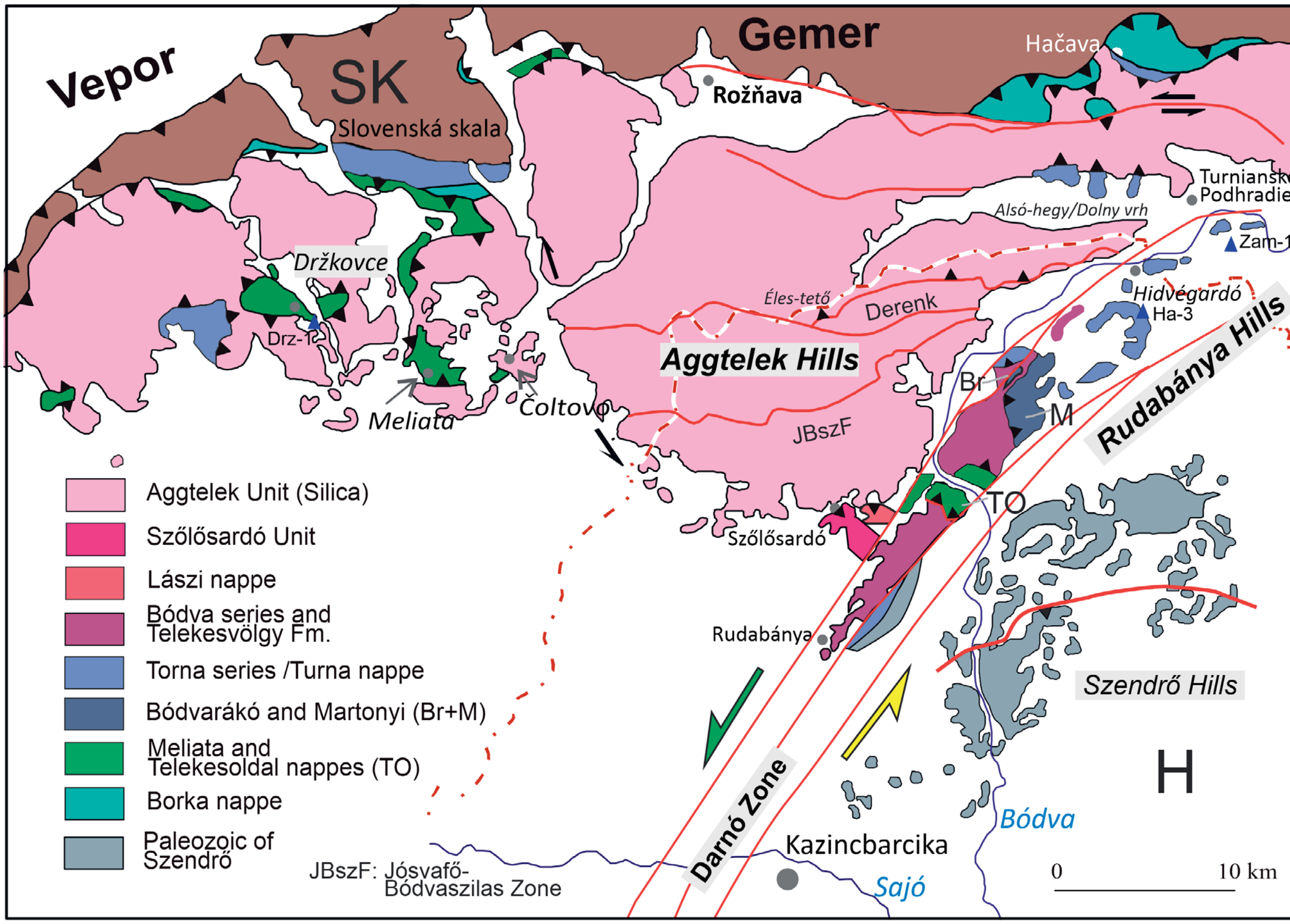


Fig. 11. Tectonic setting of the wider Aggtelek-Rudabánya area, after Less et al. (1988, 2004), modified by this study and Kövér et al. (2009a)

zone is marked by the blueschists of the Bôrka nappe (Fig. 11).

Until the paper by Kozur & Mock (1973), the whole IWC was believed to be an autochtonous unit (Balogh 1948; Balogh & Pantó 1952; Bystrický 1964) with metamorphosed Paleozoic (with no fossil evidence) covered by non-metamorphosed Mesozoic (mostly Triassic). Based on conodonts, the firstly mentioned authors proved in Slovak territory that most of the metamorphosed rocks represent deep-marine Triassic. In this way they disproved the old concept and introduced the metamorphosed Meliata series with deep-marine Triassic forming (at least the relative) autochtonous unit of the IWC deposited on oceanic or very thinned continental crust, which is covered by the non-metamorphosed Silica nappe, composed by shallow-marine, mostly Triassic rocks deposited on continental crust. This concept, supplemented with the discovery and interpretation of blueschists of the Bôrka nappe (Faryad 1995, Faryad and Henjest-Kunst 1997) was successfully applied to the whole Slovakian part of the IWC as summarized in Mello et al. (1996, 1997, 1998), in which some new results from the Hungarian side also appeared. Geological revision of the Hungarian part of the IWC followed that in Slovakia, and it was based on Sándor Kovács's new age-determinations on conodonts on the one hand, and on geological mapping of the whole territory led by the present author, on the other. These together resulted in the stratigraphic revision of Triassic (Kovács et al. 1989) and Jurassic (Grill 1988) rocks, the determination of Ladinian age of the ophiolites incorporated into uppermost Permian evaporites including its significance for the structural evolution (Réti 1985; Kozur and Réti 1986), the new geological map of the Aggtelek-Rudabánya Hills (Less et al. 1988), and its explanatory booklet (Less et al. 2006) containing the updated tectonic model and structural evolution (Less 2000) of the area. The main novel elements in these works compared to what had been achieved earlier in Slovakia are the discovery of metamorphosed Triassic sequences deposited on continental crust (Torna/Turňa series), that of non-metamorphosed deep-marine Triassic sequences (Bódva series), the recognition of secondary nappes (klippes) and that of the role of strike-slip movements in the structural evolution. Below we summarize the state of our knowledge about the structure and evolution of the Aggtelek-Rudabánya Hills, the Hungarian part of the IWC at the very end of the past millennium, with a view to the Slovakian part, where necessary.

3.2. Structural overview

Despite of their small dimension, the Aggtelek–Rudabánya Hills, the southernmost element of the IWC, are geologically among the most complex regions in Hungary. Therefore, there are contradictory views in several aspects that are impossible to discuss here because of the limited extent available. In the "concept of Less" presented below, the region can be subdivided into two parts, to the Aggtelek Karst and to the Rudabánya Hills (Fig. 11, 12). The Aggtelek Karst as part of the Gömör–Torna Karst is clearly the continuation of the Slovak Karst, whereas the Rudabánya Hills are incorporated into the Darnó Zone. They arrived in their recent place from SW at about the Oligocene/Miocene boundary along a sinistral strike-slip (Szentpétery 1997; Less 2000). This means that until the Late Oligocene the Rudabánya Hills were located some tenth of km-s to the S of the Aggtelek Karst that was relatively intact to the sinistral movements along the Darnó zone. To the SE of the Rudabánya Hills already the Paleozoic of the Uppony and Szendrő Hills can be found; their Paleozoic rocks show already a South Alpine and Dinaric affinity. Thus, the SE margin of the Rudabánya Mts. is once again a sinistral strike-slip delimiting the entire IWC towards the south-east. In re-establishing the pre-Miocene structures, i.e., in pulling back the Rudabánya Hills virtually to the SW into the southern continuation of the Gemer-Torna Karst, the obtained structure is still very complicated (Fig. 10, 11, 12). In the "concept of Less" it consists of (in order of superposition from upwards): 1) the neo-allochtonous klippes of Alsó-hegy (Dolný Vrch), Éles-tető (Ostrý Vrch) and Derenk, covering 2) the folded and imbricated structures (of southern vergency in Hungary) of the mountains that are superimposed on 3) the primary nappe structure.

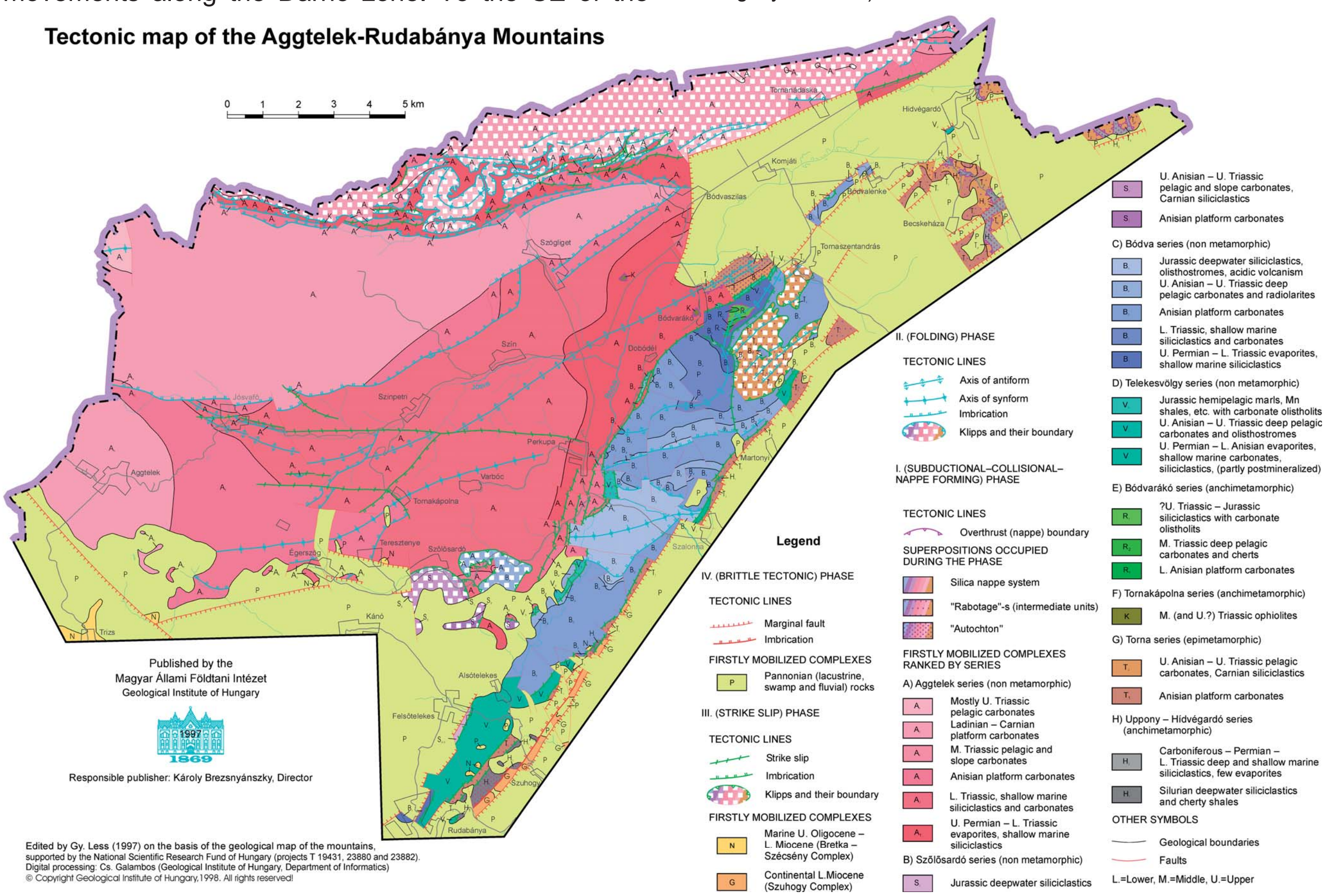


Fig. 12. Tectonic map of the Aggtelek–Rudabánya Hills (Less 1997, slightly modified).

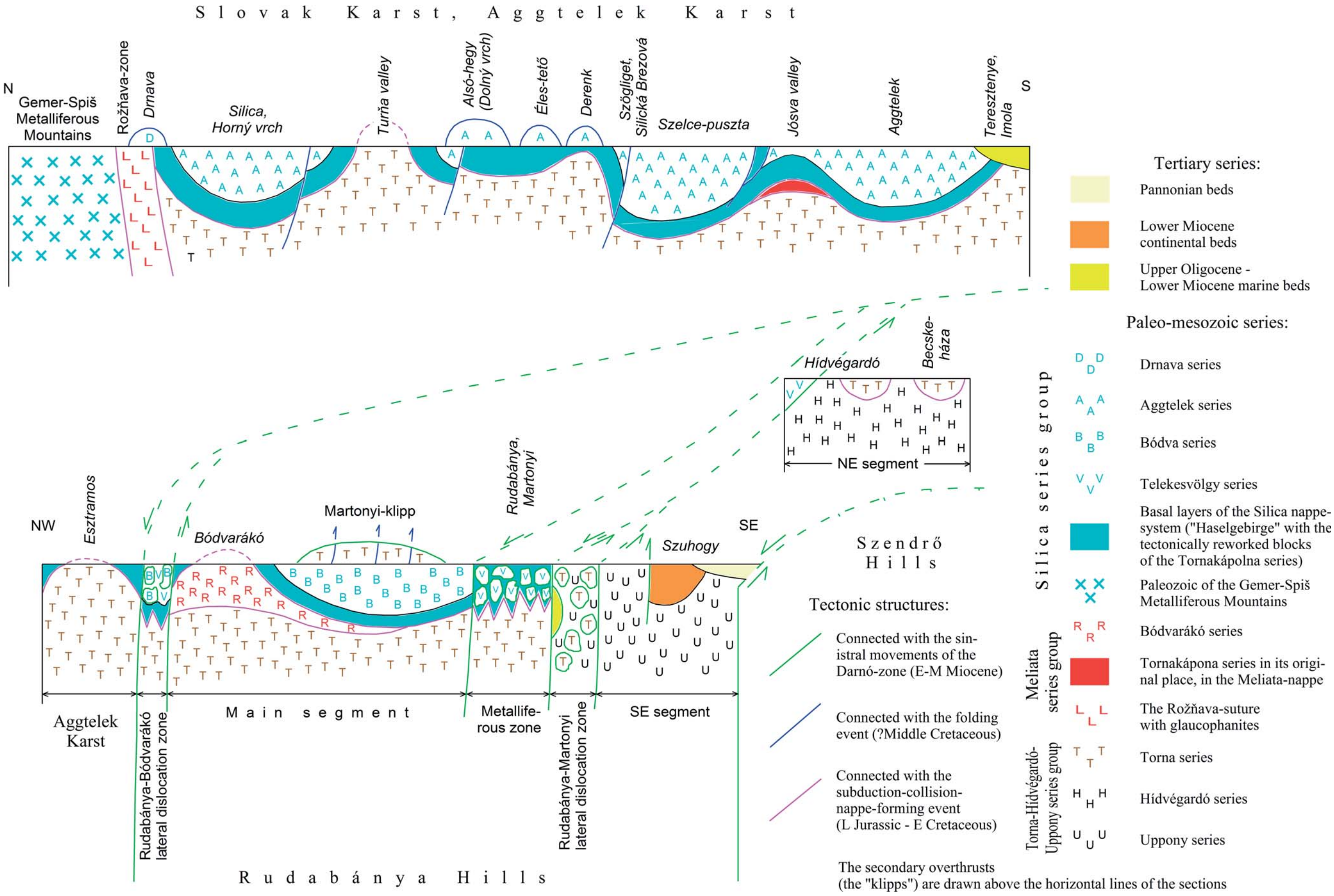


Fig. 13. Structural scheme of the Inner Western Carpathians on principal geological sections, with no scale (Less 1998, slightly modified).

3.3. Paleo-Mesozoic sequences and their primary tectonic position

This reconstructed primary nappe structure is composed of three main tectonic units that are characterized by three different groups of rocks whose metamorphic degrees are also significantly different (Árkai and Kovács 1986). These units are the Silica, Meliata and Torna (Turňa) Units despite the enormous confusions accumulated into these names. The origin of these confusions is that the meaning of these terms is not unambiguously defined, therefore they are used in terms of both rock sequences (and also of their depositional areas) and tectonic units. However, they are recently so widely used and so deeply imprinted, that the introduction of each new name would create even more confusions. These three main units are characterized below based on their rock sequences (Fig. 14) and their metamorphic degrees. More details see in Kovács et al. (1989).

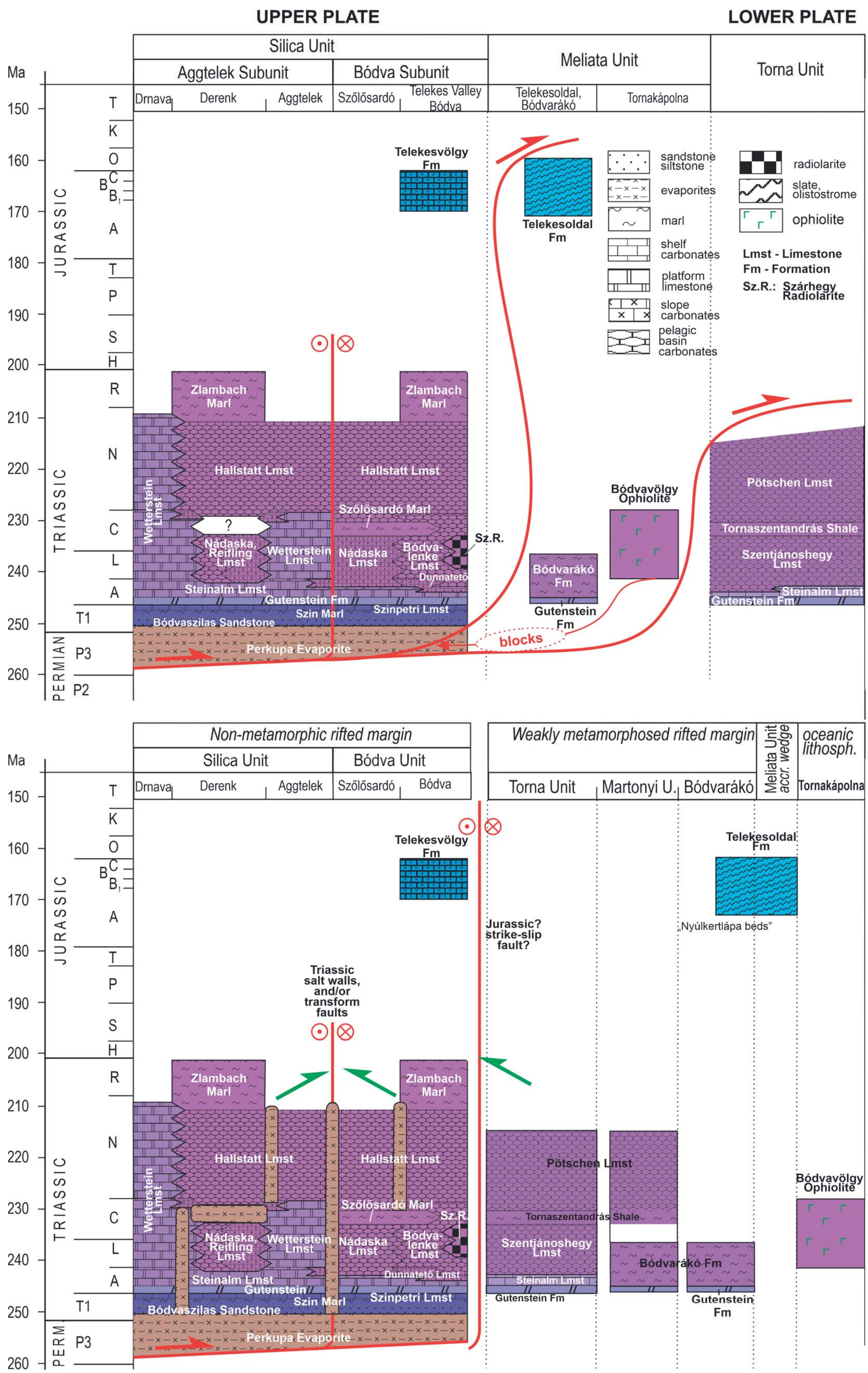


Fig. 14. Lithostratigraphic column of Paleo-Mesozoic formations of the Aggtelek–Rudabánya Hills (Kercsmár et al. 2022). Lower figure: alternative interpretation of the stratigraphy and paleogeographic positions of the units

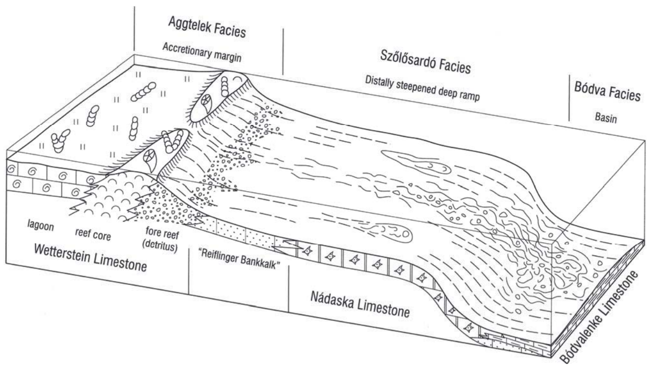


Fig. 15. Depositional model for the Ladinian formations of the Aggtelek and Bódva series of the Silica nappe system (Kovács 1997)

1. Non-metamorphosed Uppermost Permian, Triassic and Jurassic rocks deposited on continental crust are joined in the Silica series group. They form the upper structural unit of the primary nappe structure of the Gömör-Torna Karst, the Silica nappe system, originally defined by Kozur & Mock (1973).

We interpret the older Carboniferous-Permian sequence of the Brusník brachianticline in Slovakia as the remnant of the Paleozoic basement of the Silica series group in agreement with Mello & Vozárová (1983) despite that (based on borehole BRU-1) they are later grouped by Vozárová & Vozár (1992) into the Torna (Turňa) series group (see later) and the Carboniferous (Turiec Formation) is correlated by them with the Szendrő and Bükk Paleozoic in Hungary (see also Vozárová 1998). However, rhyodacitic volcanoclastic material (characteristic for the Turiec Formation) has never been found in the Carboniferous of the Szendrő and Bükk Mountains, therefore the palinspastic link of the Brusník development to the Southern Gemeric one (Vozárová 1998) is more acceptable for us. In this case the Paleozoic basement of the Silica series group could be an external Southern Gemeric one that is mostly incorporated into a later collisional zone whose exhumed remnants (Jasov and Bučina formations) are recently exposed in the lower slice of the secondary Bôrka nappe (Mello et al., 1998). Due to the thick Uppermost Permian to lowermost Triassic evaporitic layer, the Mesozoic cover (the Silica series group) could be detached from the Paleozoic basement and overthrust the collisional zone and could form in this way the later Silica nappe system. At the same time, some parts of the Paleozoic basement – locally not having had too thick evaporitic cover (like the ones represented in the Brusník anticline) – could join to the overthrust of the Silica series group and become part of the Silica nappe system.

The sequences of the Silica series group are partly different in the Gömör-Torna Karst and Rudabánya Hills. In the first it is called Aggtelek series whereas in the Rudabánya Hills its name is Bódva series. Both they start uniformly with Permo-Triassic evaporitic to sandstone beds (= the "Haselgebirge" in the Eastern Alps), followed by shallow marine, terrigenous but ever limier Lower Triassic (correlatable with the Werfen beds), then by shallow marine, Anisian platform carbonates (Gutenstein and Steinalm beds). After or without an intraplatform basinal event (Reifling and Schreyeralm Limestones) this carbonate platform survived in the Aggtelek series up to the Late Carnian (Wetterstein Limestone). However, some intra-platform basins could also exist in the Late Ladinian to Carnian interval within the Wetterstein platform (Derenk Limestone in the Derenk facies, identified with Nádaska Limestone in Fig. 14).

Meanwhile, in the Bódva series no platform carbonates can be found starting from the middle Anisian. This series is also a composite one (Fig. 5): The Szőlősardó facies is characterized by the slope deposits of the Nádaska Limestone and by the relatively thick, terrigenous Szőlősardó Marl marking the middle Carnian Raibl event. The Upper Anisian to Carnian of the Bódva facies s.s. is characterized mainly by basinal limestones (Bódvalenke Limestone) interfingering very locally with radiolarites (Szárhegy Radiolarite). The facial distribution of the upper Anisian to middle Carnian within the Silica series group (taking also into account that the Rudabánya Hills together with the Bódva series lying on its top must be pulled back far to the S before the Miocene) indicates a general southward deepening in recent coordinates. Thus it could be much more easily the northern margin of an ocean (the "Meliata-Hallstatt Ocean" as a branch of the Neotethys) than the southern one. After the very diverse Upper Anisian to Middle Carnian, the Upper Carnian and Norian of the Aggtelek and Bódva series became almost uniform: This interval is represented in both series by the same pelagic Hallstatt and/or Pötschen Limestones.

The Jurassic in Hungary is known only in the Bódva series (in the Aggtelek series it is supposed to be similar to the Jurassic of Bleskový prameň near Drnava): It has two developments (Grill, 1988): The Telekesoldal Complex is built up of monotonous black shales then by rhyolitic olistostrome, while the Telekesvölgy Complex consists of a lower, variegated marly part whereas the upper part is composed of crinoidal limestones, marls and manganese shales. According to Less (2000) the first complex lies upon the Triassic of the Bódva facies s.s. as it was crossed in borehole Szendrő-4, whereas the Triassic basement of the other complex is rather uncertain (partly because it can be found only in the Early Miocene shear zone between the Aggtelek Karst and Rudabánya Hills). Later, Kövér et al. (2008, 2009) doubted this statement and ranked the Telekesvölgy Complex into the Bódva series and rearranged the other Telekesoldal complex into the Meliata series group, as it is shown in Fig. 14b.

2. Low- to very-low grade metamorphosed Triassic and Jurassic rocks deposited on oceanic or thinned continental crust are grouped into the Meliata series group. Most of its sequences are tectonically dismembered and secondarily incorporated into the evaporitic basement of the Silica nappe system as it is shown by several boreholes both in Hungary (boreholes Bódvarákó Br-4, Komjáti K-11, Szögliget Szö-4, Szin Szi-1, the upper part of Tornakápolna Tk-3) and in Slovakia (DRŽ-1 in Držkovce, VŠ-1 in Šankovce). At the same time some remnants could stay in their original position, just below the Silica nappe system (the Bódvarákó series in the Rudabánya Mts., the lower part of borehole Tornakápolna 3 and of Brusník BRU-1). This twofold superpositional character of the Meliata series group indicates that primarily, before the overthusting of the Silica nappe system, the Meliata series group was in uppermost tectonic position. Due to its dismembered (and also redeposited) character (see later) and also due to its partly true, newly formed oceanic nature, practically nothing is known about its Paleozoic basement and very little about the Lower Triassic that is representing only in the Meliata MEL-1 borehole and resembling the Werfen facies.

Because of poor outcrop conditions, the Meliata series group is much less known than the Silica one. Three series can be distinguished. The Meliata series s.s. (which is understood here in its strictest sense, i.e., only the occurrences at the vicinity of Meliata, Držkovce and Čoltovo) is not known from Hungary. Recently it is thought to be an Upper Jurassic olistostrome with both Middle-Upper Triassic and Jurassic olistoliths (Mock et al., 1998). In the Triassic sequence that can be reconstructed from these olistoliths, basic magmatic rocks are subordinate, therefore this sequence is believed to be deposited on intermediate crust. The newly formed, true oceanic crust of mostly Ladinian age is represented by the Tornakápolna series from whose dismembered serpentinites, gabbros, basalts and radiolarites a real MORB-type ophiolite, Bódva Valley Ophiolite can be reconstructed (Réti 1985; Horváth 1997, 2000). Red Ladinian radiolarites (Čoltovo Radiolarite) characteristic for the Meliata (s.s.) series and basalts belonging to the Tornakápolna series are interfingering in Čoltovo (Mello and Gaál 1984), Jaklovce (Mock et al. 1998) and in the Darnó Hill in Hungary (Dosztály and Józsa 1992), so the close relationship of these two series is unambiguous.

The Bódvarákó series is the third among those ranged into the Meliata series group. It is outcropped in the core of an antiform in the northern part of the Rudabánya Mts. and located clearly under the Silica nappe system represented here by the Bódva series (Figs. 12, 13). Its peculiarity is the complete lack of the Middle Anisian Steinalm Limestone between the shallow water Gutenstein Dolomite (the lowermost known member of the series) and the deep water Bódvarákó Formation of Upper Anisian-Ladinian age. No evidence for the Upper Triassic in this sequence, the overlying Nyúlkertlápa beds are black shales with some olistoliths of unknown age. These beds are thought to be of Middle-Upper Jurassic age by their similarity to the Telekesoldal Complex (in Fig. 14 they are identified with each other) and the Upper Jurassic Meliata shales (Deák-Kövér 2012, Kövér et al. 2009). However, the Bódvarákó series is not a Jurassic olistostrome (like the Meliata s.s. series) because its Gutenstein Dolomite reserves a huge quantity of water as it is shown by the Bódvarákó Br-4 borehole.

3. Low-grade metamorphosed (bearing relatively high pressure based on Árkai and Kovács 1986) Triassic rocks deposited on continental crust are grouped into the Torna (Turňa) series. Primarily it can be found always under the Silica series group (the Esztramos Hill NE of Bódvarákó, Zádielské Dvorniky in Slovakia), in the core of huge antiforms. Moreover, in our interpretation in the vicinity of Honce in Slovakia, on the northern slope of the Plešivec plateau, the original Torna-Meliata-Silica tectonic superpositional arrangement is preserved as well (see also geological profile 5-6 in Mello et al., 1996). Unlike the Meliata series group, the Torna series can never be found as tectonically dismembered blocks in the basal evaporitic layer of the Silica nappe system. This means for us that primarily the Torna series forms the lowest known tectonic unit of the IWC. However, Vozárová and Vozár (1992) rank the upper complex of borehole BRU-1 at Brusník into the Torna series found above the lower complex belonging undoubtedly to the Meliata series. Based on this, they speak very often about Turňa (=Torna) nappe. However, this upper complex is overlain by an Uppermost Permian to Anisian sequence identical with that of the Silica series group. As it was expressed earlier (in the introduction to the Silica series group), in this borehole we see rather the superposition of the Silica nappe system on the Meliata series. Therefore, there are no evidence for the primary nappe position of Torna (Turňa) series, thus the term of Torna nappe cannot be justified. However, as it is shown in

Figs. 12 and 13, this series could thrust onto other units during a much younger thrusting phase but always onto less metamorphosed units. Of these, the Martonyi klippe (thought to be originated in the early Miocene) will be discussed later. However, the age of superpositioning of the Torna series onto the less metamorphosed Hidvégardó Complex (deep diagenetic ?Carboniferous black shales and Permian evaporitic beds associated with grey marls, drilled in Hungary by the Hídvégardó 3 and in Slovakia by the Žarnov ŽAM-1 boreholes) cannot be judged. Maybe this complex forms the Carboniferous-Permian cover of the anchimetamorphic Uppony type Paleozoic that can be followed along the SE margin of the Rudabánya Hills, and they together can be supposed as the most probable Paleozoic basement of the Torna series. An alternative interpretation of this sequence that it has Jurassic age and is similar to the Meliata metasediments (Deák-Kövér 2012).

The Torna series itself contains only Triassic rocks; its Jurassic is eroded. The Lower Triassic is not known from Hungary and the Slovakian data are also rather uncertain: by judging from the description of Mello et al. (1997), the Paklan and Jelšava beds can be correlated with the Szin Marl of the Silica series group. The Middle-Upper Triassic is well known and rather uniform: its standard elements are the Middle Anisian Steinalm (Honce) Formation, the middle Carnian Tornaszentandrás Shale marking the Raibl event and the Upper Carnian to Middle Norian Pötschen Limestone. The Upper Anisian to Lower Carnian is more diverse: in Hungary a marginal and a "seamount" development can be distinguished: the former with distinctive terrigenous input (represented in the secondary Martonyi klipp) and the latter with moderately deep basinal limestones in the Esztramos near Bódvarákó and at the vicinity of Hidvégardó and Becskeháza (Árkai and Kovács 1986).

Despite their strong metamorphic difference, the sequence of the Torna series is lithologically very similar to that of the Szőlősardó facies of the Bódva series belonging to the Silica series group. The lithological similarity can be explained not only by the close vicinity of the depositional areas but also by their symmetrical position related to the axis of the opening Neotethys Ocean. At the same time the different metamorphic history can be explained by their opposite position at the time of oceanic closure: the Szőlősardó facies remained unmetamorphosed because it occupied an upper plate position at the active margin while the Torna series as part of the passive margin came into a lower plate position and, therefore became metamorphosed.

3.4. Structural evolution

The structural evolution of the territory is discussed in detail by Less (2000), the hypothetic Triassic to middle Cretaceous development is reconstructed on six palinspastic profiles in Figs. 16A-F. Depositional areas on them refer to the aforementioned series and their partial facies (see also the legend).

1. Rifting and opening of the ocean (Figs. 16A-B)

The continental crust of the later Silica series group and of the Torna series was unitary until the middle of the Middle Triassic. Starting from this time it was subdivided into two (Fig. 16A), first by rifting, then by the opening of the Meliata branch of the Neotethys Ocean. The formerly unitary Silica Basin at the northern margin of the ocean was also differentiated into a northern (according to the present orientation) shallower part (the Aggtelek Basin) and to a southern, deeper part (the Bódva Basin) closer to the ocean. The Torna Basin fell into the southern margin of the ocean (Fig. 16B).

2. Subduction and obduction of the oceanic crust, formation of the Meliata nappe (Figs. 16C-D)

The Meliata branch of the Neotethys Ocean started to close from the beginning of the Middle Jurassic. The ocean subducted from S to N, below the Gemer-Silica continental crust and induced island-arc volcanism (rhyolites) (Fig. 16C). A smaller part of the oceanic crust returned, however, from the subduction channel (where it was metamorphosed in blueschist facies) and overthrust to the south onto the Torna series, which was metamorphosed in the accretionary prism. This process resulted in the formation of the Meliata nappe (Fig. 16D), which recently can only be observed in small relicts. At the end of the Jurassic the Meliata Ocean was entirely closed, and the Gemer-Silica and Torna continental crusts collided along a former suture, whose traces (especially glaucophanites originated from the Meliata series) are thrust into the recent Rožňava Zone and are represented in the Bôrka nappe (in Slovakia).

3. Overthrust of the Silica nappe system (Figs. 16E-F)

In the Early Cretaceous granitoid intrusions were generated below the Gemer-Silica continental crust mostly from the subducted oceanic crust of the Meliata Ocean. This process caused the thickening of the continental crust, which isostatically emerged (Fig. 16E). This uplift caused the detachment and gliding of the Mesozoic envelope series (the Silica series group) from its crystalline basement (the Paleozoic of the Gemerides) along the Upper Permian to Lowermost Triassic evaporites at very low-angle slopes. This resulted in the overthrusting of the Silica nappe system onto the Torna-Meliata nappe pile and in the reworking

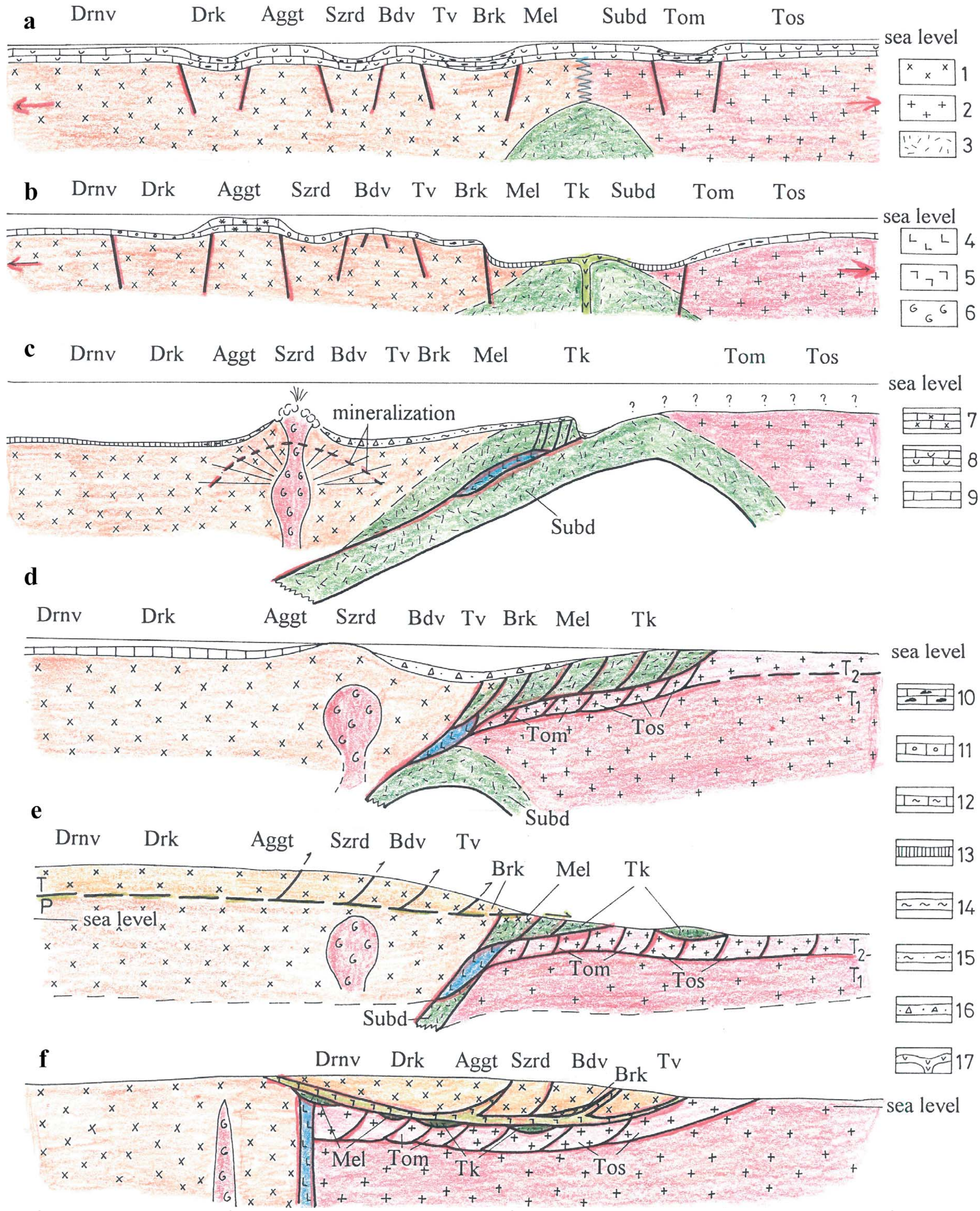


Fig. 16. Structural development of the Aggtelek–Rudabánya Hills and Slovak Karst during the Middle Triassic to Middle Cretaceous interval in a series of principal palinspastic profiles with no scale (Less 1998, 2000, with slight modifications). A): The pre-rift stage in the middle Anisian. B) The oceanic stage in the Ladinian. C) Subduction and simultaneous obduction in the Middle Jurassic. D) The beginning of collision at the end of the Jurassic. E) The start of the overthrust of the Silica nappe system in the Early Cretaceous. F) The primary nappe system before starting the folding phase in the middle part of the Cretaceous. Abbreviations for depositional areas: Drnv: Drnava; Drk: Derenk; Aggt: Aggtelek; Szrd: Szőlősardó; Bdv: Bódva; Tv: Telekesvölgy; Brk: Bódvarákó; Mel: Meliata (s.s.); Tk: Tornakápolna; Subd: Subducted; Tom: Torna, margin; Tos: Torna, seamount. 1. Extreme Southern Gemeric crust, 2. Torna–Hidvégardó–Uppony type continental crust, 3. Meliata type oceanic crust, 4. glaucophanites, 5. the evaporitic basement of the Silica nappe system with tectonically reworked blocks of the Meliata series group, 6. Mesozoic granitoids, 7. reefal carbonates, 8. lagoonal carbonates, 9. red pelagic limestones, 10. grey cherty limestones, 11. slope carbonates, 12. marls, marly limestones, 13. radiolarites, 14. black shales, 15. sandy shales, 16. olistostromes, 17. basalts

of the ophiolites of the Meliata series into the evaporitic basement of the Silica nappe (Fig. 16F).

4. The folding phase

Already the whole primary nappe structure was affected by the next main event of the structural evolution manifested in folding, imbrication and secondary nappe forming, most probably during the middle and later part of the Cretaceous. The compression was of N-S direction (in recent co-ordinates, however an about 90° counter-clockwise rotation is detected by Márton et al. 1989) and first resulted probably in simple folds of great amplitude. These folds can be observed mainly in the Silica nappe system, however in the core of some antiforms; the Turňa valley window in Slovakia, the Esztramos and Bódvarákó windows in Hungary (the first in the Aggtelek while the second in the Rudabánya Mts.) where deeper units of the primary nappe structure crop out, too. Southward from the axis of the Horný vrch (Felső-hegy) in Slovakia the vergency of these folds is ever more southern. Later, the continuing compression could be decompressed only in reverse faults of southern vergency (e.g. north of Szögliget, between Bódvaszilas and Silická Brezová in the Derenk zone and north of the Jósva valley, as well as several slices in the Rudabánya Mts.).

The formation of secondary nappes (klippes) of Derenk, the Alsó-hegy (Dolný vrch) and Éles-tető is shown in Figs. 16A-C. It could happen as the terminal movement of this folding event. These klippes are built up by wings and cores of synclines (of rocks belonging to the Aggtelek series) lying upon a huge anticline (Ménes valley anticline) in which thick evaporites of the same series crop out. While forming this anticline, plastic evaporites could start to flow towards its core and then to form a huge diapiric dome that could thrust the neighboring synclines aside, on top of each other (Fig. 16A). In the next stage the evaporitic dome could crop out in the surface and became free for rapid erosion (Fig. 16B). This latter could result in a deep depression onto which the blocks thrusted away could slide back forming klippes in such a way (Fig. 16C).

5. Poorly documented relax phase

During the Late Cretaceous to Middle Oligocene the territory was mostly a dry-land that was interrupted by a marine interval only in the Senonian as it is shown in Slovak territory (Mello & Salaj, 1982). This continental period is proven by resedimented bauxitic material found in some karstic holes near Aggtelek. Otherwise, this period is very poorly documented by rocks.

6. The phase of lateral movements

During the end of the Oligocene and the Early Miocene the Rudabánya Hills arrived from the southern margin of the Aggtelek Karst to its eastern vicinity with the sinistral movements of SW-NE strike along the Darnó zone. This movement was induced by the Bükk Mts. and Szendrő Hills having approached far from SW. It is considered as internal movement within the ALCAPA's move as a whole to the NE at this time. As a result, the Rudabánya Hills moved in three main segments (documented also by Upper Oligocene to Lower Miocene rocks in different facies – Szentpétery 1997). Overthrusting of new secondary klippes (e.g., the Martonyi klippe) and movements along conjugate strike-slips of E-W direction (e.g., along the Derenk zone) are also associated with this phase. A more detailed discussion can be found in Less (2000).

7. The consolidation phase

After the consolidation of the area in the Middle Miocene it became once again a dry-land. In the Late Miocene the Pannonian Lake flooded morphological depressions generated by erosion and brittle faults as it is recorded by the 50–300-m-thick Edelény Clay containing basal lignite measures. The latest uplift of the area started at the end of the Pliocene and took place in the foreground of the general emergence of the Western Carpathians. The masses of pebble material arriving from the Carpathians (preserved in the max. 80 m thick Borsod Pebble) played the dominant role in developing the huge cave systems in the previously karstified large limestone bodies.

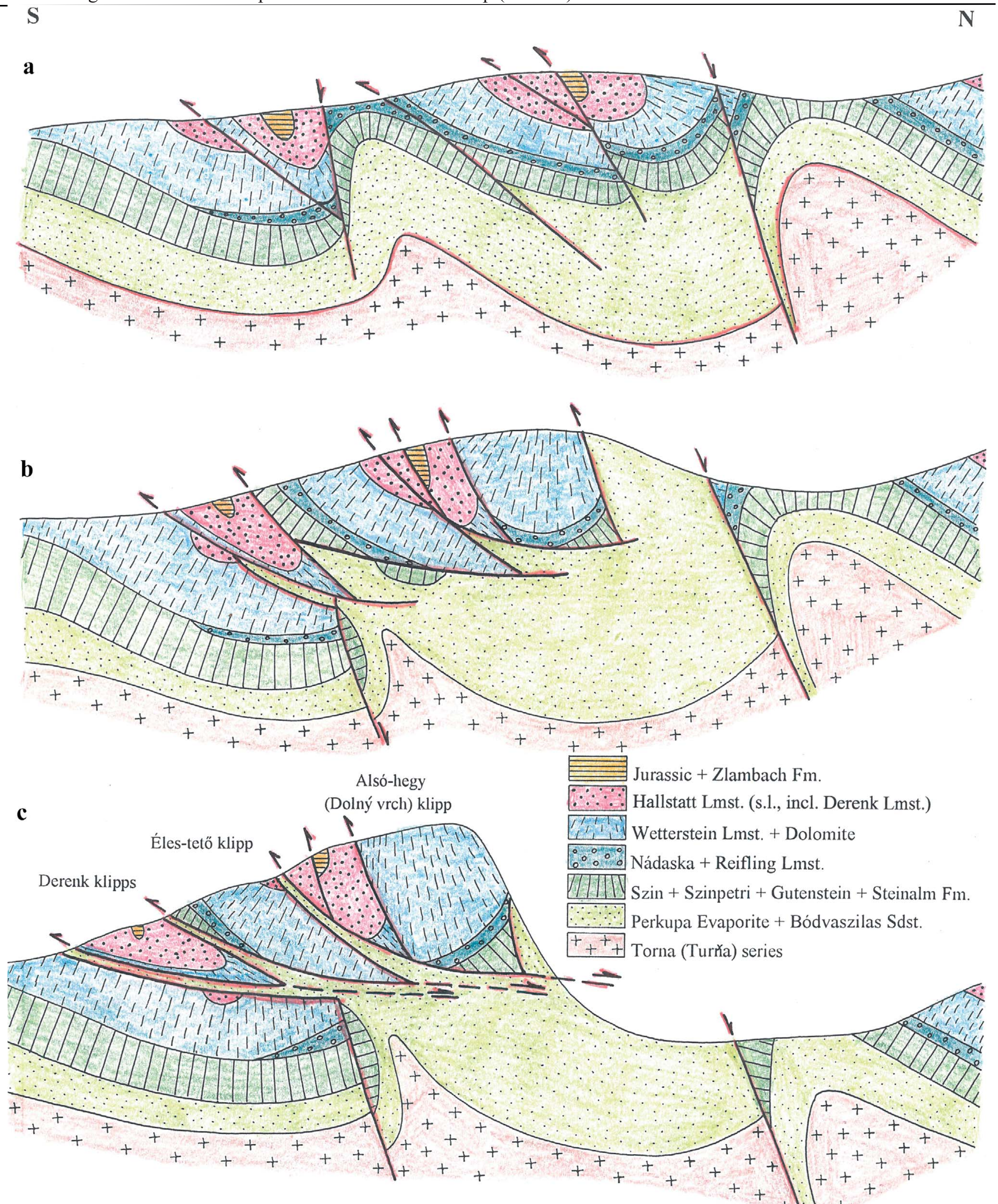


Fig. 17. Formation of secondary klippes in the Derenk Zone (Less et al. 2006). A) Generation of folds with S vergency, mobilization of the Perkupa Evaporite. B) Exhumation of the Perkupa Evaporite. C) Paleorelief before the erosion of Perkupa Evaporite and gravitational gliding of klippes. See alternative explanation in the pre-conference guidebook and by Oravecz (2019), Oravecz et al. (submitted).

4. New aspects of the tectonic units and stratigraphy

4.1. Metamorphism of some rifted margin units

Triassic and Jurassic (TO) rocks of the Torna, Martonyi and Bódvarákó units underwent very weak to weak metamorphism as demonstrated by illite and chlorite crystallinity data. The early pioneer works of Árkai (Árkai 1985, 1991, Árkai and Kovács 1986; Árkai et al. 1995, 2003, and several unpublished reports) were later complemented by additional data (Kövér et al., 2009a; Deák-Kövér 2012). The newest results were achieved by Raman spectroscopy and constraint much precisely the temperature conditions of certain TO samples (Molnár et al. 2021). These new data would constraint the metamorphic temperature between 260–280°C (Fig. 18) which are in agreement with previous estimates based on crystallinity data. The pressure conditions can be roughly estimated as ~1.5–2.5 and ~2–3 kbar in the Jurassic and Triassic rocks, respectively.

The K-Ar age data were measured on the illite separates of the samples investigated for metamorphic petrological point of view (Fig. 19). The age spectra show diverse tectonic events. The oldest ages around 140 Ma could represent mixed ages from newly grown crystals and inherited grains. The 128–109 Ma time span can correspond to the exhumation and cooling of metamorphic units and their emplacement onto the Bódva unit. On the other hand, the younger age group around 90 Ma can correspond to the renewed thrusting of the Bódva over the TO and Bódvarákó units (Fig. 19); they are found close to tectonic contacts being young in relative chronology.

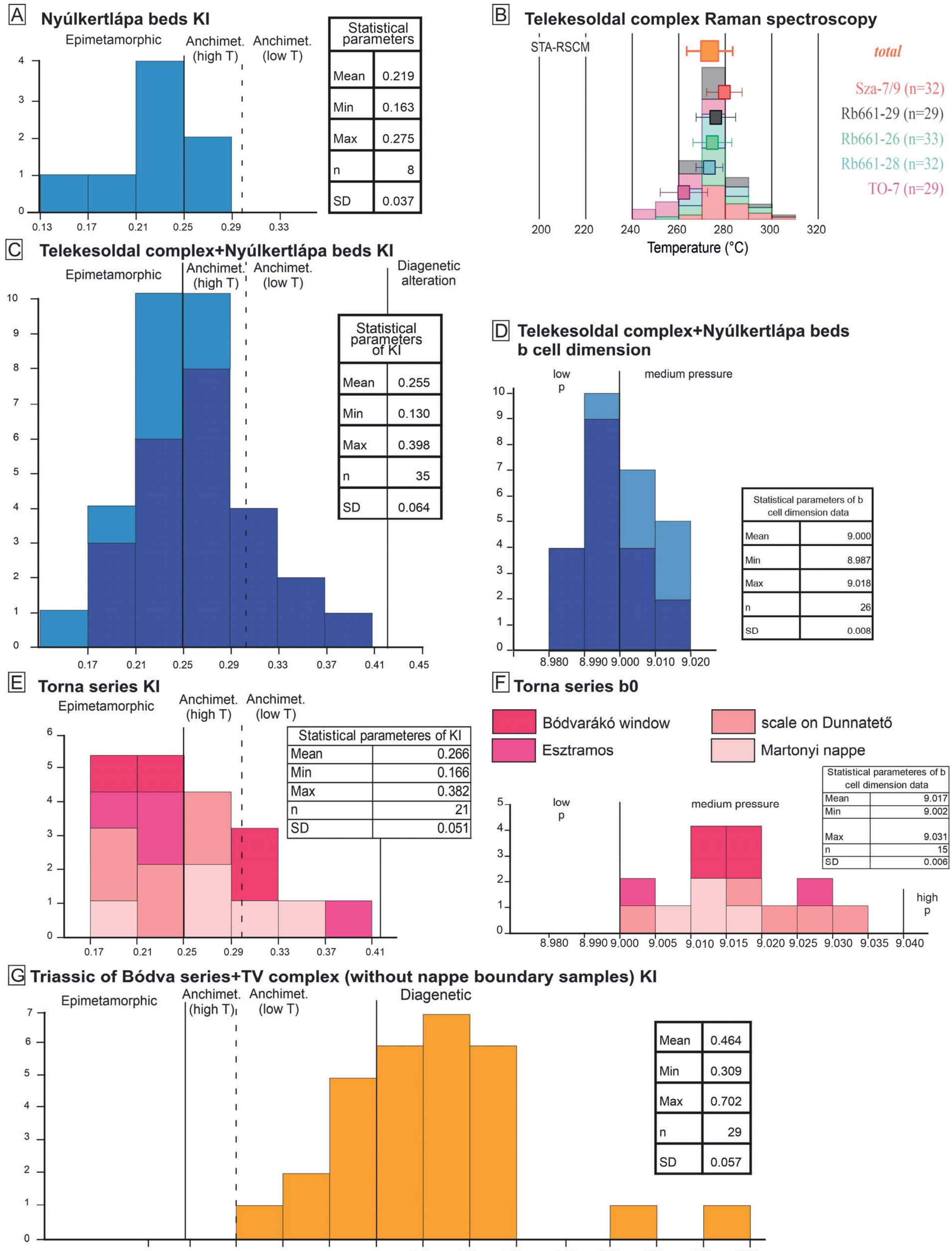


Fig. 18. Diagenetic, very low and low-grade alteration of the Rudabánya Hills based on the illite crystallinity data (Kövér et al. 2009a; Deák-Kövér 2012; integrating several data of Árkai). Note that all metamorphic Triassic series were treated as belonging to the Torna unit but were separated into sequences, as shown on Fig. 14B. A) Nyúlkertlápa beds and C) Telekesoldal and Nyúlkertlápa beds together. B) Raman spectroscopy data (Molnár et al. 2021). E) Torna units. D, F) Pressure data in the Jurassic and Triassic rocks. G) The non-metamorphic Bódva unit only suffered high diagenetic alteration. A(hT), A(lT): high and low temperature parts of the anchizone. lP, mP: low and medium pressure

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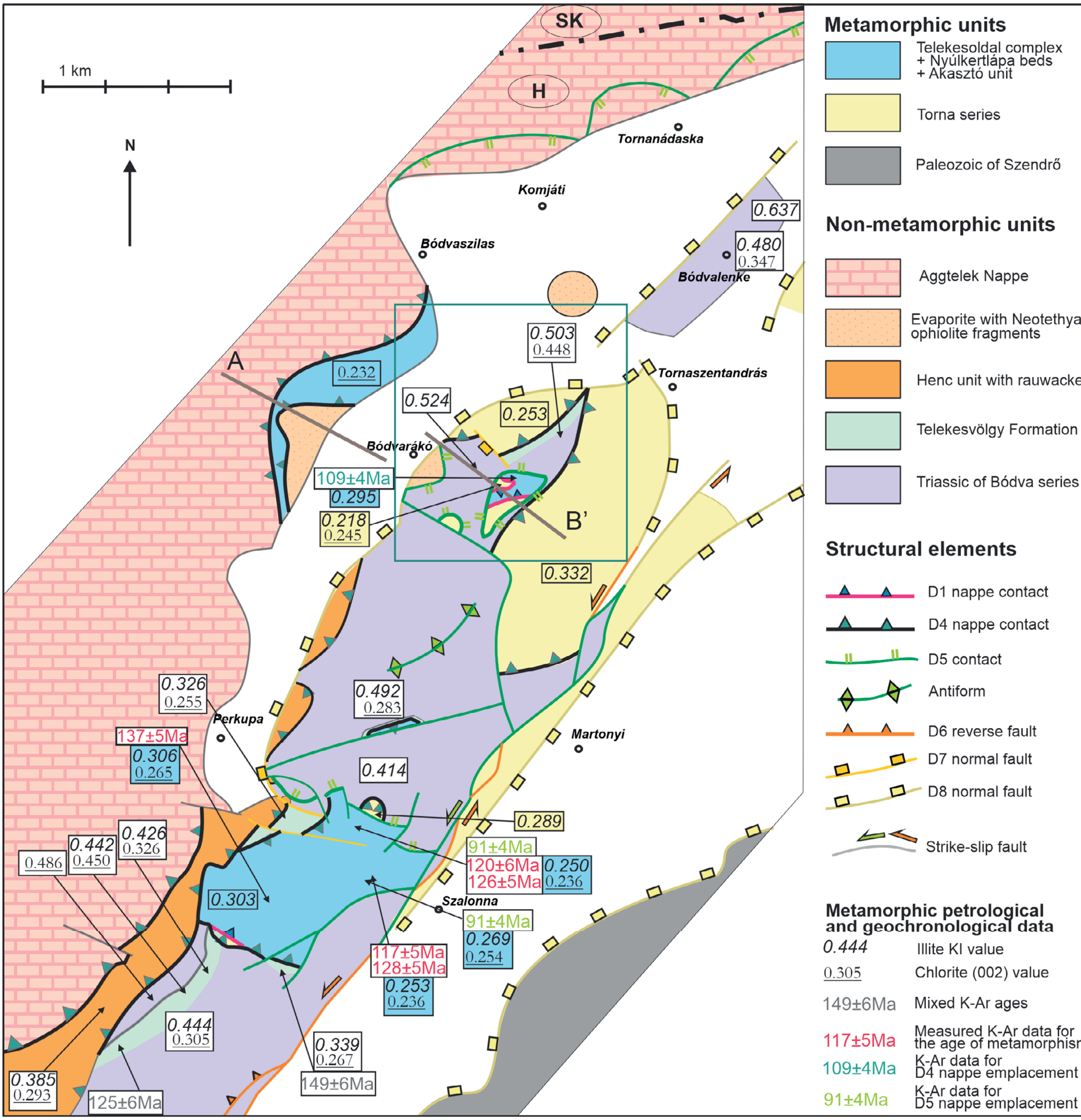

Fig. 19. Map distribution of metamorphic petrological data and radiometric ages (Kövér et al. 2009a). Frame shows the area of the pre-conference excursion, part B, see Fig. 31

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4.2. Short list of deformation phases

For the excursion, the "concept of Fodor-Kövér" suggests a preliminary list of deformation phases in the Aggtelek-Rudabánya Hills. This is a model, it should be updated in the future and should be correlated better to the deformation nearby (Lexa et al. 2003; Jerabek et al. 2015, Lačný et al. 2016, etc). Ambiguity of relative chronology is expressed with combined numbers. These phases will be explained during the successive stops.

Phases related to rifting:

DR1 phase: Triassic salt tectonics (from late Early to Late Triassic)

DR2 phase: Renewed Jurassic rifting and subsidence

D* phase: Eventual sinistral slip of Silica rocks eastward (latest Jurassic to early Cretaceous?)

Phases related to nappe stacking:

D1 phase: burial (incipient subduction), very low to low grade metamorphism of certain rifted margin units, vertical flattening, S0-1 foliation+ extensional shear bands

D2 phase: isoclinal to close intra-foliation folds with new S2 foliation

D3 phase: formation of recumbent folds during the burial or exhumation of some Torna units, contact of BR (Bódvarákó) and TO (NL) units. D3b sub-phase: kink folds

D4 phase: final exhumation of metamorphosed nappes, thrusting of metamorphosed units (T, BR, TO) over proximal parts of the margin (Bódva, Szőlősardó), with salt tectonics at the base

D5-6 phase: Thrust of Silica over the ophiolite, the exhumed TO, Torna–Turňa, BR (Bódvarákó), and other blocks

D5-6 phase: (~90Ma): triangle zone tectonics ("wedging ") at the outer (SE) margin of Aggtelek (Silica), thrusting of Bódva onto the TO, BR. Out-of-sequence thrusting and exhumation of Szendrő+Uppony Paleozoic onto the Bódva+T+TO sandwich. Reactivation of the Perkupa salt wall and additional salt tectonic deformation, including secondary weld formation.

D7 phase: thrusting of Bükk onto the Gosau and Uppony at ~70 Ma

D8 phase: E3 to M1 west-vergent reverse faulting and basin subsidence

D9 phase: Early Miocene (Eggenburgian?) south-east vergent transpressional faulting along the margins of the Rudabánya Hills; 22–20 Ma?

D10 phase: late Early to Middle Miocene rifting of the Pannonian basin (few traces only), 17–12 Ma?

D11 phase: Late Miocene normal faulting, salt wall collapse; 11–5 Ma

Most of these phases are shown on three model sections crossing of the Rudabánya Hills and marginal Aggtelek Hills (Fig. 20). On these sections, structures are projected from a certain distance, so occasionally they are more complex than in a single real cross-section but they intend to show existing structure in a combined image.

No primary thrust contact exist between the units. The only place where an early contact could exist is within the small BR (Bódvarákó) window between the Triassic and Jurassic sequences (although a sedimentary contact is not completely excluded there, see Stop B-3). The recumbent folding of the Torna unit (D3 phase) resulted in thrusting of an overturned limb over the evaporitic mélange (section A) during the D4, phase.

All sections show that the weakly metamorphic (Torna, BR (Bódvarákó), TO (Telekesoldal)) and non-metamorphic (Bódva) units are intermixed; any unit can appear in a different vertical order with respect to the other (exception of the BR (Bódvarákó), which is in lower position in its lonely occurrence). On the northern section, the Martonyi nappe is over the Bódva, but this latter thrust over the BR (Bódvarákó). On the middle section, the Bódva is over the TO (Telekesoldal) and they were folded together. On the southern section, on the contrary, the TO (Telekesoldal) is over the Bódva. In the "concept of Fodor-Kövér" the juxtaposition of metamorphic over non-metamorphic units belong to the D4 phase, while the renewed thrusting of the D5-6 phase emplaced the Bódva over the TO (Telekesoldal) on section 20B. This latter deformation seems to have southern or south-eastern vergency. The "concept of Fodor-Kövér" attributes the lower position of the BR (Bódvarákó) unit to this D5-D6 phase, while in the "concept of Less" the BR (Bódvarákó) is in its original position, and represent the real lower plate of the system, the suture being within the evaporitic mélange and the upper plate is the Silica.

In the "concept of Fodor-Kövér" the Perkupa salt wall is still between the Aggtelek and Rudabánya units, while in the "concept of Less" this boundary is just near the Bódvarákó window (Fig.11, 13, 20A, B). In the former view the mutual relationship of Silica versus Bódva is not clear, expect for the south-westernmost part, where the Szőlősardó and Lászi nappes appear above the Silica (Fig. 20, section C).

On the contrary, along the southern section (Fig. 20C) the only remnant of the evaporite could be the tectonic breccias embedding diverse Early to Middle Triassic blocks (Henc unit); so this would be a secondary salt weld. This unit thrust over the TO (Telekesoldal) (Fig.20C), so the salt tectonics, the welding, and the SE-vergent thrusting occurred together.

In the "concept of Less" the western boundary of the Rudabánya Hills is marked by the Darnó zone of supposedly Miocene age. In the "concept of Fodor-Kövér" this zone is a partly welded salt wall, along which strike-slip motion is not excluded. However, the welding and associated thrusting modified seriously this strike-slip zone and made it undulating to irregular. Some units with "unusual" stratigraphy can in fact represent original salt rafts developed already in the Triassic (rock piles

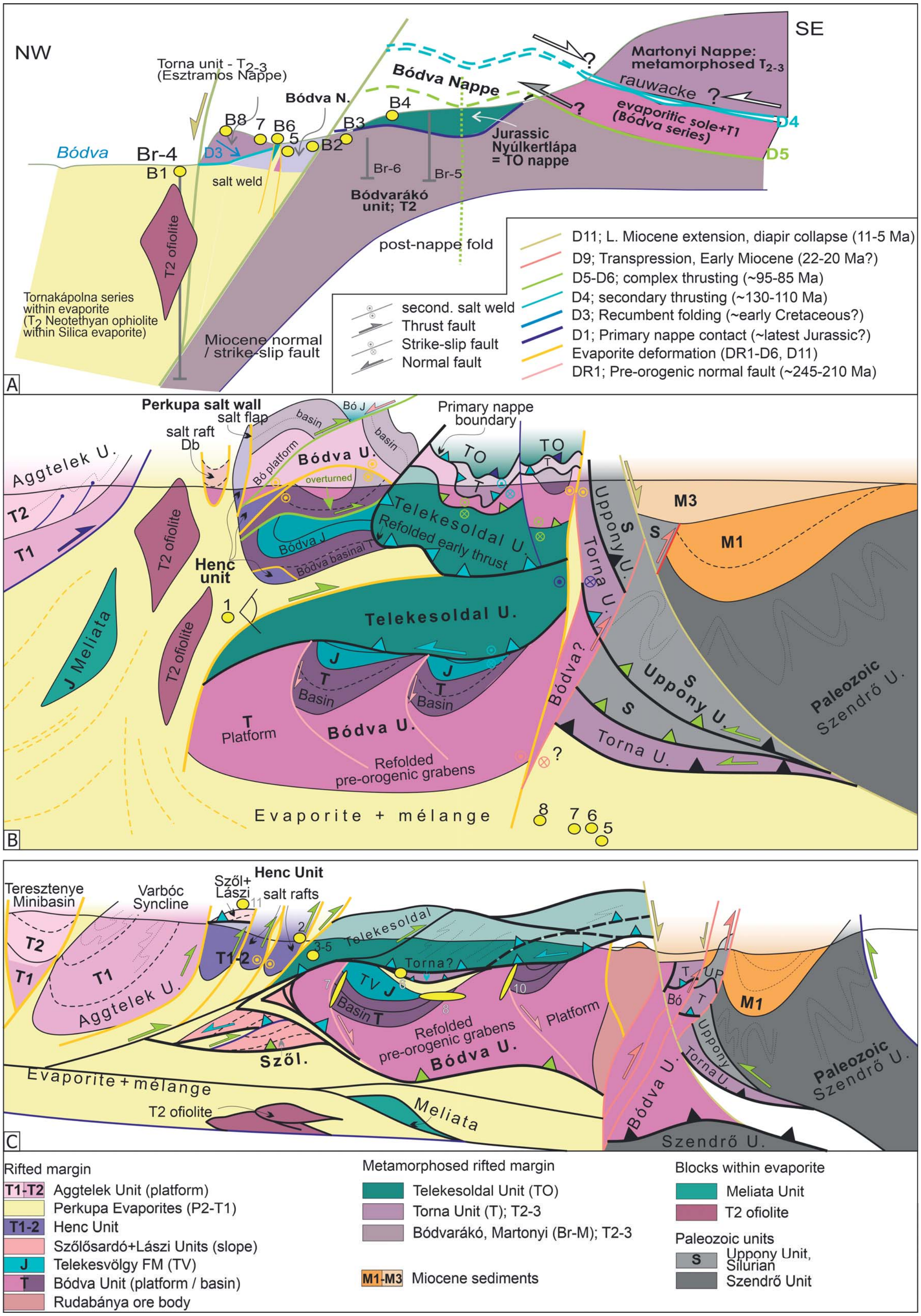

Fig. 20. Three model cross section through the Rudabánya Hills. A number of structures were projected into the sections, so they do not represent real sections. Yellow dots indicate the approximate locations of the pre- and post-conference excursion stops. A) Northern Rudabánya Hills across Bódvarákó (After Kövér et al. 2009a). B) Section at the middle Rudabánya Hills, near the Bódva gorge. C) Section through the southern Rudabánya Hills, (after Kövér et al. 2008, 2009a)

subsided into evaporite during subsidence), the example is the Db Dobódél raft in section B (Fig.20). This is the reason that this zone can only represent a Mesozoic feature, and called here as “Paleo-Darnó zone” albeit a new name would cause less confusion.

The situation is different along the eastern boundary of the Rudabánya Hills. One of the main players is the Early Miocene Szuhogy conglomerate which was moderately folded with eastern vergency during the D9 phase (Fig. 20C). In the “concept of Less” it is due to Miocene sinistral faulting, but in the “concept of Fodor-Kövér” is more a thrust with transpressional character. This deformation refolds a Paleogene to earliest Miocene contractional basin (D8 phase, Sztanó and Tari 1993) which extended over the southern Rudabánya Hills (Less et al. 1988). A number of narrow slices of both the Torna unit and of the Paleozoic of Uppony and/or Szendrő are involved in this zone. Their juxtaposition with the Bódva unit of the Rudabánya is due to the Miocene strike-slip (“concept of Less”, Fig. 13, 16). In the “concept of Fodor-Kövér” the metamorphic rocks of the Torna and the Szendrő units thrust over the Bódva, and were refolded later in the Early Miocene (Fig. 20C). It is to note that this south-east vergent thrusting is opposite to what can be seen more to the south, along the southern Darnó Zone (Fodor et al. 2005, former CETEG Meeting guidebook).

The D10 syn-rift phase has few structures expressed in the structure of the area and these occur mostly as outcrop-scale fractures. On the contrary, the D11 Late Miocene faulting resulted in subsidence of a number of small basins on both sides of the emerging Rudabánya ridge. On the SE, the normal faults cut across all previous contacts, but in the central and northern sector, the still existing Perkupa salt wall could be reactivated. The collapse of this wall could induce the Late Miocene subsidence.

4.3. Simplified concepts for the nappe stacking and original paleogeography

The “traditional concept” expressed in Chapter 3. can be challenged by the new metamorphic and radiometric data and some new concepts from the rifted margin evolution. However, the observation and several parts of the model could still be incorporated to new models.

In our approach we postulated a rifted margin where all units, not part of the Silica nappe, could be positioned on the same rifted margin before the nappe emplacement. They surrounded the Silica unit, eventually from south and east (Fig. 10B), but their original distance is not known. In this respect, we classify the Bódvarákó unit into this series (Fig. 14) and not to an oceanic unit. Facies differences within the Szőlősardó and Bódva, and within the Torna, Martonyi and Bódvarákó series seems to suggest that they occupied similar paleotopographic position between the platform and the deep basin (but probably none of them were very deep). Their different degree of alteration may suggest that their role in thrusting were different; the metamorphic units (T, M, BR) went down deeper. This different behaviour may also imply that their original distribution along the margin was not in a dip direction, but potentially along strike (Fig. 21).

Following the logic projected from the Dinaridic (Adriatic) rifted margin, the most distal unit (positioned closest to the oceanic crust) could have a reduced stratigraphy with the less influence from platform-derived clasts (Gawlick et al. 2016). This model is expressed for the Aggtelek, Szőlősardó and Bódva series (Kovács 1984, 1997, Fig. 15). However, the metamorphosed Triassic units could also be fit to such a model, but the supporting sedimentological data are scarce (see Fig. 14 for a scenario). It is to note, however, that in the modern concept of rifted margin, tilted blocks, far-travelled extensional allochtons can exist in extended magma-poor margin; this structural geometry permits the alteration of complete and reduced syn-rift Triassic sequence in the direction of the slope toward the oceanic crust. At the present understanding, no hyperextended margin can be detected in the area, but the Silica unit could be a large extensional allochton in one of the potential models (Fig. 21B).

All concepts accepted that the Bódvarákó Unit represent the deepest and most distal sedimentary rock unit in the entire Rudabánya Hills. It underwent a metamorphic alteration which was close to the epizone during the first-order nappe stacking (tectonic burial), the D1 phase. If the contact between the BR Triassic and NL Jurassic is tectonic in nature, this could form during this phase or during their exhumation.

Following the rifted margin logic, this BR+NL (TO) units should thrust over the more proximal margin, namely the Bódva unit. This is how we interpret the higher position of the Martonyi nappe and also of the Torna nappe over the Bódva Lower Triassic. It is also possible that this thrusting juxtaposed two different segments of the rifted margin, with contrasting pre-thrusting burial history. It is to note that in the “concept of Less” (Less et al. 2006, Less 2000) this juxtaposition would be the younger thrusting (see chapter 2.3) but we see a geometry derived from the exhumation. The “concept of Fodor-Kövér” does not exclude this possibility, but the suggested Miocene age seems to be unrealistic, taking into account the very mildly deformed

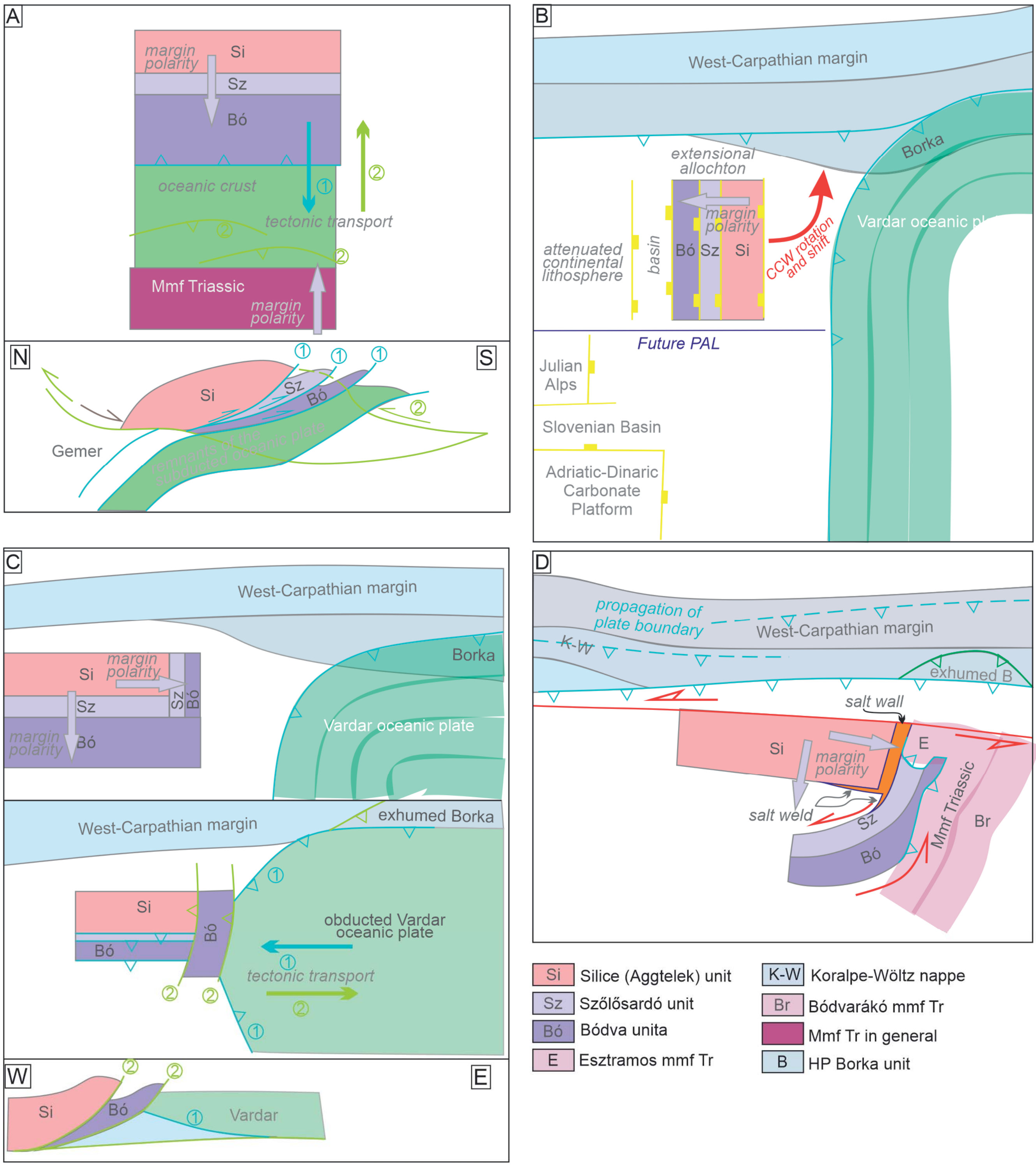

Fig. 21. Very simplified models describing potential paleogeographic position of the Aggtelek-Rudabánya units. A) Simplifying the "concept of Less". B) Rotated Silica and related pelagic units away from an extensional allochton position. C) Detachment of the Silica along the evaporite which resulted in a sort of triangle zone (after Schmid et al. (2008). D) Large-scale sinistral slip of Silica from its original position, along the developing subduction zone. Emplacement of metamorphic rifted margin over the Bódva could be during its rotation and sinistral shift. Note along strike variation of the northern Neotethyan margin; this could be due to non-cylindrical nature at the transition of the Carpathian to Adriatic segments. Mmf: margin with metamorphosed units. PAL: Periadriatic Fault

nature of the Paleogene to Early Miocene basin (Fodor et al. 2005); important thrusting is excluded.

We also agree with the original southern polarity of the Silica nappe (e.g., Kovács 1984, 1997); the platform carbonates are younger in the north than in the south, and the reefs are looking to the south (Velledits et al. 2011). If so, the Silica should have been buried under more distal units, like in the Dinarides. The other related feature to be explained is the ophiolite at the sole of the Silica unit, and not an obducted ophiolite, as observed largely in the Dinarides. Schmid et al. (2008) suggested a mega-triangle zone, where Silica was delaminated along the evaporite and the upper delaminated part thrust over the more distal units (instead of having been buried by them) (Fig. 21C). An alternative solution that the Silica unit slided laterally by strike-slip fault, sub-parallel to the margin, and arrived to a position where practically doubled the same margin. In fact, such a shift was visioned in the Eastern Alps (Stüwe and Schuster 2010) to explain the metamorphic character of the basement nappes (Fig. 21D). In this “doubled margin scenario” the thrusting of Silica nappe over ophiolite, exhumed metamorphic units (Torna–Turňa, Meliata, Telekesoldal) would simply be a normal in sequence thrusting. This strike-slip phase phases could happen between ca. 130 and 110 Ma (Barremian to Aptian) if one can accept that K-Ar ages are connected to exhumation (Fig. 19, 21D). The subsequent thrusting happened after 110 Ma probably during the classical Austroalpine phase (~110–85 Ma).

Salt tectonics played an important role in the Triassic facies development. Firstly, they determined the internal paleotopography of the Silica nappe (Oravecz et al. submitted). On the other hand, the margins of the Silica could also be marked by extensive salt walls. The pre-existing salt walls could hamper the formation of thrusting of distal units (e.g. Bódva) over the Silica, expect for the areas where salt wall was somewhat “less resistant”. This is the case for the units with slope facies (Szőlősardó and Lászi units); they seems to thrust over the marginal salt walls and onto the platform (Aggtelek) development (Fig. 12 and this volume).

On the other hand, salt walls could divert the emplacement directions away from the wall; verticalization of units along the Perkupa salt wall can be an example. This could result in opposite vergency on both sides of the salt wall. This effect, and the very complex boundary conditions could lead the renewed thrusting in variable direction. The assemblage of the thrusts might have led to triangle zone formation; the entire Rudabánya would be such a structure (Fig. 21B, 20B. C).

5. Pre-conference excursion: From rifted margin to nappe stacking: Permo-Mesozoic structural evolution of the Aggtelek and Northern Rudabánya Hills. (spotlight on salt tectonics and nappe stacking)

5.1. Part A: Triassic salt tectonics near Jósvafő

5.1.1. General description, introduction (salt walls, welds near Jósvafő)

In a series of outcrops, participants can study the traces of salt tectonics and the related deformation of the adjacent rocks. The stratigraphy is simple; the Permian to lowermost Triassic Perkupa Anhydrite Fm. could be present at shallow depths below the Quaternary and was reached by two boreholes nearby (Jósvafő Jő-2, Szinpetri Szp-1, Fig. 22). The original sedimentary cover of the evaporite succession is the lowermost Triassic Bódvaszilas Sandstone Fm. (bT1), which is also exposed under very bad outcrop conditions, while the remaining Lower Triassic formations are not present. The next member of the succession is a laminated to thin-bedded dark grey limestone, which was formerly attributed to the latest Early Triassic Jósvafő Member of the Szinpetri Fm., but recently was re-classified as part of the Gutenstein Fm. (well-bedded dark grey limestone with abundant calcite veins, Hips, 2022). On our map, we still followed the old concept, but we consider the new one closer to field classification, e.g., the two dark grey limestones are difficult to separate. This new interpretation would give an early Middle Triassic age to these rocks. Finally, the northern part of the area is covered by Middle Triassic platform carbonates (Wetterstein Fm.).

In this part of the Aggtelek Hills, there is two large fault zones that cut through the Triassic succession. At the Stop A-1 and -2, the Lower and Middle Triassic formations are separated by a young-on-older contact, which is gently north-northwest-dipping and will be visited in Stop A-2 and seen from a viewpoint near Stop A-3. The structure can be followed through a dozens of km towards ENE and was named as Jósvafő-Bódvaszilas Fault Zone (JBFZ, Mello et al., 1997; Hips, 2001). One important slip phase was clearly a reverse motion with south-eastern vergency. However, the new model of Oravecz (2019) and Oravecz et al. (submitted) suggests that the contact was initiated as a halokinetic structure with top-to-NW normal motion. The arguments are the occurrences of isolated lenses of the lowermost Triassic bT1 (Bódvaszilas) Fm., which could be associated with evaporites, too. This sandstone-siltstone lithology reappears in several sup-parallel halokinetic structures (Stop A-4, A-6). In addition, in the immediate hanging wall of the JBFZ, a 1 km thick platform carbonate was encountered in borehole Szin Szi-2; the base of which is much lower than the surface occurrence of Lower Triassic formations. Thus, reverse slip could not overprint the earlier normal fault.

The Lower Triassic formations in the southern side of the JBFZ are cut through a sub-vertical E-W striking fault zone, called Jósvafő-Perkupa Fault Zone (JPFZ, Stops A-3 and A-4, Fig. 22, Less, 2000; Hips, 2001). The JPFZ is characterized by several controversial observations. One of them is the kinematics, which seems to change along strike; in map view, the displaced stratigraphical contacts show dextral offset along its eastern segment, but sinistral offset along the middle segment. Another problematic observation is the dramatically different stratigraphy thicknesses on the two sides of the fault zone; namely, the Szinpetri Fm. is 8 to 10 times thicker in the northern fault block, while the carbonate facies indicate widespread ramp environment and even paleosurface (Hips, 2001, 2022). The geometry of the JPFZ is also unusual for a fault zone: the general westward dip of the displaced Lower Triassic formations changes on both side of the fault to an E-W striking dip, and the measured dip angles steepen to sub-vertical or even overturned positions, forming tight to isoclinal antiformal structures along the fault zone.

The first part of the pre-conference excursion will cross the JBFZ in the village of Jósvafő. The panoramic view and the Stops will present the young-on-older contact in the north (Stop A-1, A-2), the strongly folded Gutenstein Limestone in Stop A-3, and the Salt wall parallel to the JBFZ (Stops A-4) (Fig. 23).

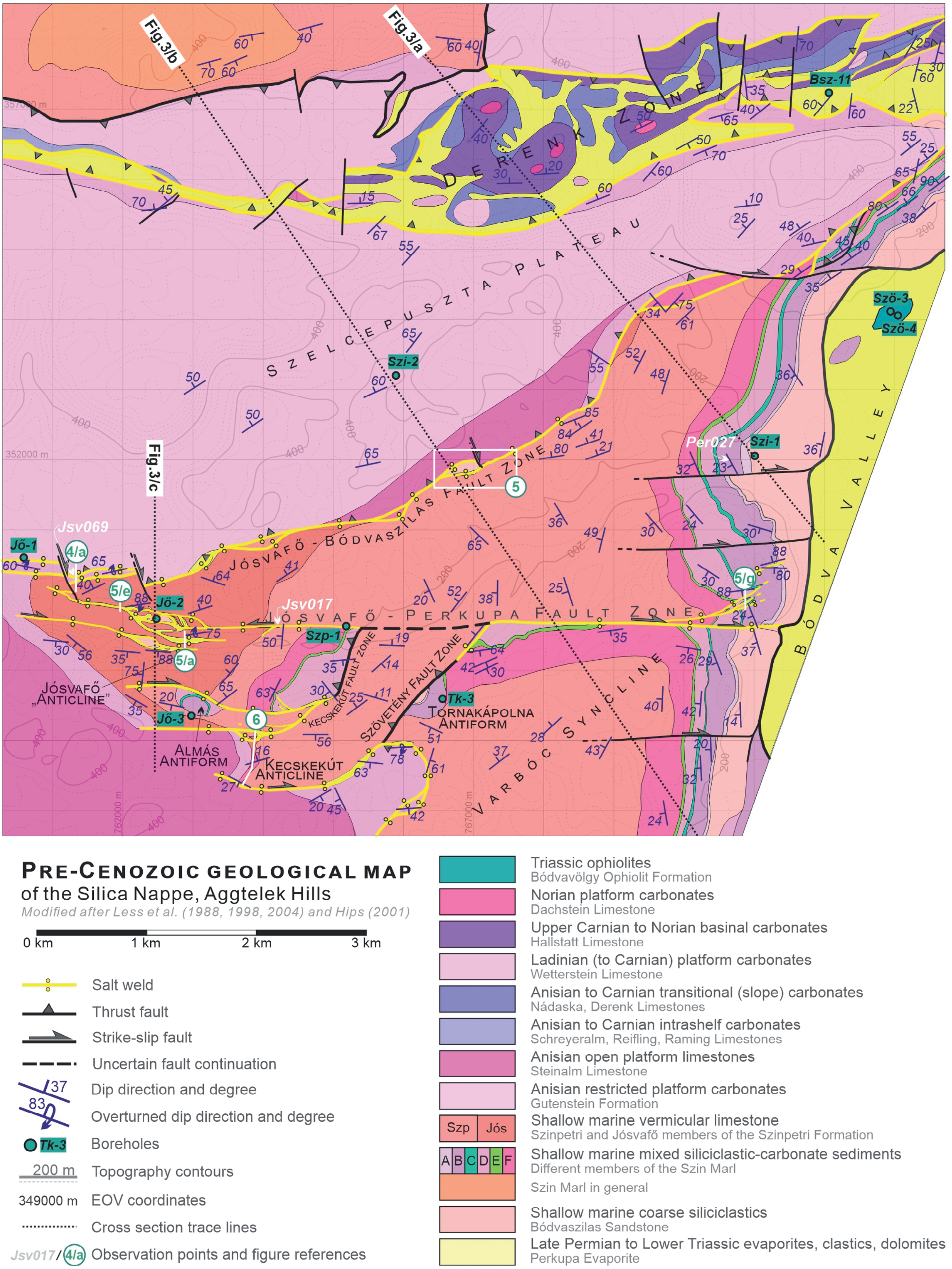

Figure 22. Pre-Cenozoic geological map of the non-metamorphic Triassic succession of the Silica Nappe in the Aggtelek Hills, NE Hungary (Oravecz et al., submitted; modified after Less et al., 1988, 2004; Hips, 2001).

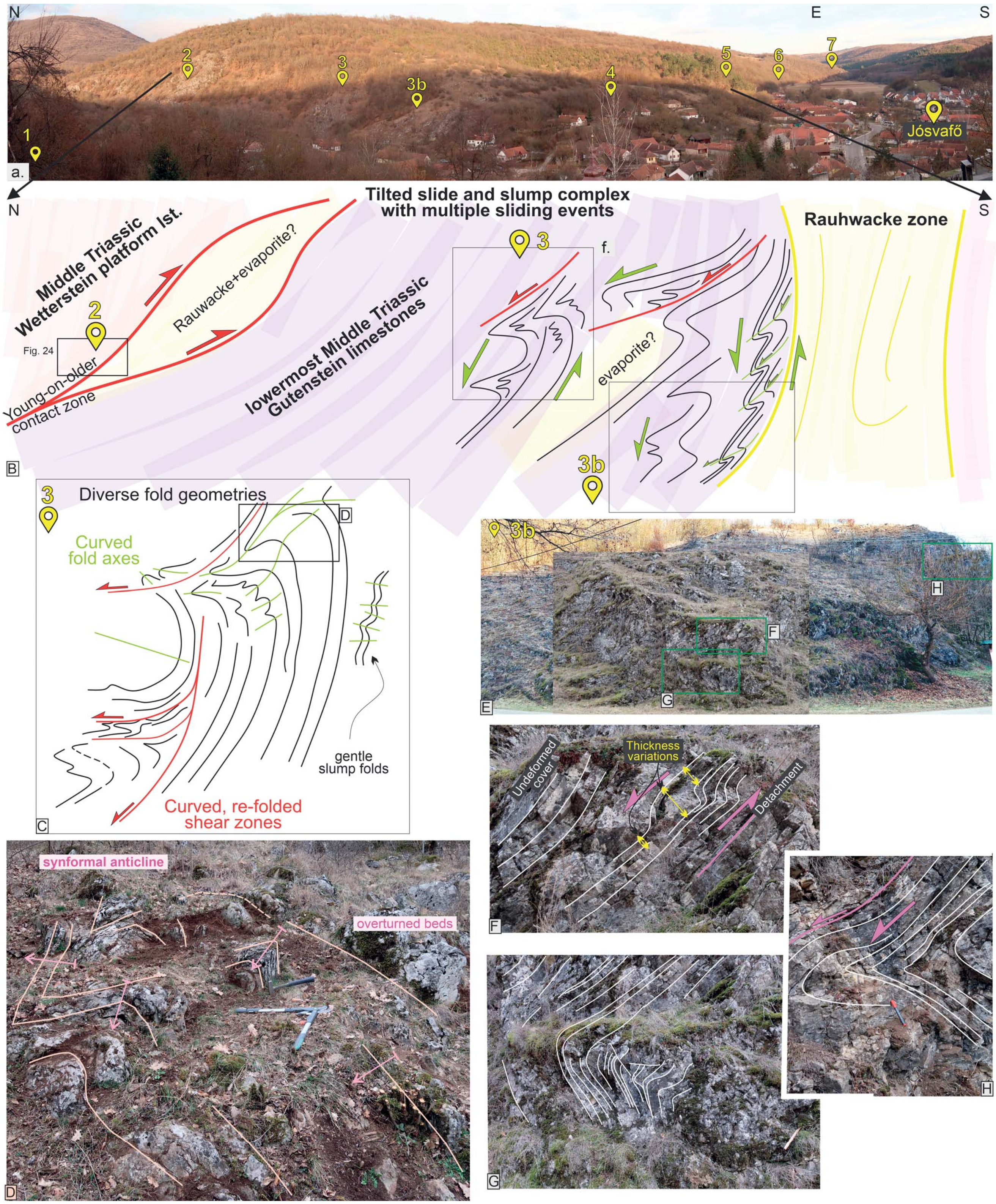

Fig. 23. Panoramic view and interpretation of the JBFZ and JPFZ looking from west (cemetery of Jósvafő). Note the south-vergent thrust which resulted in salt weld, the vertical shortening in Stop A-3, and A-3B, and the vertical salt wall crossing the village (Stop A-4). Note synformal anticline in the apical part of the major fold (D, E), sub-horizontal fold axial surfaces near the salt wall (G, H), and very early sliding for slump fold with thickening fold limb (F).

5.1.2. Stop A-1. Kossuth cave

The source at the entrance of the cave exhibits the light grey limestone of platform origin (Wetterstein Fm.). Bedding is difficult to establish, but steep to moderate northward dip is suspected in few places. The contact with the southern footwall block is covered by scree. The footwall is composed of laminated to well-bedded dark grey limestone (Gutenstein Fm.) what we will visit on our way toward the village. These rocks shows several folds; some of them are closed and overturned to the south (Fig. 24C). Together with north-dipping fracture planes the structures indicate thrusting to the south.

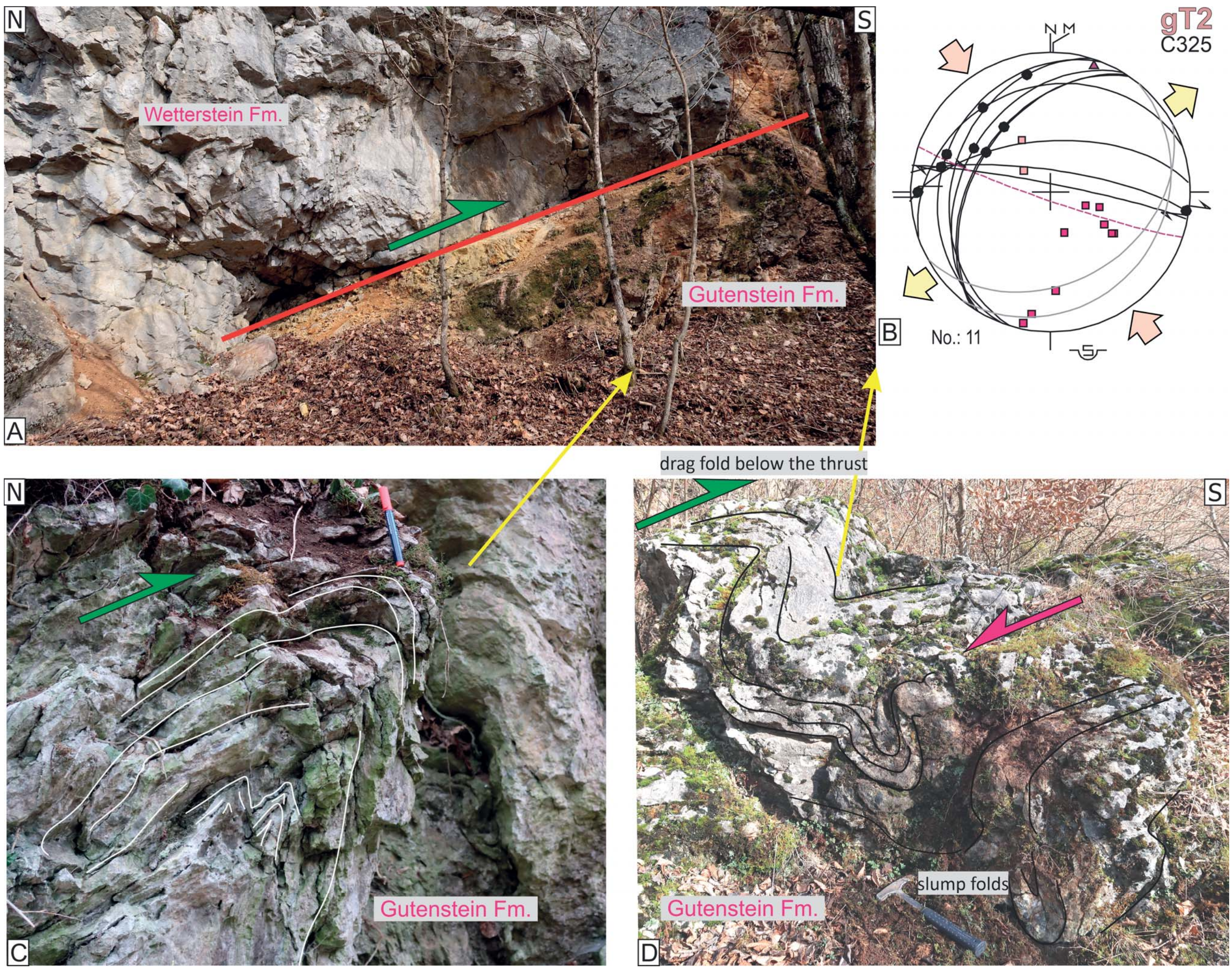

Fig. 24. Young-on-older thrusting north of Jósvafő. A) the thrust contact in Stop-A2; the Wetterstein Limestone is over the Gutenstein Limestone. B) stereogram of the measured data (Oravecz, 2019). C) Drag fold associated to the thrusting in Stop-A1, a topographically lower site in the footwall block. C) Similar drag fold just near the exposed thrust (Stop-A2). The slump fold to the right derived from an earlier (Triassic) sediment deformation event (and could be refolded during thrusting)

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5.1.3. Stop A-2. Small quarry on the Kuriszlán path

This outcrop exposes the low-angle thrust contact (JBFZ) between the Wetterstein and Gutenstein Fm., similarly as shown on the former and recent geological maps (Less et al. 1988; Fodor et al. 2006; Oravecz 2019). This a young-on-older contact, meaning that the hanging wall is younger than the footwall; part of the Gutenstein Fm. and the Steinalm Fm. missing between them. The thrust was re-mapped and could be followed eastward.

This small quarry exhibits the tectonic contact itself (Figs. 23, 24). The gently dipping thrust bears two generations of striae; one is nearly dip-slip (to NW) while the other one is oblique to the west. The latter seems to overprint the former and have normal kinematics. These faults could belong to the map-scale fault trending NNW–SSE to NNE–SSW which are parallel to the morphological slope and have the trace near the creek. The fault could displace the thrust (however, alternatively it could be a lateral ramp of the thrust system). Dip-slip striae could be associated to the thrust displacement, and the stress field was NW–SE compression (Fodor et al. 2006; Oravecz 2019) (Fig. 24B). In the nearby borehole Jósvafő Jő-1, the Wetterstein Fm. is in thrust contact with Jósvafő Mb. Gentle undulations and closed to isoclinal overturned disharmonic folds are also present; they are interpreted as slump folds. Fold asymmetry may indicate top-to-NW shear. As we will see later, this could be associated with an earlier shear along the main halokinetic structure.

5.1.4. Stop A-3. Cliffs in the village, eastern side of the Kuriszlán path

South from the quarry a moderately to steeply north-dipping package of Gutenstein Limestone is present. The steeply dipping limb becomes overturned, (first steeply and then gently) and a complex folding is present in the hinge zone with disharmonic folds (Fig. 23 C,D).Fold shape becomes more complex in the main cliff of the village, where the general dip is 30-40 to the north or north-northeast. Interlimb angle varies from gentle to isoclinal; in the latter type both limbs dip north (Fig. 23D). In chevron-type closed folds the overturned limb is south-dipping (Fig. 23 H), and in the isoclinal folds the overturned limb is sub-horizontal or even gently north-dipping. Fold shape changes along the axial surface from rounded in the core (when gentle to closed) and very angular outward (when isoclinal); in such fold parts hinges are pointed. Axial surfaces are quite curved, and frequently close to horizontal or gently north-dipping (Fig. 23C, E, G, H). Brittle shear planes may occur along the long moderately dipping limbs or along the overturned isoclinal folds; however, they terminate quickly within the package.

In some parts the short limb show thickening with respect to the long limbs; we interpret this as plastic flow within the fold. This would indicate syn-sedimentary folding (Fig. 23F). However, when layers keep their thickness, slump folding nature can hardly be established (although not excluded).

Short and long limbs can frequently be defined; in our interpretation the short limbs could be overturned and the long ones are in normal position. In this case shear sense can be determined which shows top-to-north shearing. Such shear can occur if the whole package was tilted northward. We interpret the folds as indicating a gravitational collapse of a tilted fold limb. The tilting would occur due to ascent of the evaporite and incorporated bT1 (Bódvaszilas) lenses (Stop A-4). In this model the folding, and sliding would have been initiated by the gravity, and indicate the collapse of the oversteepened Gutenstein package.

5.1.5. Stop A-4. East of Jósvafő, carriage road to Hegytető

Along a small road, moderately to steeply dipping Jósvafő Limestone is in contact with carbonate breccias. Traces of the bT1 (Bódvaszilas) Fm. are suspected because of the purple soil and very small shale fragments. This belt was mapped as bT1 already by Less et al. (1988). This 60-70m wide belt is interpreted as a secondary salt weld where the carbonate breccias and bT1 mark the former present of the evaporites. The trip will follow this salt wall eastward. The rise of this salt wall could have induced the northward tilt of the Jósvafő Limestone (Stop A-3) and its strong folding.

5.1.6. Stop A-5. Side valley in the eastern part of Jósvafő

This small gorge-like valley segment exposes a 15-20 m thick typical carbonate breccia that we interpret as rauhwackes. These rocks are generally composed of variable carbonate clasts and a matrix of crushed carbonate material, cemented by calcite of several generations. Crushing, dissolution and precipitation cycles repeated several times (lastly recently giving a cheese-like appearance to the rock).

At the northern end of the cliff (at a small waterfall), vertical beds of the Gutenstein Fm. (Jósvafő Member) follows the breccias zone; their transition is rather gradual. Several gently dipping small faults dissect the layers, but curve upward into bedding planes. We interpret these small features as tilted slide planes having been formed at sub-horizontal bed position. The whole ca. 50m wide body could be considered as vertically tilted raft between two salt walls.

5.1.7. Stop A-6. Carriage road to the wine yards of Jósvafő

The small quarry along the carriage road exposes strongly altered carbonate breccias and rauhwackes interwoven with dense gypsum and calcite vein networks. Apart from the veins, the weathered rauhwackes contain dark grey, black and sometimes riffle-green shale clasts (Figure 26). The size of these clasts mostly varies between 4 and 10 cm, but occasionally larger (~50 cm) sized clasts were observed, too, with their longer axes oriented sub-vertical. We interpret these shale clasts as remains of interbedded silicilatic formations of the Perkupa Evaporite succession. Similar sediment was exposed on the road bottom with subvertical dip (Figure 26).

Fig. 25. Salt wall in a side valley in Jósvafő. A) 15m wide rauhwacke zone. B) Rauhwacke wall just east of the Stop A5, in another side valley. Vertical Jósvafő Limestone layers with early slide planes just near the rauhwacke zone. D) Isoclinal folds north of the salt wall showing vertical shortening, due to gravitational sliding like in Stop A3

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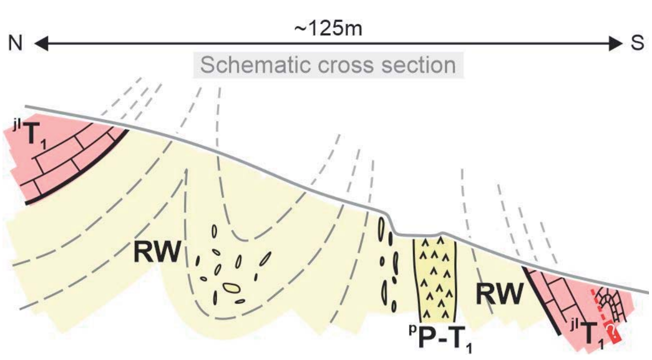

Figure 26. Schematic cross section through the E-W striking rauhwacke zone and the bounding steeply dipping Lower Triassic Jósvafő Member (Oravecz et al., submitted). Incorporated shale clasts are interpreted as the remains of interbedded siliciclastic sections of the Perkupa Evaporite succession.

5.1.8. Stop A-7. Cliffs in the first road curve east of Jósvafő

Coming from Jósvafő, the road to Szinpetri makes a sharp curve around the Jósvafő Limestone cliffs (Fig. 27). Here, two groups of smaller wavelength folds were observed in the outcrops; one group has an open interlimb geometry and top-to-N vergency, with thickness variations in the deformed beds (Fig. 27/B, C), whereas the other group of chevron-type tight folds shows angular hinge zone geometry and top-to-S vergency (Fig. 27B, D), clearly signalling two different folding events. Superimposed on these outcrop-scale folds, the Jósvafő Limestone steepens from the general 50° to 80° and the uppermost part of the cliffs are even overturned. Layer-parallel striations measured on the bedding planes show top-to-N vergency, indicating normal (top-away-from-the-hinge-zone) shearing. The steep bedding planes also show signs of subsequent reactivation, as indicated by the overprinting oblique

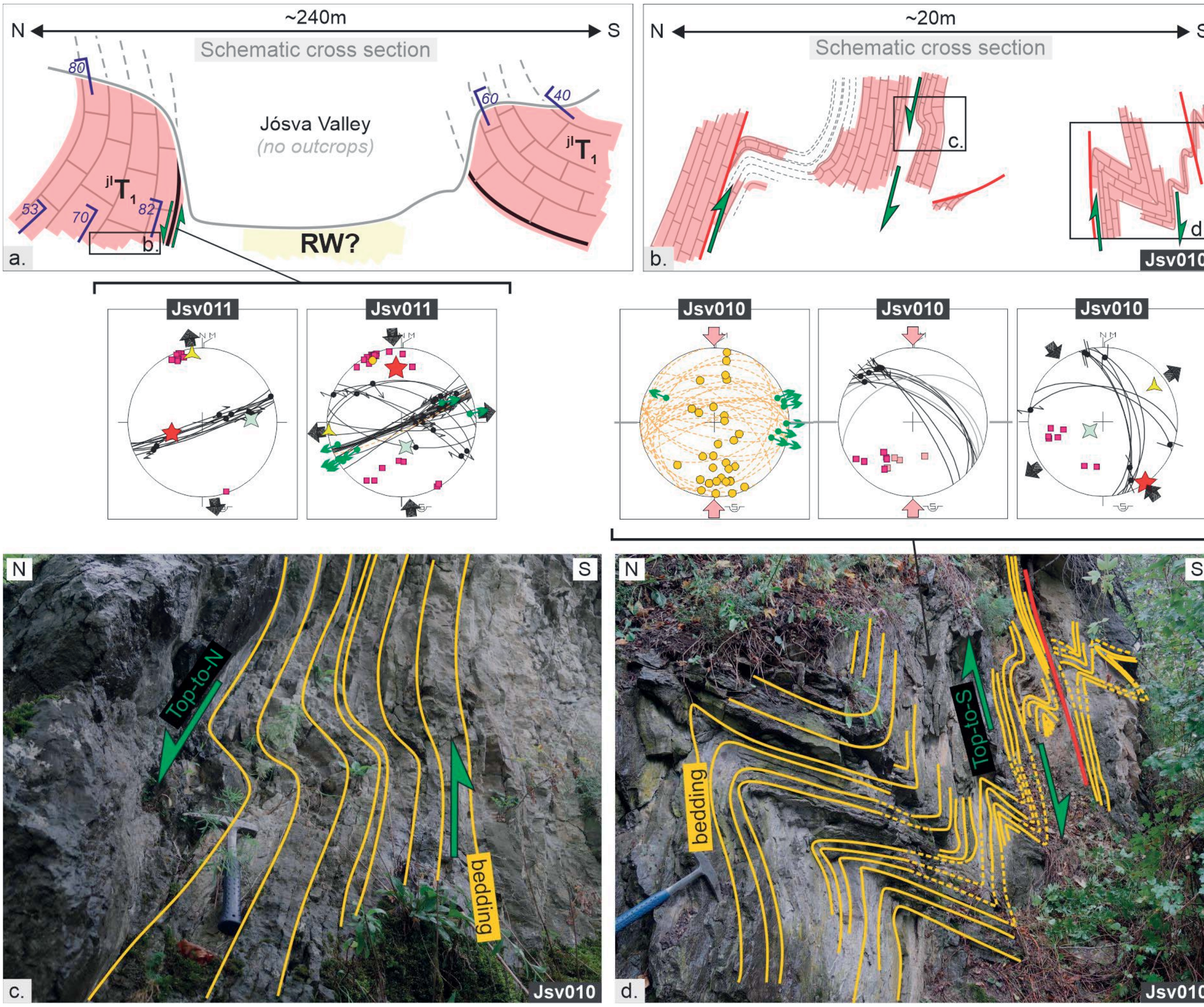

Figure 27. Field observations at the first road curve near Jósvafő (Oravecz et al., submitted). A) Schematic cross section through the Jósvafő Limestone that steepens towards the JPFZ and Jósva Valley. B) Enlarged section of the road curve outcrop. C) Interpreted field photo of the first fold group, with open and rounded interlimb geometry and top-to-N vergency. D) Interpreted field photo of the second fold group, with tight and angular interlimb geometry and top-to-S vergency

sinistral striations. Then, the sub-vertical Jósvafő Limestone disappears at the roadside, while there are absolutely no outcrops along the JPFZ, which runs in the narrow valley of the Jósva Creek. On the other side of the valley, the outcrops return and the measured dip data indicate symmetric fold geometries in the Jósvafő Limestone (Fig. 27A).

5.1.9. Stop A-8. Road cut in front of the Almás valley, east of Jósvafő

Towards east, the general dip of the Jósvafő and then Szinpetri Limestones change to steep (50-65°) westward dips, and the dominant structural features of the larger roadside outcrops and small quarries become extensional faults. The symmetry axes of these conjugate normal fault Mohr pairs are perpendicular to the bedding planes, indicating pre-tilt age for the related E-W and WNW-ESE extensional deformation (Fig. 28). The normal faults are presently tilted, sometimes sub-horizontal, and the fault planes often show compressional or oblique strike-slip reactivation, as suggested by the observed striae (Fig. 28B, C). Stereoplots of the measured striae showed that the σ1 of this superimposed compressional stress field was NW-SE directed.

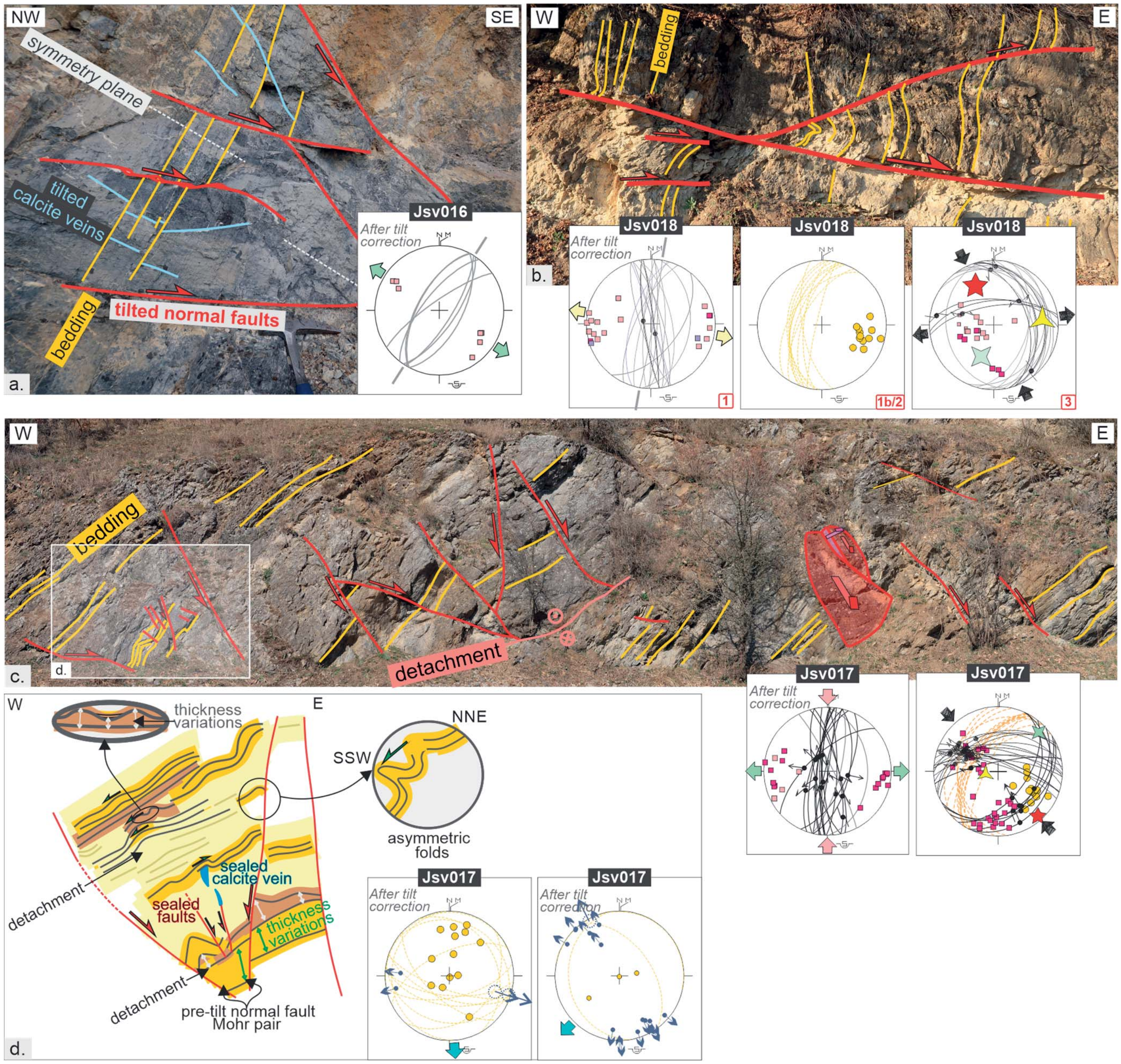

Fig. 28. Pre-tilt deformation features in the Jósvafő and Szinpetri Limestone east of Jósvafő. A) Pre-tilt normal fault Mohr pairs in the Jósvafő Limestone. B) Sub-horizontal normal faults in the Szinpetri Limestone. C) Pre-tilt extensional structures in the Szinpetri Limestone, with superimposed oblique compressional striae. D) Enlarged section showing syn-sedimentary slump folding with top-to-S and –SW sedimentary transport direction

Beside the brittle structures, the limestone layers show small-scale folding as well. The folds are a few cm in size, have generally asymmetric, open to tight geometry and rounded hinge zones (Fig. 28D). Moreover, lateral thickness changes and onlaping on the folded layers were observed as well, suggesting syn-sedimentary deformation. Back-tilted fold data indicates top-to-S and –SW directed slumping and paleo-slope direction.

5.2. Discussions of the observed salt tectonic structures

5.2.1. Arguments supporting salt tectonics

During the excursion, we make a number of structural and stratigraphical observations that require an alternative approach to the traditional structural solutions that are usually applied in fold-an-thrust belts. The presence of the Perkupa Evaporites in base of the Silica Nappe denotes that evaporite deformation could have played an important role in the structural evolution of the area, and that salt tectonics could provide a

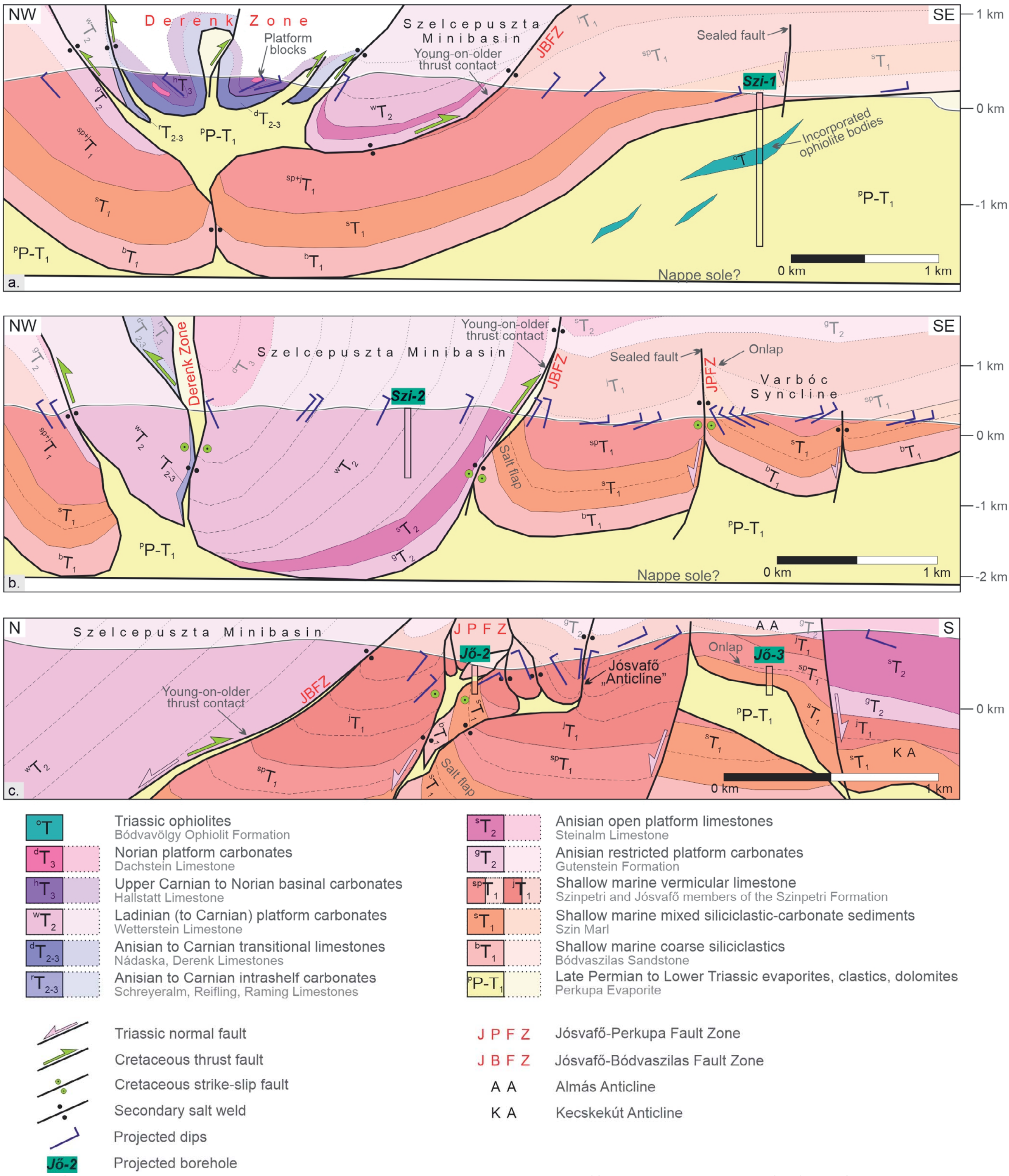

Fig. 29. Cross-sections across the most important structures in the Aggtelek Hills (Oravecz et al., submitted). A) NW-SE section through the wide middle part of the Derenk Zone and the Bódva Valley. B) NW-SE section through the narrow western segment of the Derenk Zone, the Szelcepuszta Plateau, Jósvafő-Bódvaszilas and Jósvafő-Perkupa Fault Zones. C) N-S section through the western segment of the complex Jósvafő-Perkupa Fault Zone and Jósvafő "Anticline". See section trace lines in Fig. 22

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coherent explanation to a number of our observations. Our arguments for salt tectonic deformations can be summarized as the following:

(1) Strongly altered carbonate breccias, called rauhwackes, were mapped in linear sub-vertical zones along the main fault zones and in the core of the tight

antiforms. The Jő-2 and Szp-1 boreholes positioned above these rauhwacke zones drilled through the Perkupa Evaporites in shallow depths.

(2) There are some large (a few tens or a hundred m in diameter) isolated, lens-like occurrences of the lowermost Triassic formations that occur along the two major fault zones. These rock bodies have sub-vertical structural boundaries on all sides and are completely surrounded by older formations and rauhwackes.

(3) There seem to be significant thickness changes in the pre-orogenic strata, starting from the Late Olenekian (from the deposition of the Szinpetri Limestone), while slump fold complexes and frequent early (syn-sedimentary) normal faults show active deformation and morphological changes during the second half of the Early Triassic.

(4) The major fault zones are also associated with fault-related folding. The observed fold geometries are quite unique: the antiforms are very tight or isoclinal with sub-vertical or even overturned limbs, the hinge zones are angular and have pointy (tapering) geometry, and the fold vergencies are inconsistent. Shear indicators along the fold limbs show normal sense layer parallel slip.

(5) The direction of displacement along the E-W striking fault zones is very inconsistent: some of the parallel faults show dextral, some show sinistral offset, and some even show along-strike variation of the displacement direction (e.g. JPFZ).

(6) Young-on-older type contacts are frequent in the whole Silica Nappe. The most important one in the study area is the JBFZ, which shows strong lateral variations in dip direction and dip angle.

We consider the mapped rauhwackes as complex mixtures of breccias and leached evaporite residues that formed by the interaction of evaporites, the host rocks and the fluids circulating along their tectonic contacts (Spötl, 1989; Warren, 2016, Leitner & Spötl, 2017). The sub-vertical rauhwacke zones therefore mark the former presence of evaporites that were later pressed out or dissolved, and presently form depleted secondary salt welds (Wagner & Jackson, 2016). Considering this, the visited JBFZ and JPFZ are both remnants of linear salt structures, i.e. salt walls (Fig. 29). We interpret the lowermost Triassic lenses occurring along the JBFZ as blocks (salt rafts) that were sheared off of the sedimentary cover, incorporated into the evaporites and transported to higher stratigraphical levels by the emerging diapirs. Similar incorporated rafts are commonly observed in better exposed salt structures around the world, for instance in Iran and Turkey (Weinberg, 1993; Hudec & Jackson, 2007; Kergaravat et al., 2017). The emerging diapir causes uplift and stretching in the overlying sedimentary cover, which can lead to normal faulting and sedimentary slumping, which can explain the observed slide and slump complexes at Stop-3 (Rowan et al., 2003, Poprawski et al., 2014).

When pre-existing salt structures are affected by contraction, the evaporites are squeezed from the diapirs, leaving only the leached rauhwackes and incorporated raft bodies behind. The host rocks bordering the diapirs are also pressed together along the secondary welds. As the diapir flanks are frequently dragged upward by the diapirs, the adjacent drag folds typically form pointy tight to isoclinal folds along the welds (Alsop et al., 2000; Rowan et al., 2003, 2016; Giles & Rowan, 2012; Hearon et al., 2014). This is observed for instance in the Mexican La Popa (Rowan et al., 2012) and Turkish Sivas Basins (Kergaravat et al., 2017), and it explains the unusual fold geometries observed in the Aggtelek Hills. Furthermore, we consider the normal (top-away-from-the-hinge-zone) sense of shearing along these folds as further evidences for salt-related deformation. Uneven and alternating subsidence of the two sides of the salt structures can result in the observed along-strike changes of displacement along the welds, while the welds themselves are prone to localize deformation during the continuous contractional deformation, leading to the formation of (often oblique) thrust welds (Wagner & Jackson, 2016). When the reverse displacement is less than the preceding salt-related normal slip, the total throw remains normal, leading to the development of the frequent young-on-older type thrust contacts, like the JBFZ.

5.2.2. Timing of salt tectonics

Our observations indicate a continuous syn-sedimentary deformation during the Early and Middle Triassic, which we connect to the deformation of the evaporites. Even though the sedimentary facies of most Early Triassic formations infers even ramp environment and lack of tectonic movements, we propose that the observed slump folds and pre-tilt normal faults show slight, but continuous morphological and tectonic changes contemporaneously with the deposition. These small-scale structures are already present in the lowermost part of the sedimentary cover (Bódvaszilas and Szin Fm.), however, their number and frequency significantly increases in the Szinpetri Formation. This formation is also the one that displays the highest thickness variations across salt-related fault zones. Consequently, we propose that the onset of evaporite deformation occurred as soon as the late Olenekian (age of the Szinpetri Formation), but slight primary salt

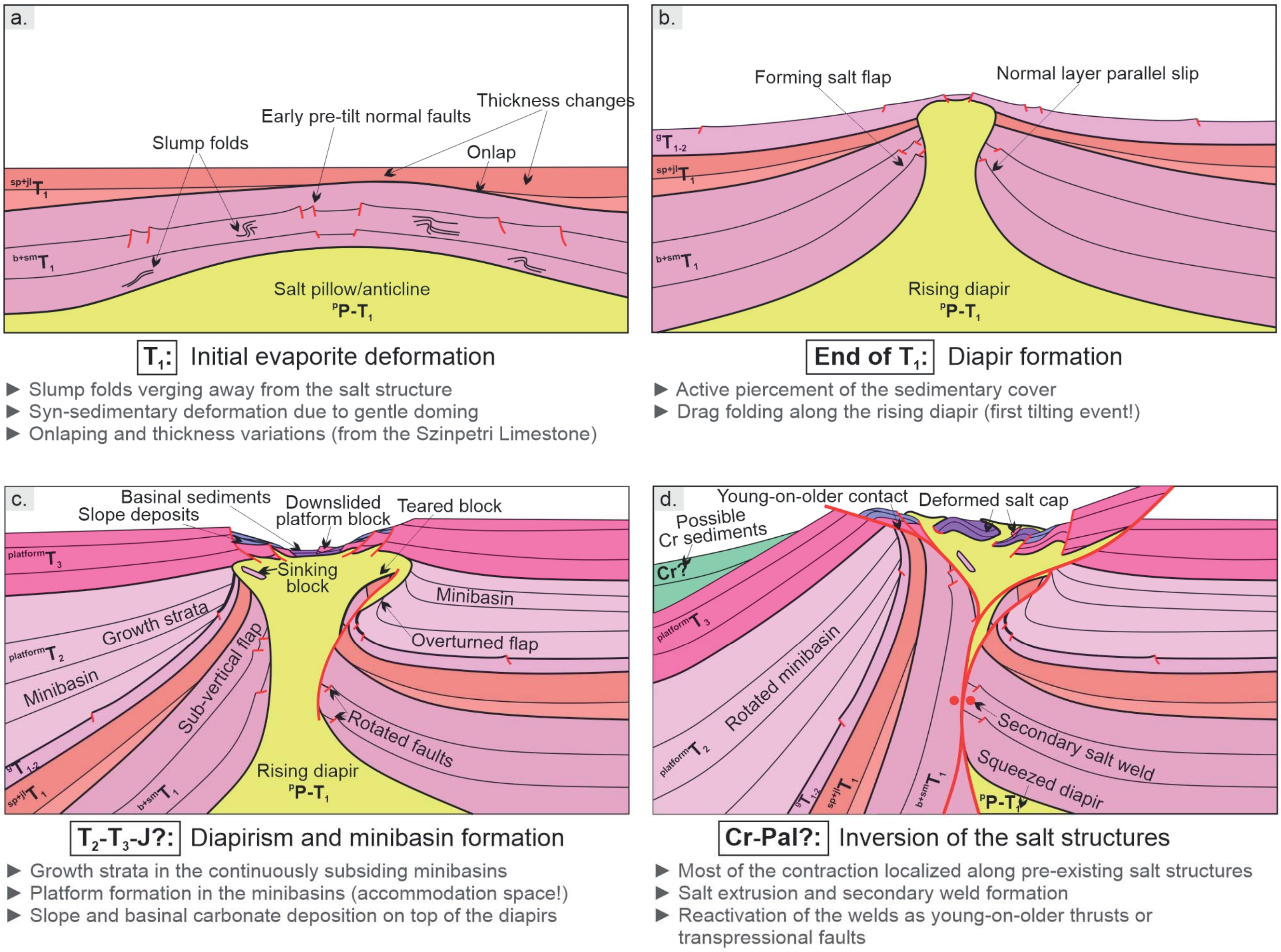

Fig. 30. Schematic model summarizing some of the main observations and presenting the evolutionary model for the Triassic pre-orogenic evaporite deformation (Oravecz et al., submitted). A) Initial gentle doming of the evaporites, with slump folds and syn-sedimentary extensional faulting on top of the salt pillows and salt anticlines. B) Diapir formation with active piercement and drag folding long the diapir (salt flaps). C) Mature stage of salt tectonics, with facies differentiation. D) Inversion of the pre-existing salt structures, with secondary weld formation and development of young-on-older type thrust contacts

movements may have started as soon as the Induan to early Olenekian. At this time, true diapirism and piercement of the sedimentary cover haven't started yet, only salt pillows and gently salt anticlines are inferred (Fig. 30A). Active piercement of the sedimentary cover seems to have started during the latest Early Triassic and lead to drag folding along the rising diapir structures (Fig. 30B). We propose that discordant stratigraphy contacts along these salt structures are not necessarily tectonic contacts, but sedimentary onlap surfaces and pinch-outs related to the syn-sedimentary tilting and folding of the salt flaps (Rowan et al., 2016).

Kinga Hips (pers. comm.) has a different interpretation on the onset of salt movement. The argument is solid; some Early Triassic Formations (mostly the Szin Fm.) has several members and they appear in the field with the same development (and maybe thickness). However, we state that the slump folding, pre-tilt normal faults, and other features can indicate a modest uprise of the salt.

In addition, the map extension of the late Early Triassic Szinpetri (spT1) Fm. is highly variable; quite thin belts south of the JPFZ, but very large extension north of it and south of the Szövetény fault. We interpret these map-view variations as due to thickness variation and not merely a differential shortening of the sequence. In stop A-8 strongly tilted, sub-horizontal normal faults, for example, could contribute to enlargement of surface size of the spT1 Fm.

Coeval with the diapir growth, the intermediate areas between the diapirs and salt walls begun to sink into the underlying evaporite succession and underwent subsidence. These areas are called minibasins, whose evolution is controlled by the evaporite deformation (Callot et al., 2016; Jackson & Talbot, 1991; Hudec et al., 2009). The facies distribution of the Steinalm and Wetterstein Limestones are in good agreement with the supposition that the Szelcepuszta plateau can be a minibasin; the reefs are located along their southern rim while more internal (northern) part is marked by lagoonal development. All these interpretations suggest that the salt walls were probably emerged during the deposition of the Steinalm and Wetterstein formations, from the middle-late Anisian.

The mature stage of salt tectonics is represented in other parts of the Silica Nappe. For instance, at northern margin of the Szelcepuszta Plateau, Late Triassic slope (Derenk Fm.) and basin carbonates (Hallstatt Fm.) are preserved in a narrow zone, called the Derenk Zone. Contrary to the traditional interpretations, in the salt-controlled environment of the Silica Unit the Middle to Late Triassic platforms did not form on the elevated footwall blocks or normal faults, but rather the subsiding minibasins, while the deep water sediments deposited on top of the diapirs (Fig. 30C). Therefore, the contact between the evaporites and the Late Triassic formations could be primary sedimentary contact, i.e. they deposited directly on the exposed diapirs.

Facies distribution similar to the Szelcepuszta minibasin could exist in the Aggtelek plateau, therefore its southern margin is supposed to be a halokinetic structure. This is even more important, because it follows the southern margin of the entire platform area and it is located between the platform, the slope and shallow bathyal part of the rifted margin (Szőlősardó and Bódva units). The original presence of evaporite is proved for the Szőlősardó slope (anhydrite quarry) but not certain below the Bódva facies. In any case, the presence of evaporite separated normal faults in the uppermost crust and below this layer, making the rift-related fault pattern more complicated.

5.2.3. Structural evolution (inversion of salt structures)

A number of previous studies have showed that pre-existing salt structures exert a strong control over the subsequent contractional deformation phases by localizing the majority of contraction, whereas the minibasins behave as quasi rigid blocks, thus their internal deformation remains minimal (e.g. Graham et al., 2012; Kergaravat et al., 2017; Granado et al., 2018; Hassanpour et al., 2018). This also means that inherited salt structures were carried within the Silica nappe during its emplacement over other units (ofiolitic remnants, metamorphosed passive margin of the Turňa, Meliata and Bôrka Units). The salt walls have been deformed, the evaporite almost completely squeezed out, finishing with the formation of salt welds in a number of cases and their reactivation as transfer faults or oblique (young-on-older type) thrust faults (JBFZ, JPFZ, Fig. 30D). In addition, the existence of inherited salt structures prohibited the formation of a typical fold-and-thrust belt within and the southern margin of the Silica nappe. Although the oblique salt walls seems to show dominantly southern vergency, the eastern margin of the Silica nappe formations can be sub-vertical showing weak north-west vergency.

5.3. Part B: Internal nappe structure of the northern Rudabánya Hills

5.3.1. Introduction into tectonic units near Bódvarákó

The complex nappe structure of the Rudabánya Hills is not solved without contradictions, partly due to poor outcrop conditions. In the excursion we present some views on the possible solutions. In this area 5 tectono-stratigraphic units are present (Fig. 18, 19, 20, 31).

The **evaporitic sole of several nappes**, mostly included into the Perkupa salt wall, which contains ophiolite fragments and other rock types derived from different tectonic units, all could be embedded into the evaporite during final emplacement of the Silica nappe.

Bódva unit: non-metamorphosed Triassic to Jurassic sequences slightly varying in the Middle to Late Triassic parts; here the lowermost Triassic Bódvaszilas Fm. (bT1), sandstone, siltstone, shale appear.

The **Torna unit (nappe**) is composed of metamorphic Triassic sequence and its classical stratigraphy includes Middle Triassic platform carbonates (Gutenstein and Steinalm limestones and dolomites), latest Anisian to early Carnian slope carbonates, Carnian shale and cherty Pötschen limestone of late Carnian to Norian age.

The **Martonyi nappe** is a metamorphosed Triassic sequence which is similar to the Torna unit but does not contain the Steinalm Limestone and was subsided during the Anisian. The Ladinian is represented by a very thin (5-10m) cherty dolomite and limestone (in the sense of Fodor & Koroknai 2000, but note different view of Less et al. 2006, and Chapter 3).

The **Bódvarákó window** includes one or two metamorphic sequences. The lower **Bódvarákó sequence of Triassic age (BR)** is very reduced, potentially tectonically truncated, and contains only two formations; the platform Gutenstein Fm. and the basinal Bódvarákó Fm. The particularity is that it shows the earliest sign of subsidence, while middle Anisian is represented by deep-water instead of shallow-water carbonates (Fig. 14), so its differ considerably from the classical Torna unit. Paleogeographically this series was placed between the Bódva and Meliata units, as the most distal units exposed. On the other hand, it is similar to the lower part of the Martonyi nappe, simply the higher stratigraphical elements are missing (Fodor &

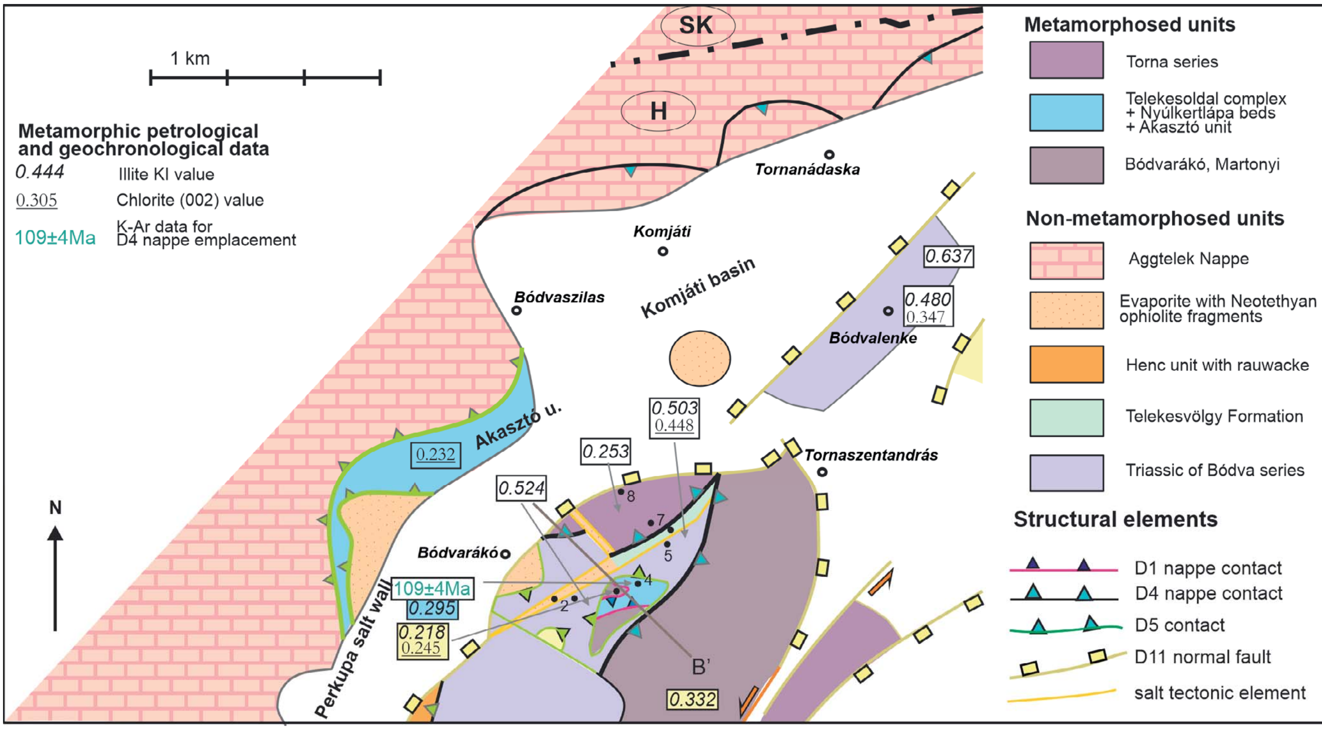

Fig. 31. Tectonic units and metamorphic petrological data in the northern Rudabánya Hills with stops of excursion part B. (Kövér et al. 2009b).

Koroknai 2000). Although Fodor & Koroknai (2000) suggested their attribution to the Torna unit, carefulnvestigation of the definition of the Torna unit (Less 1981) suggests their separation. The distal position of the BR unit is also corroborating its metamorphic alteration.

The "**Nyúlkertlápa beds" (NL**) are composed of shale, marlstone with limestone blocks or layers are considered as Jurassic, based on lithological similarities to the Telekesoldal Fm., which, in turn can be classified together with the Meliata rocks, a sort of accretionary wedge metasediments (Deák-Kövér 2012). The NL metasediments are anchimetamorphic.

Despite their mutual disposition, the continuity of the Jurassic over the Triassic rocks is not clearly demonstrated; a tectonic contact is also possible (although not obvious). The exposed metamorphic sequence of **the Bódvarákó window** is surrounded by non-metamorphic Lower Triassic sequence of the Bódva unit (Less et al. 1988, Hips 2001). The window forms an antiform with ~N–S axis, below the evaporitic mélange and the Bódva series.

Because of this disposition, there were at least two nappe emplacement phases in this area; a concept that is accepted in most interpretation, although the chronology of these two major phases is different. The first phase in our view was emplacement of metamorphosed and exhumed distal margin metasediments over the non-metamorphosed Bódva unit, and the second phase was the repetition of this sandwich that resulted in the birth of the BR window.

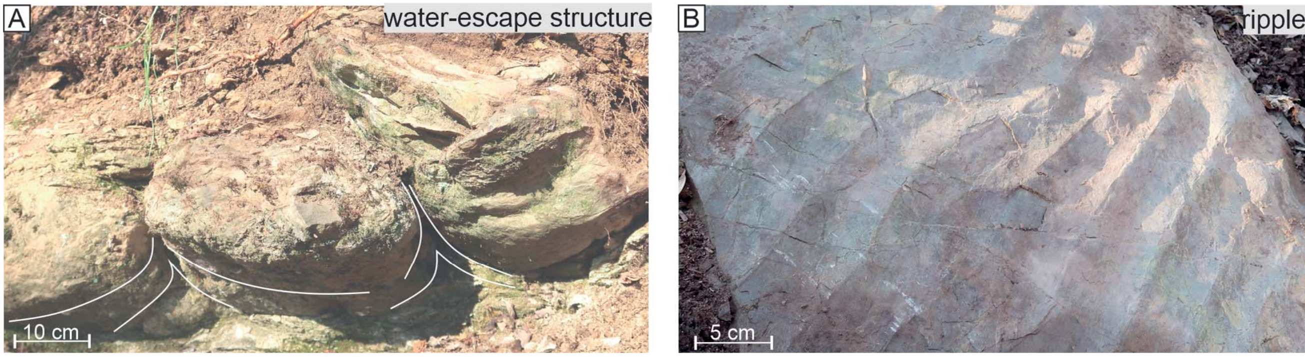

Fig. 32. Soft sediment deformation feature in Bódva unit, Bódvaszilas Fm. (Early Triassic). B) Ripples on bedding plane in Stop B-5. These preserved feature indicate non-metamorphosed character of this unit

5.3.2. Stop B-1: Bódvarákó, location of Br-4 borehole

More than 20 wells penetrated this formation and it was shown/interpreted on former maps (Less et al. 1988; Less 2000). Dismembered ophiolite suite consisting of gabbro, serpentinite, basalt was documented in a dozen of boreholes in the Bódva valley; one was penetrated by the Bódvarákó Br-4 borehole just east of the village and in the small outcrop on the western side of the valley (Pantó and Földváry-Vogl 1950; Havas 1984, Grill et al. 1984; Réti 1985; Horváth 1997, 2000, Józsa et al. 1996). Evaporitic mélange with ophiolite fragments exist below the entire Aggtelek nappe, up to the Turňa Valley window in Slovakia. All these observations clearly argue a salt

and Rudabánya Hills. The other observation is a west-vergent oblique fold wit sub-vertical limb in the bT1 clastics. This fold suggests ~E–W shortening with westerly vergency.

50m upward nice water-escape structures are preserved in a 25cm thick layer (Fig. 32). Further eastward ca. 200m similar structures are seen, and even soft-sediment lineation is visible. All these features demonstrate non-metamorphic status of this rock.

The fracture system is complex. Conjugate low-angle fractures could indicate E-W shortening. Fractures and high-angle faults seems to indicate normal slip, referring to E-W extension. The relative chronology is not clear. However, we can associate the fold in previous outcrop and conjugate low-angle fractures, all pointing to E–W to WNW–ESE shortening.

5.3.4 Stop B-3: Bódvarákó, Nyúlkertlápa, abandoned small quarry

This outcrop exposes the lowermost tectonic unit, the metamorphic Triassic-Jurassic sequence(s) of the Bódvarákó window (BR). The outcrop exhibits the pelagic formation of the Bódvarákó window while the tectonic deformation phase coeval with the emplacement of the Aggtelek (Silica) nappe over the ophiolite. This also implies that either the ophiolite suite existed on the surface or should be exhumed to the base of the Silica nappe sometime during its nappe emplacement.

5.3.3 Stop B-2: Bódvarákó, tourist path blue cross

The first sop exhibit carbonate tectonic breccia block which could be slightly slided downslope but an important tectonic boundary is just nearby. This fault would bounds the Lower Triassic Bódvaszilas clastics (bT1) and Middle Triassic rocks. The excursion crosses this tectonic zone later (Stop B-6). In the “concept of Less” this zone represents he boundary of the Aggtelek nearby borehole Br-6 penetrated the underlying Gutenstein Dolomite (Less et al. 2006).

Outcrops and boreholes show that the succession starts with the Anisian Gutenstein dolomite. The presented outcrop shows the next member of the succession, the dark grey, thin-bedded limestone with black chert lenses which alternate with black chert (radiolarite) layers (Bódvarákó Fm.). In other outcrop thin-bedded to laminated limestone also occur. Clay to siltstone films composed of illite, chlorite, quartz and plagioclase occur along bedding planes. The surface outcrop yielded Ladinian conodonts while few specimen would argue for middle Anisian (Pelsonian) age (Less unpublished report). The thickness is about 40-60m. Microfacies is radiolarian and/or filament biomicrite or biomicrosparite with wackestone to packstone texture. The depositional environment is considered as deep pelagic.

In the main wall the limestone exhibits very weak layer-parallel foliation and the flattening of radiolarians is expressed in thin section. Occasionally very weak oblique foliation could be present and is sub-horizontal or dips gently eastward. The beds are gently to moderately dipping to NE, they are cut with more steeply dipping surfaces. Because fold hinges were not clearly seen, they are interpreted as shear planes making low angle to bedding. Their geometry may permit the interpretation of as sigmoidal shear zones indicating top-to-SW shear, but this is quite uncertain (Fig. 33).

Fig. 33. Gently NE-dipping cherty limestone layers of the Bódvarákó Fm. in Stop B-3. Note steeper planes which could be shear planes.

The Triassic and the presumably Jurassic rocks (Bódvarákó- Nyúlkertlápa beds) underwent high anchi- or low epimetamorphic alteration; the Kübler-index (KI) average value is 0.219±0.037 Δ˚2Θ (Kövér et al., 2009b). A chlorite-„crystallinity" index (ChC (002) or Árkai index) shows similar distribution to the KI values (average: 0.245±0.020 Δ˚2Θ) (Fig. 18, 19).

Pressure condition of the metamorphism can be deduced from b0 parameter data. This range from top part of the low pressure to medium pressure in the Bódvarákó window (Fig. 18, 31); the average value is 9.008±0.005 Å (Árkai, 1985; Kövér et al., 2009b). Using the diagram of Padan et al. (1982), and accepting the estimated temperature range of 300–350°C near the boundary of anchi- and epizone (Árkai 1985), one can obtain ~2.5-3 kbar and ~2-2.5 kbar ranges for the Nyúlkertlápa and the southern Telekesoldal Jurassic metasediments, respectively (Figs. 18, 19, 31). The data from the Bódva Triassic are contrasting, and show only diagenetic alteration (Fig. 31). On the other hand, both Martonyi and Torna units (Fig. 31) show closely the same values although the Martonyi nappe could be slightly less metamorphosed.

A K/Ar age on illite from the Jurassic shale is 109±4 Ma; we attributed this age to the exhumation and thrusting of the metamorphic (Br) over the non-metamorphic (Bódva) units (Figs 18, 19) (Kövér et al., 2009b); in this case this age data may indicate post-metamorphic fluid migration during nappe emplacement. In this interpretation 109 Ma post-dates the early D1 phase (burial and metamorphism of the rifted margin rocks). However, the age may also reflect a partial reset of the metamorphic age (with no structural meaning).

5.3.5 Stop B-4: Bódvarákó, road above the Nyúlkertlápa leading to the Esztramos quarry

Above the quarry an old research trench exposed marlstone and shale containing micritic limestone

lenses or layers, as in the nearby borehole Br-5 (Less, 1981). The contact of the cherty limestone and this unit is not clear; it can be either a sedimentary or tectonic contact. The sequence seems to be part of the "Nyúlkertlápa beds" (NL) better exposed in the road cuts just above.

Lithologically the NL beds are built up by dark grey, greenish grey and black shale, slate, marlstone, and limestone. Sometimes it contains mm to cm sized grey limestone and marl clasts ("micro-olistoliths") Meter-sized limestone blocks could also be olistoliths, but boudinaged layer interpretation is also possible. Olistostromes represent the connection to the Telekesoldal Fm. where such gravity-flow deposits are abundant (Deák-Kövér 2012). This is the view already suggested by Csontos (1988).

The age of the NL beds could be Jurassic but it is based on lithological similarities to the classical TO formation (Deák-Kövér 2012). No conodonts or other fossils were found in the limestone blocks (despite ~20 samples). Petrological data indicate that the metamorphic alteration of NL series reached the boundary of anchizone and epizone (Chapter 4.1). All these features strengthen earlier views that this series is part of a metamorphic unit (Less 2000, Less et al. 1988; 2006). While KI indices, the lithological characteristics and the ductile deformational features are quite similar to the TO complex, we consider these units as equivalents.

Foliation is expressed but sedimentary beds can hardly be identified. Despite this, the foliation is interpreted as mostly layer-parallel S0-1. Closed intrafolial folds were observed in thin sections (D2 phase) (Fig. 34). The other structures of the outcrops are shear bands overprinting the primary foliation.

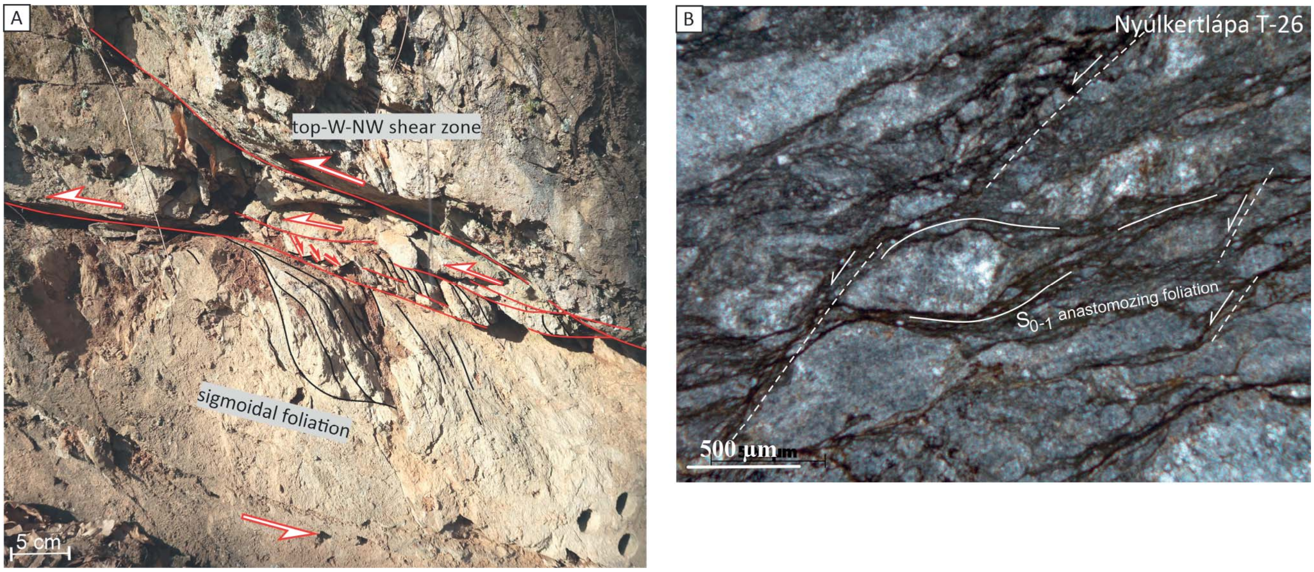

Fig. 34. Structures in the Nyúlkertlápa in Stop A-4. A) Sigmoidal brittle-ductile shear zones indicating top-to-west shearing post-dating the foliation. B) thin section image of the NL beds. Note foliation, anastomosing shear zones, sigma-clasts(?).

Formerly they were interpreted as belonging to a late-stage phase (D5) but an attribution of the early D4 phase is not excluded.

Foliation sometimes shows sigmoidal geometry and connected to low-angle brittle planes (Fig. 34). In one case these structural assemblage marks top-to-west displacement. One can attribute this deformation to the nappe stacking of the exhumed Torna and Br units over the Bódva units.

Altogether the deformation indicates top-to-west tectonic transport. This could be associate with the complex nappe stacking of Bódva, Torna, Martonyi and Torna and Bódvarákó units during the D4 and D5 phases. It is possible that this was associated to folding of the window itself.

5.3.6. Stop B-5. Bódvarákó, valley toward the Esztramos quarry

In a deep ravine starting from the sharp road leading to the Esztramos quarry, the Lower Triassic bT1 (Bódvaszilas Fm) is outcropping, exhibiting ripple marks (Fig. 32B) and molluscs. A steeply plunging chevron fold is equally preserved.

5.3.7. Stop B-6. Bódvarákó, outcrops below the dump of the Esztramos quarry

This is an enigmatic part of the area; steeply dipping zone which is composed of variable rocks of the Bódva unit, embedded in rauhwacke breccia (Fig. 31). In the stop Upper Triassic basinal limestones occur in red marlstone matrix (no more exposed). In the “concept of Less” this is the main boundary zone between the Rudabánya and Aggtelek Hills and is the continuation of the Darnó Zone. In the “concept of Fodor-Kövér” it represents a salt tectonic feature superimposed by Cretaceous contraction resulted in a salt weld.

Stop B-7. Bódvarákó, Keglevics carriage road

The old carriage road leading from the village to the Esztramos quarry exposes the late Anisian to Ladinian

Fig. 35. Well-developed mylonitic foliation with sigma-clasts in the Middle Triassic of the Torna unit, Stop B-7

basinal formation of the Esztramos sequence.

This rock exhibits well-developed mylonitic foliation (Fig. 35). While this structure seems to be parallel to formation boundaries, it is considered as being layer-parallel S0-1. Few lens-shaped foliation wrap around porphyroclasts (bioclastics or cherty limestone lenses), although most of them are in scree and not in situ. In other cases, sigmoidal foliation is present. These feature may indicate the original shear sense associated to the D1 phase, although the number of observation is small and the 3D geometry is unclear. In a nearby outcrop intrafolial isoclinal folds occur in a limestone intercalation of the Carnian slate (Fodor & Koroknai 2000). Unfortunately, no shear sense was deduced from this structure (so any new observation would be welcome).

Layer-parallel foliation is typical also for the Martonyi nappe (Fodor & Koroknai 2000) and other Torna occurrences (Fodor & Koroknai 2003) in Hungary and also in Slovak side (Lacny et al. 2016). All these structures formed during the primary burial of the Torna sequence (D1 phase).

Closed to isoclinal folds were observed in the Martonyi Nappe with a moderately developed axial-plane foliation. Such feature was not observed within the Esztramos sequence/unit. On the other hand, the Esztramos sequence has been overturned, and originally it could belong to the nappe stacking phase over the Bódva units (D4 of Deák-Kövér 2012).

5.3.8. Stop B-8. Esztramos Hill, view to the margin of the Aggtelek Hills and the Komjáti Basin

From the viewpoint the eastern end of the Szelcepuszta minibasin, the termination of the Derenk salt wall and the front of the Alsóhegy-Dolny vrh minibasin can be seen, all being parts of the Silica nappe. Near the eastern margin of the Bódva valley, on the exposed slopes of some small hills Jurassic metasediments are occurring, in vertical position; their

Mid-Jurassic age has been proved by fossils (Kövér et al.2009b). They were formerly attributed to the Lower Triassic (Less et al. 1988; Hips 2001). We named this tectonic lenses as Akasztó unit (Kövér et al. 2009a) and interpreted the metasediments (mostly shales and marly shales) as part of the Telekesoldal Fm (Fig. 31, 36). Near these outcrops one very small surface outcrops of the Bódva valley ophiolite occurs (Pantó and Földváry-Vogl 1950, see also Stop B-1). All these rocks are interpreted as part of the diapiric mélange which consists the Perkupa salt wall. (see this Perkupa salt wall in our tectonic sketch.

This viewpoint permits the discussion of the salt tectonic features between the Aggtelek and Rudabánya Hills. The presence of evaporitic rocks was long known below the Bódva valley; gypsum was excavated by underground mine (Havas 1984). More than 20 wells penetrated this formation and it was shown/interpreted on former maps (Less et al. 1988; Less 2000).

As mentioned at the stop B-1, blocks of dismembered ophiolite suite, gabbro, serpentinite and basalt were equally documented in dozens of boreholes (Havas 1984, Réti 1985, Horváth 1997, 2000). Such situation exists below the entire Aggtelek nappe, up to the Turňa Valley window in Slovakia. All these facts clearly argue a salt tectonic deformation phase coeval or after the emplacement of the Aggtelek (Silica) nappe over the ophiolite.

The mélange formation already incorporated some weakly metamorphosed metasediments, both Jurassic and Triassic, which could belong the TO, Meliata, Turňa, Torna units. Their mutual position could change over the entire salt-assisted thrusting process (so their

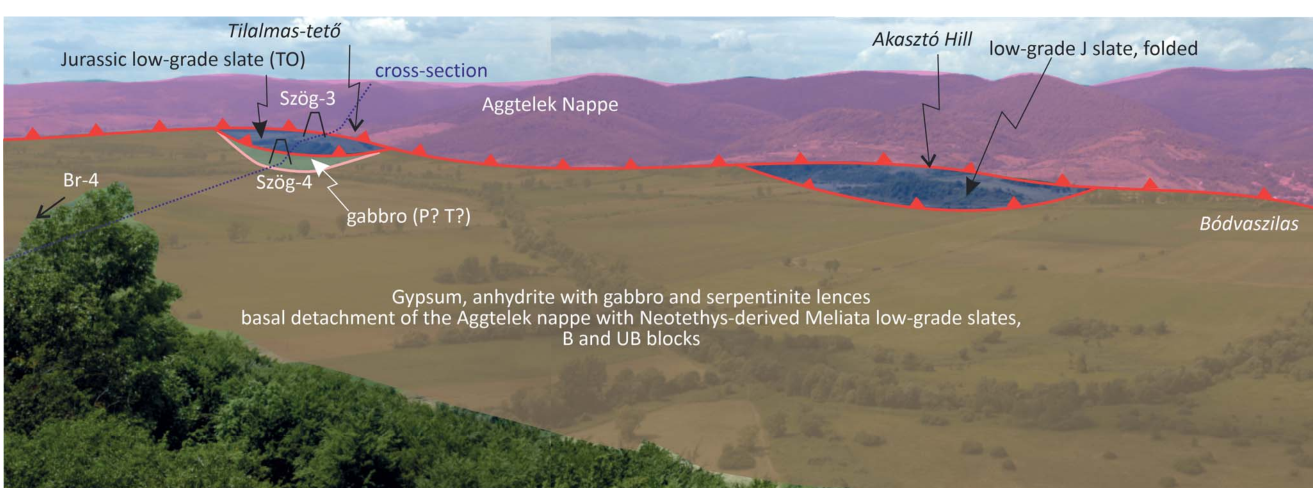

Fig. 36. View westward form the Esztramos quarry to the Bódva valley, Komjáti basin and the eastern margin of the Aggtelek Hills

relative position is not decisive for their original paleogeographic position).

This salt wall continues southward, but with a different geometry and composition. South of the Bódva gorge, the evaporitic rocks are only occasionally present, but a complex unit, the Henc unit appears. It is composed of variable lenses of Lower Triassic clastics and Middle Triassic platform carbonates embedded in a rauhwacke "matrix" (Kövér et al. 2009b). This part can represent a salt weld, and will be presented in the post-conference excursion (Figure 20). Further to the south, the Alsótelekes anhydrite dome was expoited (Zelenka et al 2005), and even further additional occurrences are present all along the western margin of the Rudabánya Hills within a complex imbricate zone.

All these salt tectonic features were involved in the Cretaceous orogeny and modified strongly the orogenic architecture.

In the "concept of Oravecz-Fodor-Kövér" the salt tectonic elements already existed prior to the Cretaceous contractional deformation. The possible Triassic role of the western margin of the Perkupa salt wall was described by Oravecz (2019) and Oravecz et al. (submitted). Another observation is the reduced Triassic succession of the a very narrow belt along the eastern salt wall. Here the Perkupa P-73 borehole penetrated a succession composed of Upper Triassic Hallstatt and Middle Triassic Steinalm Limestone without some typical formations (Fig. 20B). This situation can be present at the top of the salt domes. If this interpretation is correct, this narrow rock body now form a salt raft sunk into the evaporitic dome during either the Triassic or Cretaceous.

The evolution of the salt wall can be the following; initiation of the salt wall eventually at the end of the Early Triassic (during the deposition of the Szinpetri or even the Szin Fm.). Acceleration (or only the onset?) of evaporate movement between the platform and the slope areas; this led to minibasin formation in the platform areas and subsidence of the slope and deeper basinal areas. Brittle faults played a role of disrupting the post-salt formations, and could even lead to dolomitization (Hips 2022). However, the presence of the evaporates separated the extension of the pre-salt and post-salt faults; salt rollers could develop between the detached fault systems which later evolved into salt walls.

This deformation could continue in the Carnian (or even later) along the Derenk zone where a basinal succession formed between the carbonate platforms (Hallstatt Fm.) with a transitional slope development (Derenk Fm.).

The reactivation of evaporate structures become evident during and after the emplacement of the Silica unit over the Meliata and related units (including fragments ophiolites, Jurassic sediments,). This phase should follow (or may be associated to its late stage) the exhumation of the metamorphic units and their emplacement over the rifted margin blocks (Bódva). (D4 phase). This resulted in reactivation of salt walls, which triggered ophiolites closer to the surface. Upraises of salt walls resulted in the formation of flaps along the walls; one could be the slices of Henc unit over the Bódva rocks (Fig. 20B).

This phase could be associated to the sinistral activity of the paleo-Darnó fault. This fault branch was long-time suggested by Less et al. (1988, 2006), Grill (1988), Zelenka et al. (2005). On the present geological map no continuous straight fault can be seen between the Aggtelek and Rudabánya parts. The presence of a former deformed salt wall, its deformation, squeezing, and welding (in the southern part) can explain the obscured fault trace. This fault could have sinistral character, because of oblique position of compression deduced from brittle faults, and the cut of former NE-trending faults at the western Rudabánya margin.

The amount of displacement is not known. However, the paleo-Darnó should be accommodated at the eastern margin of the Silica nappe (eastern Turňa valley). This deformation can be associated already to the sub-horizontal emplacement of all units along the evaporitic sole.

We formulate a fundamental difference with respect to previous ideas; the deformation was basically (but not entirely) pre-Cenozoic. Major sinistral displacement along the western Rudabánya margin can be excluded because the Paleogene–earliest Miocene basin formations discordantly cover the imbricated units. On the other hand, a late Early Miocene contractional deformation is evident from former cross sections (Hernyák 1977, Szentpétery 1988, 1997) and borehole data; the amount of this is below the pre-Cenozoic displacement. The nature of this flexural basin is firmly established by Sztanó and Tari (1993) and cross section is shown by Fodor et al. (2005) further south near the Sajó river.

The Perkupa salt wall was reactivated at least in the Late Miocene. In the Komjáti Basin, an up to 170 m variegated clay sequence with lignite deposits was deposited. The basin seems to have an oval shape, and no clear boundary fault could be seen on the basis of the thickness values. The present-day morphological slopes can hardly be considered as basin-bonding faults toward which these deposits show thickening tendency (fault-bounded half grabens are not typical).

This may suggest that the subsidence is due to salt withdrawal from below the basin; a sort of collapse of the still existing salt dome. In this model, the former salt walls with reverse kinematics could be reversed and the salt represented the hanging wall of this motion and the Mesozoic rocks (independently from their nappe attribution) became the footwall. This salt dome collapse could associate with crustal transtensional deformation; the scares fault-slip data would agree with such a supposition (Fodor & Koroknai 2003).

6. Post-conference excursion: From Triassic rifted margin sequences to Jurassic deep marine sediments: nappe stacking in the Southern Rudabánya Hills and Aggtelek margins (spotlight on low-grade metamorphism and deformation)

6.1. Introduction into tectonic units near the Telekes valley

This panoramic view serves as introduction into the Telekes Valley geology (Figs. 37, 38). The excursion will cross the following units:

The **Bódva unit** of non-metamorphosed Triassic and Jurassic sequence, with maximum high diagenetic alteration. The latter is the Telekesvölgy (TV) Fm. composed of calcarenites, shales, radiolarite shales, few olistostromes with red carbonate clasts.

The **Telekesoldal nappe (TO)** and formation composed of anchimetamorphic Jurassic shale, slate, marlstone, sandstone, silicic-radiolaritic shale, few calcarenites, olistoliths and olistostromes, the latter containing Triassic rhyolite clasts and grey carbonate clasts.

The **Torna unit (T)** composed of anchimetamorphic Triassic sequence; the platform has changed to pelagic basin in the late Anisian.

The **Henc unit** composed of Early Triassic clastics, Middle Triassic platform carbonates, rauhwackes (carbonate tectonic breccias), and evaporates; this unit represents an “evaporitic mélange” in sensu lato.

The deformation history involved the underthrusting (subduction) of Jurassic TO sequence to 2–2.5 kbar, the metamorphosed Triassic Torna to ~3 kbar, associated metamorphism and crystalplastic deformation **(D1).** After additional deformations, the exhumation of these units occurred by their thrusting onto the weakly buried Bódva unit **(D4)**. New phase of thrusting of Bódva onto the metamorphosed TO and ±Torna and their common refolding **(D5)**. This phase could involve the thrusting of Henc unit over both the TO and Bódva involving salt tectonic elements.

6.2. Description of the stops

6.2.1. Stop 1. View to the overturned Bódva sequence and young thrust on the Telekesoldal unit

The view itself shows the Csipkés Hill (left) with an overturned Bódva sequence with platform carbonates at the top and pelagic basinal carbonates on the higher part of the slope; this is a recumbent fold slightly refolded later (Fig. 38). These rocks seem to thrust over the Jurassic and Triassic sequence of the Bódva while below ground level the Perkupa P-74 borehole reached again the pelagic upper Triassic of the Bódva unit. On the north-western and south-western slopes of the hill flakes of Middle Triassic rocks are attached to the folded Bódva sequence; we interpret these slices as part of the Henc unit thrust by salt tectonics during mid-Cretaceous compression.

In the background hills a small tectonic klippe of metamorphosed Torna unit is sitting above the Bódva Triassic; this is due to post-metamorphic thrusting of the former onto the latter (Kövér 2005). They were refolded during D5 phase and thrust together onto the TO unit.

On the right side, the higher Telekes-oldal (hill) is composed of the Jurassic TO rocks forming the TO nappe emplaced over the Bódva unit during its exhumation. This nappe position has been proved by boreholes (Rb-661 and -658; Kövér et al. 2008) and the map of Less et al. (1988); the excursion crosses the boundary near Stops 6 and 7. The low-grade metamorphism of the TO occurred at temperatures around 260-280°C (Kövér et al. 2009b, Molnár et al. 2021). The TO unit is thrust by the Henc unit from the direction of the view with south-eastern vergency. The viewpoint is just the transition of the Henc unit to the large Perkupa salt wall further to the north (see Pre-conference excursion, Stop B8).

6.2.2. Stop 2. Henc unit, rauhwacke and tectonic lens of Bódvaszilas Fm (bT1).

This stop show the typical features of the Henc unit. The small quarry show tectonic carbonate breccia at the base and Bódaszilas siltstone above (Fig. 39); rauhwacke is also exposed above the quarry. Other blocks of Middle Triassic carbonates (Gutenstein Dolomite and Steinalm Limestone) are present in nearby outcrops. The variable lithology, the presence of enveloping tectonic breccia led us to the suggestion that the whole unit would be a large-scale breccia or evaporitic mélange (in sensu lato) (Deák-Kövér 2012, Kövér et al. 2009b).

The moderately westerly dip of the Early Triassic clastics can suggest east-vergent (ESE) thrusting. The clastics contain fractures which are symmetric to the bedding planes and are interpreted as having been formed before the tilt, in the Triassic and Jurassic by ~NE–SW extension.

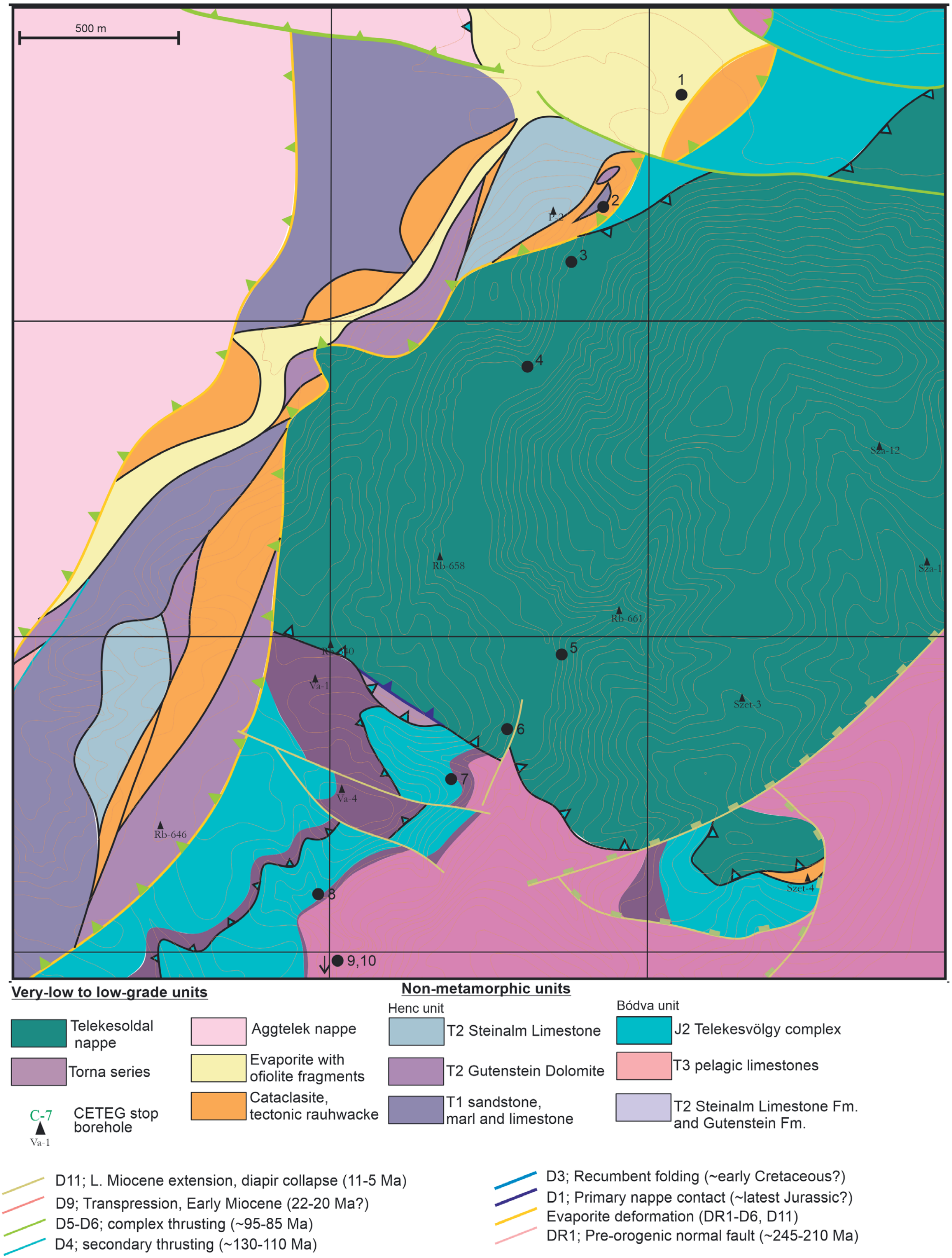

Fig. 37. Geological map of the middle part of the Rudabánya Hills, near the Telekes valley (after Deák-Kövér 2012)

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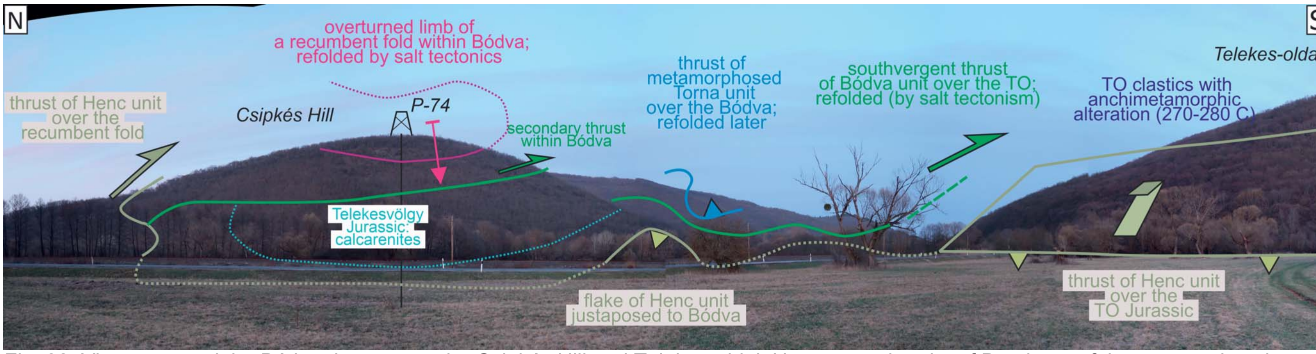

Fig. 38. View eastward the Bódva river gorge, the Csipkés Hill and Telekes-oldal. Note strong imprint of D5 phase of the structural setting and the associated salt tectonic deformation

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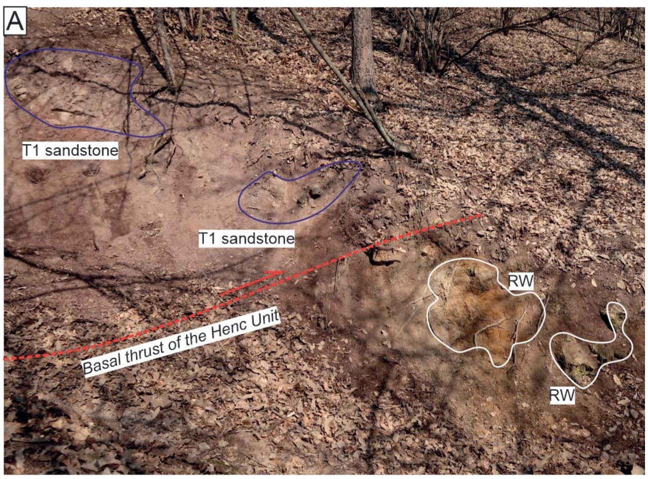

Figure 39. View north-eastward a small quarry in the north-eastern end of the Telekes valley. The Lower Triassic Bódvaszilas sandstone (bT1) is embedded in carbonate tectonic breccia (both from below and above). This rock, together with Middle Triassic platform carbonates, form the Henc unit. After Deák-Kövér (2012), Fig. 61. The Triassic rocks exhibit joint system having been formed before the tilt.

6.2.3. Stop 3. Road cut in the Telekes Valley

This outcrop exposes the northernmost part of the Telekesoldal nappe. The Jurassic shale contains a massive sandstone bed and one rounded sandstone block of 60cm size which is considered as an individual olistolith. The sequence has been folded in open to closed folds with vertical or overturned limbs (Fig. 40). The north-dipping axial planes and the fold asymmetry demonstrate southern vergency. In other parts of the outcrop planar faults and brittle-ductile shear zones occur which deformed the foliation in sigmoidal shape. The shearing partly causing the folding could be associated to the emplacement of the non-metamorphosed Henc unit over the Telekesoldal; a phenomenon similar to the large-scale thrust of Bódva over the Telekesoldal (see Stop 1).

In the southern part of the section a destroyed outcrop exposed sandstone lenses in shale. Deák-Kövér (2012) showed that some sandstone layers suffered layer-parallel extension by brittle-ductile shear zones. The sandstones lenses are considered as boudinaged segments of the same initial continuous bed.

6.2.4. Stop 4. Road curve and natural cliffs in the Telekes Valley

This outcrop exposes Jurassic TO slate with planar foliation planes. Higher up the fine-grained sediments contain 40–60cm thick calcarenite beds. These layers can show sedimentary parallel lamination, and silicification of the margin of the bed. One slided boulder contains crinoidal tests of several mm probably derived from a calcarenite bed (Fig. 40B).

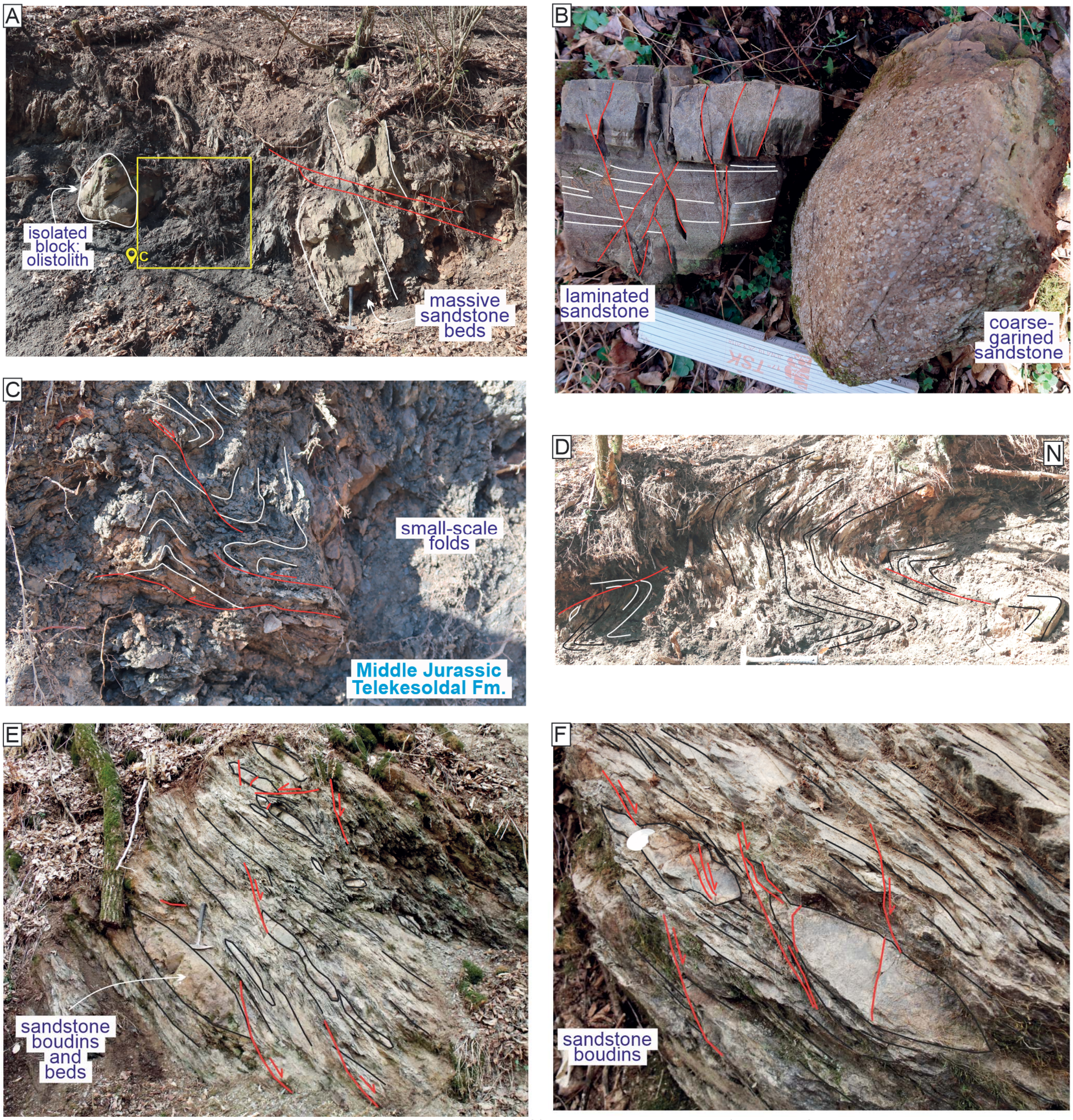

Fig. 40. A) South-vergent closed folds in the Jurassic Telekesoldal (TO) shale and sandstone. B) Blocks of laminated calcarenite with silicified top and crinoidal limestone layer in Stop 4. C, D) details of the folds. Note variable interlimb angle, overturned short limb indicating southern vergency. E, F) Boudinaged sandstone layers in Jurassic TO shale (Deák-Kövér 2012). The lens-like sandstone fragments can also be considered as olistoliths but the presence of shear zones separating them argues for boudinage

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6.2.5. Stop 5. Hunter's house of the Telekes Valley; Triassic rhyolite clast (olistolith)

This outcrop on the east side of the valley exposes a rhyolite block of ca. 80m in size and its northern contact with the Jurassic slate. The rhyolite was supposed to be part of a volcanic arc related to subduction (Szakmány et al. Máthé et al. 1989).

In the Telekes Valley, opposite of the Hunter House the contact of a 100 m sized rhyolite body and the shale is cropping out (Fig. 41A). The volcanite is a light green rhyolite with vitroporphiric texture. In the green glassy matrix 4-5 mm-scale feldspar phenocrystalls are present (Fig. 41B). The S0-1 foliation of the shale goes around the rhyolite body, late shearing at the contact

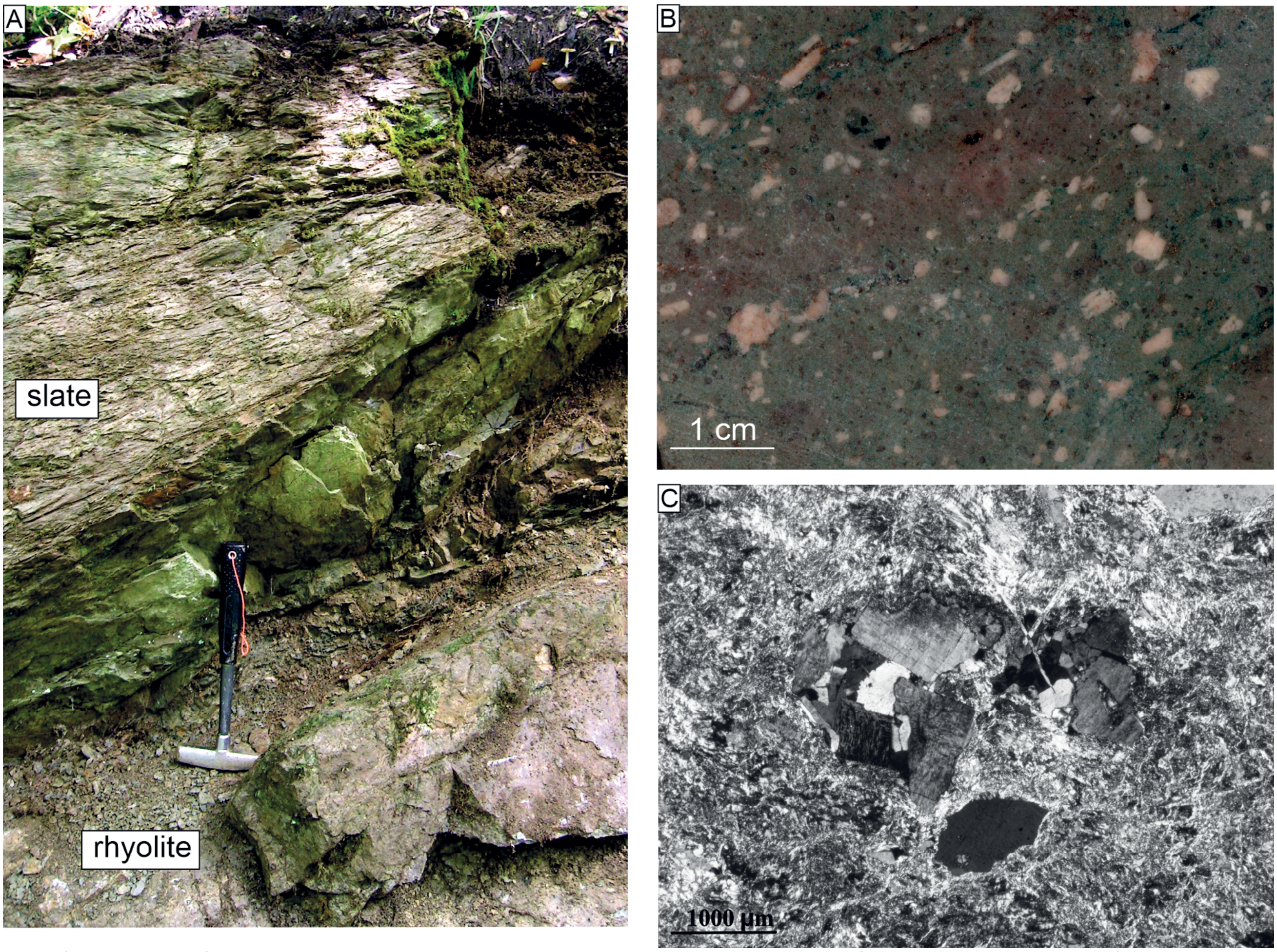


Fig. 41 A) The contact of the slate and rhyolite at the Hunter's house locality in Telekes Valley. IC, AI and Ramans spectra of the slate showed no contact metamorhism B) Green rhyolite with plagioclase porphyroclasts of the same locality. C) Slightly melted plagioclase free granite cataclasite within the rhyolite of TO from the neighbourhood of the Hounter House in the Telekes valley

can be observed. 300 m E from the Hunter House outcrop, the Rudabánya Rb-661 borehole (for location, see Fig. 37) penetrated similar rhyolite body at its bottom part, just above the tectonic contact with the Upper Permian Perkupa Evaporite Formation and a more than 10 m thick tectonic breccia. In this core the boundary of the large rhyolite-ignimbrite body (19 m apparent thickness) is sharp. Altered vitrophyric rhyolite, rhyolite tuff and ignimbrite are the main rock types. Under the microscope fragments of volcanic glass and pumiceous texture – the characteristic features of ignimbrite – are clearly visible. Thin laminae of sericite-chlorite are predominant in the matrix. The porphyritic components are pertitic orthoclase, idiomorphic quartz with resorbed margin, fractured quartz with undulatory extinction, commonly partly melted, and few large sericitic plagioclases or plagioclase-orthoclase composite grains, and few biotites. Small (mm to 1 cm-sized) rhyolite were encountered in “spotty” shale (usually silty claymarl, marl, calcareous marl) in several horizons in a 40 m thick interval above the large rhyolite body. There are clasts consisting of large quartz and feldspar crystals in a calcified matrix. Composite grains also occur together with resorbed quartz and orthoclase crystal fragments. There are lithoclasts consisting of resorbed quartz and sheared, fractured perthitic orthoclase in a squeezed chloritic, calcitized and silicified matrix.

The majority of the rhyolite clasts (To1–To5) show uniform REE patterns with a slight enrichment of LREE (Light Rare-Earth Element) over HREE (Heavy Rare-Earth Element) (La_N/Lu_N = 2.24–4.36) with a pronounced negative Eu anomaly ($2 \times Eu_N/(Sm_N + Gd_N) = 0.17–0.26$) (Fig. 41). N-MORB normalized multi-element diagram shows a continuous decrease in abundance from the incompatible trace elements to the more compatible ones (e.g., Th has 100-fold enrichment, while HREEs are showing N-MORB values or maximum twofold enrichment). Negative anomalies are observed in case of Nb, Eu, Sr, and Ti (Fig. 41)

Kövér et al. (2018) presented U-Pb ages on zircons on variable rock bodies from the Telekesoldal Fm. which clearly shows Late Triassic ages. From this exact locality, measurements on six zircon crystals with

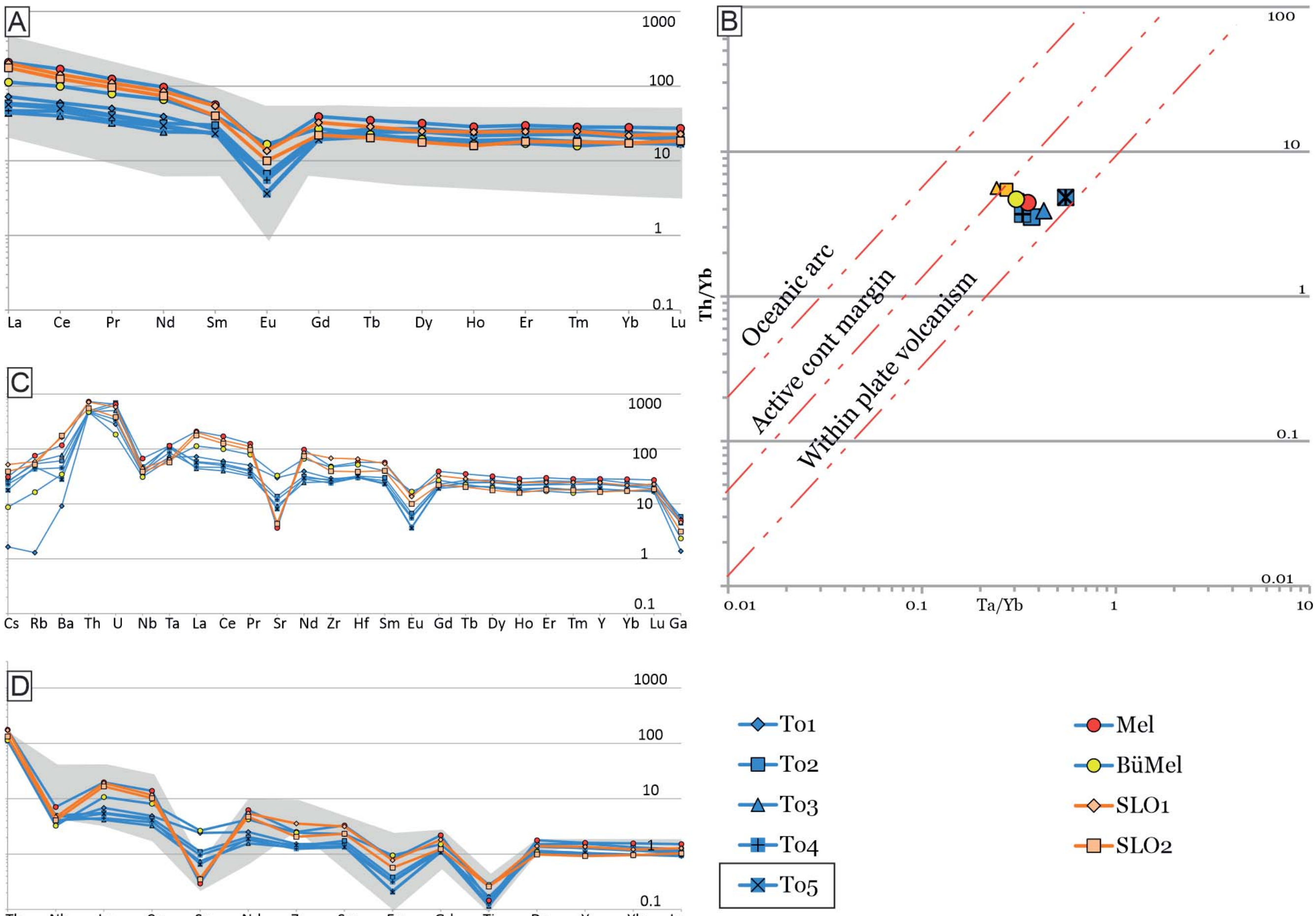


Fig. 42. Geochemical characteristics of the TO rhyolites, and their comparison to similar rocks from the Meliata nappe (Mel), Bükk Mts (BüMel) and in situ Late Triassic rhyiolites from the Dinarides (Lajse locality of Neubauer et al. 2014). A) Chondrite normalized (McDonough and Sun 1985, Sun and McDonough 1989) REE pattern of the rhyolite clasts from different mélange nappes and in situ Upper Triassic rhyolite/tuff samples showing considerable enrichment LREE, while significantly smaller enrichment in HREE. Grey band corresponds to Rift/Continental Margin-type magma of Furnes and Dilek (2017); C,D) Chondrite normalized (McDonough, Sun 1985, Sun and McDonough 1989) trace element pattern of the rhyolite clasts from different mélange nappes and in situ Upper Triassic rhyolite/ tuff samples (blue signs are for TO mélange nappe, red is for Meliata mélange, and yellow is for Mónosbél mélange, Bükk Mts, while orange is for the in situ Upper Triassic samples). Grey band corresponds to Rift/Continental Margin-type magma of Furnes and Dilek (2017). B) Th/Yb vs Ta/Yb discrimination diagram of Gorton and Schandal (2000). Within-plate volcanism is the most probable tectonic setting for rhyolite clasts from different mélange nappes and in situ Upper Triassic rhyolite/tuff samples (Kövér et al. 2018).

different morphological (elongated or tabular) and CL character yielded ages within the 219.3 ± 6.2 Ma range (Fig. 43A,B). In case of grain 4-b-2, there was no detectable difference in isotopic composition between the CL-dark core and the CL-light rim in spite of a well-visible solution event between the growths of the two chemically different parts.

There were no signs of extra heating in the metasedimentary samples taken just from the contact with respect to the regional metamorphism (~260–280°C) (Deák-Kövér 2012, Molnár et al. 2021). The former radiometric ages (Máthé and Szakmány 1989, Szakmány et al. 1989) either had large uncertainty (156±23 Ma by Rb-Sr whole rock) or Cretaceous ages (probably reflecting the post-metamorphic cooling).

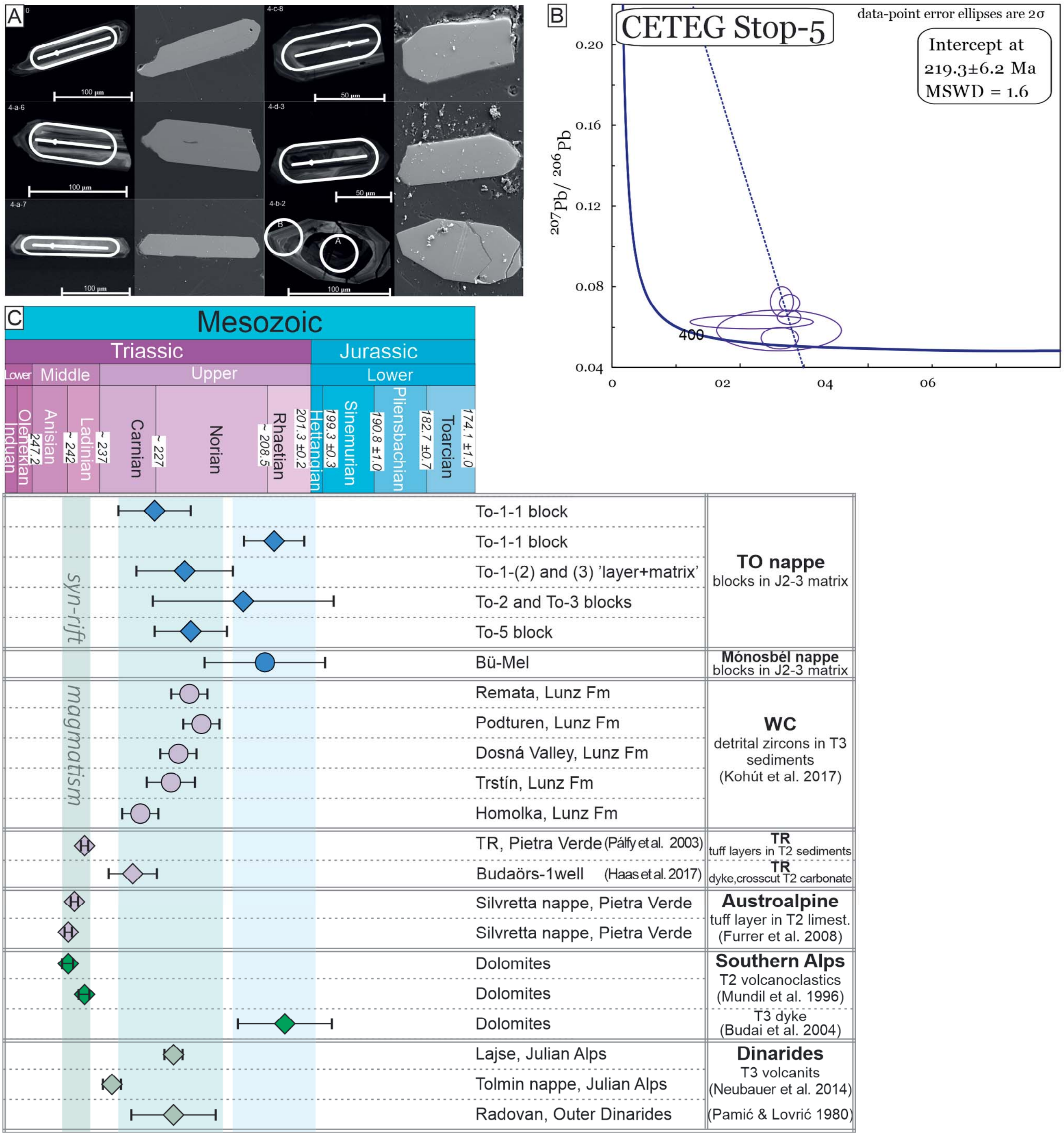


Fig. 43. U-Pb ages from rhyolite clasts and rhyolitic matrix of olistostromes of the Telekesoldal Fm., and its comparison to similar volcanic rocks from the surrounding Neotethys-related localities (Kövér et al. 2018).

6.2.6. Stop 6. Natural cliffs on the western side of the Telekes Valley, north from side valley No. 8; mylonitic carbonates

This newly discovered outcrop exposes massive or very well-foliated limestones of uncertain attribution (Some of the rock types are akin to rocks of the Torna, while others to the Bódva sequences). The thick-bedded grey limestones are often massive, while the beige, pinkish white, purple-red varieties often show thin beds and very well-developed foliation and occasionally lineation; both structures are dipping NE and indicate considerable ductile strain potentially accommodated by crystalplastic mechanisms. No microscopic data are available yet. The metacarbonates are bounded on the north by a rauhwacke zone overlain by the typical TO rocks.

While this outcrop is critically located at the boundary of the TO nappe; either it is the base of it or a separate tectonic unit just near the base of the TO nappe. The lineation may hint south-westward transport either during or just after the metamorphic conditions prevailed; however data are few in number and not analysed in detail.

6.2.7. Stop 7. Telekes Valley, 8th side valley, ridge section; Middle to Late Triassic and Jurassic of the Bódva unit

This is an old research trench which exposes rocks from the platform Steinalm Limestone, and the pelagic Bódvalenke and Hallstatt formations (Kovács et al. 1989). The contact with the Jurassic rocks of the Telekesvölgy TV Fm. is not exposed and can be slightly deformed.

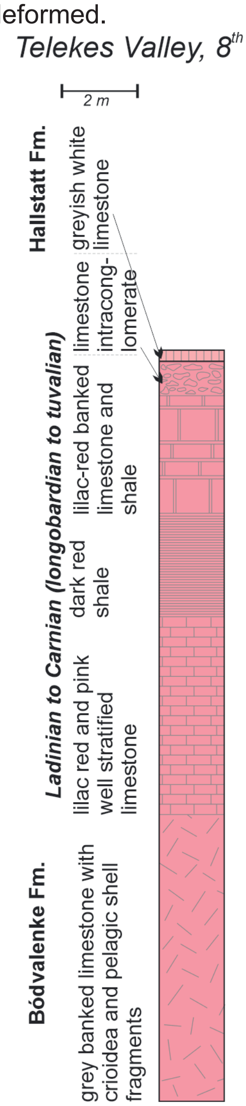


Fig. 44. Section of the 8th side valley of the Telekes Valley, after Kovács et al. (1989).

In the following part of the Telekes valley Triassic pelagic carbonates and Jurassic rocks are variably exposed on both sides. The interpretation could be tilted blocks bounded by NE–SW or NW–SE trending faults; some of them could be Triassic or Jurassic while others are related to Cretaceous folding.

6.2.8. Stop 8. Telekes Valley, 7th side valley, ridge section; Middle to Late Triassic and Jurassic of the Bódva unit

This research trench and the cliffs below expose an extremely reduced Triassic sequence. The main cliff is composed of massive platform Steinalm Formation which contains red fissure filling limestones. Conodonts show variable age from Ladinian to Late Triassic (Kovács, pers. comm.). On the hanging wall of a north-dipping fault few layers of pelagic limestone (Bódvalenke Fm.) can be discerned. The fault and all Triassic formations seem to be sealed by the Jurassic TV formation.

The platform carbonate ends with a 10cm reddish layer of limestone breccia with limestone matrix; it is considered as a condensed layer. In the trench and in the valley Jurassic manganese shale spotty marl (with bioturbation) is exposed, this belongs to the TV (Telekesvölgy) Fm. of Middle Jurassic age. Former interpretation (Less et al. 1988) considered a tectonic boundary between the Triassic and Jurassic, but at present conditions it is hard to see. In the “concept of Fodor-Kövér” the Triassic and Jurassic represent the continuous Bódva sequence. Their metamorphic characters are similar, they suffered only diagenetic alteration (Fig. 18, 19). On the other hand, the Bódva sequence has been folded in east-vergent folds; sub-vertical western limb could thrust onto units exposed in the main Telekes valley (Fig. 37).

In the valley bioclastic or micritic limestone and marlstone interlayers appear, but only in the northern side. This argues for a fault just in the axis of the valley; it has dextral kinematics based on meter-scale faults in the cliff.

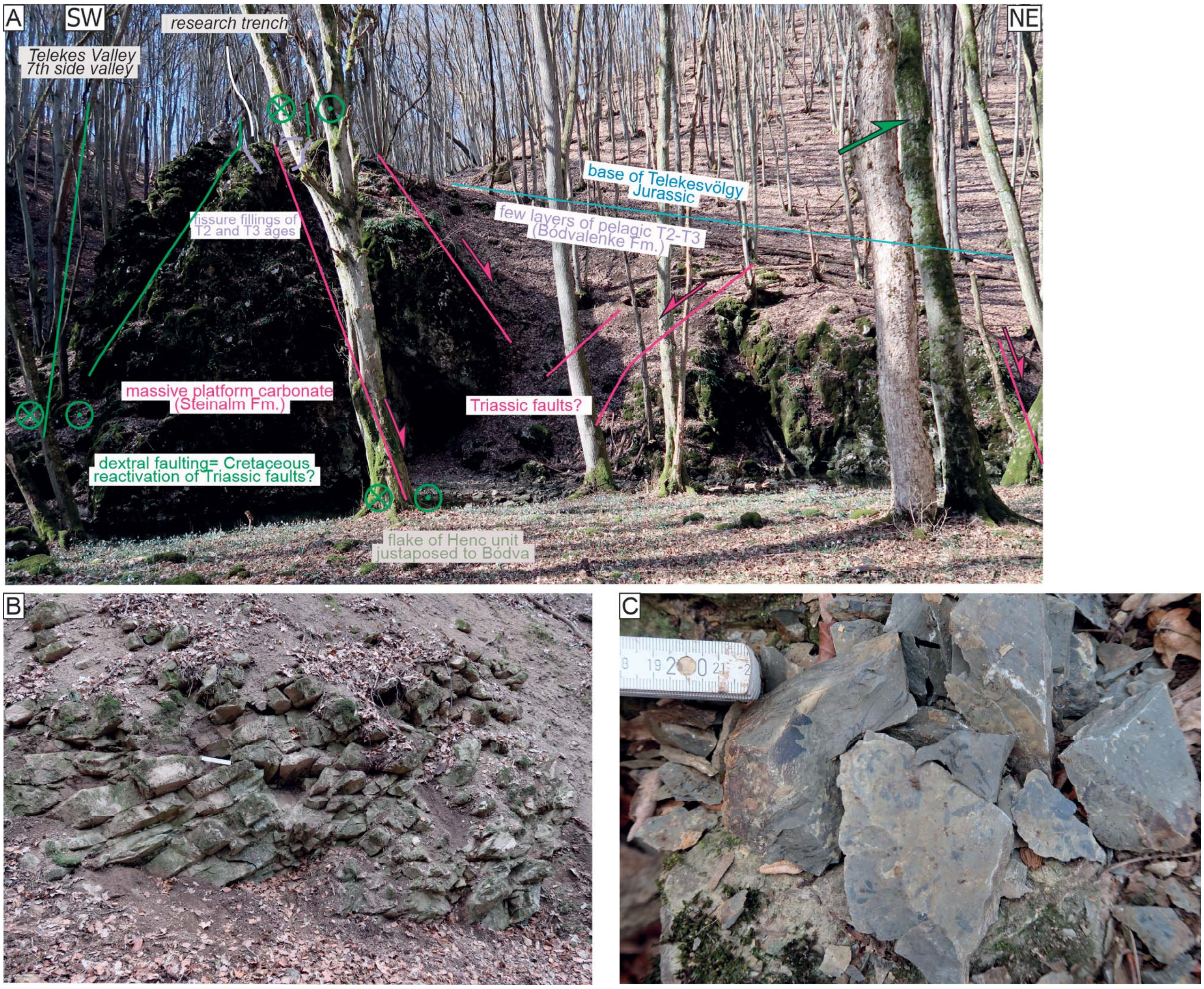
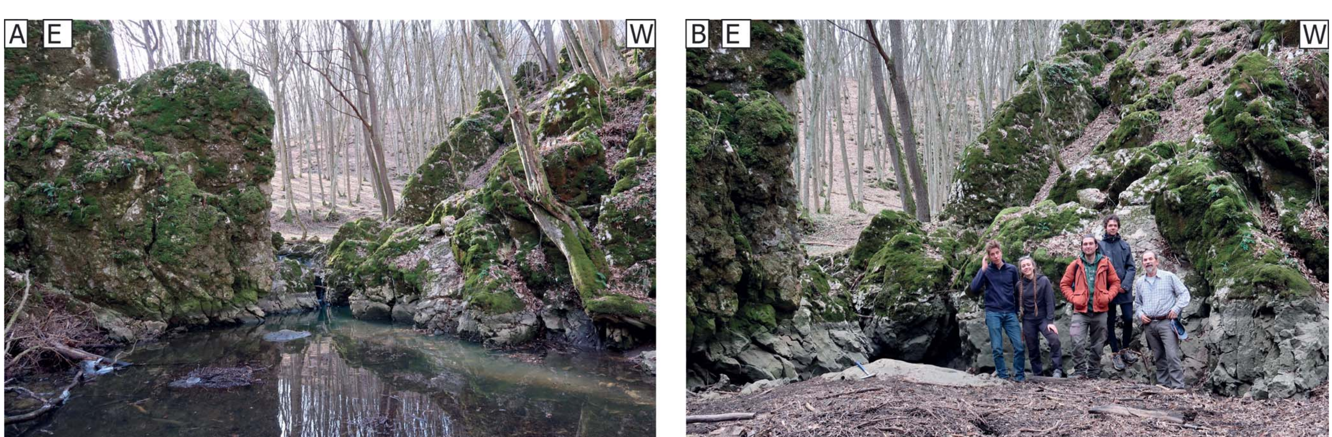


Fig. 45. Telekes valley 7th side valley. A) View if Triassic normal faults and intervening small graben. B) Micritic and bioclastic limestone intercalations in the Jurassic sequence. C) Spotted marlstone in the 7th side valley

6.2.9. Stop 9. Telekes Valley, Ördög-gát (Devil's dam)

The river crosses a 20m wide natural rock wall composed of Triassic carbonate while the former river bed formed a meander-shaped segment. The meander argue for antecedent origin of the valley potentially having been formed on soft sediments (Late Miocene?) in alluvial environment before the uplift to the range.

Fig. 46. The Ördög-gát (Devil's dam) rock wall. View with full water yield and dry condition 5 days later. The members of the "outcrop-cleaning group" from left to right: Mátyás Grósz, Katalin Csontos, Botond Salamon, Csaba Gerlei (geologist students of Eötvös University) and author László Fodor.



6.2.10. Stop 10. Telekes Valley, 6th side valley; Middle to Late Triassic of the Bódva unit

This is an old research trench which exposes rocks representing the entire evolution from the platform to the pelagic basin (platform Steinalm Limestone, the pelagic Bódvalenke and Hallstatt formations, Kovács 1989?). The pelagic limestones frequently are filament–radiolaria micrite or microsparitic micrite with wackestone–packstone texture. The intercalations are red or purple shale and few redeposited layers with carbonate pebbles of platform origin.

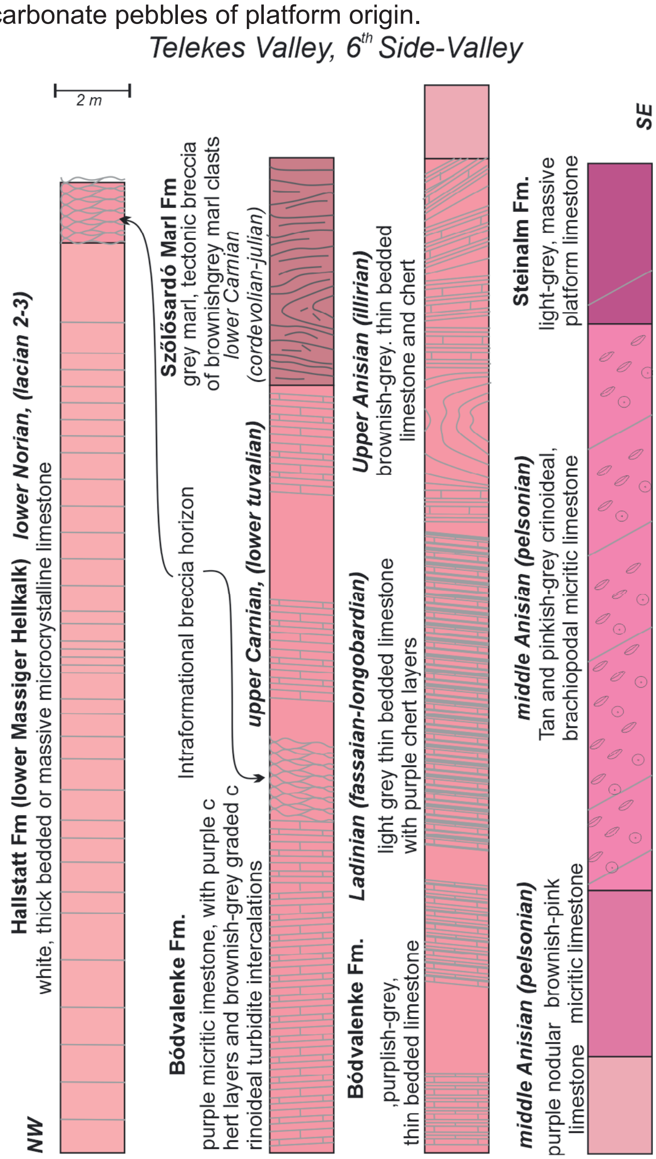


Fig. 47. Telekes valley 8th side valley, research trench (Kovács et al. 1989). Not large thickness of basinal limestones with respect to both 7th and 8th side valley.

Discussion of the Triassic sections of the Telekes Valley

The three sections of the side valleys show very considerable thickness variations from 1-2 to 40 m considering the pelagic carbonates. We interpret this phenomenon as sign of Middle to Late Triassic extensional deformation which resulted in half grabens of variable size. The orientation of the half grabens are uncertain (partly because of Cretaceous folding); normal faults could have NE–SW and/or WNW–ESE strike. If two directions were characteristic, this would suggest an orthorhombic symmetry or a setting with normal and sub-perpendicular (transfer) structures. The facing of normal faults could have been to NNE or SE.

The NE-trending normal faults could have been refolded during the D5 Cretaceous thrusting; this is shown on the conceptual cross section. On the other hand, the WNW–ESE trending normal faults could be reactivated as strike-slip faults as shown near the Telekes 7th side valley.

6.2.11. Stop 11. Lászi farm, Galica peak; Late Triassic of the Lászi nappe (over the Aggtelek unit)

On the way from the Telekes valley we climb up the ridge along the 6th side valley where Jurassic shale of the Bódva unit is exposed (TV formation). On the descend we reach again the Henc unit composed of Middle Triassic platform carbonates and Early Triassic Szin Fm., the latter thrust over the former. We reaches a small meadow near the Lászi hunter house. Our track passes along the Sárkány-kút (Dragon well or Lászi well), the Rét creek and reaches the Galica peak (Fig. 48).

The northern contact of the Galica and the hill to the east is a sub-vertical tectonic feature which is marked by rauhwacke with vein quartz while on the norther side Early Triassic rocks of the Aggtelek nappe occur (Fig. 48).

The Galica Hill is built of a massive, red, pink or light grey limestone of Late Triassic age (late Ladinian–Norian); this was attributed to the Hallstatt Fm. (Kovács 1989). In the middle of the slope filament coquina is composed of densely packed thin-shelled bivalves (Fig. 49D). On the north-eastern side limestone breccia is found with variable grey and red clasts in pinkish-reddish limestone matrix (Fig. 49C). Although some colour variation is just due to diagenetic alteration (and the texture does not change from “matrix” to “clasts”) some samples are clearly sedimentary breccia (Horváth 2010). Breccia with variable clast composition is exposed in nearby outcrops (Fig. 49B) (Horváth et al. 2012). Bedding is poorly seen, and this massive rock is interpreted as having been deposited on a fault-

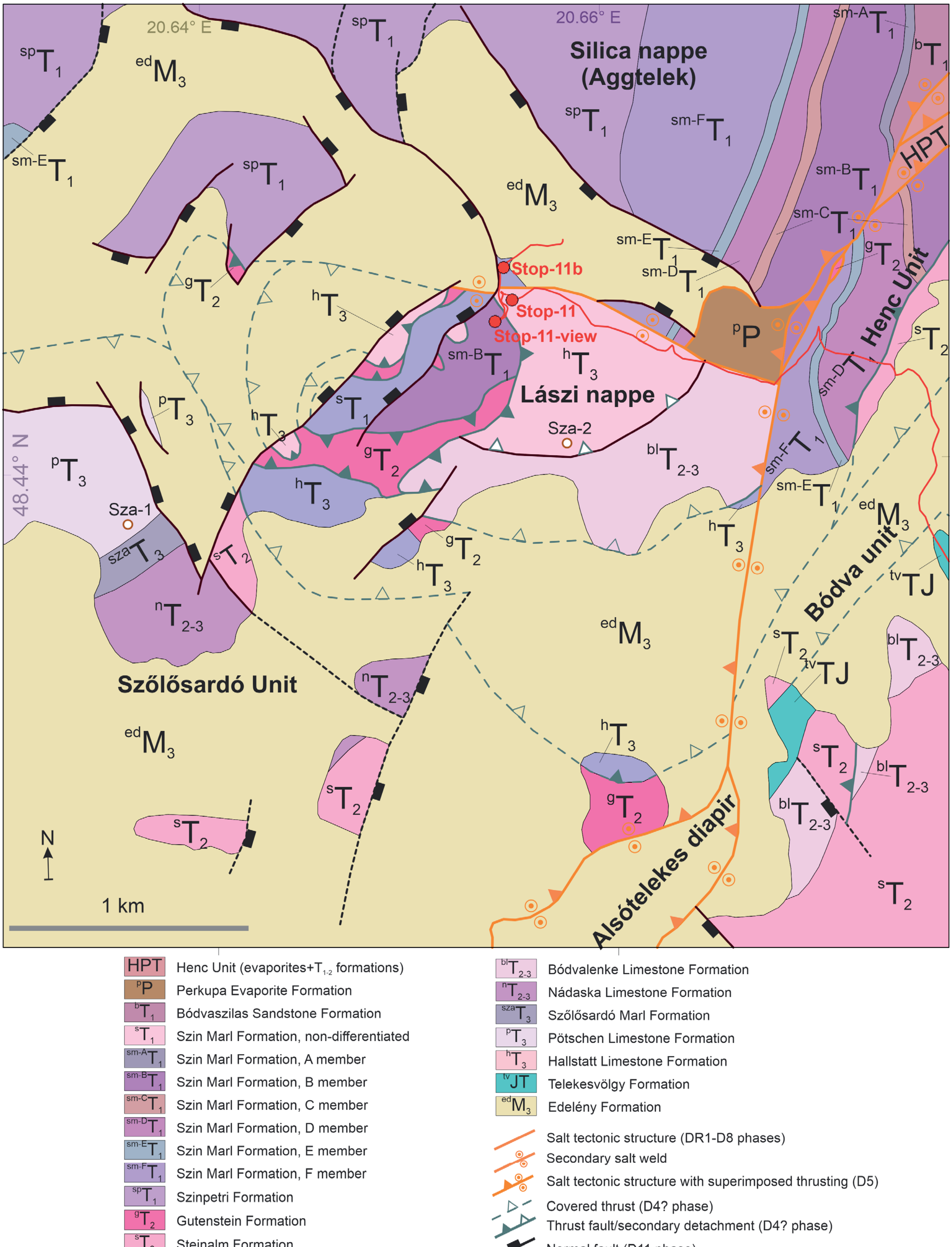


Fig. 48. Geological map around the Lászi farm showing the Lászi and Szőlősardó nappes (partly after Less et al. 1988, Hips 2001, Horváth et al. 2012).

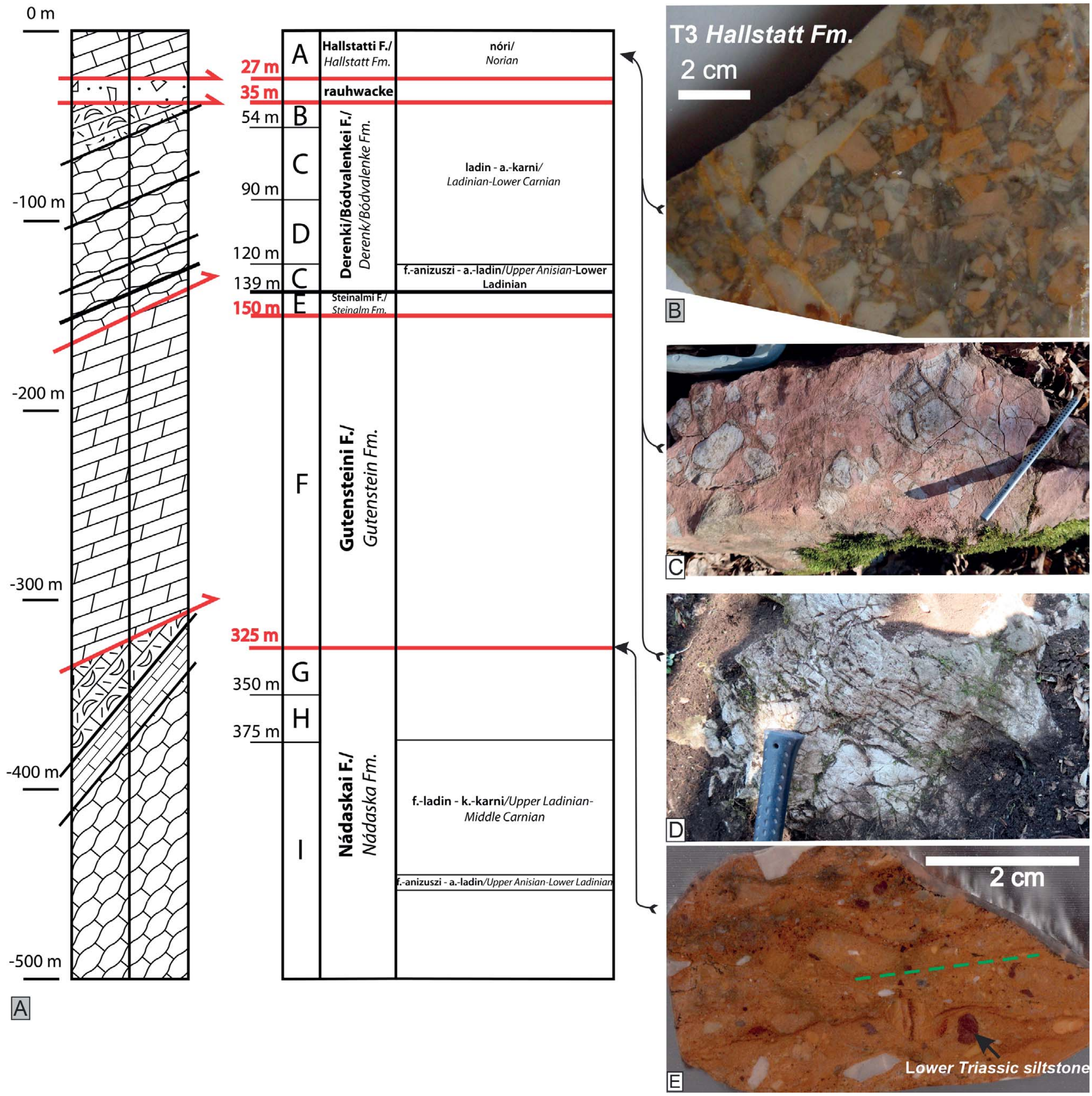


Fig. 49. Stratigraphy of the Lászi nappe. A) Szőlősardó Sza-2 borehole with three main tectonic units (after Horváth et al. 2012). B, C) Limestone breccias in the Hallstatt Formation of the Galica Hills and east of it. D) Lumashella in the Hallstatt Fm., type locality. E) Rauhwacke at the base of the Lászi nappe (Horváth et al. 2012).

controlled paleoslope. The attribution of this sequence is not unequivocal but the pelagic carbonates are similar to the Bódva unit (Bódvalenke and mostly to the Hallstatt formations). We interpret the original paleogeographic position was between the Szőlősardó tectonofacies and the Bódva area (Less et al. 2006, and Kovács et al. 1989). These rocks tectonically belong to the Lászi nappe.

On the western side of the hill, on the southern side of the creek, a view exposes the gently north-dipping thrust contact of the Upper Triassic limestones and the underlying Early Triassic clastics (Szin Fm.) (Fig. 50). Along strike of the thrust the hanging wall changes from pelagic to platform carbonates and the footwall is made of variable member of the Szin Fm. (Hips 2001); the maps indicate that this latter formation occurs in a (half-)window (Less et al. 1988, Less 1998, Hips 2001).

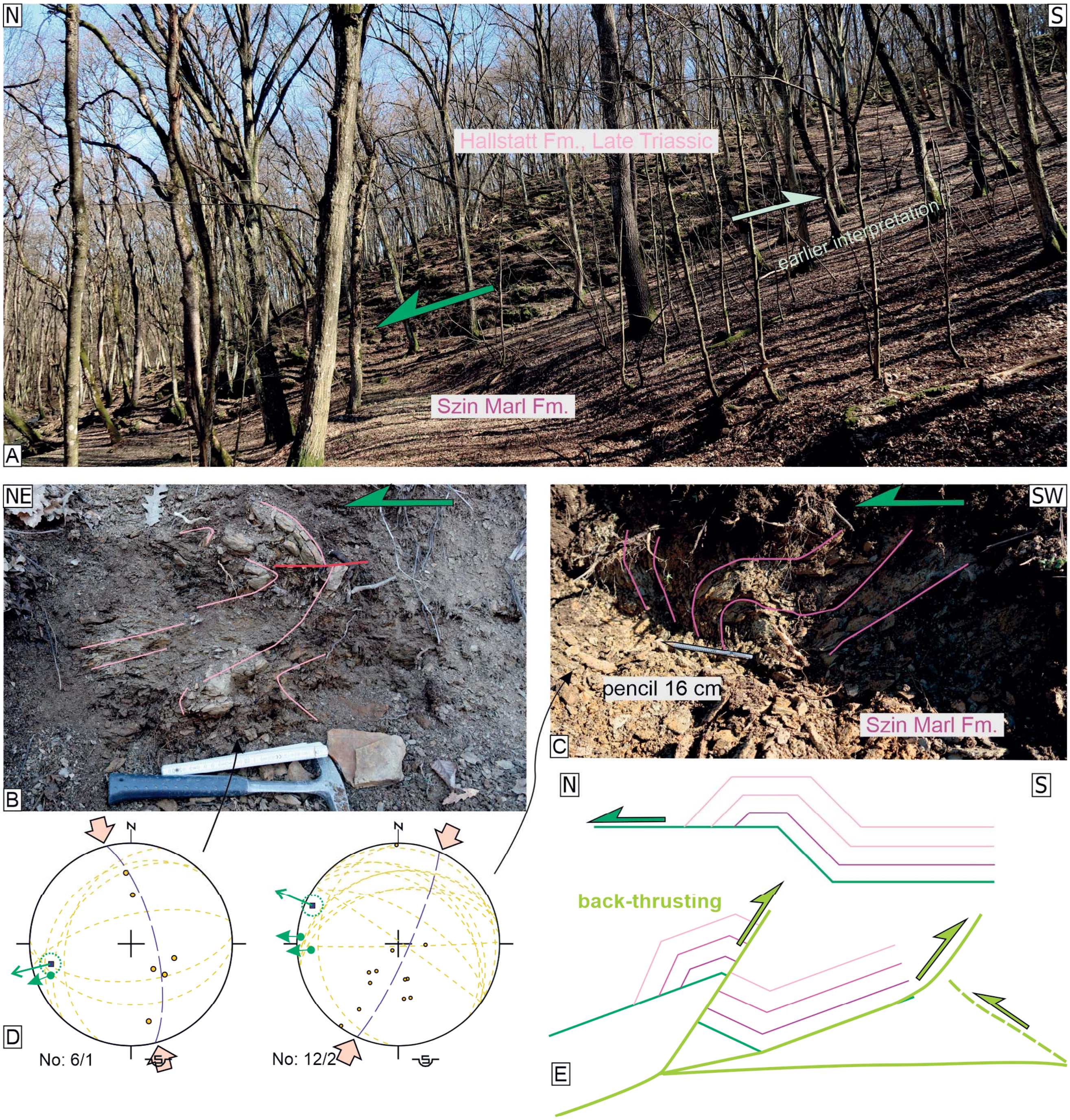


Fig. 50. Thrust and folds near the northern margin of the Lászi nappe. A) north-dipping thrust at the base of the Hallstatt Limestone displaced over the Early Triassic Szin Fm. B, C) north-vergent asymmetric to recumbent folds in Early Triassic clastics along the road to Szőlősardó. D) Stereograms of the folds. E) Model explaining the northward tilting of the originally flat thrust segment

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Discussion on the tectonic position of Triassic slope sequences (Lászi and Szőlősardó nappes)

The nearby borehole Szőlősardó Sza-2 penetrated a complex Middle to Late Triassic sequence which can be divided into two or three tectonic units (Fig. 49A). In the borehole the Hallstatt limestone is detached from the underlying Bódvalenke Fm. by a tectonic breccia zone (Horváth et al. 2012) but we consider both formations as part of the Lászi nappe; it has this characteristic massive and partly brecciated basinal succession.

The underlying Middle Triassic platform carbonate (Gutenstein Fm.) should have a tectonic contact with the Upper Triassic formations while at least the Steinalm Fm. is missing or is tectonically truncated (Fig. 48). We consider the Gutenstein (Steinalm) as a separate scale at the base of the Lászi nappe detached from the original contacts. On the map this scale reoccurs several times (Fig. 48). These tectonic lenses are pinching out because at the southern margin of the Lászi nappe the nappe contact is directly between the Upper Triassic of the Lászi nappe and the underlying Early Triassic rocks (exposed in a cave with a thick breccia, Horváth et al. 2012).

The Early Triassic rocks in the window should have detached from their original base because they are truncated both from above and from below. In addition, they are northerly displaced with respect to the “undisturbed” Aggtelek sequence just 1km to the north. Potentially they represent another scales at the base of the Lászi nappe.

The lower part of the Sza-2 borehole encountered a separate unit; the slope carbonate of Middle Triassic age which belong to the Szőlősardó nappe (Fig. 49A). The characteristic formations of this nappe are the slope limestone and the Carnian shale and originally this unit could represent the slope in front of the platform carbonates of the Aggtelek unit (Kovács et al. 1989). This nappe is now located below and just west from the Lászi nappe (Fig. 48).

Horváth et al. (2012) interpreted this contact as a south-vergent thrust. However, new road cuts just few 100m from the Galica exposes inclined to overturned folds which indicate northerly tectonic transport, as predicted by Less (1998) (Fig. 50B-D). In the case of northern vergency, the northerly dip of the basal thrust should be explained. One option would be that the present northern dip is due to a late deformation, a northward (north-westward) tilting of an earlier upper flat (Fig. 50E). This tilting could be associated to the south-east verging thrusting of the Henc unit over the TO and Bódva units. Alternatively, a foreland-dipping duplex system could be supposed. In this model the Lászi nappe has thrust over the Szőlősardó nappe (as demonstrated by the Szől-2 borehole), and both had a higher unit covering them.

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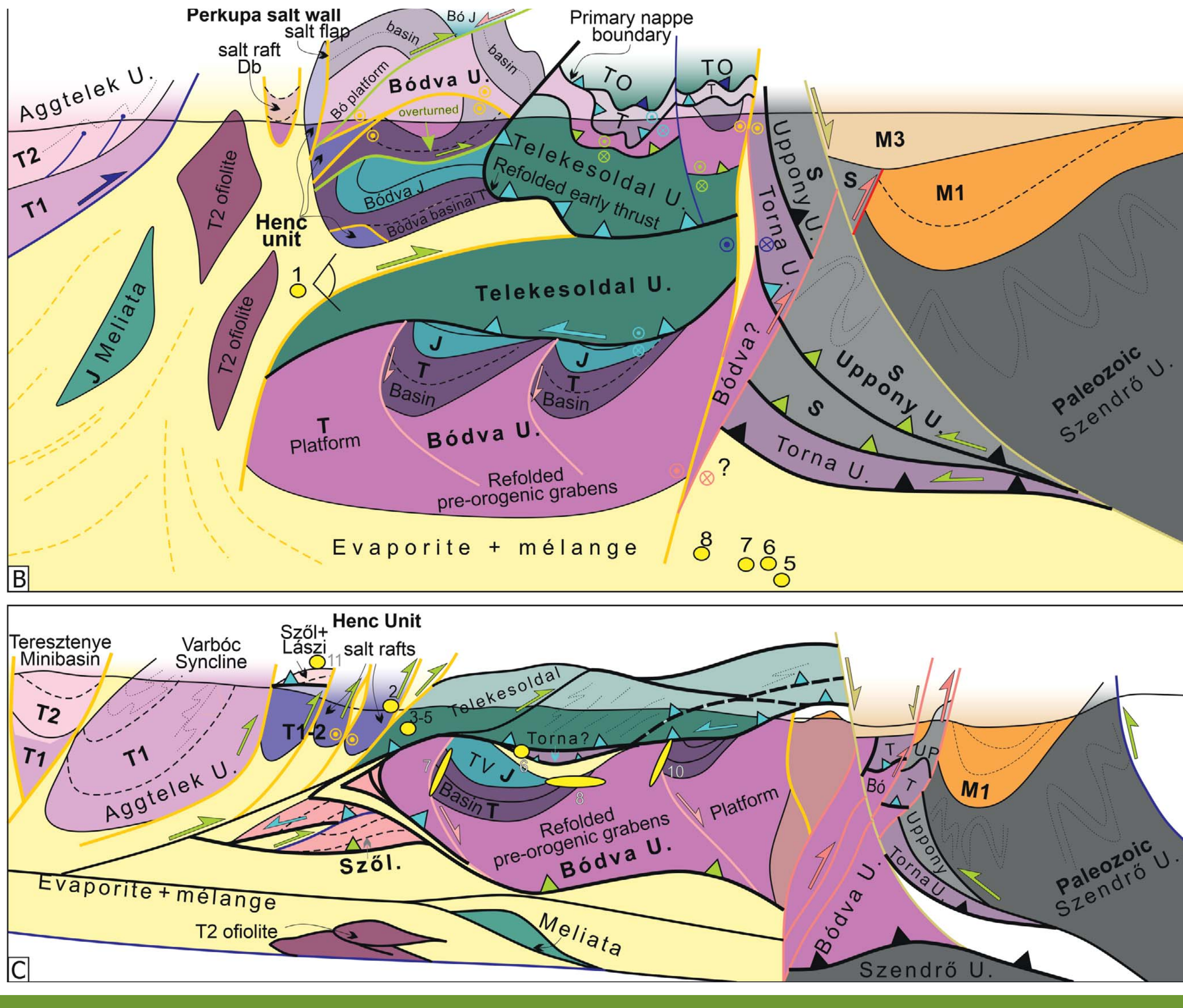

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