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THE STRUCTURAL SETTING OF LOWER TRIASSIC FORMATIONS IN THE AGGTELEK–RUDABÁNYA MOUNTAINS (NORTHEASTERN HUNGARY) AS REVEALED BY GEOLOGICAL MAPPING

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Abstract: Lower Triassic formations in the Aggtelek–Rudabánya Mountains (NE Hungary) were mapped in the main part of the Silica Nappe, and the results are presented in a new map at the scale of 1:50,000. The aim of this paper is to present the structural observations collected during mapping and to interpret the field data and map-scale structures, and by this means to demonstrate the structural setting of Lower Triassic formations in a new light. The mapped area is located south of the Jósvafő–Bódvaszilas reverse fault-zone and divided into two parts by the NE–SW sinistral strike-slip faults of the Darnó Zone. Beside these two major fault-zones, systems of E–W dextral strike-slip and NE–SW-trending reverse faults were recognized. Three groups of folds were identified: one set of folds with NE–SW axes is predominant and widely distributed in the entire mapped area, whereas the other sets of folds with E–W and NW–SE axes appear only locally. Their timing is uncertain. Characteristic associations of structural elements were recognized in three structural segments. The predominant one consists of E–W trending strike-slip and the connecting NE–SW reverse faults with a series of folds with NE–SW axes, suggesting NW–SE shortening and NE–SW elongation (according to recent co-ordinates). Map-scale anticlines and synclines were also formed in this system (e.g. the Dobódél and Keskeny-völgy Anticlines and the Varbóc Syncline). The map-scale structures reveal that the formerly proposed anticline with E–W axis running all along the Jósva-völgy does not exist; only the E–W-trending Jósvafő Anticline is proved near Jósvafő. Strike-slip duplexes and push-up fragments, consisting of mismatching blocks, are also very characteristic in the area of investigation, pointing to major lateral shear zones.

Key words: Silica Nappe, Aggtelek–Rudabánya Mountains, Lower Triassic formations, 1:50,000 scale map, structural setting, map-scale structures.

Introduction

At the beginning of the 20th century, Lower Triassic deposits were subdivided into two parts, namely ‘Seis Beds’ and ‘Campil Beds’ by Vitális (1909) in accordance with the subdivision in the Alpine–Carpathian–Dinaridic facies area. In the 1940’s, maps and cross-sections by Balogh (1948a,b, 1950, 1953a,b), and Balogh & Pantó (1952) provided new data on sedimentary rocks. They recognized characteristic horizons within the sequence, but keeping the previous names they did not indicate them on their maps. The geological mapping program of the Geological Institute of Hungary carried out between 1979 and 1985 (maps of Less et al. 1988 and Less 1998a,b) resulted in a detailed Triassic lithostratigraphic classification (Kovács et al. 1989) and structural evaluation of the Aggtelek–Rudabánya Mountains (Grill 1989; Less 2000).

As a result of recent studies, the Lower Triassic lithostratigraphic units defined by Kovács et al. (1989) can be divided into several subunits (Hips 1996), which were successfully distinguished and mapped in the field. The area between Jósvafő and Bódvaszilas was suitable for detailed stratigraphic studies. The Lower Triassic formations in the strongly tectonized zones (i.e. Ménes-völgy, near the Slovak border) and in the metasomatized field in the southern Rudabánya Mountains (Rudabánya ore mine) (cf. Less et al. 1988) were not investigated.

The objectives of this paper are (1) to present the spatial distribution of structural elements and evaluate the structural setting of Lower Triassic formations in the Aggtelek–Rudabánya Mountains on a map on the scale of 1:50,000 (Appendix 1); and (2) to describe and analyse the map-scale geologic structures. The stratigraphy of Lower Triassic rocks was discussed and interpreted in the context of sedimentary facies in earlier papers (Hips 1996, 1998). For the purpose of this paper, the basic evaluations of stratigraphic units are summarized in table format and only a brief discussion of the formations is provided.

The map (Appendix 1) presents new results only from Lower Triassic formations, other data are compiled with a few slight modifications from Less et al. (1988) and Less (1998a,b).

Location

The Aggtelek–Rudabánya Mountains rise on the northeastern border of Hungary, close to Slovakia (Fig. 1). They constitute the southernmost, Hungarian part of the Mesozoic range of the South Gemer area in the Inner Western Carpathians. The mountains are made up of three tectonic units: the uppermost Silica Nappe, the Meliata Series and the lowermost Torna Series (Kovács et al. 1989; Less 2000). These structural units extend across the Hungarian-Slovak border through the Slovak Karst to the southern boundary of the Gemer Paleozoic. On the

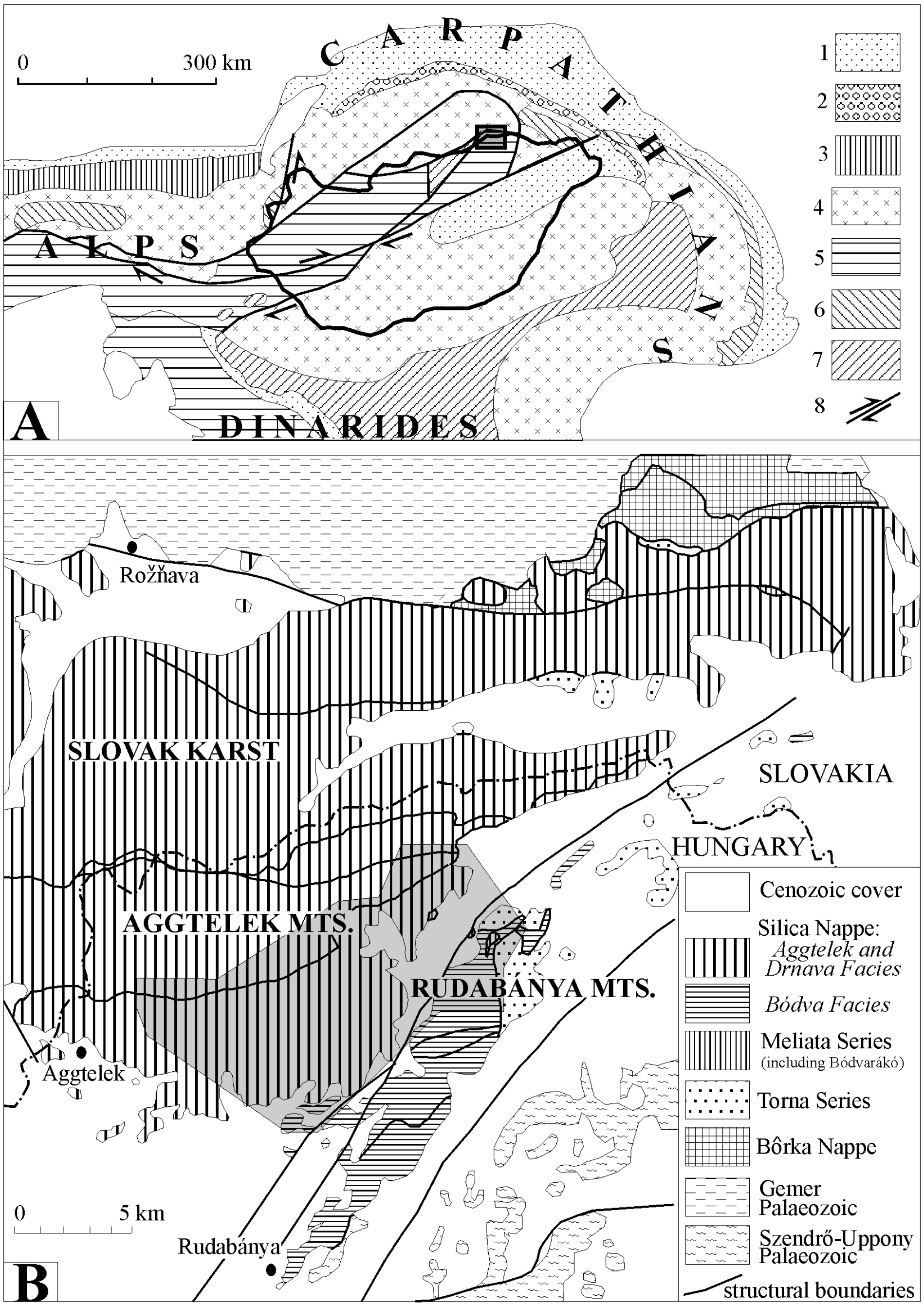

Fig. 1. A) Schematic terrane map of the Circum-Pannonian Region (after Kovács et al. 1996–97) with Hungarian national borders, and location of South Gemer area with the Aggtelek–Rudabánya Mountains presented in B; **1** — Flysch Belt, **2** — Klippen Belt, **3** — Northern Calcareous Alps, **4** — Early Alpine units related to the European continental margin, **5** — Early Alpine shelf sequences related to the Apulian (Southern Alps and Outer Dinarides) continental margin, **6** — ophiolites of the Penninic Ocean, **7** — ophiolites of the Vardar Ocean, **8** — major strike-slip zones. **B**) Geological map of the South Gemer area (after Mello et al. 1996; Kovács 1997, and Less 1998b). Location of the map of Lower Triassic formations in the central part of the mountains (presented in Appendix 1) is in darker colour.

Hungarian side, the Lower Triassic formations are found only in the Silica Nappe.

Outcrops of Lower Triassic formations

The investigated area is composed of two main territories, where Lower Triassic formations crop out at the surface. These are (1) the hills surrounding the Bódva- and Jósva-völgy and the Galyaság hills (outlined by the villages of Jósvafő, Teresztenye, Szőlősardó, Perkupa, Bódvaszilas, Szögliget, Szin, and Szinpetri), and (2) the northern segment of the Rudabánya Mountains (outlined by the villages of Bódvarákó, Martonyi, and Dobódél) (Fig. 2). These areas presented on the map (Appendix 1) will be discussed in detail below.

Fig. 2. Distribution of the Lower Triassic formations in the Aggtelek–Rudabánya Mountains (only schematically illustrated in the strongly tectonized zones). The details in the mid-part of the area are shown in Appendix 1.

Moreover, Scythian formations of small spatial distribution are known in Ménes-völgy to the north, in a narrow zone extending from the Hungarian-Slovak border eastward as far as Bódvaszilas village. Further small outcrops appear in the surroundings of Égerszög as well as in the Telekes-völgy and north of Alsótelekes, and in the metasomatized series in the ore mine in the southern Rudabánya Mountains (Fig. 2).

Good outcrops for stratigraphic investigations with quasi-continuous exposure of Lower Triassic formations can be studied in two segments. The lower part of the sequence is exposed west–northwest of Perkupa (from the Bódvaszilas Sandstone to Szinpetri Limestone Member (s.str.) (Fig. 3). The upper part of the sequence crops out along the road between Szinpetri and Jósvafő, and north and south of Róna-Bükk-völgy (Dobódél) (from the uppermost part of the Szin Marl to the uppermost Szinpetri Limestone) (Fig. 3).

The Silica Nappe was detached from its original basement. The Upper Permian–lowermost Lower Triassic Perkupa Evaporite Formation (Fig. 3) served as the sole-thrust. However, the blocks of conglomerate–sandstone series in the northern neighbourhood of Bódvaszilas is presumed to be a fragment of the underlying continental red beds (Vozárová & Vozár, pers. commun.). From the Scythian Jósvafő Limestone Member to the Anisian Gutenstein Formation a continuous stratigraphic sequence is observed in the neighbourhood of Jósvafő and southeast of Dobódél village. In other cases, the contact with the younger formations is tectonic, except in the southern part of the area where an Oligocene–Miocene cover was deposited transgressively with a gap. Along the rivers, Quaternary terrace deposits cover the Triassic formations in many places.

Stratigraphy

The Silica Nappe in Hungary can be divided into two distinct Mesozoic facies units displaced later by the Darnó faults. As a consequence, at present they are separated by sinistral strike-slip deformation zone. These are the Aggtelek and the Bódva Facies (Kovács 1984; Kovács et al. 1989; Kovács & Hips 1998). They are defined by coeval syn-rift deposits separated in the course of rifting. Platform carbonates in the Aggtelek Facies and slope and basinal deposits in the Bódva Facies, characterize the formations from Upper Anisian to

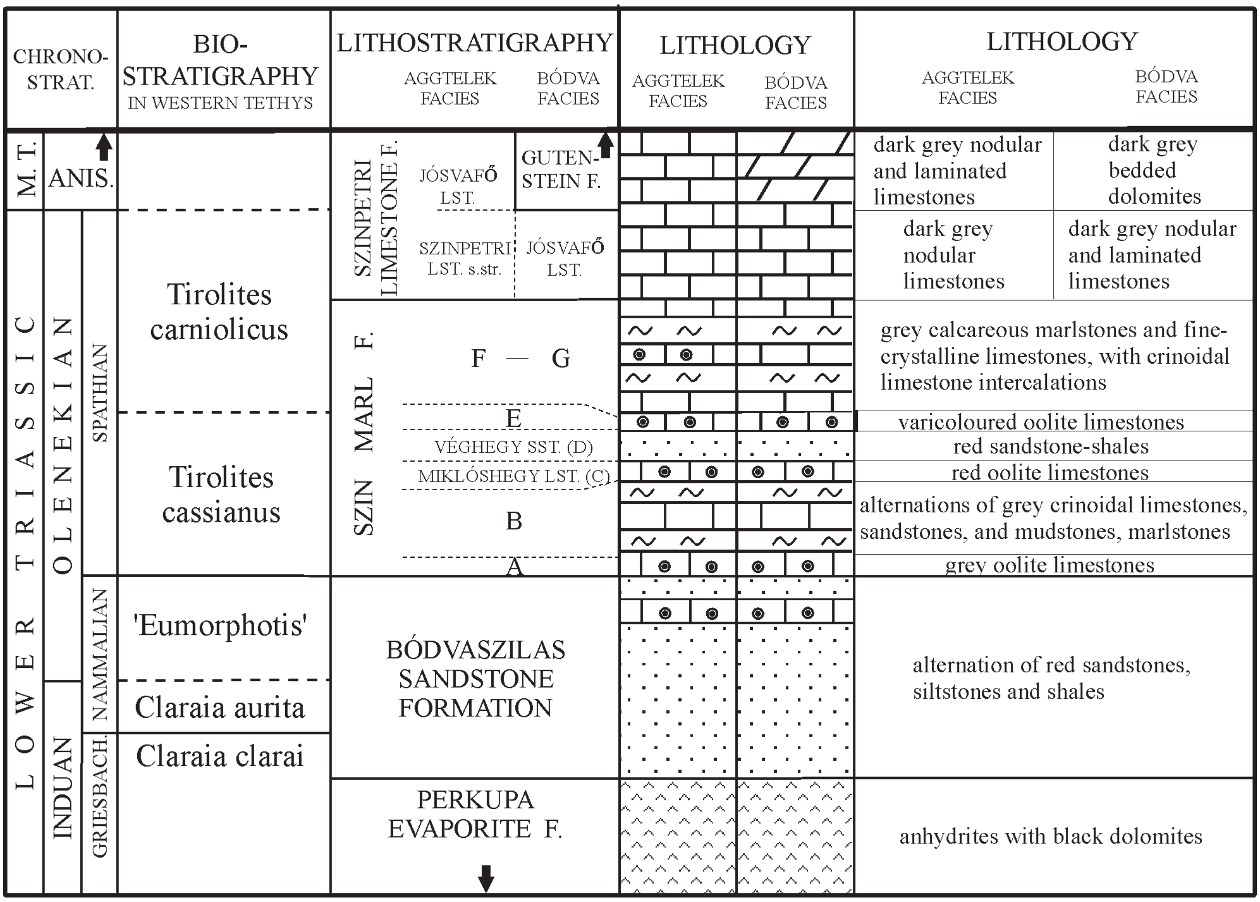

Fig. 3. Stratigraphic subdivision of the Lower Triassic sedimentary rocks in the Aggtelek–Rudabánya Mountains, after Hips 1996 (vertical subdivision is thickness proportional). (**M.T.** — Middle Triassic, **Anis** — Anisian, **LST** — Limestone, **SST** — Sandstone.)

Carnian in age. The pre-rift Lower Triassic and Lower Anisian formations, except for small facies differences, are uniformly developed in both facies units.

The Upper Permian–Lower Triassic sequence is represented by evaporitic, siliciclastic, mixed siliciclastic–carbonate, and carbonate sedimentary rocks. These can be subdivided into four formations: the Perkupa Evaporite, Bódvaszilas Sandstone, Szin Marl, and Szinpetri Limestone (Kovács et al. 1989), and several subunits (Hips 1996) (Fig. 3). The thickness of the sequence is about 800 m, not counting the mostly Upper Permian Perkupa Evaporite. The reader is referred to Hips (1998) for detailed discussion of sedimentary facies and ramp sedimentation during the Early Triassic.

In many settings of the western Tethyan depositional area, within the Lower Triassic, the boundary between the Induan and Olenekian stages cannot be determined due to the simple, low-diversity fauna. According to the recently valid stage-subdivision of the Triassic, the Scythian formations in the Aggtelek–Rudabánya Mountains could not be age-subdivided at all. A more detailed subdivision of the formations can be made only on the basis of the alternative three-fold division.

The Perkupa Evaporite Formation consists predominantly of anhydrites and subordinately of gypsums, dolomites, siltstones and shales (Fig. 4) deposited in a sabkha and connecting shallow marine environments. It is very poor in fossils, but it can be presumed that the age of the formation is upper Permian and lowermost Scythian and, thus, the Permian-Triassic boundary is located within its upper part. In the course of the overthrusting of the Silica Nappe, its own evaporitic base as a sole-thrust was strongly deformed and larger slabs of obducted Middle Triassic ophiolites were imbricated inside the evaporite series (Réti 1985).

The Bódvaszilas Sandstone Formation, previously known as 'Seis Beds', consists of an alternation of purplish red, subordinately greenish grey sandstones, siltstones and shales (Figs. 5–6). In its uppermost part, red oolite limestones appear forming a characteristic horizon. Index fossils, such as *Claraia clarai* (Emmr.), *C. aurita* (Hauer) and *Eumorphotis hinnitidea* (Bittner), indicate its Induan–lower Olenekian (upper Griesbachian–Nammalian) age. The thickness of the formation is approximately 200–250 m. It is underlain by the Perkupa Evaporite and overlain by the Szin Marl. In both cases the boundary of the formations is conformable; however, changes in lithology and colour are rather sharp.

The Szin Marl Formation is made up predominantly by alternations of brownish-grey, finely crystalline or crinoidal limestones and beige marlstones. In addition, grey, reddish-brown, or varicoloured oolites, grey coarse crinoidal limestones, clayey marlstones and siliciclastic layers, as fine sandstones, siltstones and shales are also characteristic (Figs. 7–9). The formation corresponds to the lower half of the former 'Campil Beds'. Seven 'lithofacies' units can be distinguished (A–G) within the formation (Hips 1996). They represent characteristic facies (or facies successions) which are arranged in stratigraphic sequence. They are indicated by their predominant rocks (App. 1 and Fig. 3). Two of them were already defined by Kovács et al. (1989), and although the original definitions had to be corrected, the names were kept. Upper Olenekian (Spathian) age is proved by the occurrence of *Tirolites cassianus* (Quens.) and *T.* gr. *carniolicus* Mojs. The total thickness of the formation is about 350 m. It is overlain by the Szinpetri Limestone Formation.

The Szinpetri Limestone Formation is composed predominantly of typical dark grey nodular, so-called 'vermicular' limestones. Its lower half, where marlstone and clayey marlstone intercalations or flasers occur, was named the Szinpetri Limestone Member (s.str.) (Fig. 10), whereas its upper half, where the mottled, bioturbated limestones alternate with laminated ones, was named Jósvafő Limestone Member (Fig. 11) (Kovács et al. 1989). It corresponds to the former uppermost 'Campil Beds'. On the basis of occurrences of *Stacheites* sp., *Dinarites dalmatinus* (Hauer) and *Costatoria costata* (Zenk.), its age is uppermost Olenekian (upper Spathian) and it is also possible that the upper part of the formation may extend into the lowermost Anisian. The thickness of the formation in the Aggtelek Facies is about 150–200 m, whereas in the Bódva Facies the development of the formation is reduced.

Earlier it was accepted that the lithostratigraphic boundary between the Szinpetri Limestone and the overlying Gutenstein Formation coincides with the Scythian/Anisian boundary. However, it appears more realistic that the lithostratigraphic boundary is not synchronous in the Aggtelek and Bódva Facies. Because of poor faunal assemblage, which tolerated restricted environmental conditions, this prediction cannot be confirmed in the present stage of knowledge.

Structural evaluation

In this section, the structural interpretation based on field data collected during mapping of Lower Triassic formations is described and presented in the uncovered geological map at 1:50,000 scale (App. 1). The paper provides additional data on the geological setting of the central part of the mountains. A more detailed study dealing with the deformation history of the mountains was recently published by Less (2000).

Lower Triassic formations are also known from drilling cores, and some of them are important from a structural point of view. The local data of cores significantly improved the structural interpretations based on mapping. Short summaries of the borehole data are presented for the relevant structural descriptions.

Major fault-zones and fault systems

The Darnó Zone is a significant NE–SW-trending sinistral strike-slip fault-zone (Telegdi Roth 1937, 1951; Szentpétery 1997; Less 2000) which divides the Rudabánya Mountains into segments. The western faults of the Darnó Zone ('line 1' according to Less 2000) separate the Aggtelek and the Rudabánya Mountains. The Silica Nappe is represented by the Aggtelek Facies on the western side of 'line 1' and by the Bódva Facies on the eastern side. The shear zone itself is composed of blocks in a complicated structural position, especially to the south of Perkupa (Less 1998b). To the northeast of Perkupa the zone widens and strike-slip duplexes line the tectonic boundary between the evaporites and Triassic formations along two major faults. Such small blocks are composed of

Fig. 4. Alternating layers of silty–clayey anhydrite (e.g. at the head of the hammer) and laminated anhydrite within diapiric folds, Perkupa Evaporite Formation, Alsótelekes quarry. Hammer for scale. Photo courtesy of Csaba Péró.

Fig. 5. Hummocky cross-stratified red sandstones and shales from the upper half of the Bódvaszilas Sandstone Formation, near Perkupa. Coin (2.5 cm diameter) for scale.

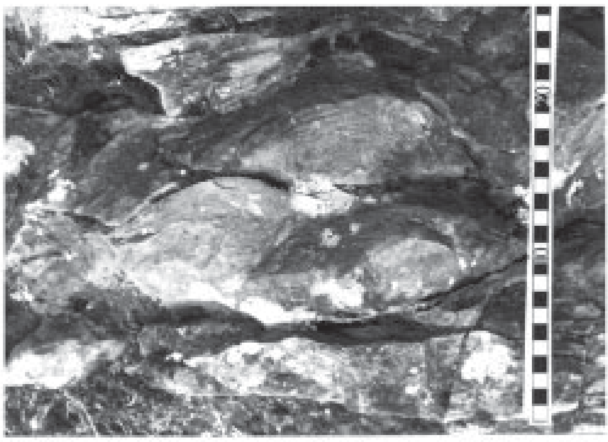

Fig. 6. Characteristic ball-and-pillow structures in red sandstones formed by water escape in the course of diagenesis, Bódvaszilas Sandstone Formation, near Perkupa. Scale in cm.

Fig. 7. Cross-bedded coarse crinoidal limestones within shales, Szin Marl Formation unit B, between Perkupa and Varbóc. Scale is 19 cm long.

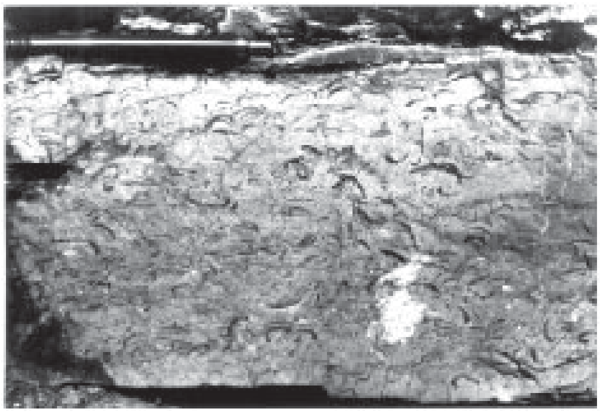

Fig. 8. One of the most characteristic lithologies of the Szin Marl Formation is red oolite limestones with blackened bivalve coquinas, Miklóshegy Limestone (unit C), Perkupa vineyard. Pen (on top left) for scale.

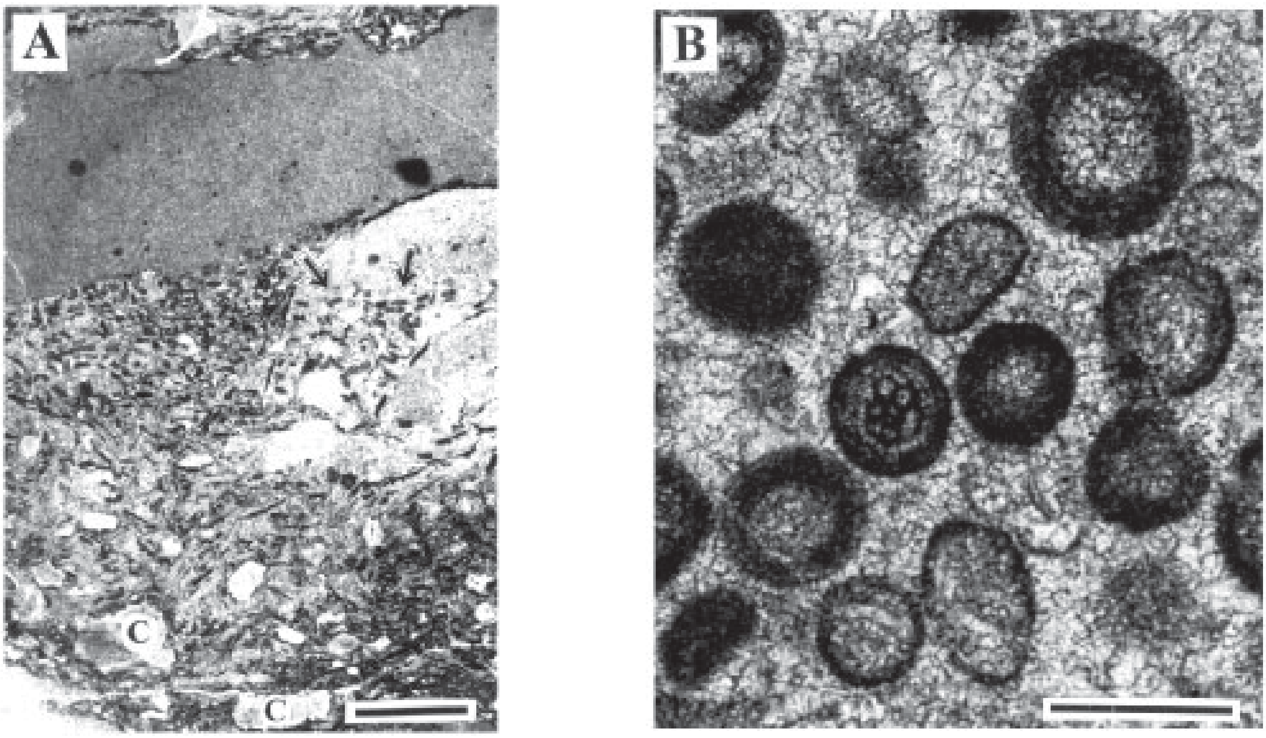

Fig. 9. Characteristic microfacies of the Szin Marl. **A** — Distal tempestite layer with graded debris of crinoidal fragments (C) and foraminifers (arrows) covered by clear muds; note the stylolitic boundary to the next tempestite layer at the top of the photo, unit B, near Perkupa. Scale bar is 2 mm. **B** — Oolite grainstone with *Meandrospira pusilla* (Ho) in the nucleus of an ooid (middle), unit C, Perkupa vineyard. Scale bar is 0.5 mm.

Lower, Middle and Upper Triassic formations to the south-southwest of Dobódél (on the left side of the Bódva River). On the right side of the river two strike-slip duplex blocks are also directly related to the other major fault. One of these blocks is composed of Szin Marl that is pinched between the Perkupa Evaporite and Bódvaszilas Sandstone. Strongly folded strata with steep dip values (70–90°) confirm the strong strain in the outcrops to the south of Bódvaszilas and in the core cut in well Bódvaszilas-9. Another strongly tectonized block of marls is situated southwest of the previous one (cf. Fig. 12: 4–4'). The deformation along this sinistral lateral displacement zone took place in the Oligocene–Lower Miocene on the basis of facies distribution according to Szentpétery (1997).

Another characteristic deformation zone is the ENE–WSW-oriented Jósvafő–Bódvaszilas Fault Zone, which continues towards Kečovo (cf. Mello et al. 1996). Blocks of Middle Triassic formations are thrust over older Middle–Lower Triassic formations with southeastern vergency (Balogh 1948b, 1953a) (Fig. 12). This is a type of young-on-older thrust. Balogh (1948b) and Less (2000) observed as a general situation that

Fig. 10. Nodular dark grey limestones from the Szinpetri Limestone Member (s.str.), Szinpetri type locality. Hammer for scale.

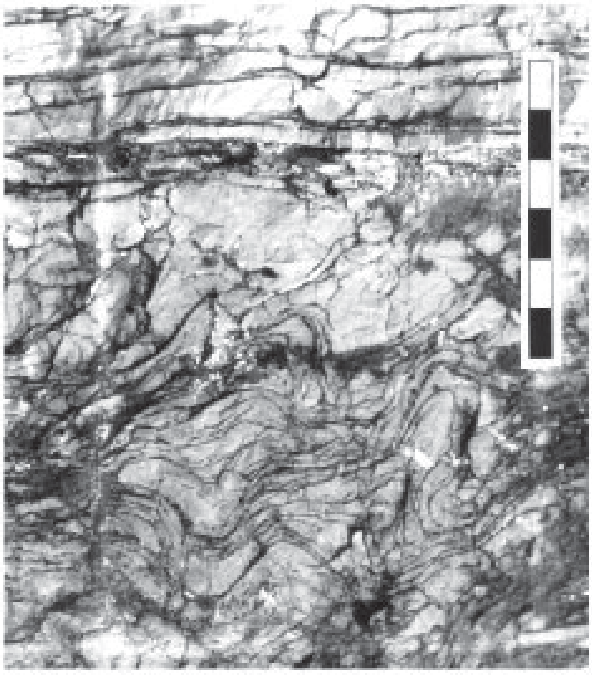

Fig. 11. Slump structures in laminated dark grey limestone, Jósvafő Limestone Member, Jósvafő type locality. Scale in cm.

south of the axis of the Horný vrch the main reverse fault zones verge southward (cf. Mello et al. 1996). Part of the Jósvafő–Bódvaszilas reverse fault-zone is measurable in the field north of Jósvafő (Fig. 13). Slickenside lineation on the fault plane indicates thrust with SE vergency, supposedly in an earlier phase which was probably followed by normal displacement afterward (Csontos pers. commun.).

The Jósvafő–Bódvaszilas deformation zone is most probably composed of additional E–W-directed lateral segments. Small-dimension, isolated lenses of mismatching rocks made up of Scythian formations older than the enclosing ones occur within this fault zone. These blocks are interpreted as push-up structures in a left-stepping dextral strike-slip system formed by compression in the transfer zone of tectonic motion (cf. Woodcock & Fisher 1986). Such strike-slip duplexes occur at bends of the main shear zone. In this manner small blocks of the Szinpetri Limestone Member (s.str.) and unit F of Szin Marl are pinched between the Szinpetri Limestone and Middle Triassic formations north–northwest of Szinpetri (Fig. 12: 2–2'). In the western neighbourhood of Szögliget, larger blocks of the Middle Triassic and Szin Marl formations are imbricated along the belt. Moreover, thick brecciated zones delineate blocks within the Szin Marl between Szögliget and Bódvaszilas (Fig. 12: 4–4').

Evaporites and the related red sandstones–shales (northeast of Jósvafő and west of Szin, cf. Balogh 1953a) most probably injected up along small opening (pull-apart) segments of the Jósvafő–Bódvaszilas Fault Zone in a later phase, supposedly at the same time as the normal displacement of the upper, Middle Triassic blocks.

A further characteristic element of the fault-system of the area is represented by E–W dextral strike-slip faults and the connecting NE–SW reverse faults, as revealed by compilation of the map. The dextral strike-slip faults are well marked by split marker horizons of the Szin Marl and formation boundaries, in the region between Perkupa, Szin and Szinpetri. These faults can barely be traced in the Szinpetri Limestone because of its monotonous development. The displacements along these strike-slip faults are between 50 and 250 m.

A system of NW–SE faults was also recognized near Jósvafő (Less et al. 1988). They cut and offset the Jósvafő–Bódvaszilas zone.

Folding

Folds are characteristic and dominant structural elements of the area (cf. Grill 1989). Their orientations (Figs. 14–15) suggest the following subdivision; however, no evidence could be observed to interpret their relative order.

Folds with NE–SW axes are predominant in the investigated area. These metre-sized, open to tight, mostly asymmetrical folds (e.g. Fig. 16) are widely distributed. On the basis of measured dip directions, map-scale anticline and syncline structures with similar orientation are recognized. These are the following: (1) the Varbóc Syncline northeast of Varbóc, which can be traced to the northwest of Perkupa; (2) another small syncline southeast of Szin; (3) an assumed anticline in Keskeny-völgy with an overthrust northwestern limb; and (4) a succession of small-scale anticlines and synclines south of Jósvafő. In the Bódva Facies (5) a similar pair of syncline and anticline (Dobódél Anticline by Balogh 1952) is formed southeast of Dobódél. The Varbóc Syncline can hardly be recognized to the SW because of poor exposure of the monotonous Szinpetri Limestone. There is a possible continuation in

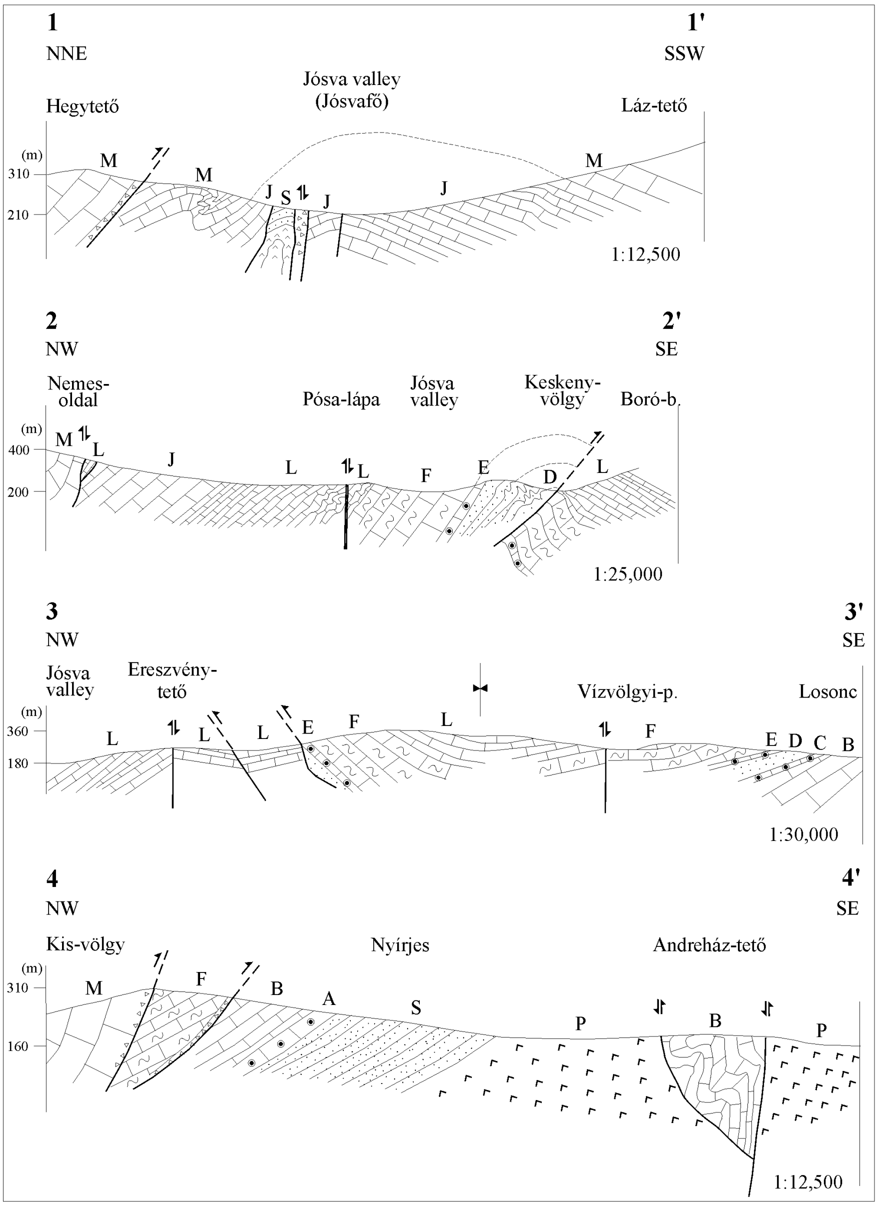

Fig. 12. Cross-sections of the central part of the Aggtelek Mountains (lines indicated on the map, App. 1). *Legend:* letters are same as those used on the map. (Not all geographical names are indicated on the map.)

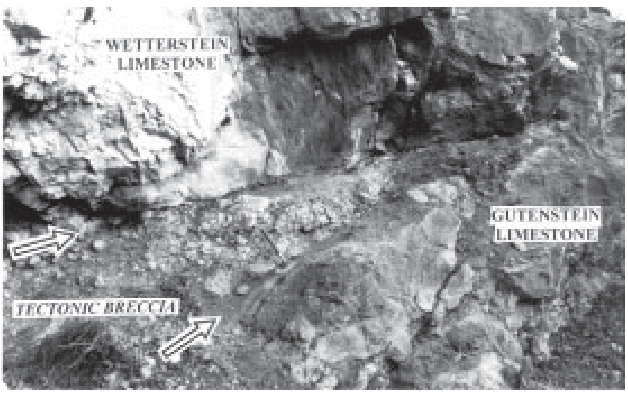

Fig. 13. Young-on-older thrust fault (arrows) of the Jósvafő–Bódvaszilas Zone exposed in a quarry north of Jósvafő (N–S cross-section). Wetterstein Limestone with brecciated base is overthrust on Gutenstein Formation. Hammer (for scale, in middle) is at the contact of the breccia and the Gutenstein Formation.

the Middle Triassic formation in the Teresztenye-plateau according to Less (1998b). (For more discussion on the combination of anticline–syncline structures with other structural elements see the sections below.)

One set of folds with approx. E–W axes is also very characteristic and widely distributed in Lower Triassic formations and the Gutenstein Formation (cf. Grill 1989). They are half metre to a couple of metre-size open or close folds. Smaller-scale anticline and syncline structures can be recognized in the eastern neighbourhood of Jósvafő on the hillside of Cseresznyés-kút north of the Szinpetri–Jósvafő road. The Gutenstein Formation (from Kecső-völgy) and Jósvafő Limestone (to Almás-völgy) are folded into a bigger anticline structure indicated by dip directions. This Jósvafő Anticline was recognized by Schréter (1935) and confirmed by Jaskó (1935) west and south of Jósvafő.

A set of folds with NW–SE (and N–S) axes is observed only locally. They are 20–50 cm to 1 m in size, predominantly closed, sometimes open, either asymmetrical or symmetrical folds. A set of smaller-scale anticlines and synclines is recognized north of Henc-völgy (Szőlősardó), east of Varbóc, and near Szinpetri. The large areal distribution of Szinpetri Limestone between Varbóc and Teresztenye also suggests one (or more smaller scale) syncline(s) of NW–SE strike, parallel to the set of anticlines–synclines north of Henc-völgy. A similar situation is presumed north of Szinpetri and Szin.

Grill (1989) in an earlier study distinguished two folding phases. The regional folding direction of the first phase is NE, and axes of this set of folds deviate with ca. 20–30° around a

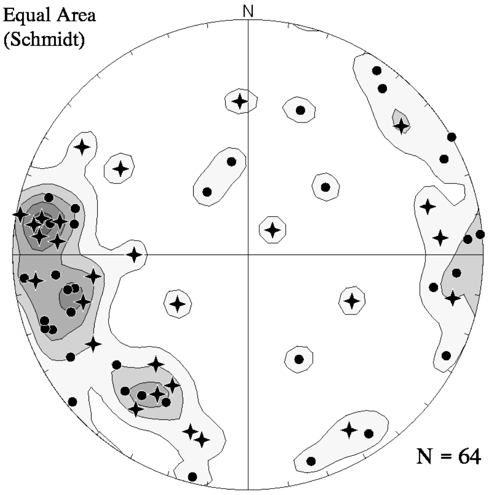

Fig. 14. Density diagram of the directly measured (stars) and constructed (dots) fold axes.

N–S direction. He dated their formation prior to Late Cretaceous. The second phase occurred in connection with the sinistral strike-slip motion along the Darnó Zone (Late Oligocene–Early Miocene) and created folds with E–W axes. Anticlines in the Jósva valley and near Dobódél originated as a result of the second phase. The directions of the measured fold hinges published by Grill (1989) are closely comparable to those presented in this study in Figs. 14 and 15. Nevertheless, there is no clear distinction between the two sets of folds on his map. NNW–SSE-trending folds can be found as interpreted elements of the second phase, and WSW–ENE-trending folds formed in the first phase. There are local folded areas where the axes of first and second phase-folds are almost parallel. Distribution of dips, which is presented on the π-diagram (Grill 1989), shows good correlation with the map in this study. Sets of anticlines and synclines published by Mello (1971) from the Slovak part of the Silica Nappe trend in similar directions as in the Lower Triassic of the investigated area.

Less (2000) interpreted one/main folding phase of the mountains prior to the Late Cretaceous. He discussed the explanation by Balogh (1948b) on the folding phase followed by continuous compression, which displaced the syncline cores (composed of rigid platform limestones) onto the top of the neighbouring anticlines with southern vergency along reverse faults (e.g. the Ménesvölgy Zone between Silická Brezová and Bódvaszilas, the Jósvafő–Bódvaszilas Zone, and several slices in the Rudabánya Mountains).

To summarize, further extended investigation on folding and connecting structural elements is needed to characterize the ductile deformation in the mountains.

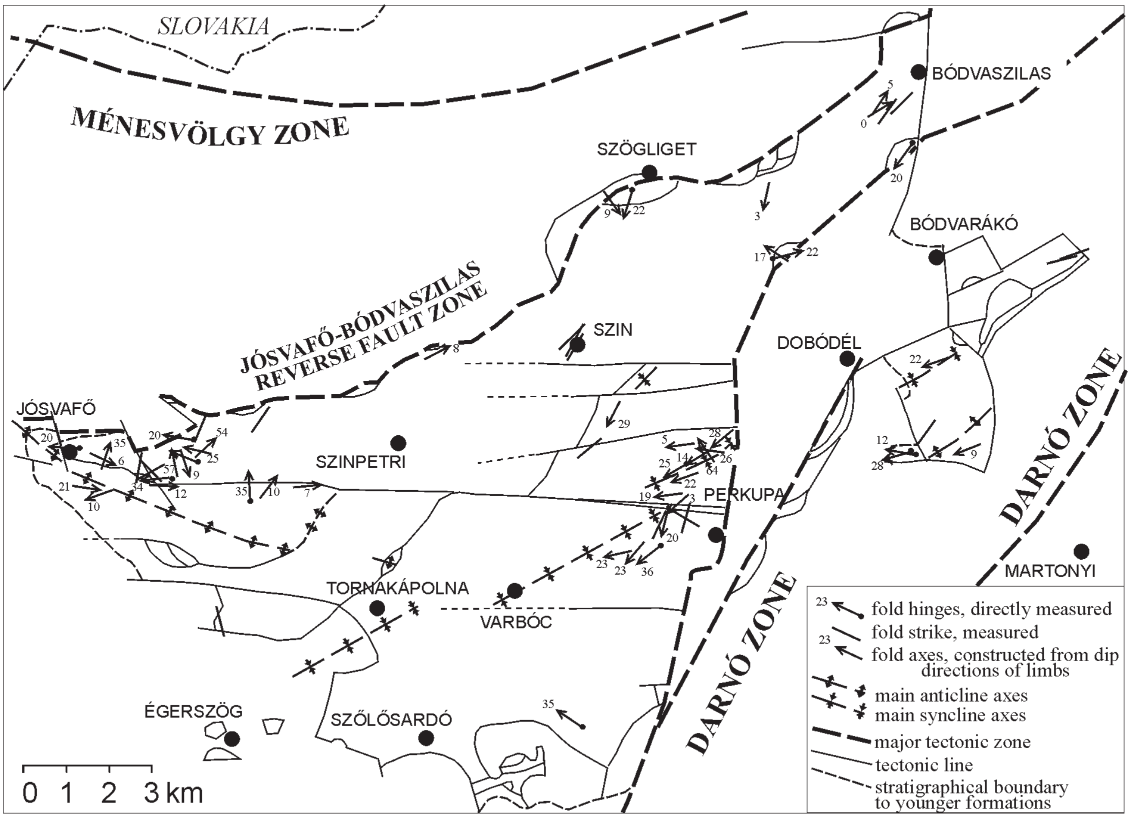

Fig. 15. Location sketch map of observed folds in Lower Triassic formations.

Fig. 16. Closed, SE-verging asymmetrical folds with NE–SW axes plunging SW in red sandstones of Szin Marl unit D, along the cart road in the Perkupa vineyard (NW–SE cross-section). Hammer for scale.

Evaporite diapirs

One feature, which cannot be disregarded, is the presence of a thick evaporite series at the base of the Silica Nappe. Thus, diapiric processes could be very important mainly in the weakened shear-zones (Grill & Szentpétery 1988). However, evidence in the surface outcrops in the investigated area is sporadic. The evaporite series was supposedly pushed up in more different times, but in a similar manner along the opening segments of strike-slip faults.

Fault-related mismatching rocks serve as a very good example for evaporite tectonics. Red sandstones–shales are observed in very restricted surface distributions along the Jósvafő–Bódvaszilas Fault Zone (northeast of Jósvafő and west of Szin, cf. Balogh 1953a), and along a brecciated zone (in the Jósvafő Limestone) east of Jósvafő in the Jósva valley (Fig. 12: 1–1') (cf. Balogh 1953a; Less et al. 1988). One of these small blocks was penetrated by Jósvafő-2 well (Less et al. 1988), red siliciclastics of the Bódvaszilas Sandstone (0.0–26.0 m), anhydrites and green siliciclastics of the Perkupa Evaporite (26.2–76.4 m), and dark grey limestones (probably Jósvafő Limestone) (76.4–84.9 m) occur. According to the borehole data the evaporite series is relatively close to the surface.

Appearances of red sandstones–shales at the surface along fault-zones may indicate upward movement of evaporites. Older rocks were most probably pushed up by underlying gypsum–anhydrite series along locally opened pull-apart portions of the fault zones.

Discussion of the principal structures

The progressive decrease in age of the Scythian formations westward resulted from general westerly tilting. This uniform younging trend is disturbed by several tectonic zones. The map-scale structures are described and analysed in this section.

Predominant structures

On the basis of the deformation style in the Lower Triassic formations, three E–W-trending segments can be distinguished in the Aggtelek Mountains. In the northernmost, between Bódvaszilas and Szin, a generally 'intact' stratigraphic position of the Lower Triassic formations can be found. Moreover, several push-up duplexes are accommodated along the front of the Jósvafő–Bódvaszilas reverse fault zone. The Middle Triassic formations are overthrust far on top of the Lower Triassic units. Thus the uppermost part of the Scythian sequence is missing at the surface.

In the middle belt, between Szin and Szinpetri–Perkupa, the E–W-trending dextral strike-slip and connecting NE–SW reverse faults are the most characteristic elements. The front of the Jósvafő–Bódvaszilas Fault Zone is lined by small-dimension duplex lenses. On the other hand, in the southernmost segment, south of Jósvafő–Szinpetri–Perkupa, combinations of anticlines and synclines with thrusts are the dominant map-scale structures in the Lower Triassic formations. In this segment, the Jósvafő–Bódvaszilas thrust fault is observed within the Middle Triassic formations north of Jósvafő.

In the Rudabánya Mountains a NE–SW striking pair of anticlines and synclines is the main structural feature in the Lower Triassic formations.

Groups of structural elements

Elements of four structural phases (Fig. 17) were recognized in the Lower Triassic formations. Their timing is uncertain. The description is given in the supposed relative order.

First phase. Elements of the first group are the folds and anticlines–synclines with E–W axes observed mainly in the neighbourhood of Jósvafő (Fig. 12: 1–1'). Their formation suggests a N(NE)–S(SW) shortening (according to recent co-ordinates), which occurred prior to the Late Cretaceous (cf. Less 2000).

Second phase. Elements of the second phase predominate in the distribution area of the Lower Triassic formation: NE–SW-striking synclines and anticlines, young-on-older thrust combined with E–W lateral segments (Jósvafő-Bódvaszilas Zone), push-up duplexes, E–W dextral lateral zones, NE–SW thrust faults, and evaporite injections. They are connected in special combinations and they are the most impressive map-scale structures of the area. Their formations suggest a NW–SE shortening and NE–SW elongation (according to recent co-ordinates).

A complex combination of structural elements was observed in the southernmost Lower Triassic structural segment. A map-scale interference structure of two anticlines (one of that was formed in the first phase and the other refolded it in the second phase) is interpreted southwest of Szinpetri village, between the Almás- and Keskeny-völgy. The half-dome structure is defined by outcropping Szin Marl and pinched between E–W strike-slip faults from the north and south and a reverse fault from the southeast. The axes of the anticlines are more or less at a 120° angle to each other. The first anticline with WNW–ESE-striking axis forms the continuation of the Jósvafő Anticline. This anticline was most probably later folded

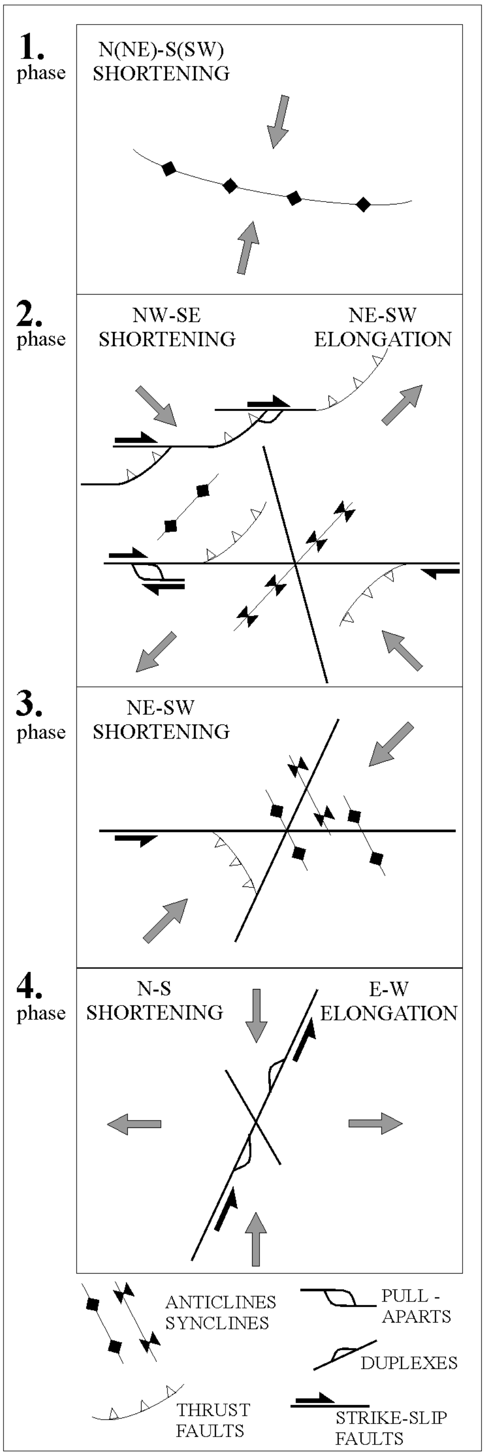

Fig. 17. Groups of structural elements observed in Lower Triassic formations (recent co-ordinates).

along the NE–SW-trending axis indicated in the Keskeny-völgy (Fig. 15). Thereafter, the northwestern limb of the second anticline was overthrust with southeastern vergency onto its southeastern limb, supposedly parallel to its axial surface. As a consequence the younger part of the Szin Marl (units D–F) crops out from beneath the Szinpetri Limestone along the Keskeny-völgy and dips to the northwest, north and west (Fig. 12: 2–2'). Older Szin Marl units (B–D) are exposed at the surface along the southern lateral faults at the head of the Almás-völgy.

Another very characteristic map-scale structure of the southern segment is the combination of the Varbóc Syncline and a major strike-slip fault zone. The E–W fault extends north of Perkupa and can be traced to the west. This fault-zone has a right lateral offset, combined with north–northwest-directed thrust. The northern limb of the Varbóc Syncline was thrust and displaced along this fault (Fig. 12: 3–3'). Most of the lateral motion along its western termination was probably transformed into a NE–SW-striking reverse fault that can be traced in the Szövetény-völgy. The overthrust process results in surface outcrops of Szin Marl units (upwards from unit D, and unit B in a separate block) from beneath the Szinpetri Limestone in the Szövetény-völgy. This pattern of folding, reverse fault, and lateral strike-slip is very similar to the situation in the Keskeny-völgy described above.

The outcrop of unit B in the Szövetény-völgy was drilled by the Tornakápolna-3 well. The drilling penetrates from unit B of Szin Marl (7.0–51.5 m) through the Bódvaszilas Sandstone (51.5–131.9 m) down into the evaporites, dolomites, radiolarites and basalt (131.9–600.0 m). This block could be interpreted as the southeastern termination of the hinge region of the WNW–ESE-trending Jósvafő Anticline, which would explain the relatively elevated position of the block.

Third phase. Small-scale NNW–SSE striking synclines and anticlines making up minor elements of the area were supposedly formed in the NE–SW shortening phase (based on recent co-ordinates). Furthermore, smaller-dimension blocks of Gutenstein Formation, Jósvafő Limestone and Szin Marl can probably be explained as a frontal thrust at the junction of strike-slip faults at the head of the Keskeny-völgy. These smaller-dimension structures are considered to belong to the third phase.

Fourth phase. Strike-slip duplexes also involving Lower Triassic formations along the Darnó Zone were already described in detail above. Structural elements formed in connection with sinistral lateral motion along the Darnó faults are part of the fourth phase (N–S shortening and E–W elongation, according to recent co-ordinates) (see details in Szentpétery 1997 and Less 2000).

It must be mentioned that Less (1998b, 2000) regards the reverse fault in the Szövetény-völgy and the lateral fault extending from Jósvafő to Perkupa (and one to north, and two other E–W trending lateral faults to south) to be part of the Darnó system.

Existence of Jósvafő Anticline

The concepts on the 'Jósva-völgy' anticline, formerly presented by Balogh (1948a,b, 1952, 1953a), Less et al. (1988), Grill (1989), and Less (1998b, 2000) need to be modified in the light of new mapping and the above mentioned observations. A major anticline with E–W axis running all along the Jósva valley is only an apparent one. The principal evidence is the dips of the Lower Triassic units (cf. Grill 1989, Fig. 3a). The general NNE–SSW strike of the Lower Triassic units along the Bódva valley cannot support the existence of an anticline structure in the eastern part of the Jósva valley.

Other evidence is the following. In the neighbourhood of Jósvafő, NW–SE and E–W trending faults cut and displaced the northern and southern limbs of an anticline with a WNW–ESE axis. This anticline was observed west and south of Jósvafő by Schréter (1935) and Jaskó (1935) and named the Jósvafő Anticline. Its southeastern continuation can be recognized in the Almás- and Keskeny-völgy interference half-dome structure. A possible updoming structure outcropping in Szövetény-völgy is interpreted as its southeastern termination. However, there is no evidence for a direct continuation of any anticline of E–W axis from Szinpetri to the east along the Jósva-völgy. The measured fold axes are E–W east of Jósvafő and NE–SW south of Jósvafő. Furthermore, along the Jósva valley, several folds and local anticline–syncline structures of NE–SW axes are present, e.g. in the Keskeny-völgy, in the surroundings of Szin, and north and west of Perkupa. Additionally some of them are combined with overthrusts or strike-slip faults. Thus, the major-scale anticline with E–W axis is only apparent. The structural situation instead indicates three independent folding phases interfering with each other.

Conclusions

The mapped area in the Hungarian part of the Silica Nappe is located to the south of the Jósvafő–Bódvaszilas reverse fault zone and divided into two parts by the NE–SW sinistral strike-slip faults of the Darnó Zone. The Upper Permian–Lower Triassic sequence can be subdivided into four lithostratigraphic units: the Perkupa Evaporite, the Bódvaszilas Sandstone, the Szin Marl, and the Szinpetri Limestone Formations. Several subunits were recognized (Hips 1996), successfully separated and mapped. Formation boundaries, characteristic members of the Szin Marl, especially red sandstones–shales and oolite limestones, and biostratigraphic results from the Bódvaszilas Sandstone, help delineate tectonic structures of the investigated area.

The Jósvafő–Bódvaszilas tectonic zone was probably active in sections and/or in several phases. The younger formations were displaced along dextral strike-slip faults and were overthrust to the southeast over the older formations after a folding phase. This is a type of young-on-older thrust. Small blocks were pushed up along the E–W lateral segments, which are accommodated along the front of the fault zone. Along the main faults of the Darnó Zone, small blocks of mismatching rocks involving Lower Triassic formations are interpreted as strike-slip duplexes.

Folds are characteristic structural elements in the Lower Triassic formations. Three groups were identified. One set of folds with NE–SW axes is predominant and widely distributed in the entire mapped area. Map-scale anticlines and synclines were also formed in this system (e.g. the Varbóc Syncline, the assumed Keskeny-völgy anticlines, and an anticline and syncline near Dobódél). Other sets of folds with E–W and NW–SE axes appear only locally but several anticlines and synclines are also recognized. The map-scale structures reveal that the formerly proposed anticline with E–W axis running all along the Jósva-völgy does not exist. The E–W Jósvafő Anticline is proved near Jósvafő but there is no evidence for its continuation eastward of Szinpetri.

Evidence for evaporite tectonics is sporadic in the surface outcrops. Fault-related mismatching rocks are observed in the neighbourhood of Jósvafő. Older rocks were supposedly pushed up by upward-moving, underlying gypsum–anhydrite series along opening segments of lateral faults.

On the basis of the deformation style in the Lower Triassic formations three E–W trending segments can be distinguished in the Aggtelek Mountains. Characteristic elements of four structural phases were recognized; however, their timing is uncertain. The first phase consists of folds and anticlines–synclines with E–W axes observed mainly in the neighbourhood of Jósvafő. Elements of the second phase predominate in the distribution area of the Lower Triassic formation: NE–SW striking synclines and anticlines, young-on-older thrust combined with E–W lateral segments (Jósvafő-Bódvaszilas Zone), push-up duplexes, E–W dextral lateral zones, and NE–SW thrust faults. They form special combinations and are the most impressive map-scale structures of the area. Elements of the third phase, which are the small-scale NNW–SSE-striking synclines and anticlines and frontal thrusts at junctions of strike-slip faults, are in a minority. Strike-slip duplexes involving Lower Triassic formations were recognized as parts of the Darnó Zone-related structures (fourth phase).

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Dictionary of Hungarian words used on the map

hegy — hill; *kút* — spring; *patak* — creek; *völgy* — valley.

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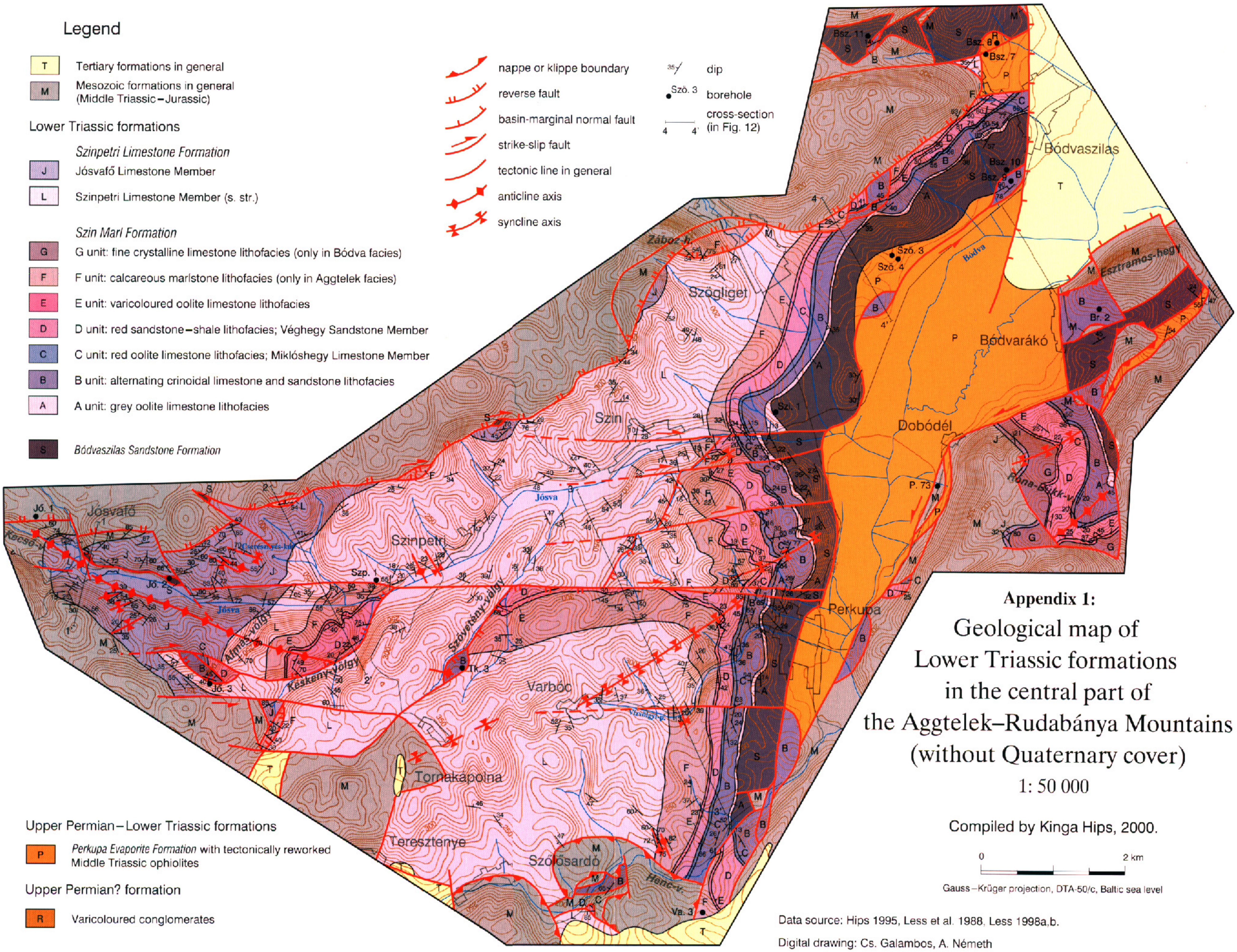

Appendix 1:

Geological map of Lower Triassic formations in the central part of the Aggtelek–Rudabánya Mountains (without Quaternary cover)

1: 50 000

Compiled by Kinga Hips, 2000.

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