Excursion Guide

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Pre-Conference Excursion: Geologic Overview of N Hungary, Bükk Mts.

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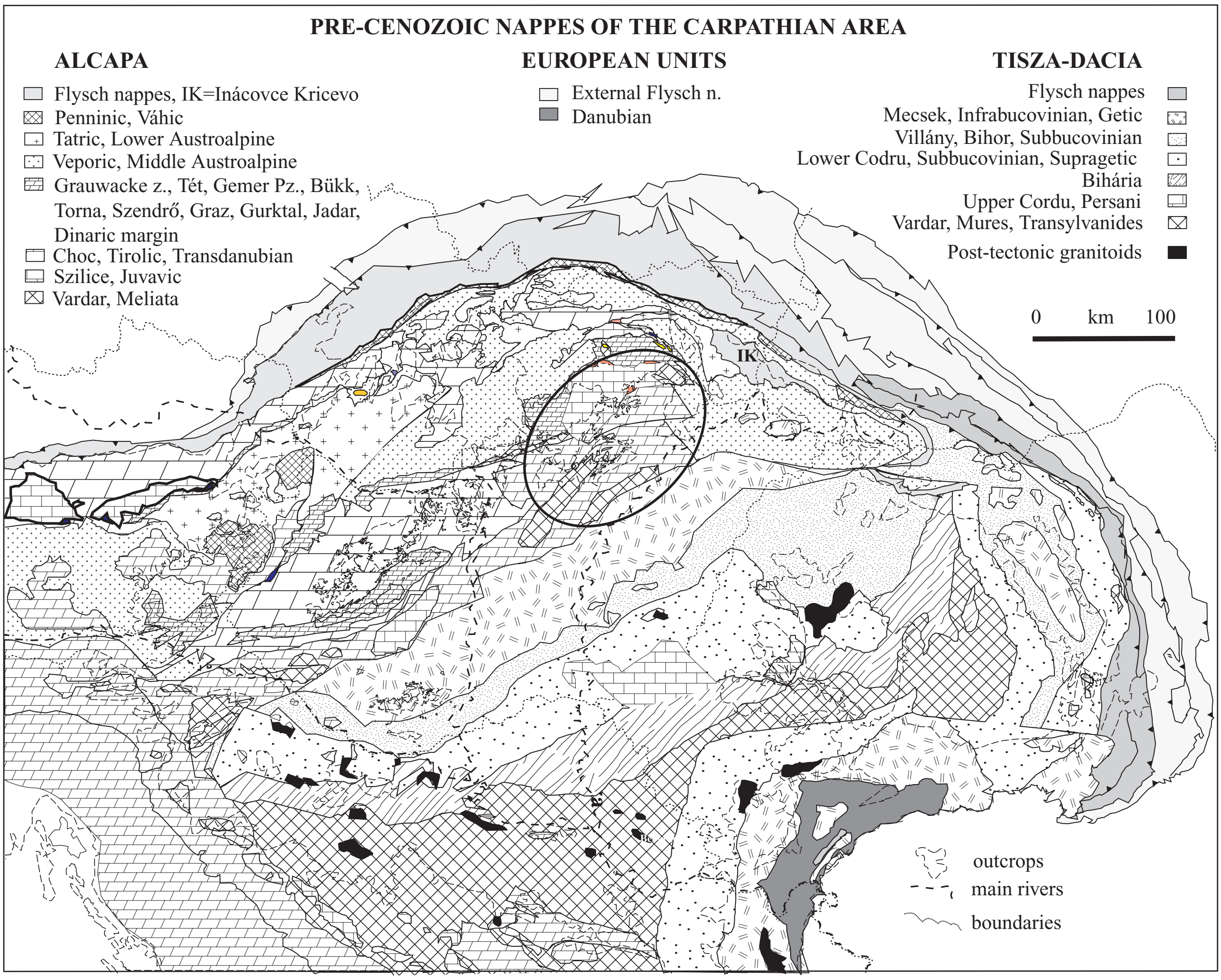
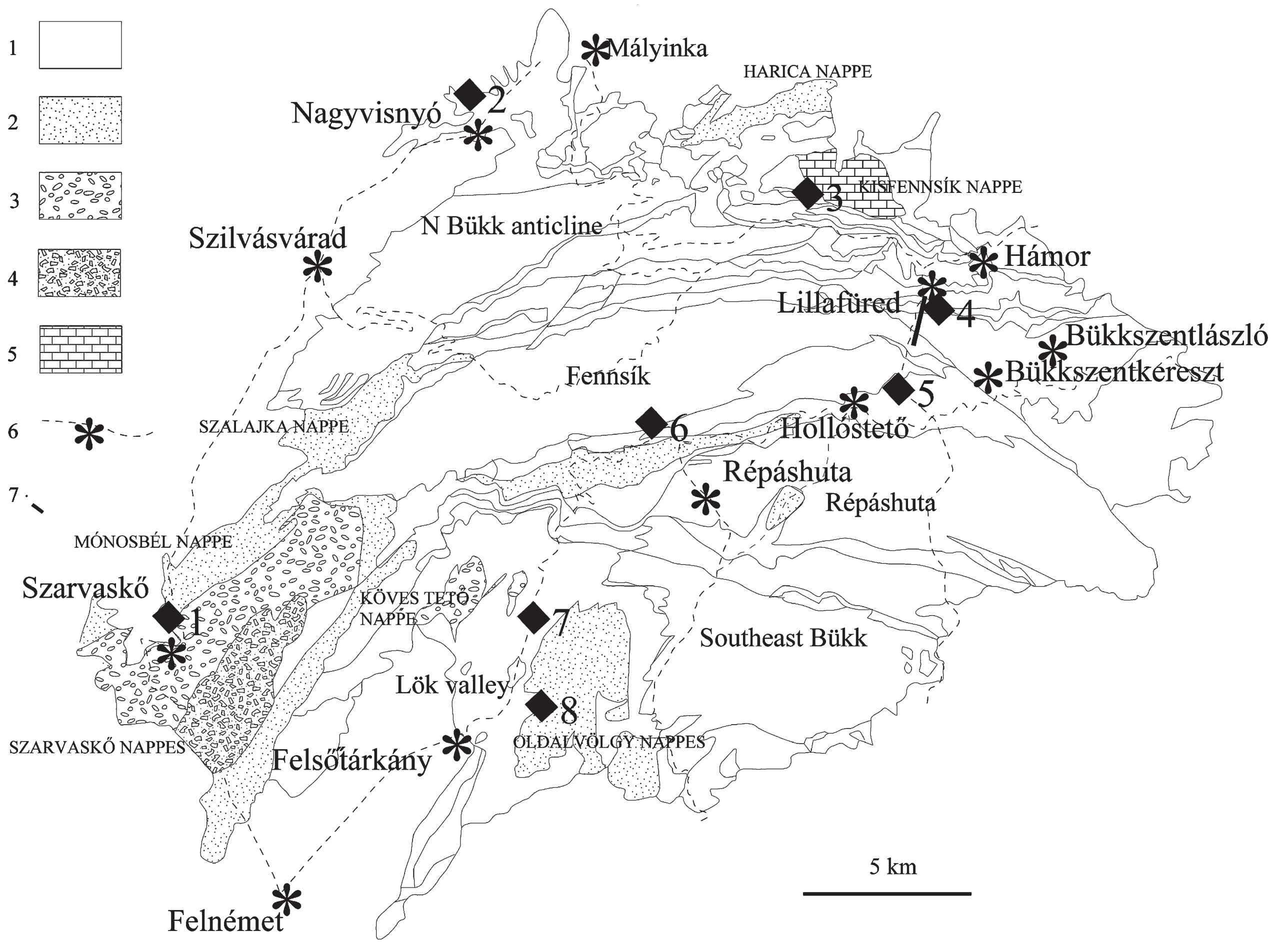
N Hungary is located at the southern border zone of the Alcapa unit, comprising the West Carpathians (Fig. 1). The North Hungarian units have a SW-wards elongated tail enclosed between the Balaton- and the Mid-Hungarian faults. The Alcapa unit is subdivided into a number of internal nappes. The nappes exposed in N Hungary build up a relatively old nappe stack in the Alpine-West Carpathian edifice and are composed of three southvergent nappes (from bottom to top): the Torna-Bükk parautochthonous with Paleo-Mesozoic anchi to epimetamorphosed rocks; the Szarvaskő-Mónosbél (Meliata) nappes with oceanic or back arc basin origin: anchimetamorphic to nonmetamorphic rocks; and the Szilice (Silica) unit composed of non-metamorphic platform and platform margin rocks (Árkai and Kovács 1996). All the nappes have strong Dinaric and/or South Alpine character. North Hungary may be considered as a truncated and transported segment of the western Dinarides (Zagreb region).

The internal structure of the N Hungarian nappes differ with the metamorphic degree of the rocks. The anchi-epimetamorphic



■ **Fig. 1.** Mesozoic tectonic units of the Carpathian area with Cenozoic formations removed. Modified from Csontos and Vörös. (2004) after Árkai (1990), Árkai and Balogh (1989), Beck-Managetta and Matura (1980), Čanović and Kemenci (1988), Dicea et al. (1980), Ebner et al. (1998), Flügel (1988), Fülöp and Dank (1987), Fusán et al. (1987), Glushko and Kruglov 1986, Grecula and Együd (1989), Gnojek et al. (1991), Haas et al. (1988, 2000), Hovorka (1985), Mahel' (1973), Năstăseanu (1975), Pamić (1998a), Pap (1990), Protić et al. (2000), Săndulescu (1975a, 1976, 1980b, 1988) Săndulescu and Visarion (1978), Šimunić et al. (1979), Soták et al. (1993) Tari 1994, Wessely (1988), and own work. Grey ellipse marks the target area.



■ **Fig. 2.** Main structural units of the Bükk Mts (after Csontos 2000). 1, Fennsík parautochthonous. 2, 3, 4, Szarvaskő type nappes. 5, Kisfennsík nappe. 6, Settlement, main roads. 7, Locality of visited outcrops. Thin lines represent lithologic boundaries. Names in italics represent main development areas within the Fennsík parautochthonous, small caps represent individual nappes belonging to the Szarvaskő type.

units show closed to isoclinal folds, several generation of cleavages, late kinks and imbricate structures, while the non-metamorphic ones are gently folded and have thrusts and other brittle structures. The whole nappe pile is affected by very intense Paleogene and Neogene strike-slip faulting and folding. The uppermost, Szilice unit is most probably a gravity nappe (Plasienka 1999) and as such, it has a northward prolongation over other Inner West Carpathian nappes.

In the Bükk Mts themselves two nappe systems may be separated based on stratigraphic, structural and geodynamic arguments (Fig. 2, Csontos 1999). The lowest unit is the Fennsík parautochthonous, overlain by the Szarvaskõ nappe system. A third, Kisfennsík nappe composed of Megalodontbearing limestones is an imbrication of the Fennsík unit (Fórián Szabó and Csontos 2002). There are four arguments to support nappes:

1. older Middle-Late Jurassic series on top of younger, Late Jurassic ones in the SE Bükk Mts;
2. totally different lithostratigraphic development of adjacent or superposed Jurassic units;
3. lack of mafic magmatites (intrusives) in tectonically lower units while intrusive and effusive rocks are present in upper units; and
4. different geodynamic character of overlying units (oceanic, suggested by geochemistry of mafics in the nappes, versus rocks of a thinned continental crust in the parautochthonous).

In the Fennsík parautochthonous (Fig. 3), on top of Upper Carboniferous to Permian clastic, a Lower Triassic oolithic shallow marine carbonate is deposited. After a shorter clastic event the development of an Anisian shallow, dolomitic platform is observed everywhere. This continues by an ephemeric dolomitic breccia (emersion event), and development of vast Aniso-Ladinian bimodal volcanism, very similar to that of the Southern Alps (Szoldán 1990). This event marks the beginning of a facies-differentiation related to rifting and subsidence of different domains during the Middle Triassic-Middle Jurassic. In shallower areas, volcanism was followed by platform development in the Ladinian-Early Carnian, in some places possibly even in the Norian. These platforms are now found either as isolated areas in the southern part of the mountain, or as roughly E-W stretching karstic high plateaus (Fennsík, Répáshuta imbricates). Between these plateaus, or in some cases (N Bükk Mts) above some platforms, clastic-carbonatic, or cherty carbonatic basins developed in the Carnian-Norian. It is interesting to note that some basin developments are associated with a within-plate (Szoldán 1990) mafic volcanism of possible Carnian age.

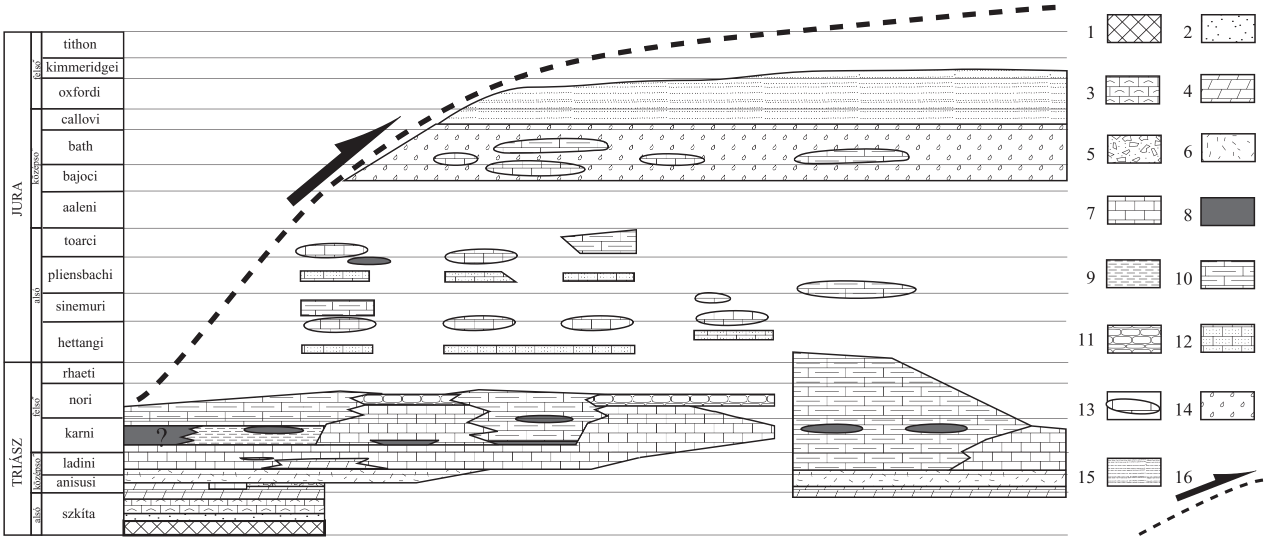
By the end of the Norian, all former plateau areas were drowned and either a varicoloured micritic, or a grey cherty basinal limestones covered the whole parautochthonous (Fig. 3). This carbonate cover may have persisted until the earliest Jurassic. The bigger part of the Lower (?)-Middle(?) Jurassic is represented by a very thin, redeposited sequence composed of varicolour crinoidal micrites, grey cherty limestones and olistostromes. The olistoliths are frequently derived from nearby Triassic plateau areas (e.g. a big Norian reef in the Bányahegy section, Riedel et al. 1988) or from cherty limestones (mostly in the S Bükk area). This redeposited sequence has no biostratigraphic marker, its age is inferred from its stratigraphic position. It is covered by a uniform reddish radiolarite blanket of Bajocian-Callovian (Kozur 1984, Csontos et al. 1991b) age, which itself frequently contains limestone olistoliths. These sediments grade into a black, distal turbidite composed of silt and fine sandstone layers, of unknown, but possibly Late Jurassic age. This youngest Mesozooic formation is preserved only in the southern part of the Bükk Mts.

The Szarvaskő nappes, preserved within synforms, are also located in the western, southwestern area of the Bükk Mts. The chaotic development suggests an accretionary prism origin. A hypothetic stratigraphic sequence (Fig. 4) begins with a dark shale containing sandstone and sometimes radiolarite lenses. These can be considered either as olitoliths, or as boudinaged lenses of former layers. Mafic intrusions, synchronous with the overlying pillow basalts intrude this sequence. The magmatic activity is thought to be mid-Jurassic (160 Ma) based on radiometric dating of a contact aureole (Árva-Sós et al. 1986). The basalts are overlain by shales, then a shaly sequence containing dark allodapic limestones, radiolarite lenses and redeposited volcanites. On top of this comes a more massive allodapic limestone horizon or an equivalent breccia, both composed of oolithic limestones. The redeposited material was dated by foraminifers to be Callovian-Oxfordian (Bérczinė and Pelikán 1984, Csontos et al. 1991a). A thicker radiolarite formation of mid-Jurassic age (Kozur 1984, Csontos et al. 1991b) may also be found in the vicinity of the allodapic carbonates. This stratigraphic sequence may be repeated several times as imbricates.

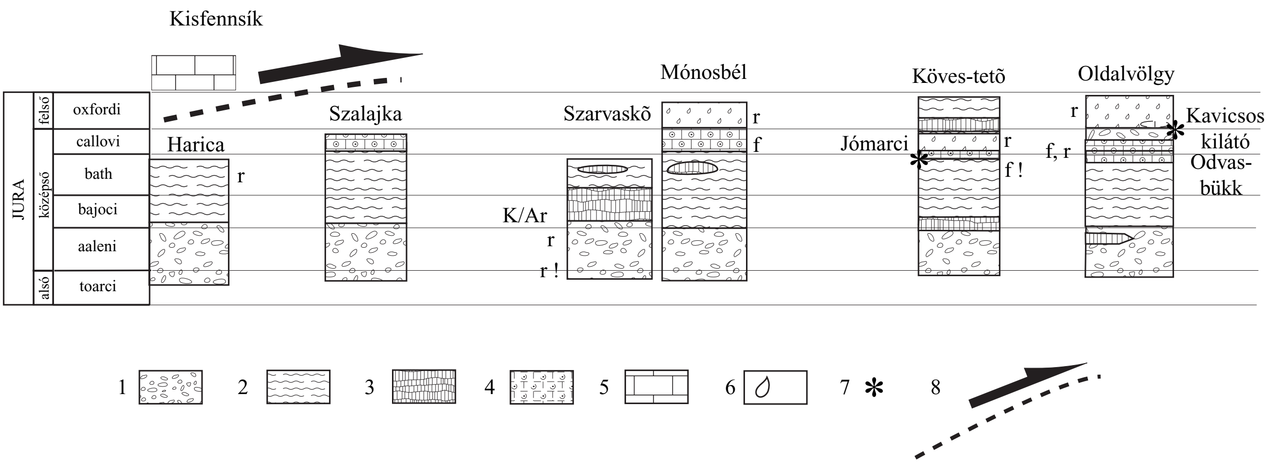
The paleogeographic position of the Fennsík and Szarvaskõ units is determined 1, by their structural position; 2, by their relations to the Transdanubian Range (TR), and to the South Alpine and Dinaric areas (Kázmér 1987) and 3, by the composition of redeposited material in frequent Jurassic olistostromes. Southvergent early structures, cutoff of nappe surface (in northern Bükk area) and a possible pre-foliation southwards overturned fold in the nappe sequence all suggest a southwards nappe transport for the Szarvaskõ-type nappes upon the Fennsík parautochthonous (see also Balla 1987). Later northvergent thrusts and strike-slip induced bending-arching only complicated the original structural grain. Paleomagnetic data indicate that all these units suffered a bulk 90° counterclockwise rotation (e.g. Márton 1990, Márton and Fodor 1995) in the Tertiary, so after reconstruction of these rotations the nappe transport becomes roughly west-directed. Reconstruction of nappes puts the Szarvaskõ development area to the east of the Fennsík unit.

The main trends of structural evolution of the Bükk Mts are delineated by several ductile and brittle tectonic phases (Fig. 5). These can be grouped into 9 events.

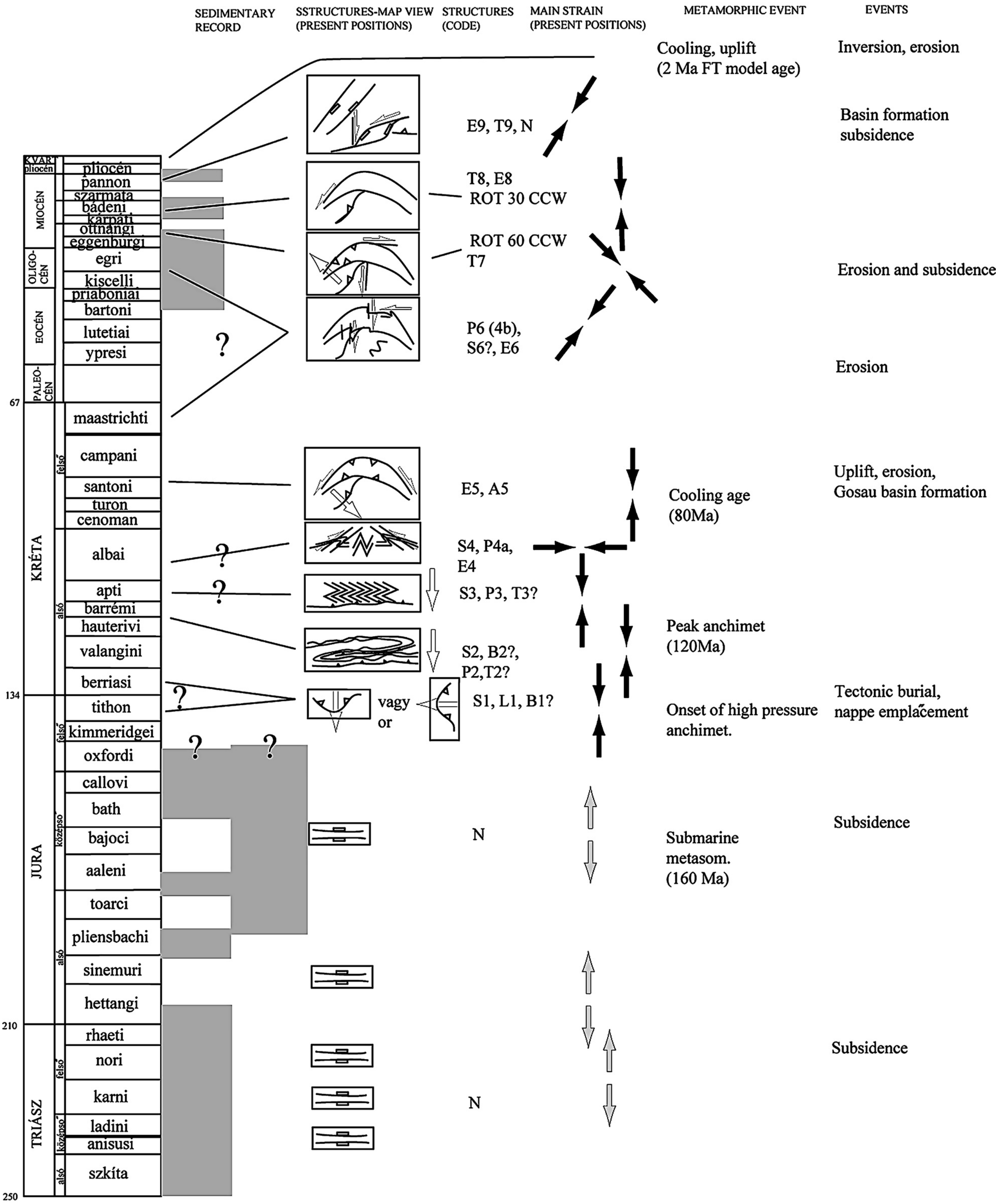
1. Emplacement of the Szarvaskő nappes (Late Jurassic?, after the age of last underthrust dated sediments), probably synchronously with layer-parallel flattening (S1), and eventually shear along E-W stretching lineation. This latter may be due to nappe transport.
2. During Hauterivian-Barremian (120 Ma radiometric age, Árkai et al. 1995) development of main foliation (S2) and syncleavage folds (P2) in both the rocks of the Parautochtchonous and Mónosbél-Szarvaskő nappes. These folds are dominantly south-vergent. They have Triassic-Liassic? carbonate cores and determine the basic structure of the Bükk Mts (Fig. 2). A large scale boudinage (B2) resulting in tectonically sheared major fold limbs and eventually elongation lineation giving E-W elongation may be synchronous with this tectonic episode. Anchimetamorphism seems to be synchronous with this event (Árkai 1983). Major folds are generally linked to reverse faults which cut the overturned southern limbs. A fault propagation origin for these folds seems probable. Limit of the tectonic imbricates reactivates former (Triassic) facies boundaries.
3. During mid-late Cretaceous, development of E-W trending chevron folds (Fig. 5; P3). This event turns the generally north-dipping main schistosity to occasionally south-dipping. E-W strike thrust faults may be active during this event.
4. During Mid-Late Cretaceous, but after E-W trending chevrons (Csontos 1988, Fodor 1989) development of originally N-S chevron folds (P4). Both chevron folds may locally have crenulation cleavage parallel to their axial planes. Both fold sets are flexed by later arching (Fig. 5).
5. During mid-late Cretaceous the whole mountain is ductilely sheared and arched along the NE-SW left lateral Darnó and NW-SE right lateral conjugate shear system (Fig. 2). Arching of all previous structures is pre-Paleogene, since Paleogene and Early Miocene rocks show a uniform paleomagnetic rotation pattern throughout the area (Márton and Márton 1996). Shortening inside the arc is accommodated by new or reactivated earlier thrust faults, some of which are northvergent.
6. Probably post-dating arching (between Late Cretaceous and Paleogene) N-S axis chevrons (P6) and a weak crenulation cleavage develop. Major, map-scale folds may be related to strike-slip shear bands arranged alternatively into an E-W shortening or NE-SW shortening strain field (Fig. 5). May be this event explains the development of weak cleavage in Early Oligocene Tard clays.
7. During Early Miocene there is quasi-perpendicular shortening across the Darnó zone (Telegdi Roth 1951, Schréter 1952, Sztanó and Tari 1993, Fodor et al. 1992, 1999). This shorten-



■ **Fig. 3.** Stratigraphic chart of the Fennsík parautochthonous (after Csontos 2000). The columns are proportional to time. 1, Lower Triassic (Gerennavári) oolithic limestone. 2, Lower Triassic (Ablakoskővölgy) variegated sandstone. 3, Lower Triassic (Ablakoskővölgy) marly slate and limestone lenses. 4, Anisian (Hámor) black limestone laminite and dolomite (in some places with patch-reef). 5, Anisian (Sebesvíz) dolomite-breccia. 6, Aniso-ladinian (Szentistvánhegy) metaandesite, rhyolite, piroclastites and tufites). 7, Ladinian (-Carnian?) (Fehérkő) light coloured platform-carbonate (dominantly cyclic limestone, occasionally marl, dolomite); Carnian?- Lower Norian? (Fennsík) cyclic platform-carbonate, occasionally with dolomitic, marly interlayers. 8, Carnian (Szinva, Létrás) volcanite (mafic lava and intrusion), shale, tufite, occasionally allodapic carbonate. Kisfennsík volcanite? 9, Carnian? (Vesszős) black shale, with bituminous limestone interlayers. 10, Carnian-norian-Lower Jurassic? (Felsőtárkány), Carnian-Norian (Hollóstető), Norian (Rónabükk) grey, cherty limestone with marly interlayers. Jurassic allodapic cherty limestone bodies. 11, Upper Norian? – Lower Jurassic? red-yellow (Répáshuta) mikritic limestone. 12, Jurassic? variegated resedimented (Juhászkút) sequence, matrix of which is mostly purple micritic, crinoidal limestone. 13, Bigger, more frequent olistoliths, allodapic horizons in the resedimented series. 14, Middle Jurassic (Bajocian-Callovian) red (Bányahegy) radiolarite, occasionally with carbonate olistoliths and allodapic limestones. 15, Upper Jurassic black (Lökvölgy) shales (roofing slate). 16, Overthrust surface of the Szarvaskő nappes.



■ **Fig. 4**. Stratigraphic chart of the Szarvaskő-type nappes (after Csontos, 1988 and Csontos et al. 1991b). The columns are proportional to time. 1, Lower Jurassic? dark (Tardos, Vaskapu) shale with sandstone layers and lenses. 2, Middle-Upper Jurassic? grey (Oldalvölgy) shale with limestone lenses and occasionally with allodapic limestone layers. 3, Middle Jurassic (Bajocian and younger) (Szarvaskő) basalt and related intrusives. the darker intrusives are related to Mid-Jurassic basalts and do not indicate earlier magmatic activity. 4, Middle-Upper Jurassic (Bathonian-Callovian) thick oolithic (Bükkzsérc) allodapic limestone, occasionally with resedimented volcanic material; olistostrome (Mónosbél) composed of oolithic limestone. 5, Middle-Upper Jurassic (Bajocian-Callovian-Oxfordian) black-red (Bátor) radiolarite with autigenic breccia and occasionally olistoliths. 6, Kisfennsík Megalodont-bearing limestone. 7, Place and name of special olistostromes. 8, Supposed overthrust surface of the Kisfennsík nappe. r= radiolarian-age; r!= redeposited radiolarian-age; f= foraminifer-age; f!= redeposited foraminifer-age; K/Ar= radiometric age determination.



■ **Fig. 5.** Schematic summary of the structural evolution in the Bükk Mts (after Csontos 1999). In the first column representing sedimentary record, grey bands indicate time covered by sediments. The two bands are related to the record in the Parautochthonous and in the Szarvaskő nappes. The second column indicates cartoons of the main structures in their present positions. Because of very important block-rotations in Tertiary the original directions and positions were occasionally much different. In the third column the successive events are indicated by the code used in Csontos (1999). S: schistosity, cleavage. P: folds. B: boudinage. T: thrusts. L: lineation. N: normal faults. E: strike-slip faults. A: arching. ROT: rotation. Without earlier Mesozooic normal faulting nine main structural events could be separated.

ing also creates northwest vergent thrusts (Fodor et al. 1992). After this period, in the Ottnangian (18–17 Ma) the whole region undergoes 60° CCW rotation (Márton and Fodor 1995).

8. During the early middle Miocene there is a smaller left lateral shear along the Darnó zone (Fig 5). A smaller 30° CCW rotation is recorded (Márton and Fodor 1995).
9. In the Late Miocene-Quaternary an alternating extensional-compressional regime is settled. Due to inversion, folds and thrusts develop even in Pannonian (Late Miocene) strata, but dominant structures remain pull-apart basins along ENE-WSW faults (Vatta-Maklár trough, Tari 1988). Quaternary is an inversion period with at least 600 m of uplift (Dunkl et al. 1994).

Stop 1. Szarvaskő, Várbérc Gorge, Roadcut; Tardos, Abandoned Quarry and Tóbérc, Abandoned Quarry

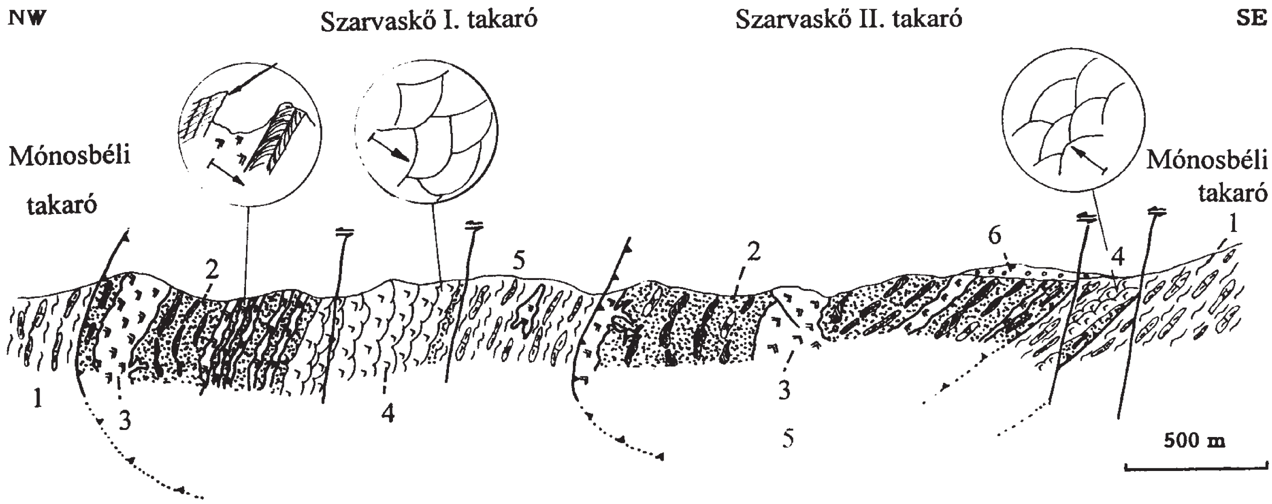
Three exposures are visited north of Szarvaskő village, along the main Eger-Szilvásvárad road (Fig. 1). These three exposures offer an upper crustal section in the Szarvaskő nappes. The sequence is subvertical or slightly overturned and younging towards the SE. The outcrops form the northwestern limb of a large synform (Fig. 1.1). The series of outcrops show a mafic extrusive-intrusive complex within/above dark sedimentary rocks of the Szarvaskő nappes.

The Várbérc gorge is located at the northern limits of Szarvaskő, under the remains of a medieval fortification. The first visited cliffs are at the hairpin bend of the road. The gorge is made of 0.5-1m big pillows made of hyaloclastic basalt. The thickness of the mafic effusives is estimated to 3-400 m-s, but it is locally thinned or thickened tectonically. The lava tubes dip about 25° to the NE. With the help of tectonic reconstruction, Balla (1982) deduced that the original slope of the volcano was 20°–30° and the volcanic centre must have been located to the E of the gorge.

Thin sections reveal an ophitic-intersertal texture without vescicles. Phenocrists are represented by Plagioclase, Augite, and Olivine pseudomorphs. The material is altered to Albite Chlorite, Prehnite and Carbonate.

The nearby abandoned quarry is located opposite the Tardos motel at the fork towards Ózd. The quarry was opened for a dyke intruded in a sandstone-shale complex. The almost entirely exploited dyke is a thin, microgranular gabbro sheet. The green intrusive rock is rigid, massive. It contains Plagioclase, brown Amphiboles, Piroxenes and rarely Pyrite. All the minerals are slightly altered. The texture of the rock indicates a shallow depth for the intrusion.

At both sides the mafic dyke has thermal contact. It intrudes in a cross-bedded sandstone-shale containing mainly sandstone,



■ **Fig. 1.1.** Constructed section of the Szarvaskő valley (after Balla 1983, Csontos 2000). Small circles indicate criteria (e.g. polarity of pillows) used for younging directions, which are indicated by small arrow. 1, Mónosbél nappe: Dark shale with grey, micritic limestone lenses and layers (Oldalvölgy Fm). 2, Szarvaskő nappes: dark shale with sandstone layers and lenses (Tardos Fm). 3, Mafic intrusives (Szarvaskő Fm). 4, Dark green pillow-lava (Szarvaskő Fm). 5, Dark shale with grey, micritic limestone lenses and layers (Oldalvölgy Fm). 6, Tertiary.

rarely black radiolarite lenses. These are partly olistoliths, partly boudinaged lenses of more competent material. The shales are rich in burrow marks. The sedimentologic features reinforce the overturned position of the strata.

The third outcrop is a major abandoned quarry (Tardos) for gabbros, near the level-crossing of the railroad. The huge sheet is subvertical and has at both sides thermal aureole. The coarse grained gabbro is mainly fractured and shows internal variations in grainsize, texture. Larger grainsize characterises the entry of the quarry, while smaller grainsize is found in distant walls. The bigger grainsize is often found at vein-like parts, where feldspar is enriched.

Near the entry in the scree light brown rock fragments are found. These are coming from the sedimentary rocks baked by the intrusion. The rocks are quartzites and shales transformed to albitite (Réti 1985). Radiometric investigations have shown that the whole rock gives the age of slight metamorphic overprint-85My, and selected minerals as Amphibole and Muscovite have indicated a more realistic 165My for the original age of the mafics (Árva-Sós et al, 1987). These minerals come from the exo- and the endo-contact zones. The latter age is in agreement with the data gained by the analysis of radiolarite pebbles in the host shale complex, and of black radiolarite layers near the mafic volcanites. These indicate Middle Jurassic age, extending to the higher part of the Middle Jurassic. It means that the age of the Szarvaskõ type mafic activity is most probably Middle Jurassic.

The chemical composition of the mafic rocks points to an ocean-floor tholeiite, but it is not a true ophiolite-member, rather a result of back-arc basin volcanism (Józsa 2000, Koller et al. 2001)

The whole magmatic-sedimentary series have undergone synschistose deformations as the autochtonous did. The traces of these deformations are well preserved in the sandstone-shale complex, and they can rarely be seen in the volcanic rocks as well.

This part of the Szarvaskõ sequence has suffered less metamorphic transformation as the rest of the mountain, but at some places it can reach the lower part of the anchizone.

Stop 2. Nagyvisnyó, Abandoned Quarry

The big quarry is located in Nagyvisnyó village, to the northwest of the railway station (Fig. 1.). It exposes Permian limestones belonging to the Bükk parautochthonous. It is in normal position, on the northern limb of a major anticline.

The classical section of the Bükk mountains exposes black, bituminous marine Permian limestones with rich fossil content. Especially algae as Mizzia or Gymnocodium, forams and ostracods are useful for fine stratigraphic correlation. Similar marine Uppewr Permian limestones are unknown in the near surroundings of the Bükk mountains, its closest counterparts outcrop in the Southern Alps and in the Dinarides. The well layered formation comprises medium thick, rigid, mostly micritic limestone banks and thin, black clay or marl interlayers. On the weathered surface of the limestone biogene debris like algal remains, molluscs, brachiopods, corals and forams can be seen. Bioturbation is also frequent. The marly layers are rich in forams. Microfacies of the rock is in great part mudstone and wackestone. Some ooid bearing grainstone beds and dolomitic mudstone layers also occur in the series.

The lower part of the Upper Permian calcareous series succeeds a lagoonal environment with variegated sandstones and clays, chlorite rich green shales with evaporites and thick, vuggy dolomites. In its upper part the bituminous limestone passes into thicker, brachiopod-rich marls. The cover of this Upper Permian formation is a well bedded oolithic limestone of Lower Triassic age. Some researchers demonstrate a hiatus between the Permian and the Triassic suite (Hips et al. 2004).

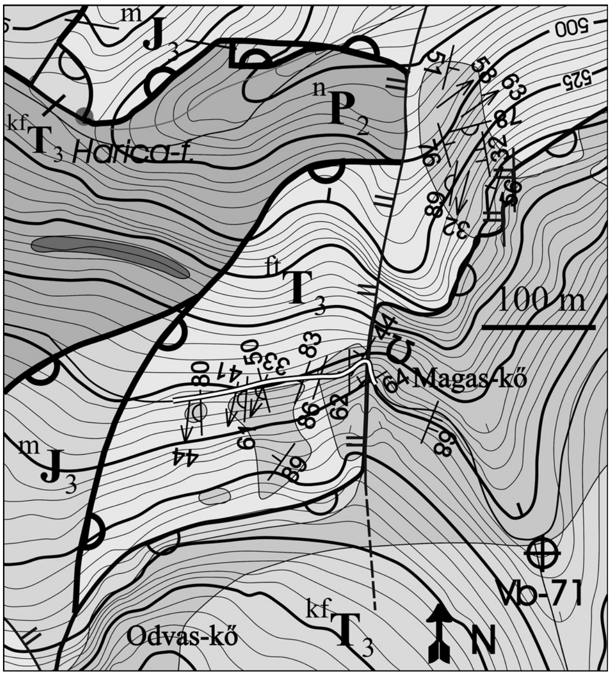
Nice late folds and an associated weak cleavage can be observed in the limestone layers and more pronouncedly in the marly layers. Smaller and more important faults, especially strike-slip ones are also observed in the quarry.

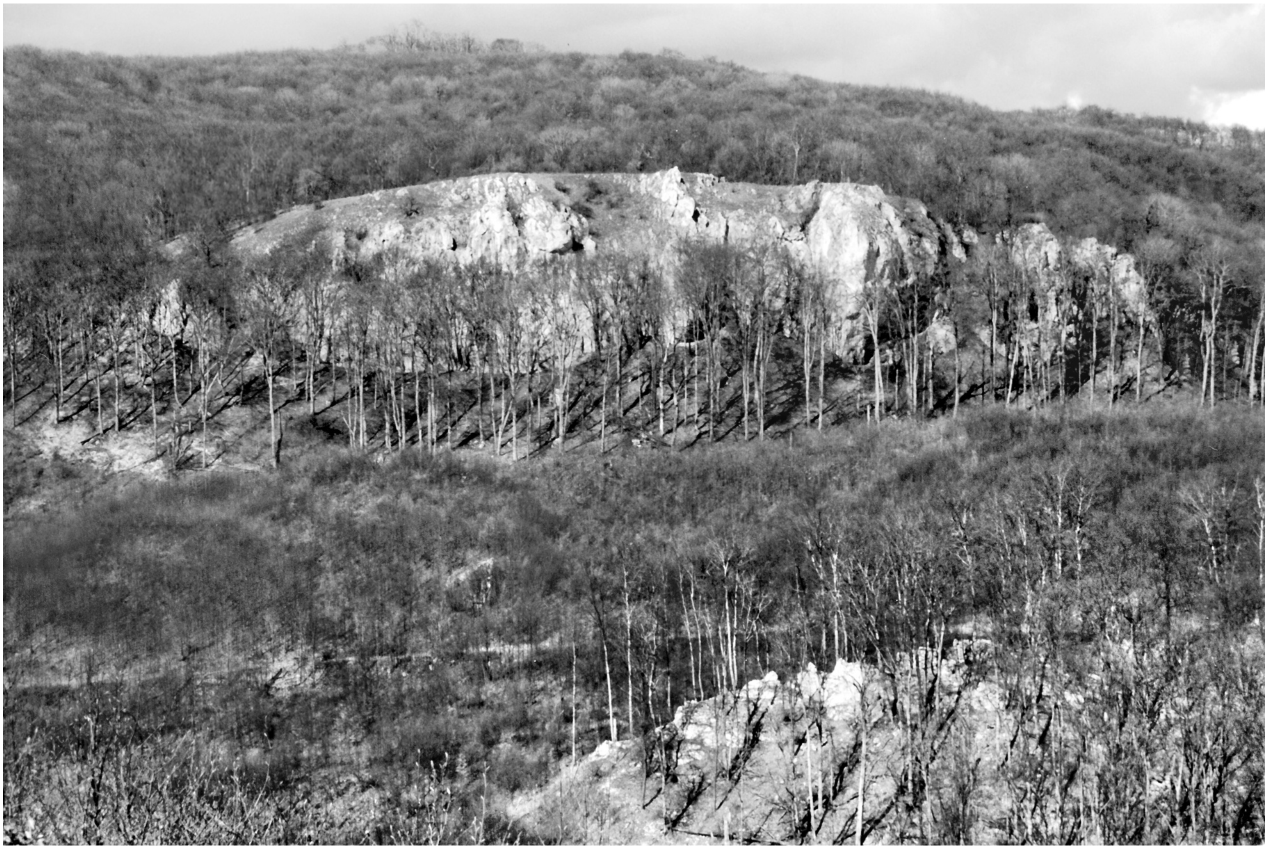
Unlike the rocks of the same formation in the Central Bükk Mountains, this exposure has undergone only diagenetic transformations.

Stop 3. Magas-kő, Roadcut

Roadside cliffs across the steep, northern slope of Magos-kő expose overthrusted and intensively folded cherty limestones of the Little High Plateau (Kis-fennsík). The plateau emerging in the NE part of the Bükk Mts. dips N beneath the Cenozoic cover, while the western and southern (Fig. 3.1), sharp edges are representing tectonic boundaries. These slices of Mesozoic Bükk parautochthonous type sequences of the Little High Plateau are thrust over the Northern Bükk Anticline. The road cut runs near to a complex, subvertical overthrust zone where poorly preserved Jurassic (?) shales and Upper Triassic limestones are placed over and beside Permian to Lower Triassic rocks (Fig. 3.2). Thrusting was accompained by the development of late-phase zig-zag folds parallel to the NNE-SSW strike of the tectonic zone. Lateral movements on cleavage plains are also observable.

■ **Fig. 3.1.** Southern edge of the Little High Plateau (Kis-fennsík), view from South. Lower cliffs are Carboniferous rocks in the core of the North Bükk Anticline, while upper cliffs are overthrusted Upper Triassic massive limestones.





■ **Fig. 3.2.** Geological map of the Magas-kő area (detail from Forián-Szabó and Csontos 2002) with the visited section in the middle. East of the complex overthrust boundary, outcrops of deformed cherty limestone ($^{ft}T_3$) can be studied, which is in tectonic contact with platform limestones ($^{kf}T_3$) towards E. This visible tectonic contact is possibly a younger overthrust plane with respect to those drilled by the borehole Vb-71 (SE corner of the map), where 175 m thick platform limestone lies on top of cherty limestone.

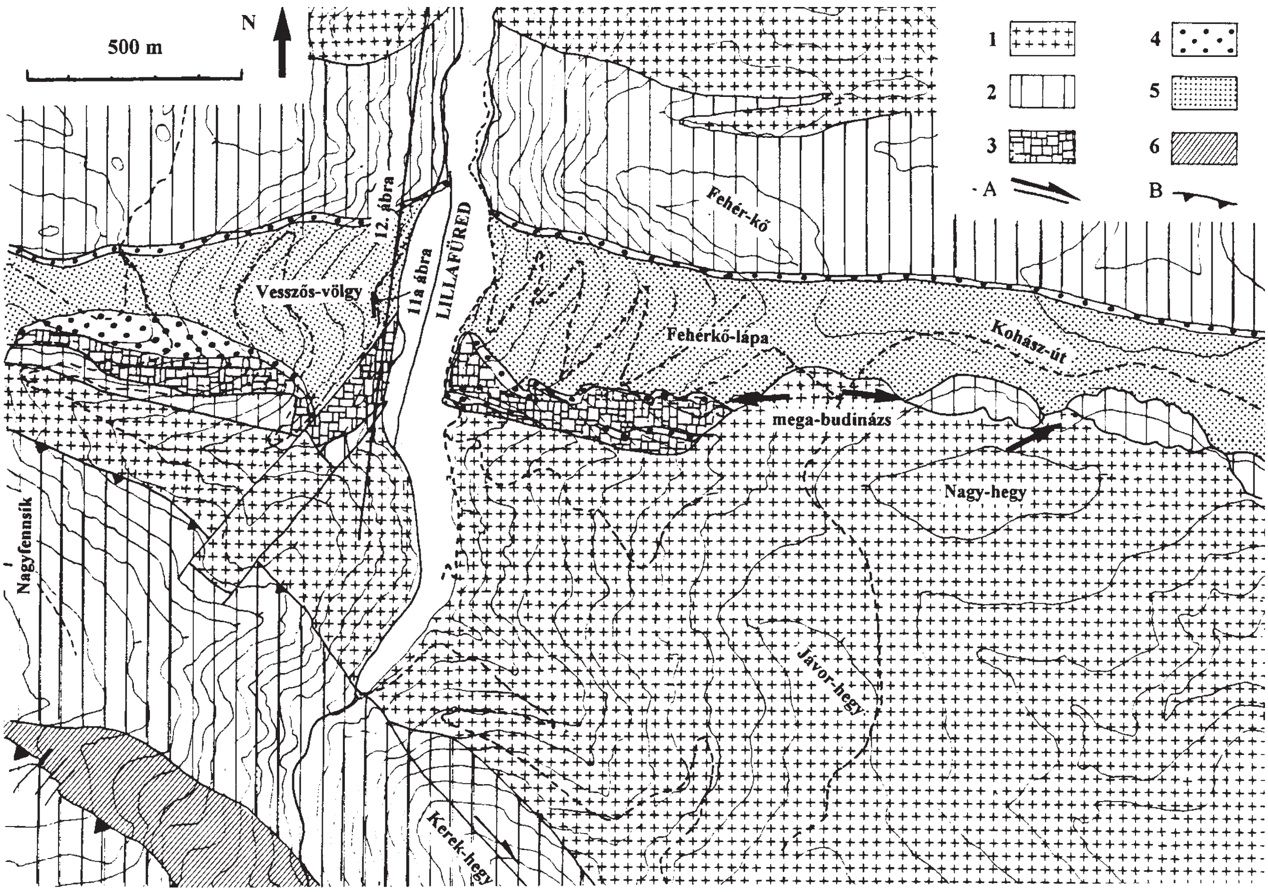
Stop 4. Lillafüred, Roadcut of the Main Road

The section is situated along the Eger-Lillafüred main road (Figs. 1, 4.1). The narrow valley offers excellent exposures of the Triassic sequence of the Fennsík parautochtonous. The strata are subvertical to overturned (Fig. 4.2). Because of strong internal deformation and folding, bedding is often difficult to observe. Only the southern limb of a large anticline will be visited.

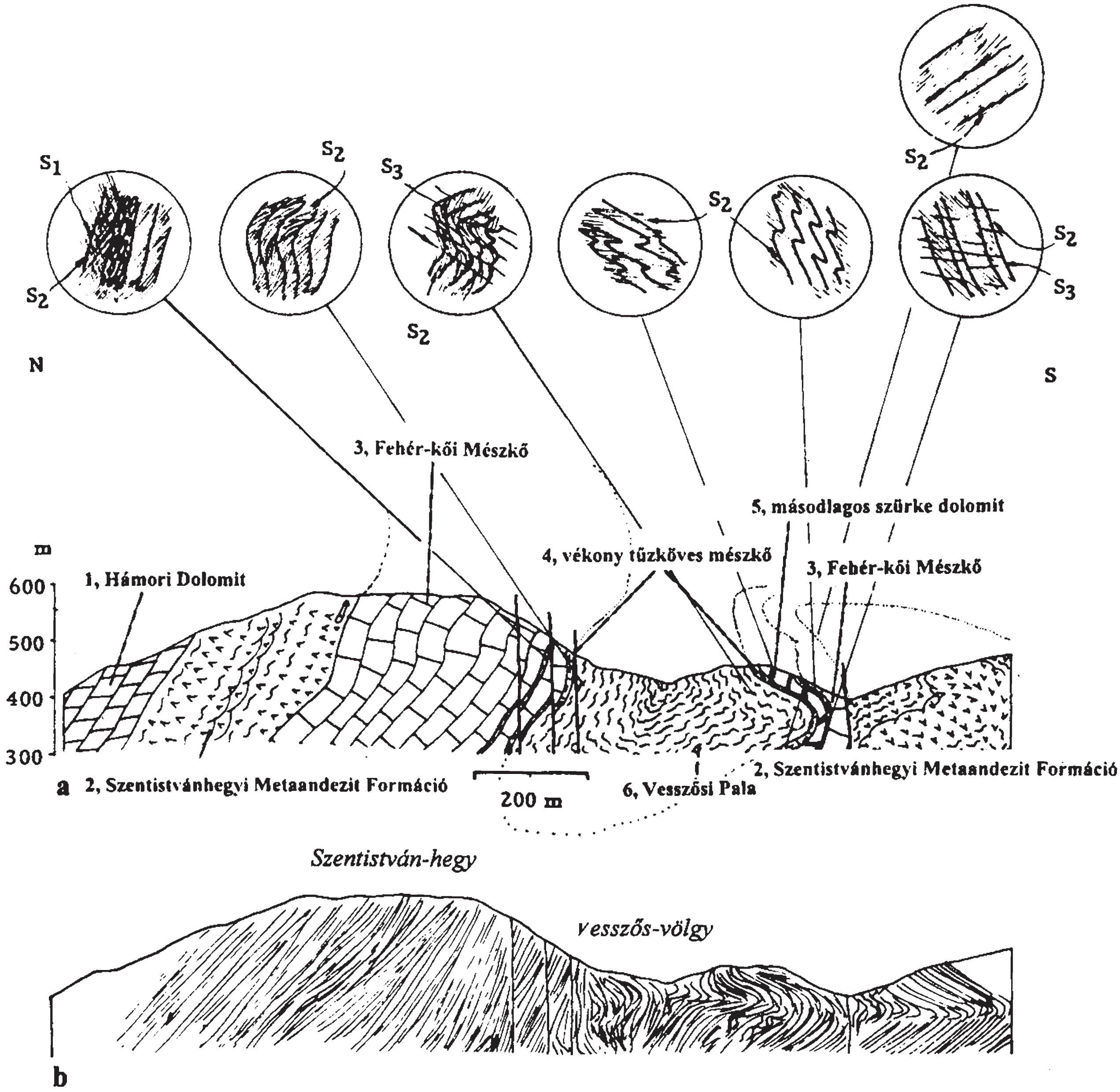
The first visited rock type constitutes a sharp crest opposite the hotel. The grey, dark grey limestone is thinly bedded and thin interbeds of dark marl are also observed. The limestone contains yellowish ooids or small intraclasts. This oolithic shallow water limestone contains Lower Triassic foraminifers.

The next formation, a black, slightly bituminous dolomite lies conformably over the oolithic limestone (Fig. 4.2). The rigid rock seldom contains laminae. Because of the strong deformation sedimentologic phenomena are not well preserved. The dolomite represents a uniform, more or less restricted carbonate platform environment. Some kms further, from the same rock-body, Anisian foraminifers were found.

At the forest railroad tunnel, the dark dolomites are followed by purple and green "porphyries", i.e. strongly altered and flattened volcanic rocks. Harder lavas and more ductile tuffitic material are recognizable. Rarely the volcanic rocks contain sedimentary interlayers or debris. Practically all the minerals are recrystallized, the most frequent ones being albite, chlorite calcite and quartz. The geochemical analysis made from the same rock body but from less altered material shows a calco-alkaline character and acid to neutral original composition. Radiometric dating on the metavolcanites has given the age of a metamorphic overprint or cooling (85–95 MY). The volcanic rocks are indirectly dated to be Upper Anisian-Lower Ladinian in a nearby parallel section. They represent the well known volcanic event of the Southern Alps and Dinarides.



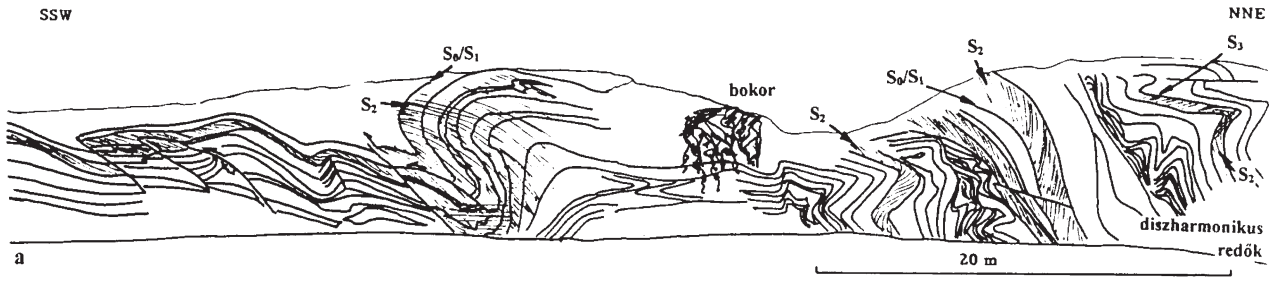
■ **Fig. 4.1.** Uncovered geological map of the surroundings of Lillafüred valley (from Csontos 1999). 1) Aniso-ladinian (Szentistvánhegy) metavolcanite. 2) Ladino-carnian (Fehérkő, Fennsíki) light limestone-marble. 3) Ladino-carnian(?)platform-carbonates transformed into grey dolomite. 4) Carnian(?) grey, thin-bedded cherty limestone. 5) Carnian (?) (Vesszős) shale. 6) Carnian (Szinva) metavolcanite. Arrows indicate map-scale boudins of platform-carbonates, embedded in more ductile material of shales and tufites. Mega-boudinage caused considerable layer-perpendicular flattening (and coeval E-W stretching) of the platform carbonates. The sequence affected by boudinage is held equivalent to the carbonates to the N (Fehérkő) and to the S (Fennsík; see also Figure 12).



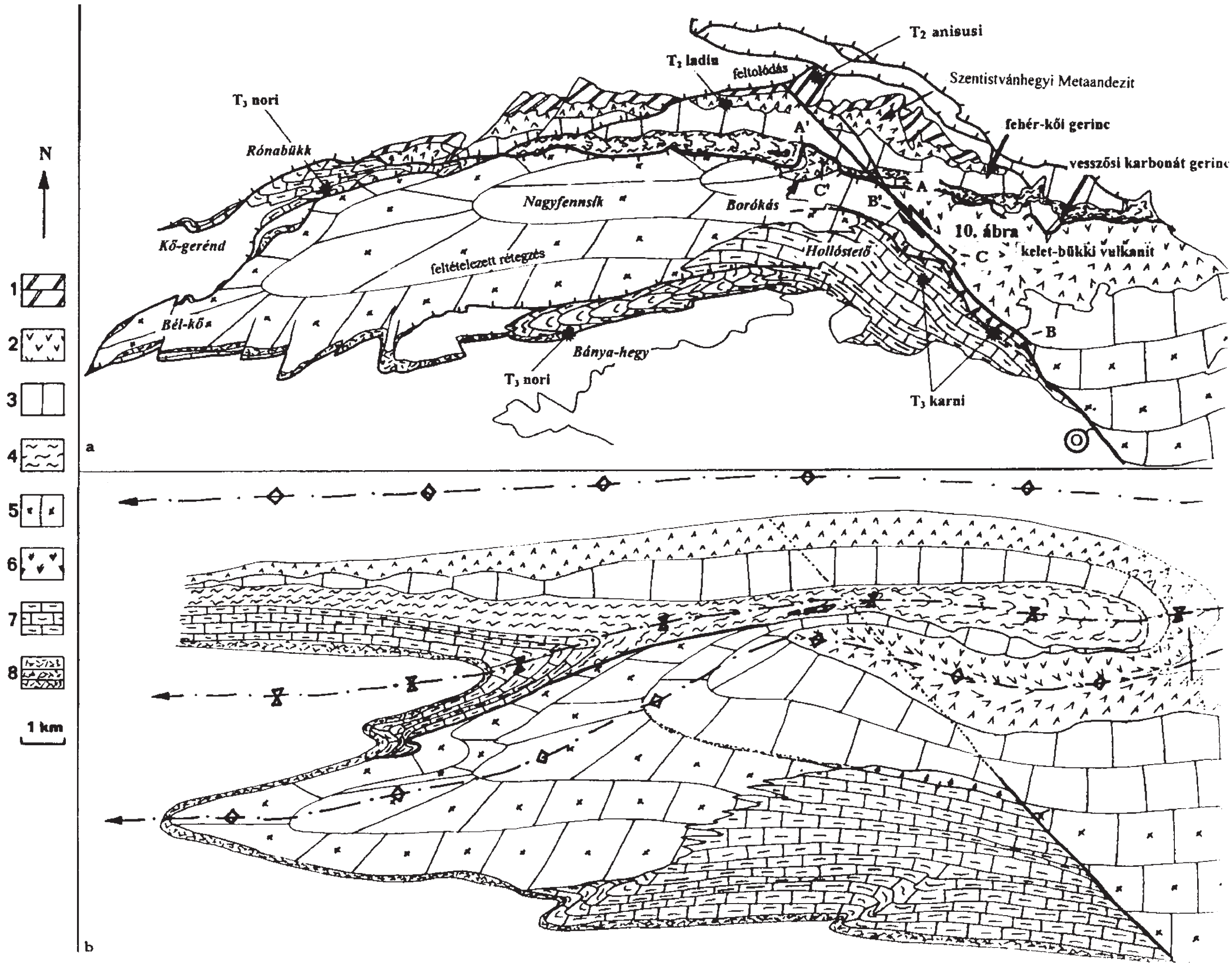
■ **Fig. 4.2.** Cross section of the Lillafüred-valley (from Csontos 1999).
a, Stratigraphic section. Lithologies: 1) Anisian (Hámor) dolomite. 2) Aniso-ladinian (Szentistvánhegy) metavolcanite. 3) Ladino-Carnian (Fehérkő, Fennsík) light limestone-marble. 4) Carnian (?) thin, grey cherty limestone. 5) Ladino-Carnian(?) secondary dolomite. 6) Carnian (?) (Vesszős) shale. Small circles indicate observed bedding/schistosity relations and outcrop-scale structures. Bedding is indicated by thicker lines. S1: first schistosity. S2: main schistosity. S3 weak cleavage.
b, Attitude of main schistosity (S_2), indicated by thin lines, in same section.

Strong elongation lineation is well observed in the rock. Two cleavages are also seen on Y-Z sections. Thin section study of X-Y sections indicates a very strong elongation parallel to lineation, with a mylonitic texture, but without well expressed shear markers.

The next member of the stratigraphic sequence is a whitish marble with small grey stripes. The marble seems to be unbedded, but in fact the thin bands are the remnants of the tidal flat loferitic laminae. The marble is recrystallized, at some places it contains flattened stromatactis structures and cylindrical fossil remains. In the upper part, pinkish, marly yellowish horizons of probable tuffitic origin occur. The uppermost part shows transition to darker grey, cherty, well bedded limestones and marls. The marbles and limestones have not yielded fossils yet. Analogies suggest that their age is Ladinian, may be Lowest Carnian. Boudinaged chert nodules suggest a very strong flattening parallel to bedding. Occasionally an oblique S2 cleavage can rotate these chert boudins. The relations of S0/S1 to S2 suggest an



■ **Fig. 4.3.** Post-schistosity folds (P_3) at the forest road-cut of Vesszős-valley (from Csontos 1999). The dysharmonic folds affect the main schistosity, too. Dysharmony is accommodated by local layer-parallel detachments or smaller thrusts cutting only few layers. S_0/S_1: layering; S_2: main schistosity; S_3: weak cleavage synchronous with dysharmonic folds.



■ **Fig. 4.4.** Reconstruction of the surroundings of Fennsík area (from Csontos 1999).

a, Gelogical sketch-map of present situation (only Middle Triassic-Lower Jurassic formations are indicated). 1) Anisian (Hámor) dolomite. 2) Aniso-ladinian (Szentistvánhegy) metavolcanite. 3) Ladino-carnian (Fehérkő) light limestone-marble. 4) Carnian (?) (Vesszős) shale. 5) Upper Triassic light (Fennsík) platform-limestones-marbles. 6) Carnian (Szinva) metavolcanite. 7) Carnian-norian (Hollóstető and Rónabükk) grey cherty limestone. 8) Liassic (?) redeposited series. Stars indicate the location of fauna, with determined ages. A, A', B, B', C, C' indicate offset points, which are reunited by reconstruction (Figure b). O: Bükkszentkereszt strike slip zone.

b, Original (reconstructed) situation representing an approximately Early Cretaceous situation. Antiforms and synforms are indicated by conventional symbols.

overturned limb of a major south-vergent anticline (Fig. 4.2). On the opposite hill-side major boudins of hectometric size can be mapped. These also show a strong flattening and E-W elongation of the limestone layer (Fig. 4.1). The rocks of the visited section have undergone the highest metamorphic transformation in the Bükk mountains: all of them reach the higher part of the anchizone, may be even the lower epizone (Árkai 1983).

The contact of the limestone with the following black shales to the south is uncertain, but mapping suggests that they had an original stratigraphic contact. The shale consists of greenish grey siltstone and fine sandstone, with black, bituminous laminated limestone intercalations and some tuffitic horizons. The shaly matrix frequently contains pyrite. The limestone intercalations often constitute thicker horizons with several medium thick layers. The shales have not been dated here, but a very similar lithological unit has a Norian cover composed of dark, well bedded, cherty limestones dated with conodonts (Kovács, pers. comm.). Higher up along the forest road a more carbonate-rich shale is found. The outcrops show polyphase folding: syn-S2 cleavage P2 folds are distorted by later P3 folds (Fig. 4.3). These latter are more rigid and may have crenulation cleavage and small thrust faults at their core. Mapping and structural analysis suggest that the black Carnian shales constitute the core of a syncline, which is created by P2 folding and re-deformed by P3 folding (Fig. 4.2).

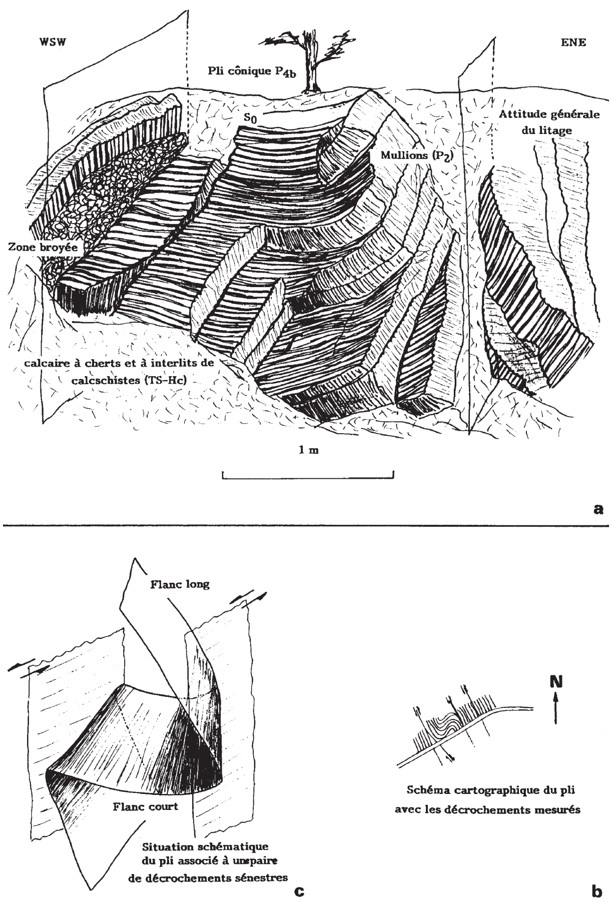
Continuing higher along the forest road we reach a thin carbonate bar of complex composition (Figs. 4.1, 4.2). The very deformed, reduced section contains grey, pink recrystallized dolomite, white micritic recrystallized limestone with yellowish and shaly interlayers and grey, sometimes cherty limestone. It is suggested that this carbonate bar is the stratigraphic equivalent of the much thicker white limestones of the main valley section. In this view the carbonate bar would be located on the southern limb of the major aforementioned syncline. This suggestion is corroborated by the presence of sheared volcanic rocks to the south. The thin carbonate bar is followed over a long distance as a sheared and elongated, thus tectonically reduced body, which may be joined to the main white limestone body of the High Plateau (Fennsík) (Fig. 4.4).

Stop 5. Hollostető, Roadside Cliff

All along the main road between Eger and Miskolc (Fig.1), we find nice exposures of dark, sometimes bituminous, cherty limestones. The visited outcrop shows lithological and structural characteristics of the Hollóstető cherty limestone formation, making part of the Fennsík parautochthonous suite. As the whole massif, this section has also suffered weak metamorphic transformations, although these are not so obvious in the visited outcrop.

The formation consists of medium-thick beds of dark grey limestone with thinner, dark, yellow intercalations of shale, marl or sandstone. The limestone layers sporadically contain yellowish grey chert layers or chert nodule horizons, which are parallel to bedding. The limestone has considerable detritic content: sand grains are often observed as yellowish dots in the grey, micritic matrix.

The cherty limestone lies over a volcano-detrital complex containing neutral-mafic lavas, pyroclastics and intermixed sedimentary material: crinoidal limestones and shales. Laterally they pass to High Plateau-type light grey limestones. Their uncertain cover is red radiolarite of supposed Upper Jurassic age. The cherty limestone seldom contains green, mafic metavolcanites or intrusives. These occur only in small lenses. The facies of the limestones is not uniform: e.g. some dark, dolomitic lenses and layers are also found at its base. These show strong



■ **Fig. 5.1**. **a**, View of the conical fold of Hollóstető (after Csontos 1988). The originally cleaved, folded rock is affected by mullions, exposed as rods of carbonate in the soft marly matrix. **b**, Map sketch. c, 3D view boudinage and layer-parallel elongation. Some brown sandstone lenses are also observed at diverse sites within the formation.

Apart from some rare sections of thin-shelled macrofossils, only conodonts have been found so far in the cherty limestone formation. The samples coming from a couple of hundreds of metres from the visited outcrop yielded Lower Carnian conodonts.

The whole formation is folded and cleaved (Fig. 5.1). The steeply dipping penetrative S2 axial plane cleavage is well seen in the marly interlayers, but also in the calcareous layers. Synschistose folding is indicated by the mullions, which are well developed in the whole section. Mullion thickness is dependent on the thickness of the marly interlayers. The mullions are at their turn folded by a major chevron fold seen at the outcrop (Fig. 5.1). This conical fold of steep axis was most probably generated as a drag-fold in a strike-slip zone. Brittle faults of similar nature are also very abundant in the section.

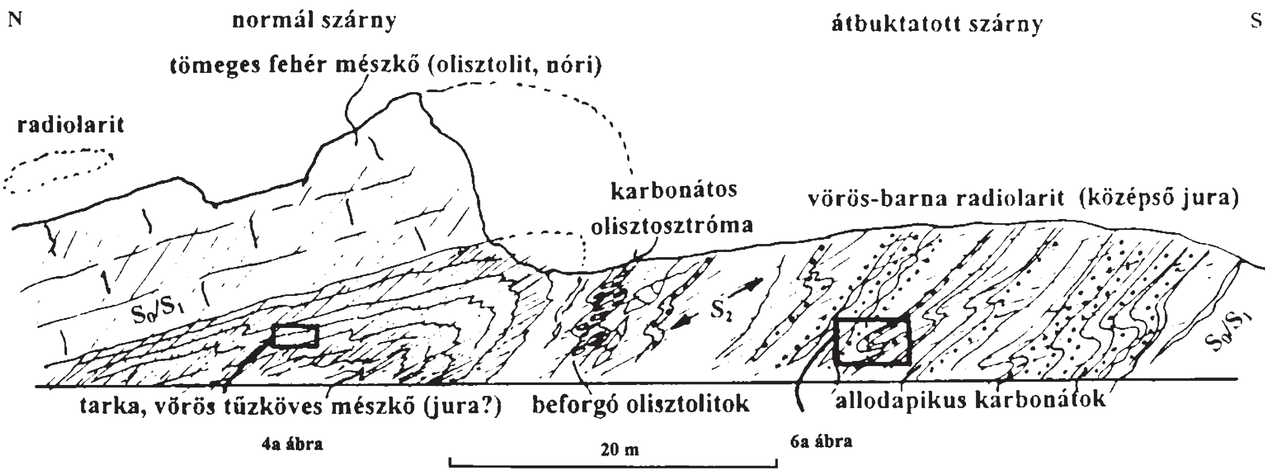
Stop 6. Bányahegy, Type Section along the Roadcut

The cleaned outcrop is situated along the Eger-Miskolc main road, at the vicinity of the Kiskõhát road-fork (Fig. 1). It shows a complicated series of the parautochthonous, containing red, yellow, violet crinoid limestones containing olistoliths, and red shales, red and yellow radiolarites. Because of intense deformations, the relations between the rock types are subject to debates. The outcrop can be divided in two more or less distinct parts (Fig. 6.1).

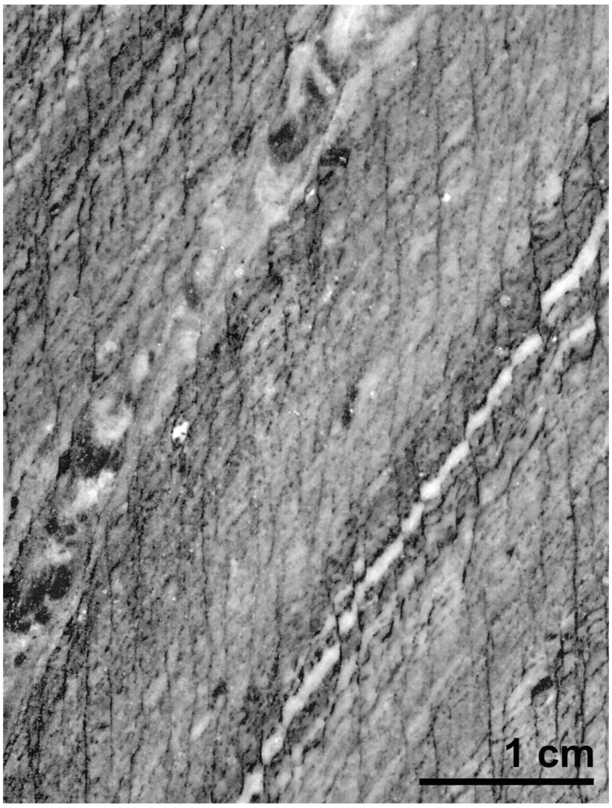
At the northern side of the outcrop one can see a thinly layered, varicoloured limestone-calcschist sequence, containing crinoid ossicles and some red chert layers and nodules. It contains smaller or larger lenses of whitish, ligth grey limestone/marble. The biggest lens is sitting as a cliff on top of the variegated calcschist. The contact between the two rock types is sedimentary. A very gentle unconformity is observed without any trace of cataclastic or mylonitic deformation zone. The whitish cliff is an isolated body containing rich fauna. In spite of deformation suffered by this lens too, some parts yielded reef fauna of Norian age (Riedel et al, 1988): Sponges, corals were identified. Some molluscs, brachiopods, algae can also be seen.

Nice S2 axial plane cleavage and transposition surfaces parallel to apparent bedding and bedding-parallel S1 cleavage are well observed in this part of the outcrop (Fig. 6.2). Both varicoloured calcschist and the major olistolith are affected by these two penetrative cleavages. In the northern part of the outcrop a strong asymmetric, layer-parallel boudinage is observed in red chert nodules (Fig. 6.3). Both X-Y and Y-Z sections show very strong flattening and elongation. In Y-Z sections top-tothe-south shear can be identified. Perpendicular sections do not show uniform shear. The lens-like appearance of smaller olistoliths is also partly due to boudinage and ductile parasitic folding.

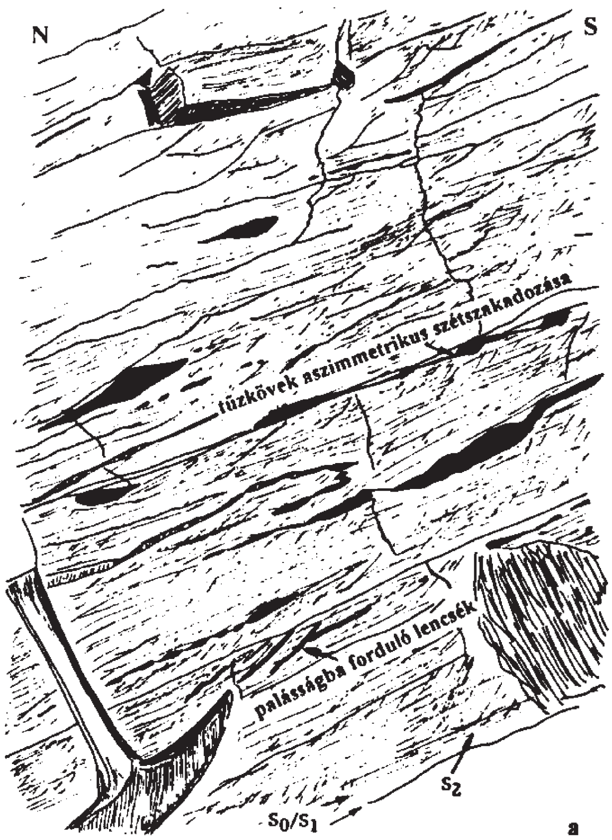
Relations of S0/S1 to S2 suggests normal limb of a major fold, hence calcschists are in the lower part of the stratigraphic section, and the big olistolith is above. At the car parking a red radiolarite cover of the olistolith was mapped. The anticlinal hinge can be found by using bedding/schistosity relationships. Red chert layers best represent beddingand schistosity is the dominant surface. The hinge is found at the southern termination of the variegated calcschist exposure (Fig. 6.1).



■ **Fig. 6.1.** Sketch of the Bányahegy key-section. Litologies: the core of the antiform in the northern half is composed of variegated, mainly red, pink micrite with red chert layers and nodules. The overlaying cliff is a massive, light-grey limestone with shallow-water fossiles. The southern half of the exposure is dominated by red, brown, occasionally green radiolarite with grey allodapic limestone beds, occasionally olistostromes. All these rocks are boudinaged and folded. S_0/S_1: layering and parallel schistosity; S_2: main schistosity. Inserts indicate location of details in later figures.



■ **Fig. 6.2.** Bedding parallel cleavage overprinted by a second cleavage in laminated marly limestone and chert (polished surface, Bánya Hill road cut, normal limb)



■ **Fig. 6.3.** Detail of the Bányahegy key-section (normal limb, see Figure 3). At the centre of the picture the layer-parallel red chert nodules-seams are asymmetrically boudinaged, indicating southwards directed shear. Layering has a silky shine because of oriented phyllosilicates. Main schistosity transposes some dissected chert nodules parallel to itself (near hammer). Hammer for scale.

The second, southern part of the exposure begins where calcschists end. Here reddish shale makes up a thin, steeper zone. A smaller thrust between the calcschists and the red shale was supposed, but when completely cleaned, the exposure did not show that. On the contrary, the red shale seems to follow the calcschists by a steeply north dipping, folded surface. The shale contains various limestone lenses and at least one thick layer of olistostrome. The material of this is composed of various limestone lenses. These lenses are transposed along S2 foliation. Parasitic folds and bedding/cleavage relations suggest overturned limb. An elongation lineation is subparallel to P2 fold axes. X-Y sections show also strongly flattened limestone lenses. These show asymmetric boudinage with top to E transport. When reconstructed from the reversed limb, this shear becomes top-to-west.

The red shales quickly and gradually pass to a red, green, well-layered radiolarite. This consists of centimetric lenses of highly siliceous material derived from radiolarian shells, with mm thin clayey-shaley interlayers. The radiolarites themselves also contain limestone olistoliths of diverse nature and allodapic limestone beds (crinoid limestone). Parasitic folds and bedding/cleavage relationships suggest that this rock is also found on the overturned limb of the anticline. The red radiolarites pass to yellow, brown or greenish radiolarites with frequent grey, allodapic limestone lenses. Some of the layers are folded; these are tectonic and not sedimentary folds. The layers of the yellow radiolarite are also thin, well seen because of clayey interlayers. The slight grading of some allodapic beds-together with structural data-indicates overturned limb of an anticline. Kinking and en echelon tension gashes also affect the highly cleaved material.

As a structural summary there is a major fold with normal (northern) and reversed (southern) limbs at the exposure. However, the two limbs do not show exactly the same stratigraphy. The big olistolith is missing on the reversed limb, while the olistostrome in shaley matrix is missing (or unfound) on the normal limb. This discrepancy might be explained by the same stratigraphic position of the big olistolith and the olistostrome. In other words the big olistolith is missing, because the original boulder ended and was laterally replaced by equivalent, smaller clasts of the same gravity flow. Since the bigger olistolith was more rigid than the olistostrome, it might have helped to preserve original flattening structures at the normal limb, moreover, it might have controlled the location of the anticline hinge.

The radiolarites are followed by black shales (Fig. 6.1). In other sections with better exposure, these are the equivalents of the roofing shales of the Lök valley (next stop). Because of the very strong poliphase deformation and silicification, no radiolarians are retrieved from the radiolarites themselves. Some badly preserved, very probably Jurassic radiolarians were found in the red shales (Csontos et al, 1991). The same red radiolarite horizon in the same lithological context was found to be Kallovian-Oxfordian at several other sites of the Bükk Mountains. Therefore we infer a similar age for these radiolarites as well.

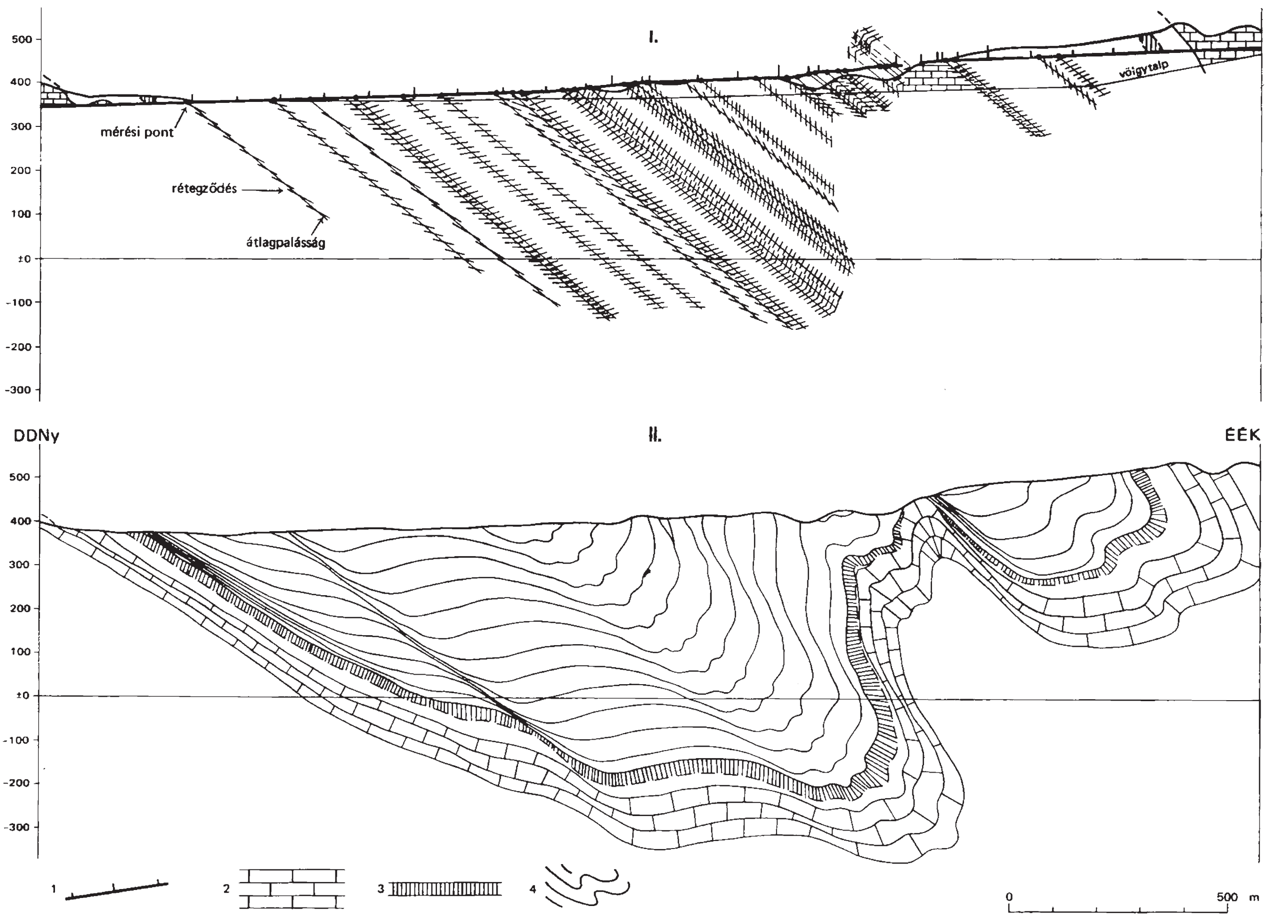
Because of the practically gradual transition from the variegated calcschists to the radiolarites and because of their very similar characteristics (e. g. presence of olistoliths of similar nature) we suppose a late Middle Jurassic age for the limestone series. Although the sequence might be condensed, it is not very probable that the same unstable passive margin was persisting from the Upper Triassic until the Upper Jurassic.

Stop 7. Lök-völgy, Roadcut

The outcrop is a cleaned roadcut of the Eger-Miskolc main road, just opposite the 15 km mark (Fig. 1). Thinly foliated black shales of the Bükk parautochthonous, previously used as roofing shales, can be observed in this exposure.

The shales are thinly bedded and consist of the alternation of fine, often graded sandstone layers and black-grey siltstone beds. These are impregnated by fluids in different manner, which causes slight colour changes. The sandstone beds are made of quartz, illite, chlorite and small amount of plagioclase. The texture of the shale is strongly oriented. In some layers radiolarians or their fragments are also found.

At the middle of the outcrop, several small conglomerate lenses can be seen. The material of the often non-rounded pebbles is essentially radiolarite, but shale and minor limestone



■ Fig. 7.1. Cross section along the Lök valley (from Balla et al. 1987). Measurements of bedding were performed perpendicular to bedding/cleavage intersection lineation. Bedding data were projected on the cleavage. Fold was constructed supposing a similar form. a, measurements; b, section. 1, road with measuring points. 2, Triassic/Jurassic carbonates; 3, red radiolarite; 4, black Lök valley shales.

pebbles also occur. In agreement with bedding/cleavage criteria, grading shows a southern younging. The deposition took place in a distal turbidite fan.

In spite of the rich fossil content, no determinable radiolarians could be freed from the rock. The equivalent of the conglomerates has yielded Middle Jurassic radiolarians elsewhere in the mountain. That age is only approximative, since it dates the pebbles, not the matrix. The black roofing shales always form the cover of the red radiolarite horizon of the parautochthonous, which is dated to be Kallovian-Oxfordian (Csontos et al. 1991b). Hence the shales can only be younger than that age. Their Lower Cretaceous age can not be excluded, but no fossils indicating that age were found so far.

The shales are strongly cleaved: at least two, may be three foliations can be observed. The most apparent cleavage is the second one. It is an axial plane cleavage to big, tight folds. These may be reconstructed using a special measurement method (Balla et al. 1987). A major syncline is reconstructed from these data (Fig. 7.1).

Normal and reverse shears can also be seen in the outcrop. The black shale mass has undergone anchimetamorphic transformations, with synchronous or later silicification. This latter gives the rock the sufficient resistance for roofing application.

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