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Neogene and Quaternary development of the Turiec Basin and landscape in its catchment: a tentative mass balance model

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Abstract: The development of the Turiec Basin and landscape evolution in its catchment has been reconstructed by methods of geological research (structural geology, sedimentology, paleoecology, and geochronological data) as well as by geophysics and geomorphology. The basin and its surrounding mountains were a subject of a mass balance study during periods of tectonic activity, accompanied by considerable altitudinal differentiation of relief and also during quiet periods, characterized by a development of planation surfaces in the mountains. The coarse clastic alluvial fans deposited beneath the offshore pelitic sediments document the rapid Middle Miocene uplift of mountains on the margin of the Turiec Basin. The Late Miocene fine-grained sedimentation represents the main fill of this basin and its origin was associated with the formation of planation surfaces in the surrounding mountains. The rapid uplift of the western and northern parts of the catchment area during the latest Miocene and Early Pliocene times further generated the deposition of coarse-grained alluvial fans. The Late Pliocene basin inversion, due to uplift of the whole Western Carpathians mountain chain, was associated with the formation of the Early Quaternary pediment and ultimately with the formation of the Turiec river terrace systems.

Key words: Quaternary, Neogene, Western Carpathians, Turiec Basin, landforms development, basin analysis, mass balance.

Introduction

The Turiec Basin (TB) is located in the interior of the Central Western Carpathians extending in the NNE–SSW direction. It is about 40 km long and 10 km wide (Fig. 1). Its northern margin is formed by the Krivánska Malá Fatra Mts which is predominantly composed of the Variscan crystalline basement of the Tatric Unit. The western flank of the basin is part of the Lúčanská Malá Fatra Mts and the eastern flank is in the Veľká Fatra Mts. Both these are composed of Mesozoic complexes of the Fatric or Hronic nappes and the Variscan crystalline complex of the Tatric Unit. The Tatric crystalline basement of the Žiar Mts and the volcano-sedimentary complex of the Kremnické vrchy Mts restrict the basin to the south (Fig. 2).

The well-preserved outcrops, boreholes, and geophysical data offered a unique opportunity to study the development of this basin and surrounding mountains in relationship to tectonic evolution. Climatic changes and tectonic pulses strongly influenced landscape evolution, and this is clearly visible in the evolution of landforms. Therefore, the concept of mass balance for periods of tectonic activity and quiet periods of planation surface development, together with analysis of the basin sedimentary record and structural history is presented in the following text.

Methods

To understand the geodynamic development of the TB and its catchment, all existing geological, geophysical, and geomorphological data were used in conjunction with new research carried out by the following methods: (1) geological and geomorphological mapping, (2) sedimentology and paleoenvironmental study with sequence stratigraphy, facies, and pebble analysis, and (3) biostratigraphy and paleoecology. Additionally, (4) structural geology focused on fault slip analysis, paleostress reconstruction, fission track thermochronology data, geophysical research, morphostructural analysis of tectonically induced landforms, fault scarp and faceted slope analysis, analysis of the longitudinal profile of valleys, mountain front sinuosity, valley floor to valley height ratio, the valley cross-section ratio and analysis of valley textures, and (5) remote sensing based on the analysis of aerial photo stereopairs and of Landsat TM and Spot Panchromatic satellite scenes were also utilized.

The mass balance model of the TB catchment area was interpreted on the basis of the relationship between accumulation and denudation and on landform properties. The accumulation was computed from the maximum recorded or expected thickness of sediments within a chosen time span.

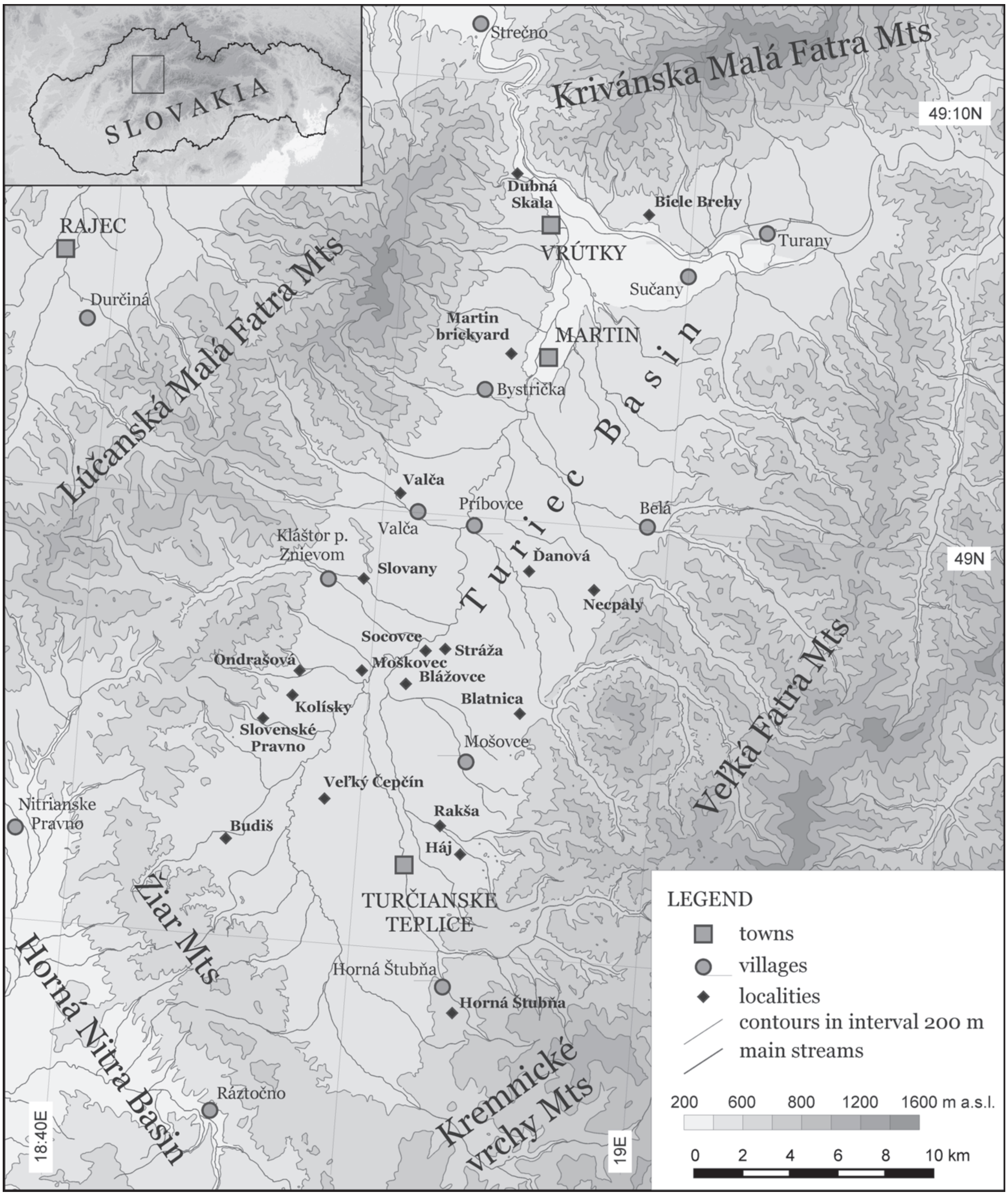

Fig. 1. Geographical position of the Turiec Basin with localization of the main outcrops and studied sites.

The expected sediment thickness was obtained by analogy from the surrounding regions and by considering regional gradients of depositions. The denudation rate was determined on the basis of: (1) Apatite fission track (AFT) ages at 120 °C and AFT thermal modelling results at 60 °C. Time and space changes in the thermal gradient, with a basic gradient of ~30 °C·km$^{-1,}$ due to Neogene volcanic activity were also considered; (2) Altitudinal differences of the flattened surfaces and river terraces of various ages indicated the amount of denudation between their formations; (3) The relationship between tectonic uplift, landforms and the denudation rate. Tectonic uplift and paleorelief was estimated on the basis of paleogeographical reconstructions, on the "grain size" of clastic sediments and on morphotectonic markers. The tectonic uplift provided higher relief suitable for rapid denudation, and dependencies between relief rock resistance and the denudation rate were also considered (Gunnell 1998).

Turiec Basin

The Turiec Basin is a westward dipping halfgraben with sedimentary fill attaining thicknesses up to 1200 m (Killenyi & Šefara 1989). This basin has two main depocentres, one

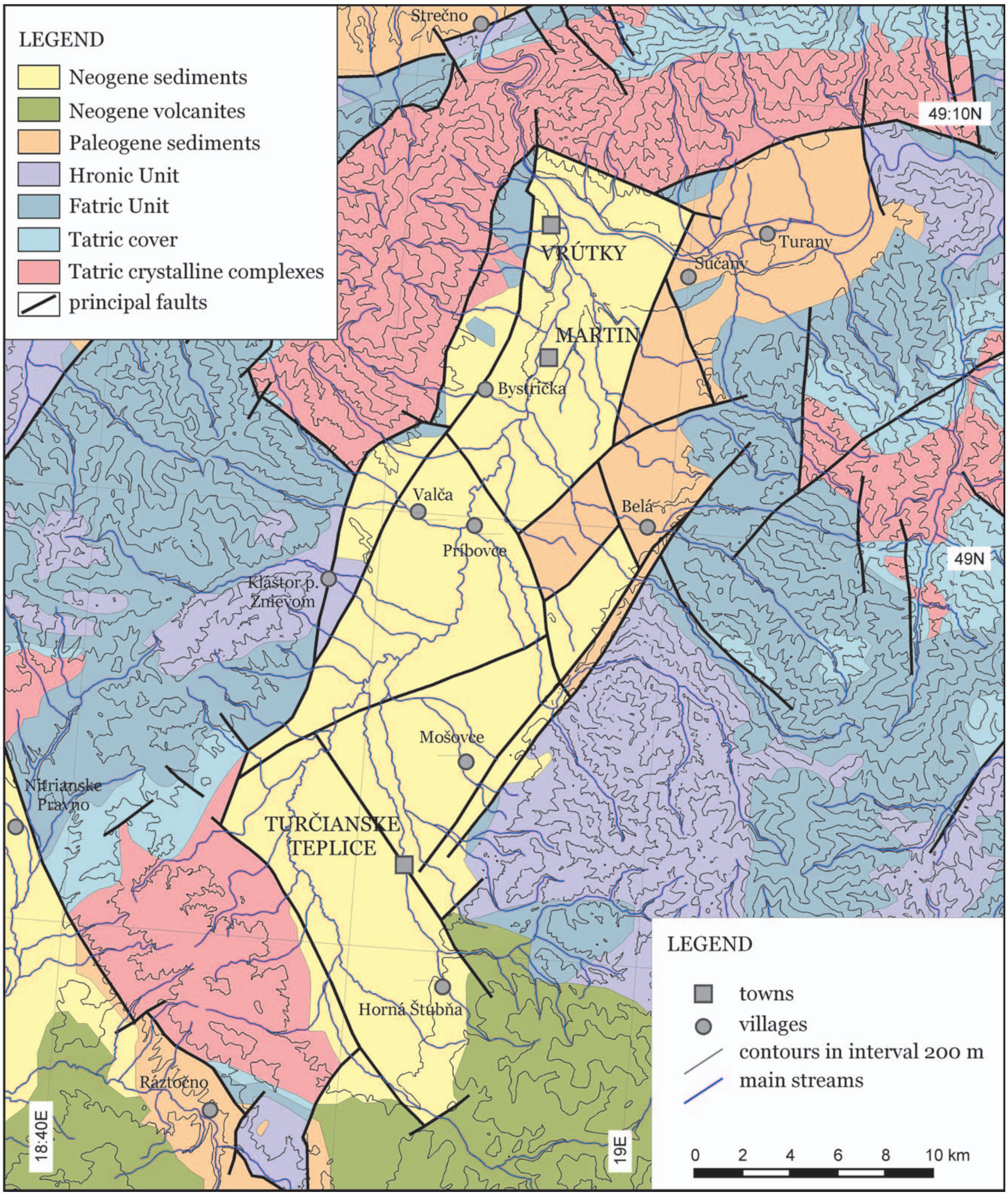

Fig. 2. Schematic geological map of the Turiec Basin catchment area.

located in the northern part (BJ-2 and ZGT-3 boreholes, Fendek et al. 1990; Gašparik et al. 1995) and the other in the southern part (GHŠ-1 borehole, Gašparik et al. 1974). The sites of these depocentres and the position of the pre-Neogene basement were documented in the first attempt to do 3D inverse gravimetric modelling (Bielik et al. 2009), (Fig. 3).

The pre-Neogene basement of this basin consists of the Central Western Carpathian paleo-Alpine tectonic units which mainly comprise Mesozoic complexes, and also from Paleogene post-nappe sedimentary cover in its northern part.

The TB fill is predominantly composed of Upper Miocene sediments with an occurrence of the Middle Miocene deposits mainly in the south. The main subsidence of the basin first appeared during the Late Miocene and this was followed by terminal sedimentation during the Pliocene.

Paleogeography and the paleoenvironment

The TB displays all the features of a long term isolated lake within the Western Carpathian mountain chain. Although this was substantiated by the endemic fauna existing from the late Middle Miocene to Pliocene (Pokorný 1954; Sitár 1966; Gašparik et al. 1974; Brestenská 1977; Pipík 2000, 2001), on the basis of new ostracod assemblage stud-

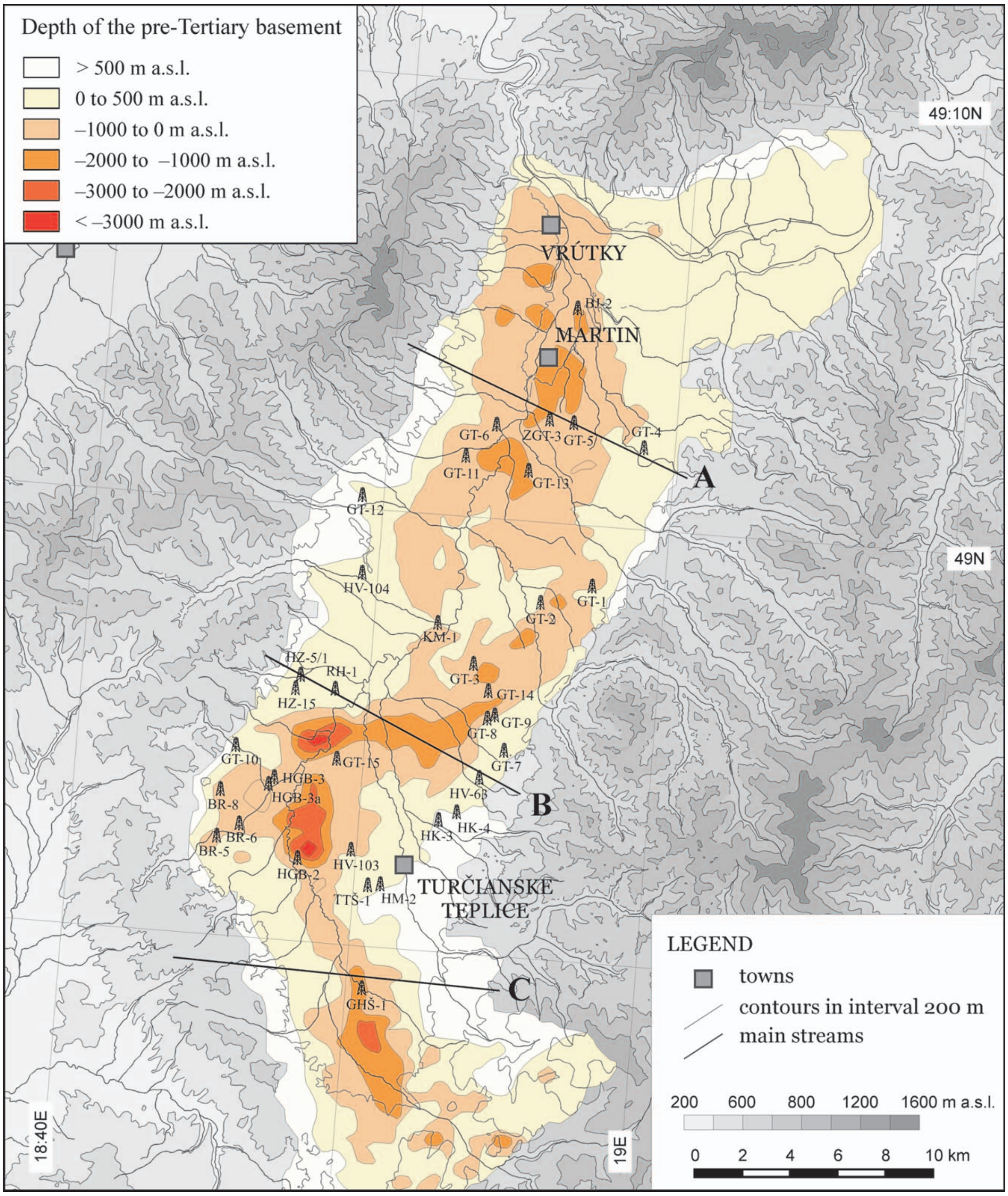

Fig. 3. First attempt to do 3D inverse gravimetric modelling of the depth of pre-Tertiary basement and location of depocentres of the Turiec Basin (after Bielik et al. 2009).

ies, the main part of the fill was deposited during the Late Miocene (Pipík et al. in print).

The abundant and diversified endemic fauna and flora of the former Lake Turiec, such as pollens, macroflora, ostracods, gastropods, bivalves, fish otoliths, and sponges of the family Spongillidae, document a geographically and biologically well-structured terrestrial and aquatic ecosystem. The lake was bathymetrically divided into a littoral zone in the north and a deep water zone in the south. The water was thermally stratified with a deep water environment below thermocline occurring only in the central and southern parts of the basin (Pipík 2001; Pipík et al. in print). The hydrological regime can be defined by the main input of water(s) from the north, by river(s) drifting fine-grained clayey sediments which were occasionally mixed with silt, sand, and fine-grained gravel. A temporary aquatic environment, where the salt content could increase in warm periods, formed on the lake shores and further inland (Pipík et al. in print).

The nearest terrestrial environment around Lake Turiec corresponded to an alluvial plain with marshy biotopes (*Vestalenula*, *Nelumbium*, and *Myrica*). A forest was formed near the shore (*Alnus*, *Populus*) with a wet habitat (*Carychium*, *Succinea*, *Goniodiscus*, and *Vertigo*) but this changed to a hilly landward landscape (*Fagus* and *Carpinus*) covered by forest (Pokorný 1954; Němejc 1957; Rakús 1958; Sitár 1966, 1969; Ondrejičková 1974).

Paleoecological and morphological study of the TB ostracods distinguished at least three stratigraphical associations in the sedimentary fill (Fig. 4). The oldest, poorly diversified assemblage composed of *Darwinula stevensoni*, *Candona*, *Cypria*, *Mediocypris* and *Leptocythere*, is located below a rhyolite tuff horizon of the Jastrabá Formation at a depth of approximately 700 m below the surface and comes from cores of ZGT-3 and BJ-2. This assemblage is regarded as Sarmatian (late Langhian) and occurred in sediments of the Middle Miocene initial rifting stage in a slightly haline lake environment.

The second well-diversified Early to Middle Pannonian association appears within the overlying strata. This was deposited during the basin synrift phase and it documents a change of the water environments to an isolated freshwater, ecologically and bathymetrically differentiated lake. This is indicated by the large number of endemics, the spatial distribution of ostracods, the shapes of the

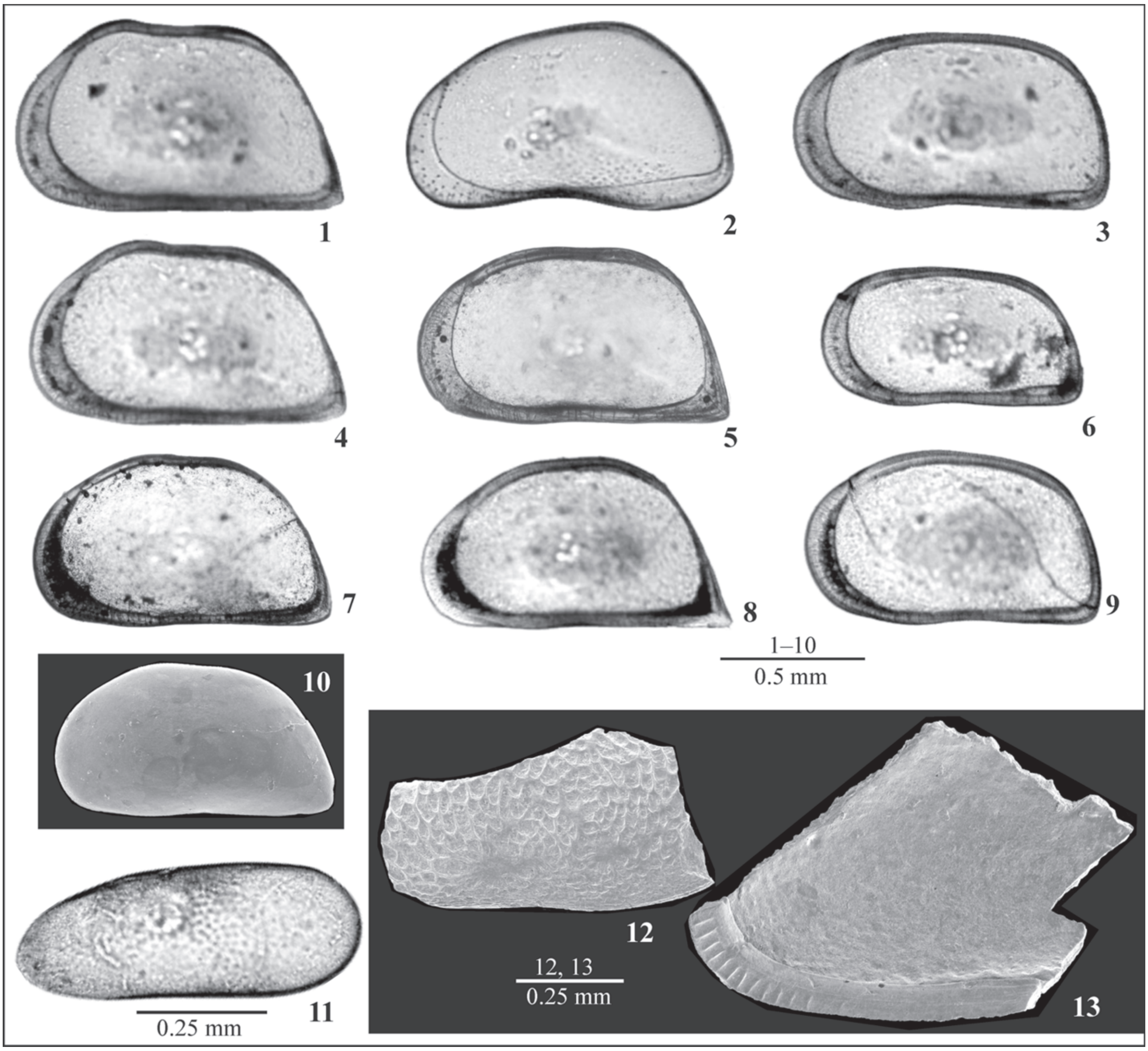

Fig. 4. Ostracod assemblages of the Turiec Basin evolutionary stages. **1–6** — Ostracods of the high stand of the lake water level; 1 — *Candona sitari* Pipík & Bodergat, 2007; 2 — *Candona clivosa* Fuhrmann, 1991; 3 — *Candona lacustris* Pipík & Bodergat, 2006; 4 — *Candona ossea* Pipík & Bodergat, 2007; 5 — *Candona aculeata* Pipík & Bodergat, 2007; 6 — *Candona palustris* Pipík & Bodergat, 2006. **7–10** — Ostracods of the synrift stage; 7 — *Candona nubila* Pipík & Bodergat, 2007; 8 — *Candona subaculeata* Pipík & Bodergat, 2007; 9 — *Candona stagnosa* Pipík & Bodergat, 2006; 10 — *Candona simplaria* Pipík & Bodergat, 2007. **11–13** — Ostracods of the basin initial rifting stage; 11 — *Darwinula stevensoni* (Brady & Robertson, 1870); 12 — *Mediocypris* sp. 1; fragment of the valve in external lateral view; 13 — *Mediocypris* sp. 1; fragment of the valve in internal lateral view. Note, that taxa 2 and 11 have a large stratigraphical span and high ecological tolerance and they can also be found in other stages of the Turiec Basin evolution.

Candoninae, and the isotopic signatures of $^{87}Sr/^{86}Sr$ (Pipík et al. in print).

The third very rich ostracod association in the upper part of the basin fill documents a long-term biogeographic isolation and evolution of endemic fauna. Sediments here can be regarded as deposits from high stands of lake water levels (Pipík & Bodergat 2006, 2007). By the end of this evolutionary stage, when the accommodation space of lake was exhausted, the lacustrine environment gradually changed during the Late Pannonian–Pontian to an environment of marsh, swamp, and alluvial plain.

Lithostratigraphy and depositional chronology

The TB fill is composed of the Turiec Group, previously named the Turiec Formation (Hók et al. 1998). According to recent knowledge concerning the origin and dating of individual formations and members, the constituents of this "Group" underwent multiple changes (Rakús & Hók 2002). The last most recent definition of the Turiec Group lithostratigraphy is presented in Fig. 5.

The Upper Badenian Turček Formation represents a volcano-sedimentary andesite complex reaching the southern part of the TB from the Central Slovak Neovolcanic Field (Konečný et al. 1983; Nemčok & Lexa 1990; Lexa et al. 1998). Here, this formation developed from andesite lava flows, tuffs, and tuffite layers deposited above the Mesozoic basement and clays with a tuff admixture (Figs. 5, 6). The tuffs and tuffite layers reach the base of the superimposed Budiš Member (GHŠ-1 borehole, *sensu* Gašparik et al. 1974).

This Sarmatian–Lower Pannonian Budiš Member was recognized only at the southern edge of the TB (Figs. 5, 6, and 7) and it represents sediments of dense gravity flows deposited in an alluvial fan environment. Arkose sandstone derived from granitoid crystalline complexes of the Žiar Mts (Fig. 8) contains layers of clay with coal, blocks, boulders of granitoids up to several cubic meters in size, and also rocks of the Mesozoic sedimentary cover (HGB-2 and HGB-3a boreholes; cf. Havrila 1997). The blocks boulders and associated pebbles exhibit more complete rounding toward the basin. The matrix is clayey and composed of kaolinite with varying content of sand (Gašparik et al. 1991). The maximum thickness of the Budiš Member is more than 600 m and towards the north and east, the Budiš Member intercalates with offshore clays of the lower part of the Martin Formation (HGB-3 borehole; Vandrová et al. 1999; Pipík 2002) (Fig. 5).

The Middle to Upper Pannonian Abramová Member represents deposits of alluvial fans on the south-western margins of the basin (Figs. 5, 6, and 7). Coarse-grained conglomerates/gravels and pebble sandstones/pebble sands at the *Abramová-Kolísky, Ondrašová*, *Moškovec*, and *Socovce* sites are mainly products of subaerial, sporadically subaquatic transport by gravitational flows over a short distance (Fig. 1). The conglomerates and pebble sandstones are poorly bedded, with both normal and opposite graded beds observable. Layering is not always visible and the bedding planes are documented only on the contact of the various sandstone and conglomerate grain sizes. Here, the pebbles are poorly rounded and they are composed exclusively of

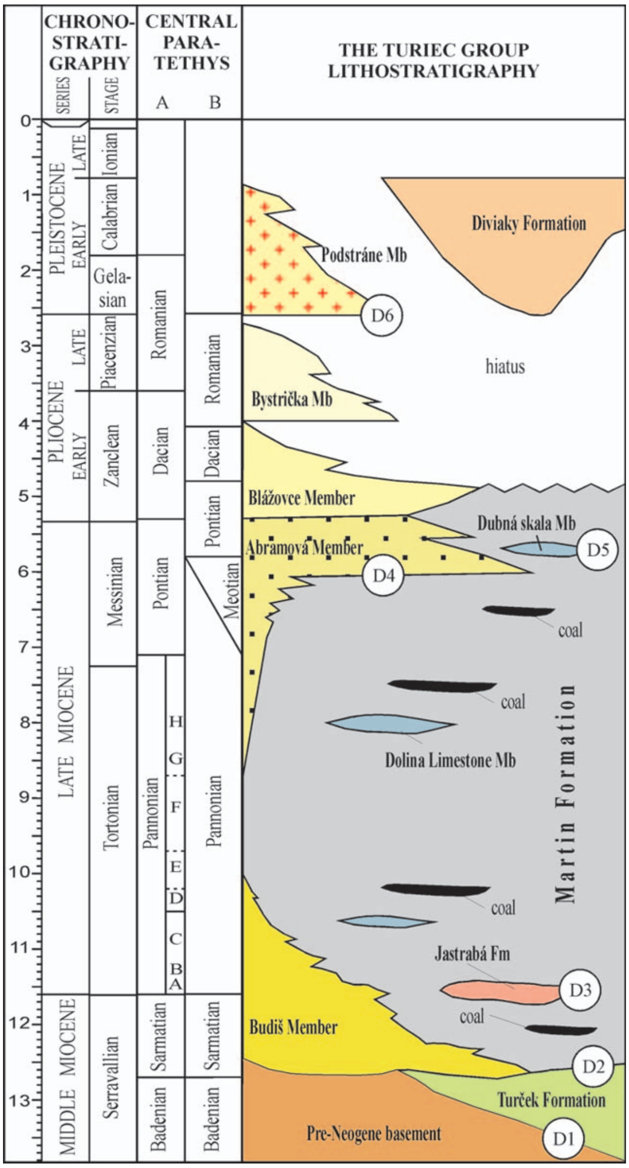

Fig. 5. Lithostratigraphy of the Turiec Basin infill — The Turiec Group; important dated surfaces: (**D1**) boundary, restricted to the southern part of basin, represents the base of the Middle Miocene sedimentary record, which started with the Turček Formation (Konečný et al. 1983; Nemčok & Lexa 1990; Lexa et al. 1998) base of formation can be correlated with the base of the Late Badenian regional stage (13.65 Ma, Kováč et al. 2007) or the Serravallian stage (13.82 Ma, Gradstein et al. 2004); (**D2**) boundary represented by the Budiš Member base dated to 12.7 Ma coeval with the base of the Sarmatian regional stage (Harzhauser & Piller 2004, 2007); (**D3**) level represented by the rhyolite tuffs of the Jastrabá Formation, dated to the Sarmatian/Pannonian boundary (Lexa et al. 1998). The base of the Pannonian regional stage is dated to 11.6 Ma (Vasiliev et al. 2005; Harzhauser & Piller 2007); (**D4**) approximate base of coarse alluvial fans of the Abramová and Blážovce Members (Late Miocene–Late Pliocene) documenting the rapid uplift of the entire area between 6–4 Ma; (**D5**) upper boundary of the Upper Miocene basin fill marked by the Dubná skala Member dated to the latest Pannonian–Pontian; (**D6**) surface dated above the 2.6 Ma level covered by the Diviaky Formation and Podstráne Member. Note, the Central Paratethys chronostratigraphy is according to A) Rögl (1998) and Kováč et al. (1998b) and B) Harzhauser & Mandic (2008).

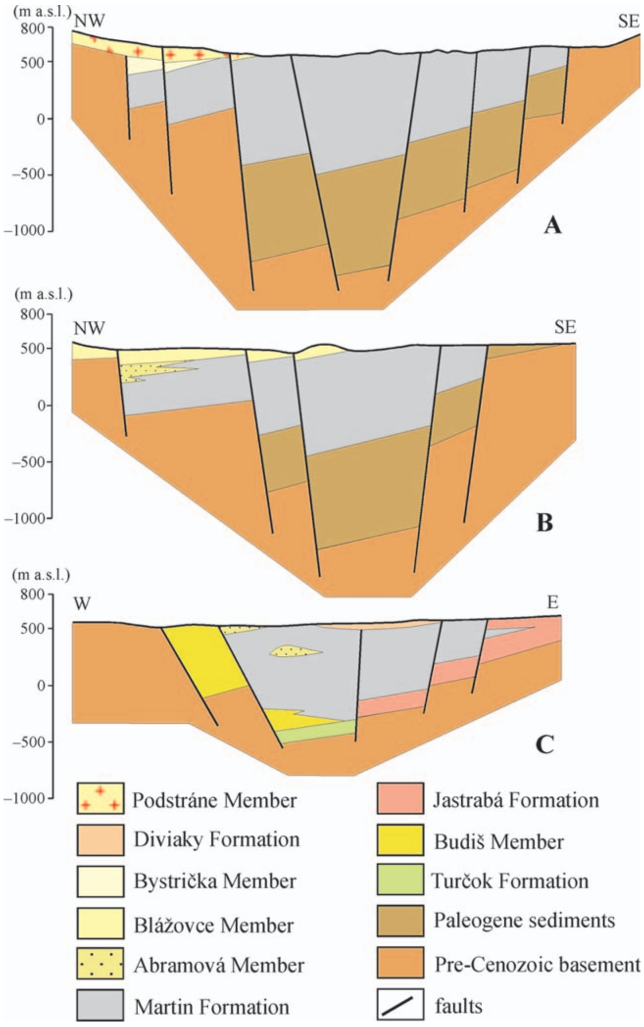

Fig. 6. Schematic cross-sections in the northern (**A**), central (**B**) and southern parts (**C**) of the Turiec Basin (location of cross-sections see Fig. 3). Identification of various sedimentary bodies participating in the basin architecture is supported by geological mapping, borehole study and by the results of vertical electrical sounding (VES) (Bielik et al. 2009).

Triassic dolomite and limestone of the Hronic Unit, with the grain size decreasing from the foothills towards the basin (Figs. 4, 8). This poorly lithified member attains a maximum thickness of about 400 m. Although the Abramová Member alluvial fans mostly cover the pre-Neogene basement or overlie the pelitic basin fill, in some places they partly intercalate with clays of the Martin Formation (Fig. 5). The age of this member is determined by a presence of the Upper Pannonian *Candona aculeata-armata-stagnosa-nubila-simplaria* assemblage and *Candona eminens-laterisimilis* assemblage found at the *Socovce* and *Abramová-Kolísky* sites (Fig. 4).

The occurrence of the rhyolite tuffite is quite surprising at the Abramová-Kolísky site (Fig. 8), since it cannot be compared with the rhyolite tuffs of the Jastrabá Formation, drilled in the GHŠ-1 borehole at a depth 550–551.5 m in fine-grained basinal facies (Gašparik et al. 1974). The problem is their age, because the Jastrabá Formation is dated to the Sarmatian/Pannonian boundary (Konečný et al. 1983; Gašparik et al. 1995; Lexa et al. 1998) and the surface outcrops considered here are assigned to the Late Pannonian (Pipík & Bodergat 2006, 2007). Therefore, this rhyolite tuffite is regarded as redeposited rhyolite tuff derived later, eroded from a currently non-existent younger part of the Jastrabá Formation located in the Central Slovak Neovolcanic Field.

The Upper Pannonian–Pontian Blážovce Member represents deposits of alluvial fans on the western margin of the basin, along the western foothill of the Lúčanská Malá Fatra Mts (Figs. 5, 6, and 7). The proximal parts of the fans were deposited in subaerial conditions, while the distal parts often bear signs of deposition in a lacustrine environment. These Blážovce Member alluvial fans overlie the alluvial fans of the Abramová Member (Fig. 9).

The proximal part of the alluvial fans deposits contains a sedimentary succession at the *Slovany* and *Valča* sites, consisting of boulders, breccias, and conglomerates with sandstone intercalations (Fig. 9). The size of these boulders and pebbles decreases from the mountains towards the basin and the sediments are mostly products of subaerial and partly subaquatic transport by gravitational flow over a short distance. The conglomerates vary from matrix supported conglomerates to pebble supported conglomerates. Layering is not always visible, and the bedding planes were often documented by contact with varying sizes of sandstone/conglomerate grains. The conglomerates are poorly sorted with a lot of subangular clasts and the pebble material is derived from Triassic dolomite and limestone of the Hronic Unit. The sandy-clayey matrix of ochre-brown colour contains quartz, calcite, dolomite, illite, and montmorillonite (Gašparik 1989), and the conglomerates' internal structure is mostly chaotic, showing imbrications with inclination towards the west in a few places. The thickness of the member at the basin margin is about 350–400 m. Some lobes of the Slovany and Valča alluvial fans are partly intercalated into the Upper Pannonian basinal clays of the Martin Formation (KM-1 borehole and Stráža site near Socovce village), and the beds are generally inclined towards the west-northwest (17–25°).

The *Blážovce* site represents a distal part of the Blážovce Member alluvial fans, at which layering of conglomerates and sandstones is much better developed compared to previous sites. Sand and silt layers have thicknesses from 0.5 to 2 m at this site (Fig. 9). At the outcrops, cross and trough beddings are present in some places which documents deposition in an aquatic environment with an impact of fluvial or lake hydrodynamics. The age of the Blážovce Member can be determined only indirectly using the Late Pannonian age of the underlying Abramová Member and the Late Pannonian–Pontian age of the Martin Formation which was deposited in the axial part of the basin.

The sedimentary succession of the Pliocene Bystrička Member represents the youngest deposits of an alluvial fan situated on the north-western margin of the basin (Figs. 5, 6, and 7). Coarse clastics with signs of gravity flow transport have variegated petrographical composition containing pebbles of Mesozoic dolomite, dolomitic limestone, cherty limestone, Allgäu Formation, radiolarite, and grey-marly limestone as well as rocks of crystalline complexes. Pebbles, cobbles,

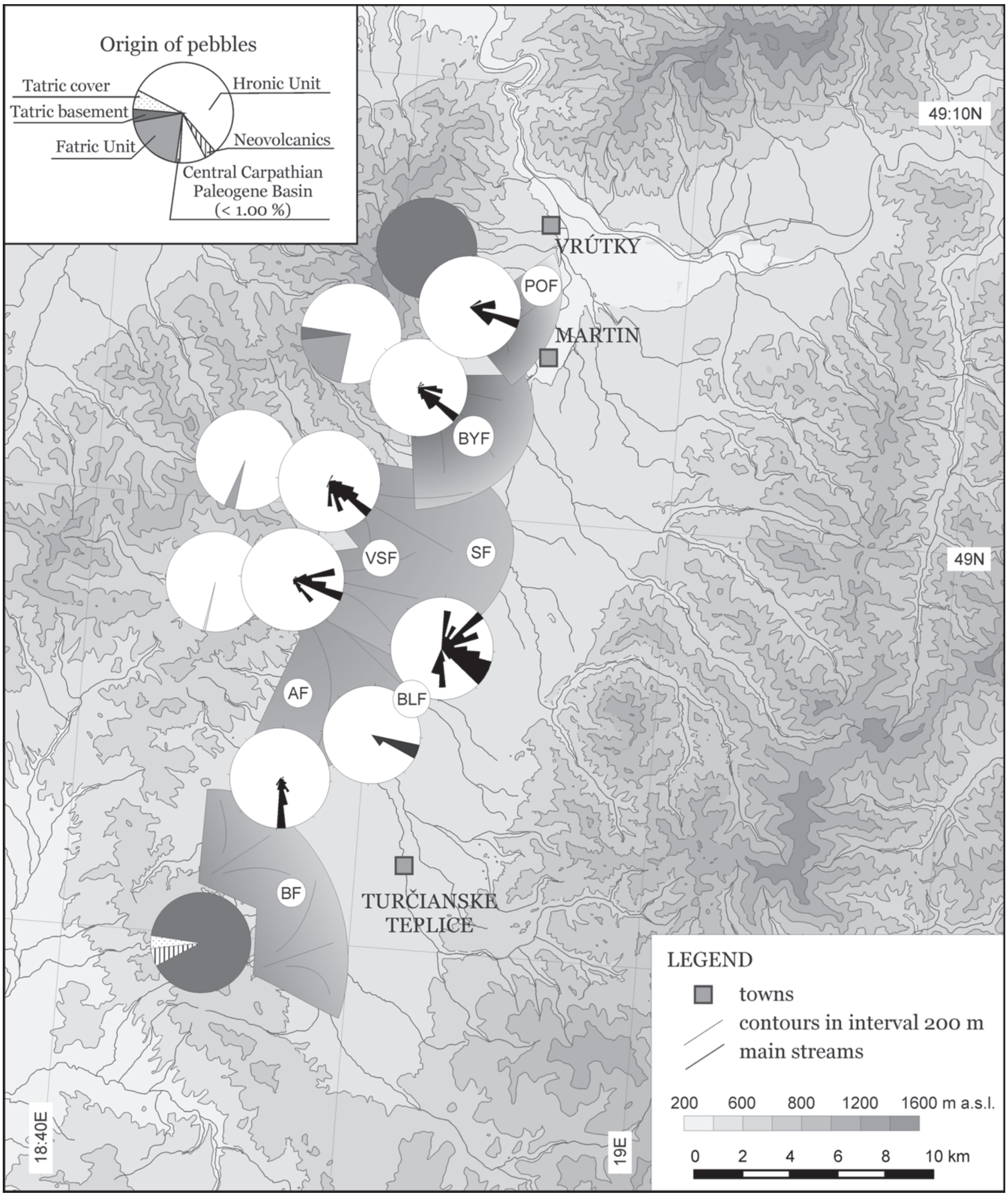

Fig. 7. Miocene and Pliocene alluvial fans system on the western slopes of the Turiec Basin. **BF** — Budiš aluvial fans; **AF** — Abramová aluvial fans; **VSF** — Valča and Slovany aluvial fans; **SF** — Socovce aluvial fans; **BLF** — Blážovce aluvial fans; **BYF** — Bystrička aluvial fans; **POF** — Podstráne aluvial fans.

blocks, and boulders of up to some cubic meters from dolomite and limestone were found in the proximal part of the alluvial fan. Towards the basin, the size of these pebbles diminished and their roundness varied from well-rounded granitoids to subangular shaped dolomites, while granitoids suffered kaolinite weathering. The conglomerate matrix is composed of carbonate clays and clays with sandy admixture, and the bedding often with amalgamated layers is not well-developed. The estimated thickness does not exceed 300 m and therefore the superposition and petrographical composition of the Bystrička alluvial fan suggests a Pliocene age.

The Pleistocene Podstráne Member located in the northern part of the basin is composed of gravels and sands derived from crystalline complexes of granitoids, crystalline schists, and amphibolites (Figs. 5, 6). Sediments of alluvial fans were mainly deposited by subaeric gravitational flows. The pebble material of sporadic cobbles up to 80 cm is well-rounded, while the matrix consists of grey-brownish clays, sandy clays, and sands in various relationships. The imbrication of pebbles supports the assumption of eastward transport from the Lúčanská Malá Fatra Mts. The gravels and sands are intercalated with yellow-brownish sandy clays while the alluvial fans are subhorizontal

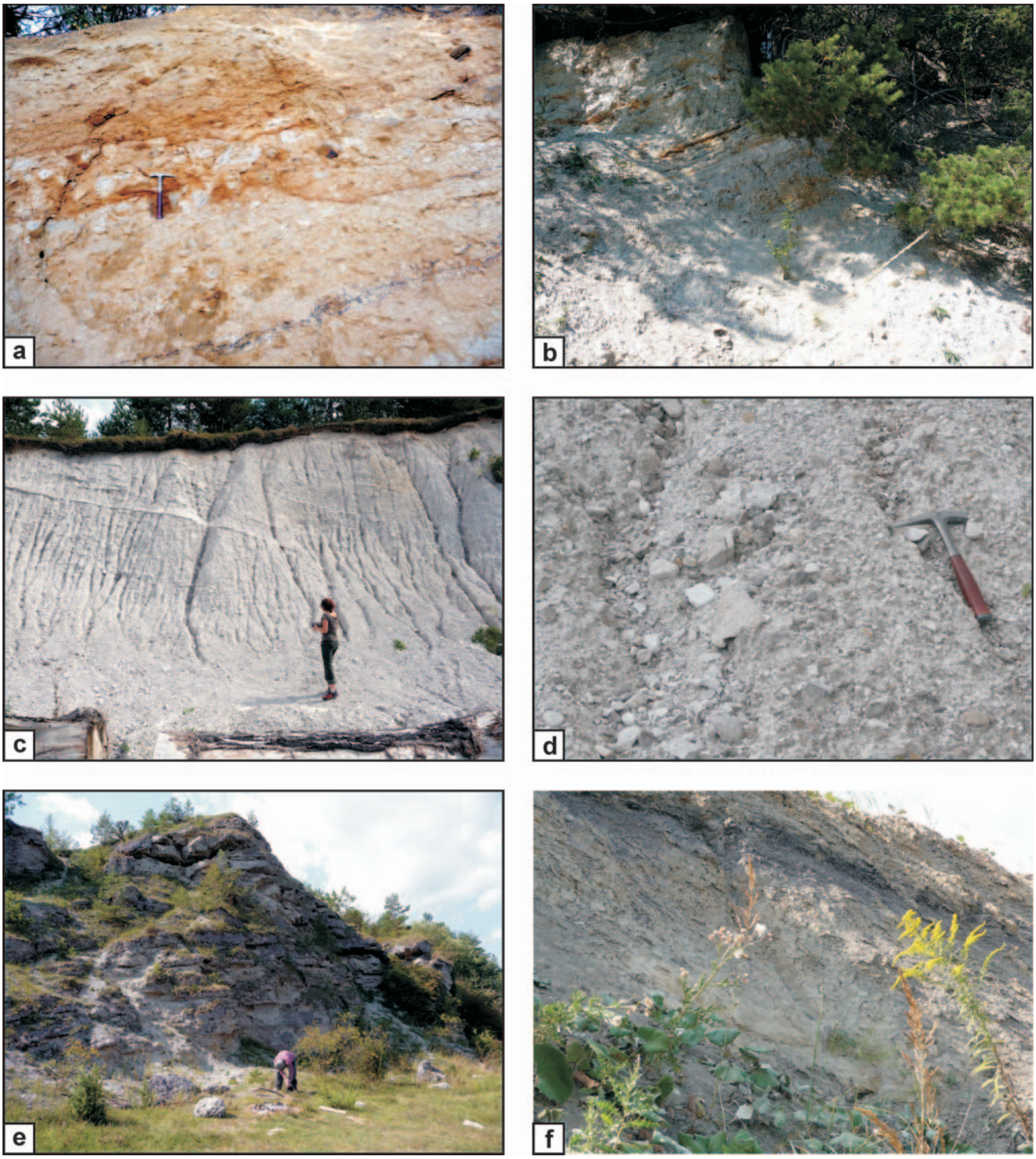

Fig. 8. a — Budiš Member: coarse clastic conglomerates with granite pebbles of the Žiar Mts; **b** — Abramová Member: Redeposited rhyolite tuff layer in coarse clastic conglomerates with Mesozoic pebbles of the Hronic Unit. **c, d** — Abramová Member: coarse clastic conglomerates with Mesozoic pebbles of the Hronic Unit at Ondrášová site. **e** — Abramová Member: coarse clastic conglomerates with Mesozoic pebbles of the Hronic Unit at Socovce site. **f** — Martin Formation clays and silts with intercalation of coal seams at Martin brickyard.

with erosive contact with both the underlying Martin Formation and the Bystrička Member alluvial fan. Based on a planation of the pebbles' source area and the rapid Quaternary uplift of the Lúčanská Malá Fatra Mts, an age of conglomerates can be roughly dated to the latest Pliocene to Pleistocene.

The Pleistocene Diviaky Formation consists of gravel, clay with gravel, and clays (Buday 1962). Montmorillonite clay is light grey, greenish grey or yellow-brownish with a small content of sand admixture (Figs. 5, 9). Sometimes, they are intercalated by layers of fine-grained micaceous quartzite sands. The gravels are composed of dark grey andesite pebbles, quartz, and also granitoid pebbles. The internal structure of the gravels is predominantly chaotic and poorly sorted, but an imbrication of pebbles is sometimes observed. Stratigraphically,

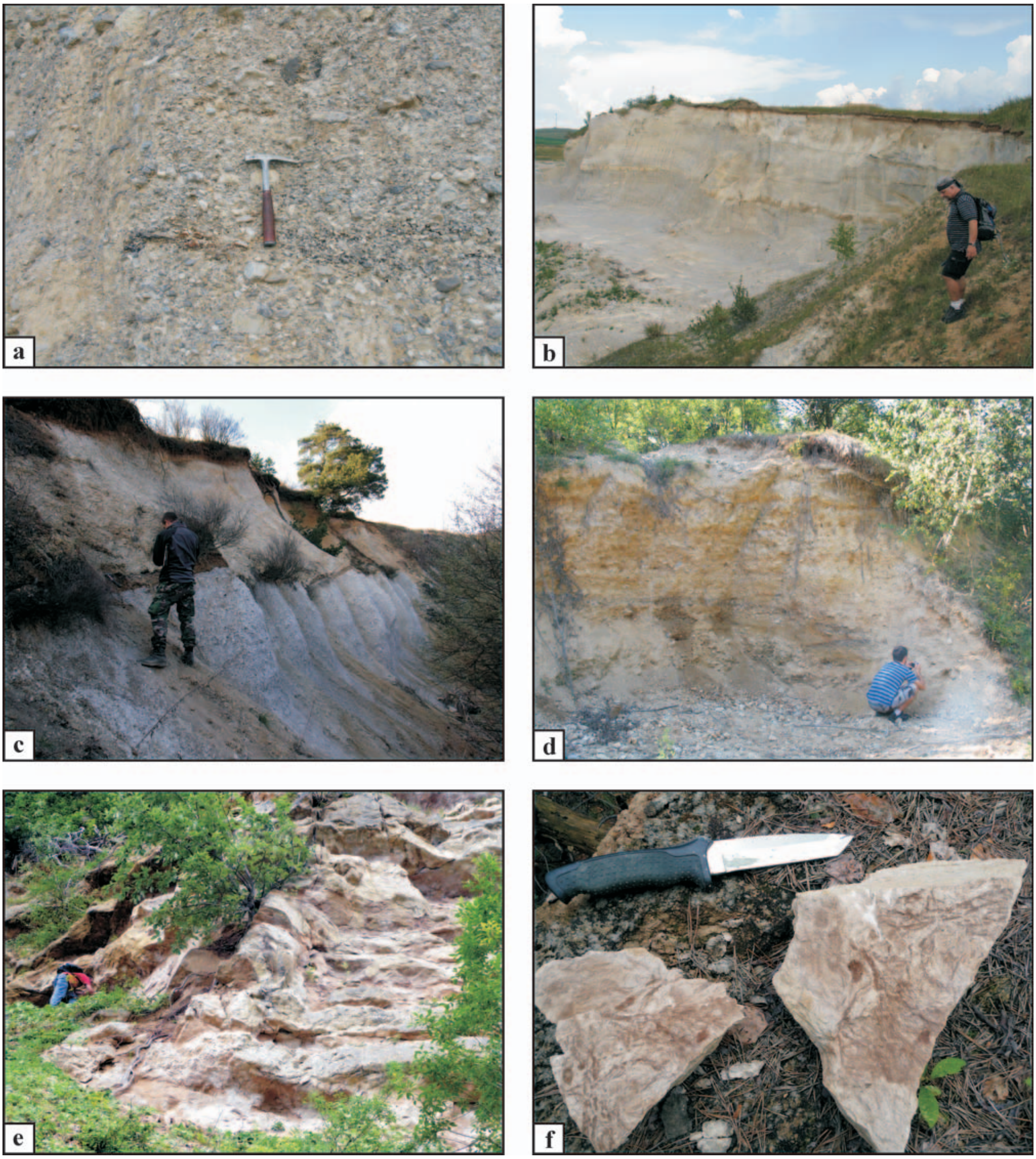

Fig. 9. a, b — Blážovce Member: coarse clastic conglomerates with Mesozoic pebbles of the Hronic Unit at Blážovce site; **c** — overlap of the Abramová alluvial fans (below) by the Blážovce Member (Slovany alluvial fans, above); **d** — Diviaky Formation: conglomerate with pebbles from Central Slovak Neovolcanic Field. **e, f** — Dubná Skala Member: freshwater limestone with *Glyptostrobus* flora.

the formation is placed in the Pleistocene and the uppermost gravel part is geomorphologically classified as the Middle Pleistocene terrace/alluvial fan material (Činčura 1969; Minár & Bizubová 1994; Gašparik et al. 1995). The thickness of very flat alluvial fans occurring in the southern part of the basin does not exceed 40–60 m.

The basin pelitic facies comprises the Sarmatian–Pontian Martin Formation which represents the principal part of the TB fill (Figs. 5, 6) with presence of the *Candona aculeata-armata-stagnosa-nubila-simplaria* ostracod assemblage (Pipík et al. in print). Grey clay is a dominant lithological type in this formation which contains various amounts of sand and silt admixtures. There are also clay with coal pigment, thin lignite coal seams, sand, and sand-with clay content and sandstone (Fig. 8f). Sporadically, there are also fine- to medium-grained carbonate conglomerate, freshwater limestone and tuffite.

In the southern part of the basin, the clay contains volcanic products, especially fine-grained tuff and tuffite from the Jastrabá Formation dated to the Sarmatian/Pannonian boundary (Lexa et al. 1998). These were recognized on the surface from the south-eastern margin of the basin near Mošovce, Blatnica, and Necpaly villages (Březina 1957; Gašparik et al. 1995) and from boreholes as several decimeter thick layers in the Martin Formation (Figs. 5, 6). The youngest deposits of the basin fill are composed of light grey, and sometimes light green or blue calcareous clay and silt with varying sandy admixtures (Gašparik et al. 1995). They contain a coal pigment, plant remnants, and mollusc shells of *Congeria*, *Melanopsis*, *Theodoxus*, *Pyrgula*, *Hydrobia*, *Kosovia* and littoral ostracods.

Freshwater limestone of grey to brown pale colour contained various clay and sandy admixtures. The limestone layering is occasionally well-developed, or it is massive. The beds are 0.5 to 7 m thick and contains abundant marshy and littoral lake fauna (Pipík et al. in print). Freshwater limestone bodies and travertine are products of thermal water springs with a high amount of calcium carbonate which rose to the surface along the NNE–SSW border faults of the Turiec Basin. According to the BJ-2, GT-13 and GT-14 boreholes in the central part of the basin, the freshwater limestones are lacking there.

The Dubná skala Member represents the largest body of the freshwater limestone with thickness up to 150 m (Figs. 5, 9), composed of limestone, travertine, clay, and sandy clay. Several thin and small carbonate conglomerate lenses and layers with a maximum thickness of 2 m are present in the clays and these consist exclusively of dolomite and limestone pebbles with a matrix of clays and freshwater limestone. The limestone is rich in *Charophyta* thallus, the remains of *Typha* sp. (water plants) and also *Glyptostrobus* sp. typical of marshy biotopes. Terrestrial gastropods Helicidae, Pomatisidae, Strobilopsidae indicate proximity of the terrestrial environment lacustrine to freshwater lake (aquatic gastropods Lymnaeidae).

Lignite seams with thickness from tens of centimeters to 1.5 m are located in varying depths of the Martin Formation sequence (Gašparik et al. 1995) (Fig. 5), mainly in its northern part. These lignite seams are characterized by low maturity and calorific capacity, and by fossil woods in the growth position with trunks, roots and a well-preserved xylem structure.

Micro-conglomerates consisting of fine- to medium-grained conglomerate bodies inside the Martin Formation are present as clays with decimeter to several meters of thickness. Pebbles are composed of carbonate rocks and the matrix is composed of sandy clays and sands. These are situated in various parts of the sedimentary record from the base to the top.

Miocene to Quaternary tectonic evolution

The Turiec Basin has been described as a halfgraben of a basin and range structure (Nemčok & Lexa 1990). Nevertheless, analysis of structural data shows that its tectonic history documents compressional tectonic pulses alternating with periods of extension. The Neogene and Quaternary structural pattern changes in the basin catchment are well expressed by paleostress field rotation (Kováč et al. 1998a; Hók et al. 1998; Pešková et al. 2009; Vojtko et al. 2010) and they have also been verified by our measurements of small-scale tectonic structures (Fig. 10).

Basin pre-rifting and initial rifting stage

The Oligocene tectonics in the Western Carpathians can be characterized by a strike-slip tectonic regime with W–E oriented compression (Pešková et al. 2009; Vojtko et al. 2010). The Lower Miocene paleostress field with WNW–ESE to NW–SE oriented compressional axis (σ_1) generated tectonic structures which had no effect on the opening and formation of the present TB. Although the Middle Miocene structural pattern seems similar to the Early Miocene, the principal paleostress axes rotated approximately 30–40° clockwise and the dominant tensional axis σ_3 originated in the ENE–WSW direction (Kováč et al. 1989; Hók et al. 1998; Kováč 2000; Pešková et al. 2009; Vojtko et al. 2010).

The Late Badenian transtensional to extensional tectonic regime led to subsidence in the southern part of the TB. The volcanic products of the Central Slovak Neovolcanic Field reached the southern part of basin, where the volcano-sedimentary complex of the Turček Formation was deposited as witnessed in the GHŠ-1 borehole (Gašparik et al. 1974) and later, also the Sarmatian sediments of the Martin Formation.

Restricted occurrences of the Sarmatian coarse clastic sediments in the southern part of the basin (Budiš Member), and the distribution of sedimentary facies and products of rhyolite volcanism in the Jastrabá Formation led to our assumption that these were deposited in a separate basin depocentre which was opened along the NW–SE to NNW–SSE oriented normal faults and along the ENE–WSW dextral strike-slip faults presently covered by Upper Miocene strata. In the northern part of basin, pelitic fine-grained sediments with *Darwinula stevensoni*, *Candona*, *Cypria*, *Mediocypris*, *Leptocythere* (BJ-2, ZGT-3 boreholes; Pipík 2001) were deposited at the same time.

Basin synrift stage

At the commencement of the Late Miocene, the paleostress field began to change through clockwise rotation of the principal compression axis σ_1 from the NNW–SSE to a NNE–SSW direction (Hók et al. 1998). The measured structures in Fig. 10 support the model of a dextral transtensional to extensional tectonic regime (Kováč & Hók 1993). This same paleostress field was also computed in the western and northern parts of the Central Western Carpathians during this period (Kováč et al. 1994; Kováč 2000; Pešková et al. 2009; Vojtko et al. 2010). This model also conforms to knowledge of the mantle diapirism and volcanic activity in the neighbouring Central Slovak Neovolcanic Field (Nemčok & Lexa 1990).

The Pannonian subsidence of the TB is well-documented by the facies development of the Martin Formation deposited in a basin restricted by uplifted mountains. The area along the basin axis was mostly filled with pelitic lacustrine sediments, and clays intercalated with bodies of freshwater limestones and coal seams towards its margins.

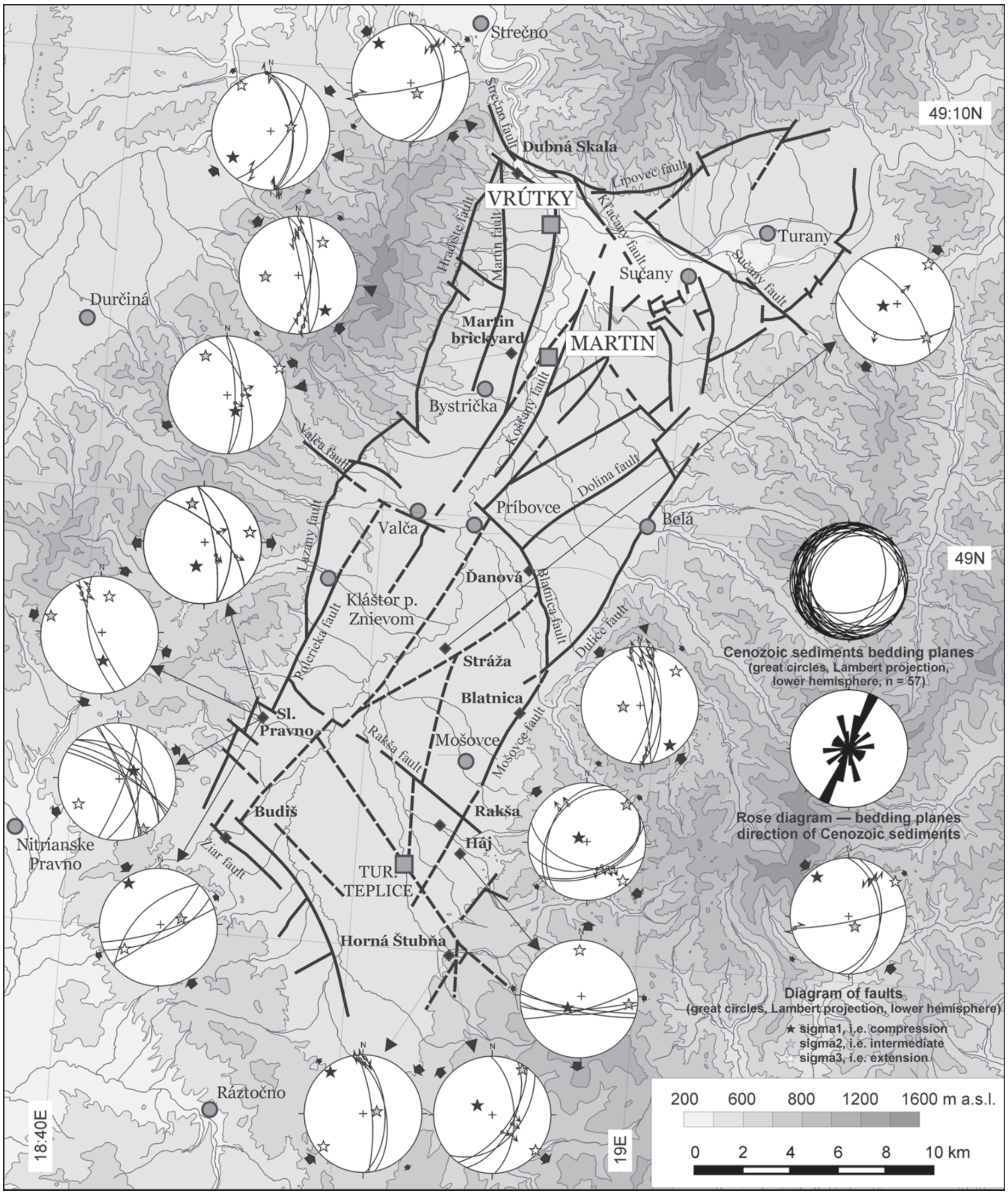

Fig. 10. Paleostress field measurements and structural pattern of the Turiec Basin.

During the latest Pannonian and Pontian, the paleostress changed again and the compression axis σ_1 gained a NE–SW to ENE–WSW orientation. The coarse-grained alluvial fans of the Abramová and Blážovce Members at the basin western flank were deposited on the pre-Neogene basement and Middle Miocene pelitic deposits (Figs. 5, 6). Their origin is closely connected to tectonic activity associated with an accelerated uplift of the central part of the Lúčanská Malá Fatra Mts.

The NNE–SSW oriented main fault system on the western margin of the TB played a dominant role during basin evolution. The marginal faults with an eastward inclination were accommodated by antithetic faults of the same strike, and this activity caused westward tilting of all sedimentary successions of the basin fill. The halfgraben shape of the basin is proven by interpretation of the 4AHR/86 seismic line, by drilling exploration, and also by the structural measurements where layers and bedding planes dip 5–30° westward.

Basin postrift stage and basin inversion

The change of tectonic regime, with a partial clockwise rotation of the principal compressional axis σ_1 from the NE–SW to the NNE–SSW direction during the Pontian and Early Pliocene, led to the end of subsidence and the entire accommodation space of the TB was completely filled. The end of deposition was followed by the uplift of the whole TB catchment area which led to inversion of the basin, or was coeval with it.

During the Late Pliocene or at the Pliocene/Pleistocene boundary, the orientation of the principal paleostress axes underwent a final change, and the paleostress tensor was characterized by a NW–SE oriented compression and perpendicular tension. This change was observed in the entire western and northern regions of the Central Western Carpathians and it significantly influenced the evolution of the broader area (Vojtko et al. 2008; Králiková et al. 2010). The basin synrift subsidence along the NNE–SSW trending normal to oblique slip faults at the western margin of TB was substituted by NNE–SSW transtensional sinistral oblique slips and NW–SE trending normal faults (Hók et al. 1998).

A rapid uplift of the crystalline basement of the Lúčanská and Krivánska Malá Fatra Mts caused conspicuous altitudinal differentiation especially in the north-western part of the TB along the NNE–SSW sinistral oblique-slip faults. Erosion and transport of coarse clastics are documented by the Late Pliocene Bystrička Member and the Pleistocene alluvial fans of the Podstráne Member containing exclusively material from the Tatric crystalline complex (Figs. 6, 7). The NW–SE normal faults were active during the Pliocene and Quaternary periods. This is shown by the Rakša fault limiting the northern boundary of the Pleistocene Diviaky Member by the Blatnica and Valča faults restricting outcrops of the Paleogene sediments at the surface in the eastern part of the basin and by the Sučany fault which represents the outer boundary of the Late Miocene fill of the TB (Fig. 10).

Morphotectonic markers

The youngest tectonic stages are well-reflected in the morphotectonic markers, especially in foothill lines which are quite obvious on satellite images in visible, infrared and radar wavelength spectra, and also in digital terrain models (Fig. 11). The NNE–SSW striking of the Hradište fault zone copies the mountain front, and it strongly delimits massive landforms such as faceted slopes and flattened surfaces. The S index of Bull & McFadden (1977) attains the value of 1.20–1.25 for the eastern front line of the Lúčanská Malá Fatra Mts and its low value documents a predominance of tectonic processes over denudation. The fact that the mountain front was not destroyed intensively by exogenic processes strengthens the hypothesis of active tectonics during the Quaternary Period. Therefore, these tectonics played a considerable role in the shaping of the contrasting landforms, despite the highly active weathering and denudational processes in the Western Carpathians during the neotectonic period (Vojtko et al. 2011).

Although several faceted slopes along the Hradište fault zone are predominantly denuded, the faceted slopes in the northern part of the fault trace are well-preserved where the ratio of the mountain front faceting is approximately 0.80–0.85 (cf. Wells et al. 1988) (Fig. 11). Facets of the Lúčanská Malá Fatra Mts front average 200–300 m in height, with the most distinctive facets along the northern boundary of the TB with the Kriváňska Malá Fatra Mts at heights of 400–500 m. These landforms are possibly a consequence of the distinctive young Quaternary uplift of the Kriváňska Malá Fatra Mts. Facets of the Veľká Fatra Mts are only 100–200 m high, and they are completely absent in a large part of the northern foothill. A similar situation is found in the foothills of the Žiar Mts and this signifies a decelerated and only slight tectonic uplift of these mountains during the Quaternary Period.

A remarkable mosaic of landforms has been discovered at the front of the faceted slope line with many alluvial fans of different areal extent and volume. The Pliocene to Holocene alluvial fans were deposited by gravity flows and stream sedimentation and their presence on the eastern part of the mountain front line is a result of sudden change in slope inclination. They are composed of sandy-gravel material derived from the small valleys carved into the faceted slopes (Fig. 11). Some regularity can be detected in the distribution of the Quaternary alluvial fans and river terraces, where the older landforms dominate in the south and the younger ones in the north.

Knickpoints in river longitudinal profiles mainly in the foothills of the Malá Fatra Mts indicate recent tectonic activity (Sládek 2010). Other knickpoints regularly appearing about 1.5–2 km upstream may reflect an older Quaternary tectonic event, although such regularity is less distinct in other mountain boundaries. Quaternary tectonic activity is also most likely a cause of block landslides in some parts of the boundary between the mountains and the TB (Sládek 2010).

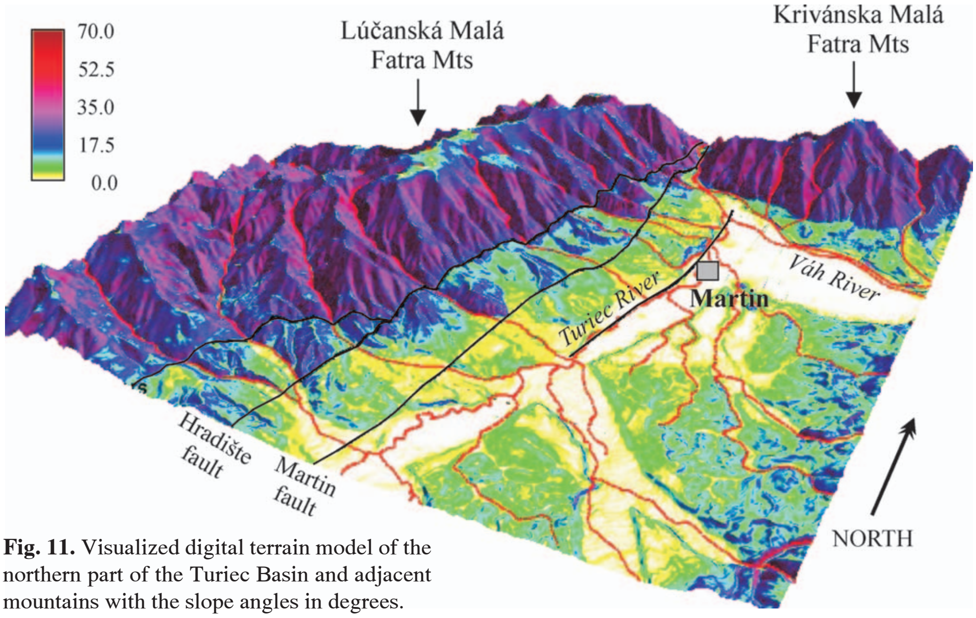

Fig. 11. Visualized digital terrain model of the northern part of the Turiec Basin and adjacent mountains with the slope angles in degrees.

In the southern part of the basin, altitudinal differentiation of up to some meters in the surface of river terraces correlates with topolineament faults, and with a presence of mineral springs and young travertine bodies (Hók et al. 2010). This indicates a very young vertical tectonic movement. Small falling (Háj) and rising structures (Dubové) are most likely an extreme manifestation of this youngest tectonics (Činčura 1969; Minár & Bizubová 1994; Minár & Tremboš 1994).

Landforms and denudation chronology

The landforms of the basin and in the surrounding mountains bear valuable morphogenetic and morphochronological information (Figs. 11, 12). Planation surfaces are the oldest (Neogene–Quaternary) landform segments that can be correlated with Neogene lithostratigraphy. Quaternary river terraces, alluvial fans, and slope sediments represent postlimnic stages in the basin's development.

Planation surfaces

The traditional denudation chronology of Mazúr (1963) distinguishes three planation surfaces in the region. Two of these are compatible with present geological data (Fig. 12). Preservation of the oldest Badenian–Sarmatian 'Top level' is no longer in accord with recent apatite fission track thermochronology results (cf. Danišík et al. 2010).

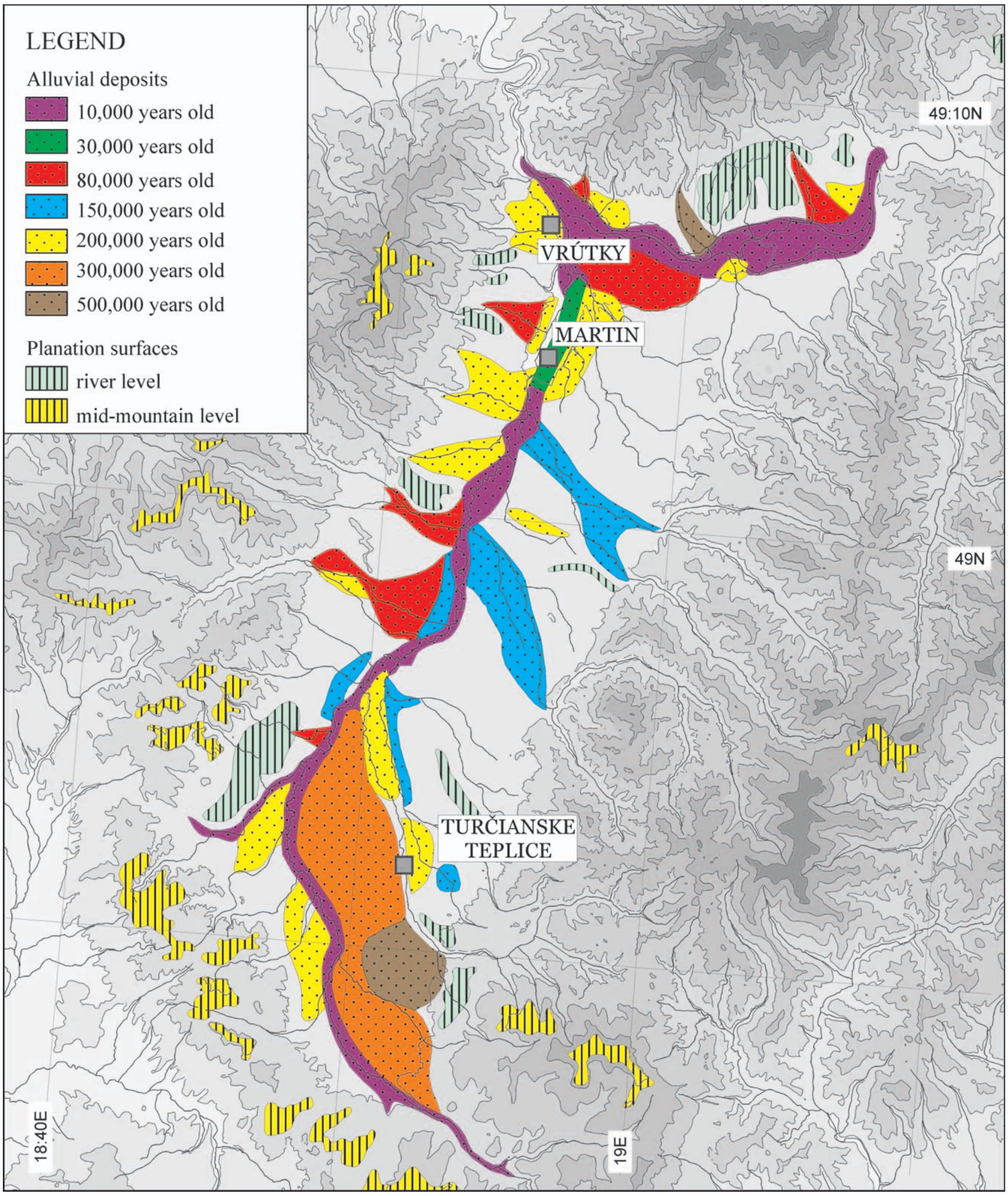

Fig. 12. Planation surfaces and alluvial deposits of the Turiec Basin.

The 'Mid-mountain level' is an initial planation surface and has the characteristics of a pediplain (Mazúr 1963), etchplain (Lacika 1995) or tectoplain (Minár 2003). The surface severed the Sarmatian volcanites in the highest central part of the Kremnické vrchy Mts. The remnants of this highest surface are assumed to range from approximately 1500 m a.s.l., in the Malá and Veľká Fatra Mts to only 700 m a.s.l. in the Žiar Mts (Lukniš 1962). This indicates considerable tectonic differentiation of the territory after formation of this level which can be correlated with deposition of the fine-grained Martin Formation during a tectonically quiet period of the Pannonian regional stage (*sensu* Harzhauser & Piller 2007). A decrease in fault activity during this period most likely allowed an acceleration of the regional planation (Minár 2003; Minár et al. 2011).

According to Lukniš (1962) and Mazúr, (1963), the 'River level' has the character of a pediment mainly located from 40 to 100 m above the actual Turiec and Váh Rivers. The 'River level' position approximately above the highest Pleistocene river terraces (Early Pleistocene on the north and Middle Pleistocene on the south, Činčura 1969) defines its age as Early to Middle Pleistocene. A local stepped character of the level implies a younger indistinct structural differentiation. However, indication of two all-aged pediments also exist (Minár & Bizubová 1994; Sládek & Bizubová 2008). The extreme height of the 'River level' of about 300 m above the Váh River in the Strečno Gorge of the Malá Fatra Mts demonstrates rapid Quaternary uplift of the mountain.

River terraces

A system of Quaternary river terraces and terraced alluvial cones developed in the basin (Mazúr 1963; Činčura 1969; Gašparik et al. 1995). The radiometric dating is unavailable but position, gravel weathering, and heavy hypersthene mineral characteristics enable us to distinguish between three major groups of river terraces.

The high terraces from the Early to Middle Pleistocene are 45–90 m above the Turiec and Váh Rivers and they are preserved only as small and eroded remnants on the foothills of the basin. Their maximum accumulated thickness normally attains 2–3 meters. These relatively high terraces decline about 15–30 m from the northern to the southern parts of the basin. This may be a consequence of a different Quaternary tectonic regime, together with a time lag in rejuvenation of the basin drainage system to the south. The highest terraces in the adjacent Váh Strečno Gorge are 130 m above the Váh River, which indicates some dozen meters of Quaternary tectonic differentiation between the basin and the surrounding mountains.

The Middle terraces of the Middle Pleistocene are 10–30 m above the Turiec and Váh Rivers, and these are the most widespread in the basin. The northern and southern parts of the basin differ in the number and character of terrace steps. There are two steps in the north and three in the south. While the top 25–30 m level in the northern TB is attributed to the older Riss (~Saalian) glaciation, the same level in the southern part of basin is assigned to the Mindel (~Elsterian) glaciation (Činčura 1969). The Quaternary subsidence and normal stratigraphic sequence of the fluvial sediments in the central southern part of the TB up to Elsterian, or to the older Saalian in the southernmost part, may supply an explanation (Minár & Bizubová 1994). This would also support the mixed Elsterian–Saalian character of the pebble material of terraces situated in the southern part of the basin and also their exceptional thickness exceeding 20 m (Činčura 1966; Minár & Bizubová 1994).

The low terraces of the Late Pleistocene–Holocene are 3–8 m above the Turiec and Váh Rivers. They have a maximum alluvial deposit thickness of approximately 15 m and they predominantly occur in the northern part of the TB. The Late Pleistocene pebble material of these terraces is mostly buried by Holocene alluvial sediments in the south, which again supports a minimal recent tectonic uplift of the central southern part of the basin.

The higher Middle terraces and part of the High terraces are covered by a fine-grained material of several meters in thickness and undetermined lithological origin. This is most likely loessial loam or wash loam (Činčura 1969; Gašparik et al. 1995).

Mass balance approach model

Some accurately datable milestones in the geological history of the Western Carpathians are used for reconstruction of the period boundaries and they are applied in the hypothetical mass balance model of the development of the TB and its catchment area (Table 1). Summarized data on erosion transport and deposition were harmonized to the presented scenarios, but the results should not be overestimated because of the insufficiency of some used input information.

Oligocene to Early Miocene epoch of uplift and rapid cooling of the crystalline basement associated with denudation before reaching surface conditions (33–22 Ma)

This epoch is defined by using AFT ages and thermal modelling of the Žiar Mts (Danišík et al. 2008) and by AFT ages known from the Veľká Fatra Mts (Danišík et al. 2010). This presumes a similar tectonic paleogeographic situation on the whole area of the TB and its surroundings before the basin opening during the Middle and Late Miocene. This work, in contrast, assumes that the whole catchment suffered much more intensive denudation in the south and west than in the north and east. This is supported by recently preserved Paleogene sediments occurring only in the northern part of the basin, and also by the SW–NE increase in Paleogene sediment thickness in the broader region (Fig. 2).

Early Miocene epoch of subsidence, burial of the pre-Neogene basement and development of planation surfaces (22–16 Ma)

During this time span it is presumed that the TB catchment was flooded by the Central Paratethys Sea and a thick pile of Lower Miocene strata was deposited. Currently, this is documented by the denudation remnants of the Eggenburgian transgressive Rakša Formation in the southern part of the basin

Table 1: Comprehensive mass-balance model of the Turiec Basin region development. T [km] — total denudation (–) or accumulation (+) effect estimation, *D/A* [mm/kyr^{-1}] — denudation (–) and accumulation (+) rate, R [km] — mean relief. Planation periods are highlighted. The Northern (N) and Southern (S) subregions are distinguished for the Turiec Basin and Malá Fatra units.

Age [Ma]	**Turiec Basin (S)**			**Kremnické vrchy Mts**			**Žiar Mts**		
	T	*D/A*	R	T	*D/A*	R	T	*D/A*	R
33–22	–3.5	*–318*	1.1	–3.2	*–291*	1.0	–3.5	*–318*	1.1
22–16	+1.3	*+217*	0.0	+0.2	*+33*	0.1	+1.5	*+245*	0.0
16–13	–1.2	*–400*	1.4	+1.5	*+500*	1.5	–0.8	*–266*	0.9
13–11	+0.5	*+250*	0.0	–0.1	*–50*	0.1	–0.5	*–250*	0.8
11–6	+0.7	*+140*	0.0	–0.1	*–20*	0	–0.4	*–80*	0.2
6–4	+0.3	*+150*	0.0	–0.2	*–100*	0.2	–0.3	*–150*	0.4
4–2	–0.1	*–50*	0.1	–0.4	*–200*	0.6	–0.3	*–150*	0.4
2–1	+0.1	*+100*	0.0	–0.2	*–200*	0.6	–0.1	*–100*	0.2
1–0	–0.05	*–50*	0.1	–0.25	*–250*	0.8	–0.2	*–200*	0.6

Age [Ma]	**Turiec Basin (N)**			**Malá Fatra (S)**			**Malá Fatra (N)**			**Veľká Fatra**		
	T	*D/A*	R	T	*D/A*	R	T	*D/A*	R	T	*D/A*	R
33–22	–2.9	*–264*	0.9	–3.2	*–291*	1.0	–3.5	*–318*	1.1	–1.5	*–136*	0.3
22–16	+1.0	*+165*	0	–0.8	*–133*	0.4	–1.0	*–166*	0.4	–0.2	*–33*	0.1
16–13	–1.0	*–333*	1.2	–1.3	*–433*	1.5	–1.5	*–500*	1.6	–0.4	*–133*	0.3
13–11	–0.2	*–66*	0.1	–0.8	*–400*	1.4	–0.8	*–400*	1.4	–0.2	*–100*	0.2
11–6	+1.0	*+200*	0	–0.8	*–160*	0.4	–1.0	*–200*	0.6	–0.3	*–60*	0.1
6–4	+0.1	*+50*	0	–0.6	*–300*	1.1	–0.6	*–300*	1.1	–0.6	*–300*	1.1
4–2	–0.2	*–100*	0.2	–0.6	*–300*	1.1	–0.8	*–400*	1.4	–0.6	*–300*	1.1
2–1	0	*0*	0	–0.25	*–250*	0.8	–0.3	*–300*	1.1	–0.25	*–250*	0.8
1–0	–0.1	*–100*	0.2	–0.3	*–300*	1.1	–0.4	*–400*	1.4	–0.3	*–300*	1.1

(Gašparik 1989) and also by the presence of Lower Miocene sediments in the neighbouring Bánovce and Horná Nitra Basins, where the sedimentary fill is more than 1500 m thick. AFT thermal modelling from the Variscan basement of the Žiar Mts also records an Early–Middle Miocene thermal event (Danišík et al. 2008). A possible interpretation is influence of the burial by Lower Miocene sediments at 1000–1500 m during its first phase (19–16 Ma). Observed surface planation in the surrounding mountains is documented by buried "planation" surfaces below the Badenian volcanites in the Kremnické vrchy Mts.

Middle Miocene epoch of uplift of crystalline complexes associated with denudation (16–13 Ma)

Erosion of the Lower Miocene strata began after the vast sea level fall at the beginning of the Middle Miocene (Haq et al. 1988; Haq 1991). The rapid denudation in the mass balance model (300–400 mm/kyr^{-1}) correlates with assumed erosion of a huge pile of soft sediments (clay and silts of the "Lower Miocene schlier formations"). AFT modelling in the Žiar Mts shows decreased warming (Danišík et al. 2008) despite a peak of volcanic activity in the Central Slovak Volcanic Field (Konečný et al. 2002). We presume an elimination of the volcanic heating effect due to the rapid uplift and denudation. The younger AFT age of the Malá Fatra Mts in comparison with the Veľká Fatra Mts underlies the earlier and stronger denudation of the Malá Fatra Mts, while accumulation in the Kremnické vrchy Mts is derived from assessment of the volcanic deposition.

Late Middle and early Late Miocene epoch of rapid uplift and cooling of the crystalline basement associated with basin subsidence (13–11 Ma)

Subsidence of the southern part of the TB was associated with a rapid uplift of the Žiar Mts and neighbouring part of the Malá Fatra Mts (see the thermal modelling in Kráľ et al. 2007; Danišík et al. 2008). Rapid erosion and subsidence of the basin's southern depocentre is documented by the presence of the huge alluvial fans of the Budiš Member (Figs. 5, 6, and 7). Based on distribution of the AFT ages in the wider region, we propose a gradient of tectonic uplift, conditioned by collision of the ALCAPA with the European Platform, towards the Pieniny Klippen Belt (Kováč et al. 1994; Minár et al. 2011). This conditioned both a higher denudation rate in the Žiar and Malá Fatra Mts and also an inverse denudation regime in the northern part of the TB.

Late Miocene epoch of subsidence, burial of the pre-Neogene basement and development of planation surfaces (11–6 Ma)

The subsidence of the TB was associated with the accumulation of clayey fill in the Martin Formation and the development of planation surfaces which are actually preserved in the central parts of all the surrounding mountains (Figs. 5, 12: 'Mid-mountain level'). The results of AFT thermal modelling confirm thermal stability in the Malá Fatra Mts (Danišík et al. 2010) and also most likely in the Žiar Mts (Danišík et al. 2008).

Latest Late Miocene to Early Pliocene epoch of rapid uplift (6–4 Ma)

An accelerated uplift and erosion of the Malá Fatra Mts is documented by the presence of coarse-grained alluvial fans of the Abramová and Blážovce Members which contain exclusively pebbles of Mesozoic rocks. The fans on the western margin of the basin are partially coeval, but mostly overlay with fine-grained basin sediments, mostly clays, freshwater limestone, and coal seams of the Martin Formation (Figs. 5, 6, and 7). The best preservation of the 'Mid-mountain level' in the Žiar and Kremnické vrchy Mts indicates the low relief denudation of both.

Middle and Late Pliocene epoch of uplift associated with denudation (4–2.6 Ma)

Subsidence of the TB ceased and this was followed by accelerated uplift of the mountains and basin floor during the stage of basin inversion. The Pliocene alluvial fans of the Podstráne Member consist of pebble material of Mesozoic rocks and crystalline basement, or exclusively of pebbles of crystalline rocks (Fig. 5, 7). In the axial part of basin, the fine-grained fill began to be eroded as a consequence of the general uplift of the area. While the northern part of the basin was drained by the paleo-Váh River, the estimated denudation rates based on recent relief properties suppose the southerly-flowing paleo-Nitra River as an alternative drainage source for the southern part of the TB.

Early Quaternary period (2.6–1 Ma)

The Early Quaternary period was tectonically quiet and led to the formation of a pediment — the 'River level', associated with deposition of coarse clastic alluvial fans on the basin margins and lacustrine — fluvial river sediments in subsiding areas in the southern part of the basin (Diviaky Formation). Differences between the northern and southern parts of the TB are also reflected in a significantly lower relative height of the 'River level' in the southern part (Fig. 12).

Middle to Late Quaternary period (1 Ma to Recent)

The present river net was formed during the Middle and Late Quaternary. A left tributary of the Váh River unified the recent Turiec River catchment by head-ward erosion capturing. However, previous isolated development of the southern part of the Turiec Basin can still be documented by the lower denudation effects linked with the lower height of the river terraces. A mountain edge is characterized by a new acceleration in tectonic activity, and the preservation and heights of the facet slopes enable us to distinguish tectonic activity in these particular mountains (Figs. 11, 12).

Conclusions

Research carried out in the TB and its catchment area enabled a redefinition of the Turiec Group lithostratigraphy (Fig. 5). The most important factor was the division of the Miocene alluvial fans into three periods: (1) latest Middle Miocene–earliest Late Miocene; (2) latest Late Miocene–earliest Pliocene, and (3) the latest Pliocene–Quaternary.

Connections between landforms and basin development, including the impact of erosion, transport, and accumulation on various sedimentary facies over time and space explained important relationships through both the reconstruction of basin paleogeography and the distribution of paleoenvironments.

The model of the Miocene to Quaternary tectonic evolution documents tectonic pulses caused by changes in the paleostress field and tectonic regimes. The confirmation of the strong impact of the Pliocene and Pleistocene tectonics on landscape development is extremely important and this is also documented by morphotectonic analysis.

Dating of the altitudinal relief differentiation and development of flattened surfaces helped the preparation of the mass balance model which serves as a "final control" of landscape evolution of the Lake Turiec–Turiec Basin catchment area from the Miocene to the Quaternary.

The Neogene to Quaternary mass balance model of the Turiec Basin and its catchment area was prepared on the basis of comprehensive thermal geochronology, sedimentological and geomorphological data (Table 1). This model documents periods of tectonic activity and also quiet periods with the development of planation surfaces in the mountains adjacent to the Turiec Basin. Three quiet and five tectonically active periods in the basin catchment can be distinguished.

The tectonically quiet periods of landscape planation associated with deposition of fine-grained sediments were: (1) The Early Miocene epoch (22–16 Ma); (2) The Late Miocene epoch (11–6 Ma) of the Mid-mountain level development associated with fine-grained sedimentation of the Martin Formation, and (3) The Quaternary period (2.6–1 Ma) which represents River level development.

The tectonically active periods of the TB catchment area consist of: (1) Oligocene–Lower Miocene conversion (?) 34–22 Ma with erosion of the Paleogene strata; (2) Middle Miocene conversion 16–13 Ma with erosion of the Early Miocene strata; (3) Middle Miocene uplift of the Žiar Mts and subsidence in the TB southern and central parts 13–11 Ma; (4) Upper Miocene to Pliocene rapid uplift of the Malá Fatra Mts subsidence along the western edges of the basin 6–2.6 Ma, and (5) Quaternary uplift from 1 Ma to the present of the surrounding mountains and the development of a river terrace system, together with the deposition of coarse clastic fans on the basin margins.

The recent relief was formed by the domatic uplift of the planated Western Carpathians. Therefore, mountains with similar altitudes, such as the Malá and Veľká Fatra Mts herein, exhibit totally different FT ages. It can be generally stated that the erosion of the internal zone of the Central Western Carpathian Žiar Mts and Veľká Fatra Mts in the Turiec Basin area suffered a significantly lower degree of denudation than in the external zone of the Malá Fatra Mts. Consequently, these less eroded crystalline basements display older apatite fission track (AFT) ages than the more eroded complexes with younger AFT ages near the Pieniny Klippen Belt suture zone. Unfortunately, Pliocene to Quaternary development and denudation is not reflected in detected AFT ages from the study area.

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