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Tertiary Development of the Western Part of Klippen Belt

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Abstract: The scope of this work was to find Tertiary changes in orientation of the strain field in the western part of the Klippen belt, to study the kinematic character of faults and to date their activity.

Structural interpretation of data obtained from the western part of the Klippen belt (up to the Orava section) indicates that it was affected by several phases of deformation. As observed in the field the compression of Klippen belt, oriented perpendicular to its strike, occurred during the first phase, responsible for the development of slip-fault and fold structures. This stage dates back to Oligocene? - Lower Miocene. Gradual reorientation of the stress field resulted in the development of strike faults and shear folds. The evolution of the Klippen belt between Lower and Middle Miocene has been influenced by transpressional regime. Generally, the maximum strain $\sigma 1$ was oriented N-S to NNE-SSW. Subsequently, the extensional regime, characterised by the development of randomly oriented downslip faults, prevailed in the area of the Klippen belt during Upper Miocene.

Introduction

The Klippen belt (Pieniny Klippen belt), situated between the Western Carpathian externides and internides (sensu Mišík et al., 1986), represents a narrow independent structural belt with extraordinarily complicated structure. It stretches from Vienna through central Považie (Váh River valley) to Orava and extends via Polish Pieniny to eastern Slovakia, Ukraine and Romania (Fig. 1). The following features are characteristic for Klippen belt: primary absence of pre-Mesozoic rock, scanty representation of Triassic rocks, variable developments of Jurassic and Cretaceous rocks and klippe-type tectonic style (Pieniny type klippen - Andrusov and Scheibner, 1968). Most of the klippen have tectonic origin. The klippen are represented by lenses of predominantly Jurassic and Lower Cretaceous limestones, detached from more plastic formations, composed mainly of Middle and Upper Cretaceous marls (klippen envelope). These lentiform, or isometric bodies, are situated in marlstone, or in flysch rocks of the klippen envelope. Although the envelope units were originally placed in normal stratigraphical superposition on top of rocks representing the klippen, their contacts were generally tectonic (Andrusov 1974).

The Klippen belt was affected by several deformational events whose effects suggest multistage brittle - ductile and brittle deformation and relatively small depth, at which the tectonic deformations have taken place. Paleogeographic analysis indicates that the sedimentation area of the Pieniny geosyncline was considerably broad, the estimations being within the range from 30 (Scheibner 1963) to 100 km (Swidziński 1962). In seismic sections the Klippen belt appears as indistinct, subvertically oriented suture belt situated between the blocks of Outer and Inner Western Carpathians

Methods

Structural analysis of the western section of the Klippen belt (Fig. 2) included a study of its deformational effects and of their timing. Field studies of individual sections of the Klippen belt (Fig. 3, 4) and surrounding units included a statistic evaluation of mesoscopic manifestations of Tertiary deformation represented mainly by faults, fissures and folds.

Direct inversion method (Angelier 1994) has been applied to evaluate the fault planes and movement indicators. This method assesses the orientation of the main stress field tensors on the basis of fault plane orientation and slide vectors of the movement indicators on discrete fault planes. Statistic sets of measured elements allowed to assess (together with the study of geologic map) the courses of faults, their kinematic character and, if the stratigraphic datings of investigated localities were available, also the times spanning their activity.

The fault planes are plotted using stereographic projections (Schmidt net, lower hemisphere). The fault plane projections are represened by large arcs and the striations on them by dots. The arrows assigned to dots show the sense of movement, while large arrows indicate the strike of compression, or extension, respectively (Tables 1, 2, 3, 4).

Structural development of the Klippen belt during Tertiary

Structural interpretation of data obtained from western section of the Klippen belt (up to the Orava section) indicates that several phases of deformation have taken place.

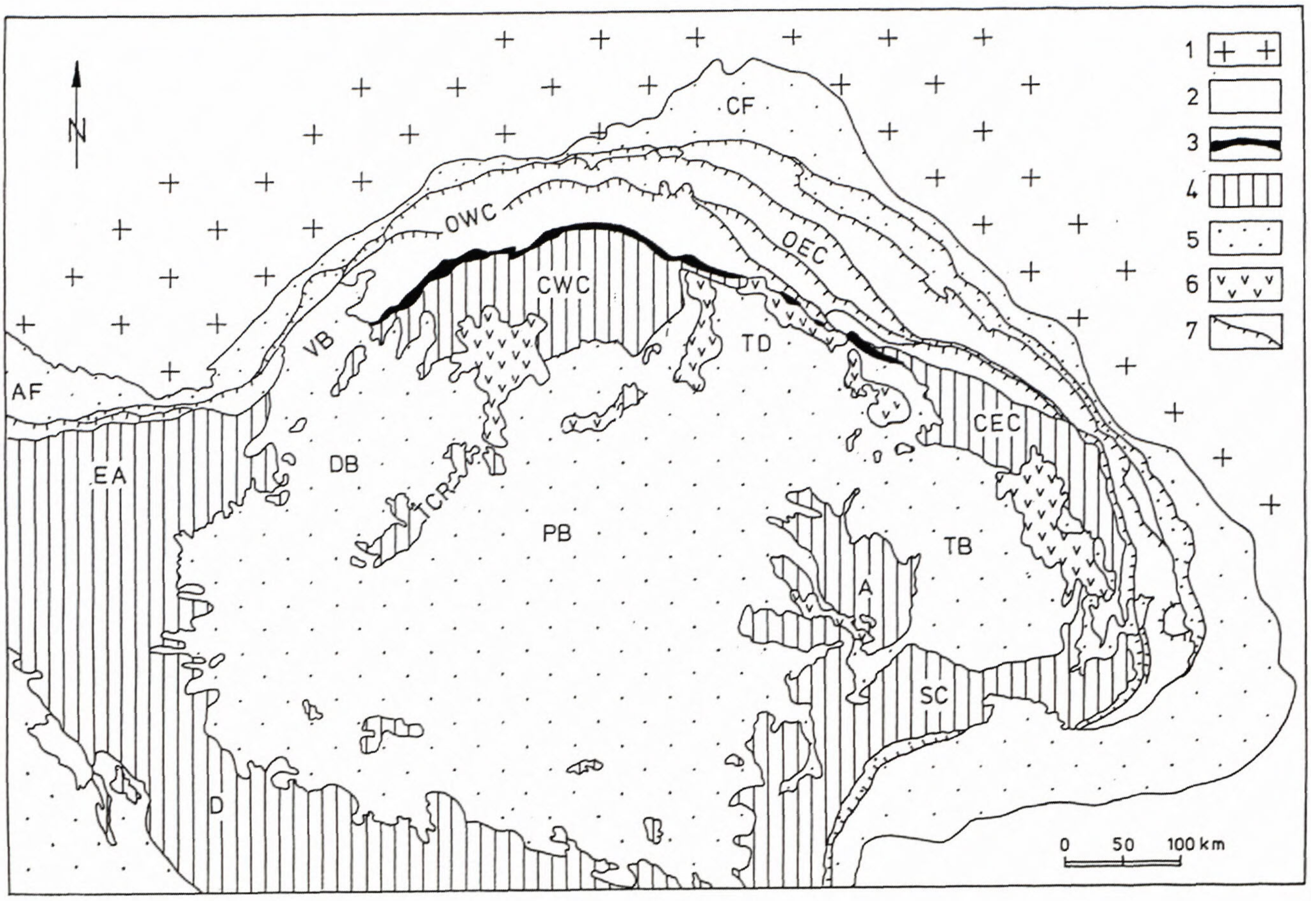


*Fig. 1 Geological sketch of Carpathian arc and Pannonian basinal system (*KOVÁČ *et al. in press).*
1 - North- and East-European platform, 2 - flysch zone of externides, 3 - Klippen belt 4 - Inner Carpathians, 5 - Neogene basins, 6 - Neogene volcanics, 7 - thrust lines, AF - Alpine foredeep, CF - Carpathian foredeep, OEC - Outer Western Carpathians, CWC - Central Western Carpathians, CEC - Central Western Carpathians , SC - Southern Carpathians, EA - Eastern Alps, A - Apuseni, D - Dinarides, VB - Vienna Basin, DB - Danube Basin, PB - Pannonian Basin, s.s., TB - Transylvanian Basin, TD - Trans-Carpathian Depression.

As observed in the field, during the first phase, the rocks which now form the Klippen belt, became subject of a compression oriented perpendicularly to the belt's strike. In most klippen there are shear thrusts (Table 1) and folding structures accompanied by strike slips (Table 2). At the northern fringe of the Inner Carpathian Paleogene, at the contact with Klippen belt, southvergent back thrusts and imbricated systems of partial thrusts (seen e.g. at the Gäceľ locality - part Dolný Kubín) have been formed. This phase which, we presume, was coeval with the overthrusting of flysch nappes in the western part of Carpathians (Vienna Basin area), dates back to Oligocene? - Lower Miocene. Cessation of nappe overthrusting processes in the western part of Carpathians in Karpatian stage marked an end of compressional phase. Succession of tectonic events and change of strain field in the area of Brezovské Karpaty were characterised by a clock-wise rotation of compressional process, i.e. from NW - SE to NE - SW (MARKO et al., 1991; FODOR, 1995). At the same time the paleogeographic situation at the end of Otnangian, when the sedimentation area of the Western Carpathian sea has been connected with the Alpine foredeep and during Karpatian there developed a new marine connection with the Mediterranean area in the south, indicates that important changes in tectonic regime with activisation of strike slips have taken place.

Progressive reorientation of the strain field gave way to gradual formation of strain slips and shear folds. A sinistral shear zone has been formed in the area of Klippen belt (Table 3). This transpressional regime influenced the development of Klippen belt between Lower and Upper Miocene. Maximum strain σ_1 was oriented generally in NNE - SSW direction.

Subsequent extensional regime, characterised by randomly oriented downslip faults, predominated in the Klippen belt area during the Upper Miocene (Table 4). The downslip faults can be observed at all investigated localities in the Klippen belt's area.

The effects of successive individual deformational stages can clearly be observed at many places. At the Podbielsky Cickov locality (abandoned quarry in the valley with homonymous name, some 2 km from Podbiel)

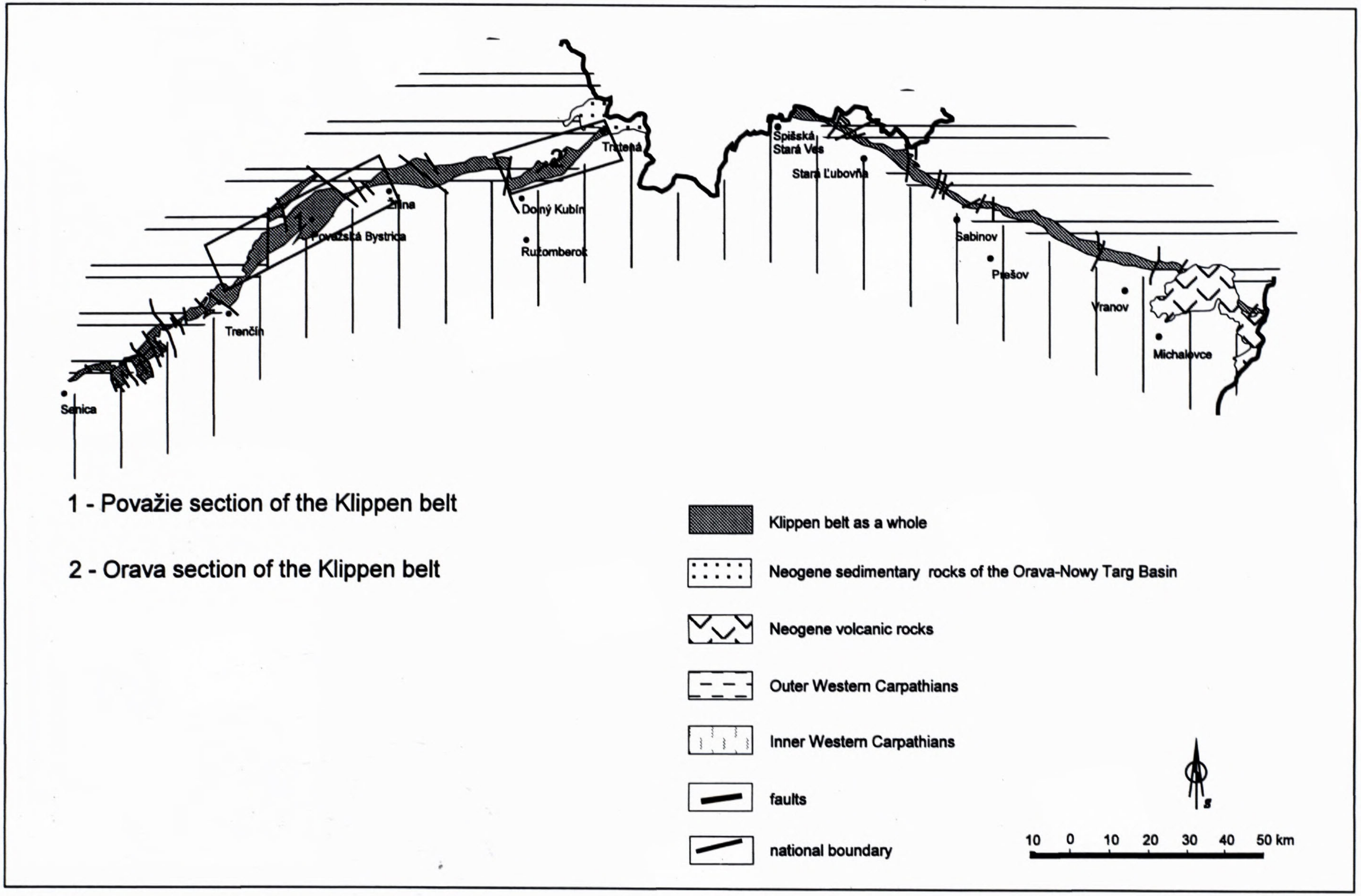


Fig .2 Schematic tectonic sketch map showing Klippen belt and the areas investigated the mesoscopic faults, which formed due to bend gliding in a process of pure compression, can be observed. The course of axial planes of faults indicates that the strike of maximun compression was oriented perpendicularly to the strike of the Klippen belt. Ensuing deformational process was responsible for formation of shear folds (Fig. 5).

Data on magnetic anisotropy and paleomagnetic data

As indicated by magnetic anisotropy data from the western section of the Klippen belt the deformation has taken place predominantly under brittle conditions (Hrouda et al., 1992), whereas plastic deformation was here weaker compared to Sliezska, Bystrická and Rača Units (Hrouda, 1993a). However, we can contend that generally, the deformational effects within the Klippen belt were stronger compared to marginal units of the Flysch belt, but weaker relative to Inner Carpathian units (Hrouda, 1993b). As regards the intensity of deformational effects in individual sections of the Klippen belt proper, it was generally about equal, excepting the Žilina section, which was characterised by relatively stronger effects (Hrouda, 1993b).

The results of research into orientation of magnetic foliation and lineation in the investigated section of the Klippen belt indicate that some differences exist between this and the adjoining section of the Flysch belt. In fact, the Klippen belt was affected by events which have no equivalent in the Flysch belt. (Hrouda et al., 1992). Although not as clear-cut as they should be, the courses of poles and magnetic foliation (Hrouda 1993a Fig. 5-11) suggest NE-SW direction of the compression and complicated deformational history of the Klippen belt and adjoining sections of the Flysch belt.

Interpretation of paleomagnetic data (Fig. 6) evidences a counterclockwise (CCW) rotation of rigid blocks along the margin of moving block of Western Carpathians. Measured values show approximately 40-60° CCW rotation of the Sliezska Unit, 60° CCW of the Magura Unit in NW part of the Flysch belt (Krs et al., 1982,1991) and 28-43° in NE part of Vienna Basin (Túnyi and Kováč, 1991, Kováč and Túnyi, 1995). While the maximum CCW rotation in the western part of Central Western Carpathians could have reached between Eocene

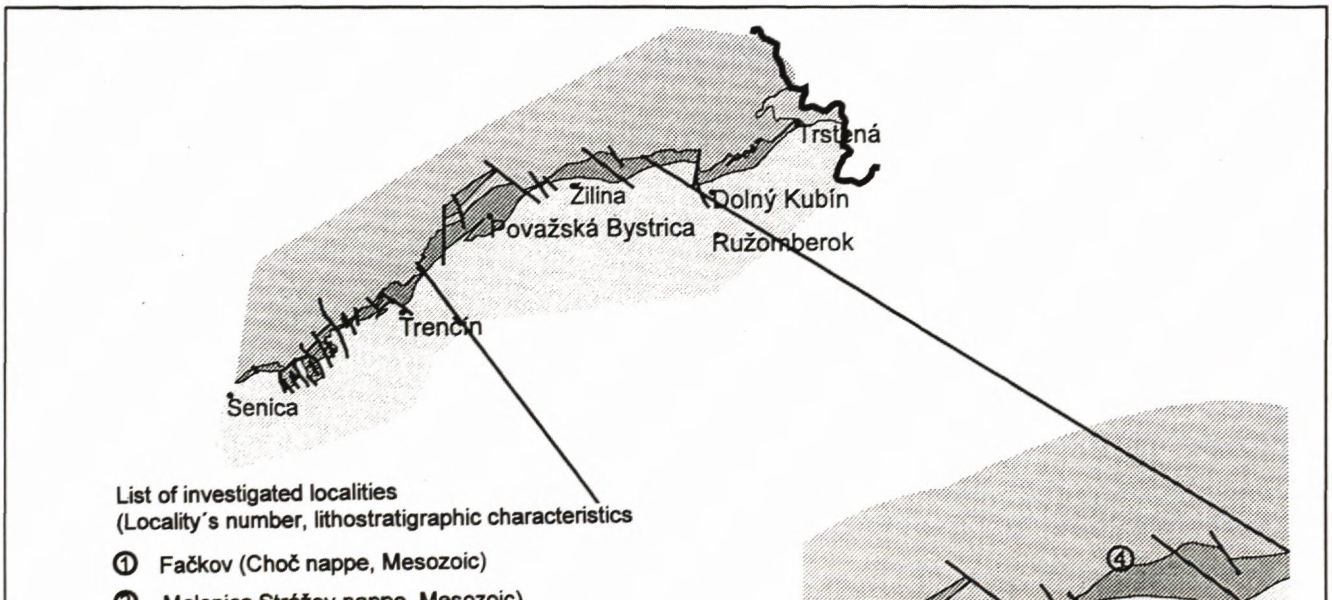


Fig. 3. Schematic tectonic sketch map showing Považie section of the Klippen belt and the localities with structural measurements in broader surroundings

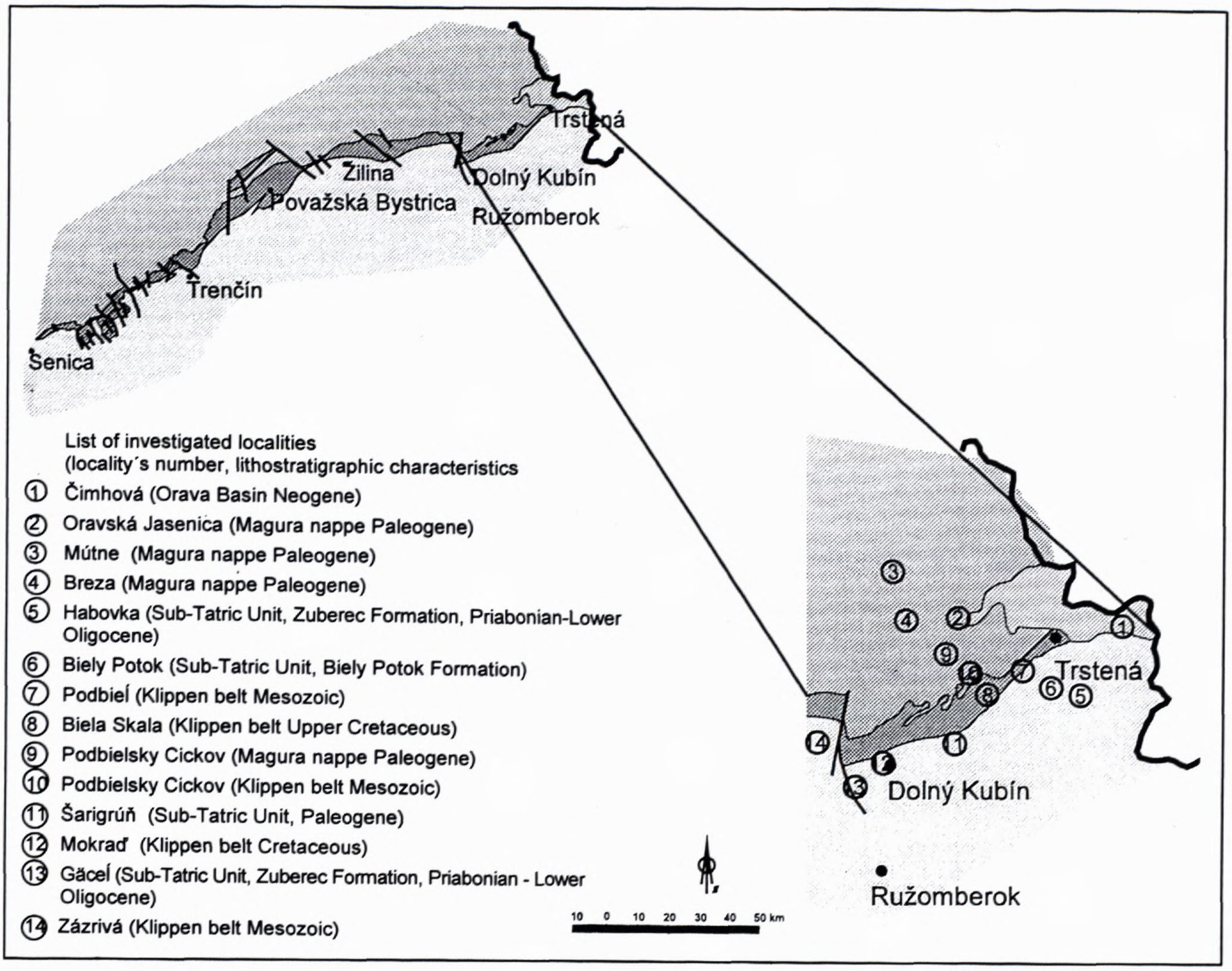


Fig. 4. Schematic map of Orava section of the Klippen belt showing the localities with structural measurements

and Oligocene 40-60° (Kováč and Túnyi, 1995), at the end of Lower Miocene it probably reached only 30-40° (Kováč and Túnyi, 1995).

The paleomagnetic rotation data together with the results of orientation of pole courses and magnetic foliation clearly record transpressional tectonic regime in the area of the Klippen belt.

Paleotectonic development

As the opening prograded during Lower Jurassic the sea bed relief in the "sedimentation area of the Klippen belt" became dissected. Jurassic transgression proceeded from west to east (Birkenmajer 1986). Between Middle Jurassic and Lower Cretaceous there prevailed sedimentation of pelagic sediments. The Middle Cretaceous times have seen an equilibration of sedimentation conditions in a process of deepening. There are records that the onset of the flysch "trench" sedimentation occurred in the Upper Cretaceous and continued with gradual tectonic spatial shortening and piling of both, the Klippen belt units and overthrusted units of the Central Western Carpathians, to form north-vergent fold-nappe belt, the present-day Klippen belt (Maheľ, 1978; Mišík 1978, Plašienka, 1995).

Formation of the fold-nappe belt continued during Paleogene. Partial emersion has taken place. Thrusting of the Pieniny and Kysuca sequences over the Czorsztyn sequence occurred during Paleocene, while during Eocene the deep water sedimentation has been initiated. At the contact with Central Carpathian block the Klippen belt has been strongly deformed during Oligocene and the Klippen belt formations have been erected and locally reworked to form south-vergent structures (Andrusov, 1938). The along-strike movements between Miocene and Pliocene were associated with the faults and fissures developed mainly in competent rocks, while the uncompetent rocks became subject of folding. Uneven transport of individual blocks of Central Western Carpathians resulted in the development of sigmoidal bends in the Klippen belt (Andrusov, 1927).

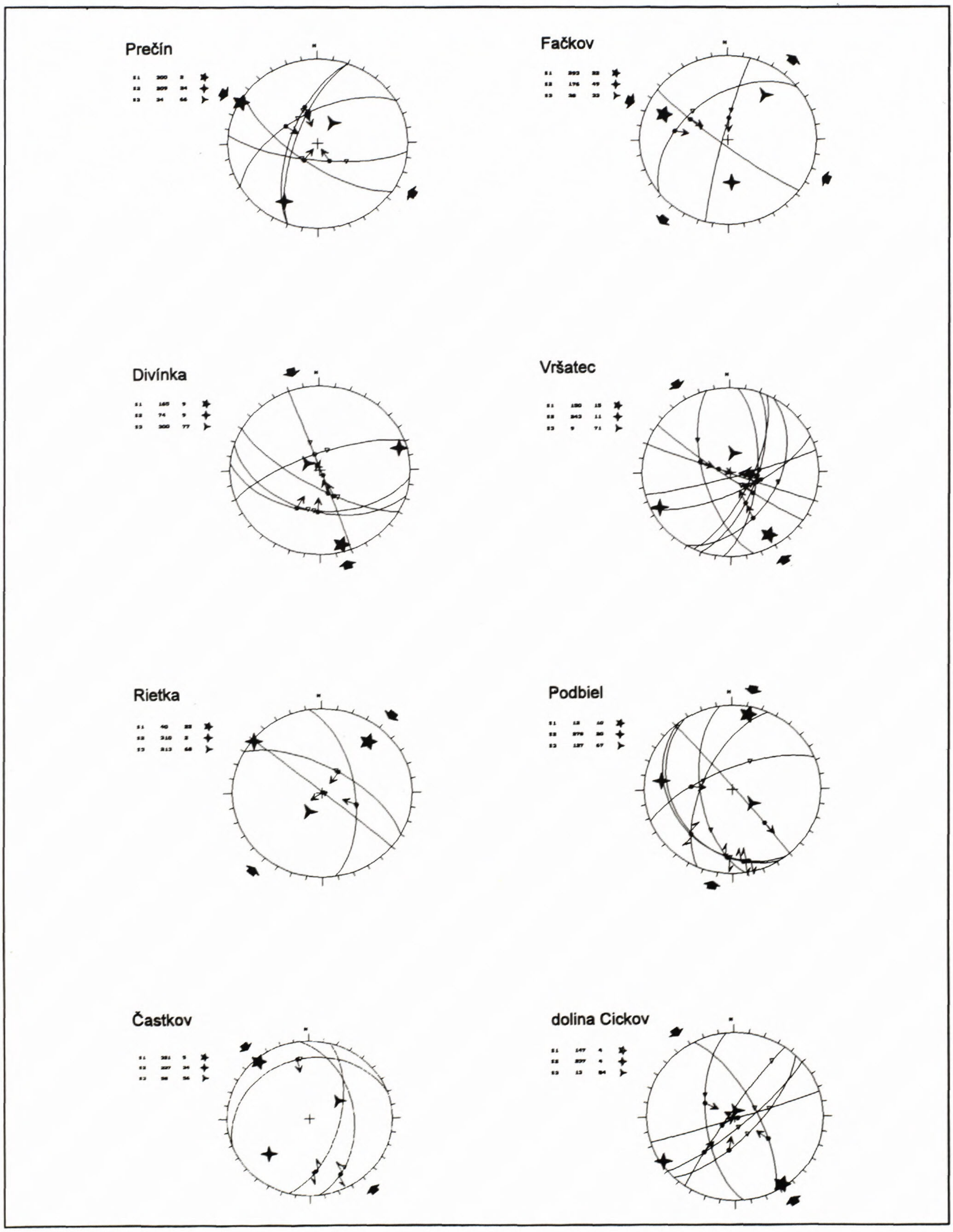


Table 1. Structural measurements in the area of Klippen belt and surrounding units Cickov valley

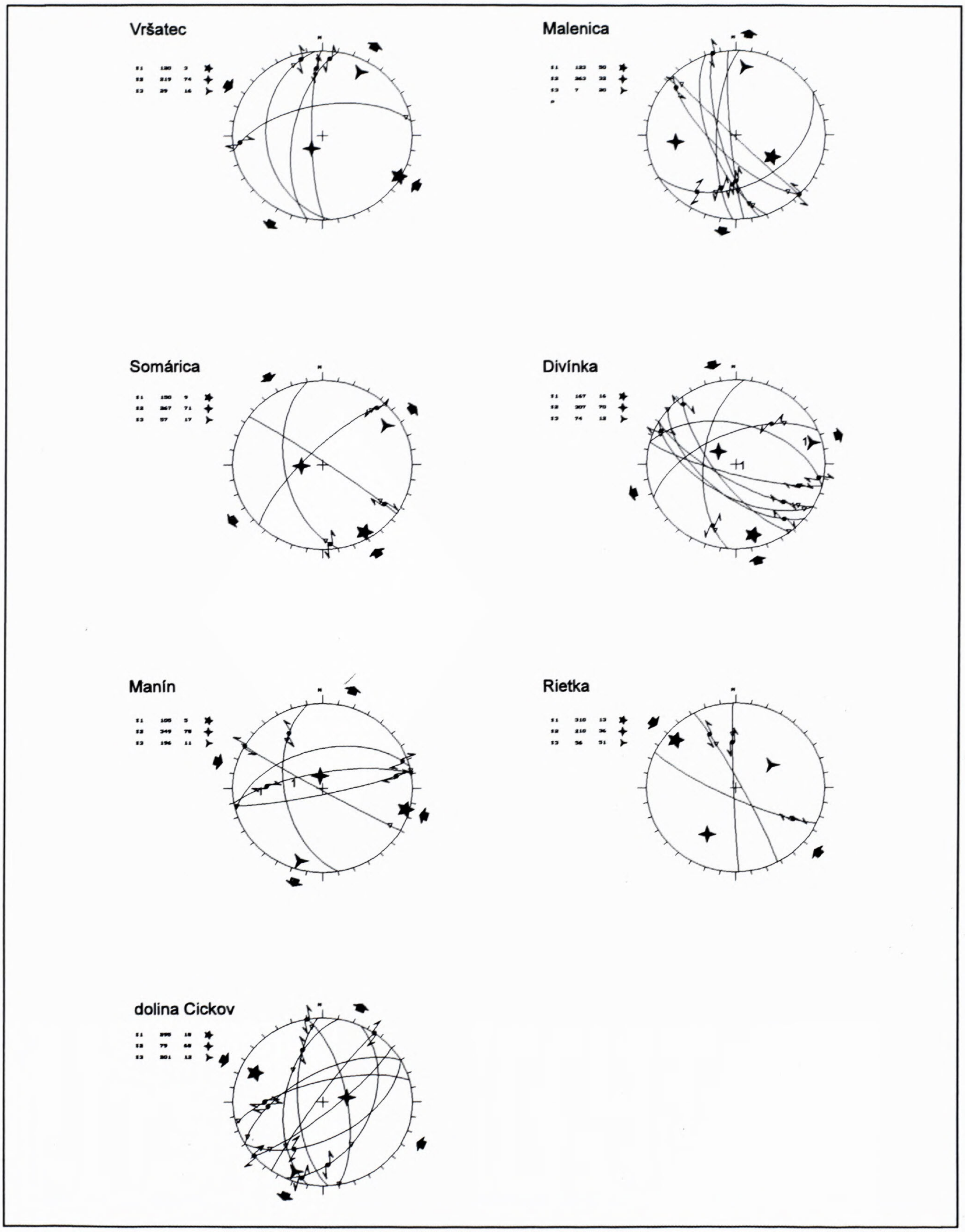


Table 2. Structural measurements in the area of Klippen belt and surrounding units Cickov valley

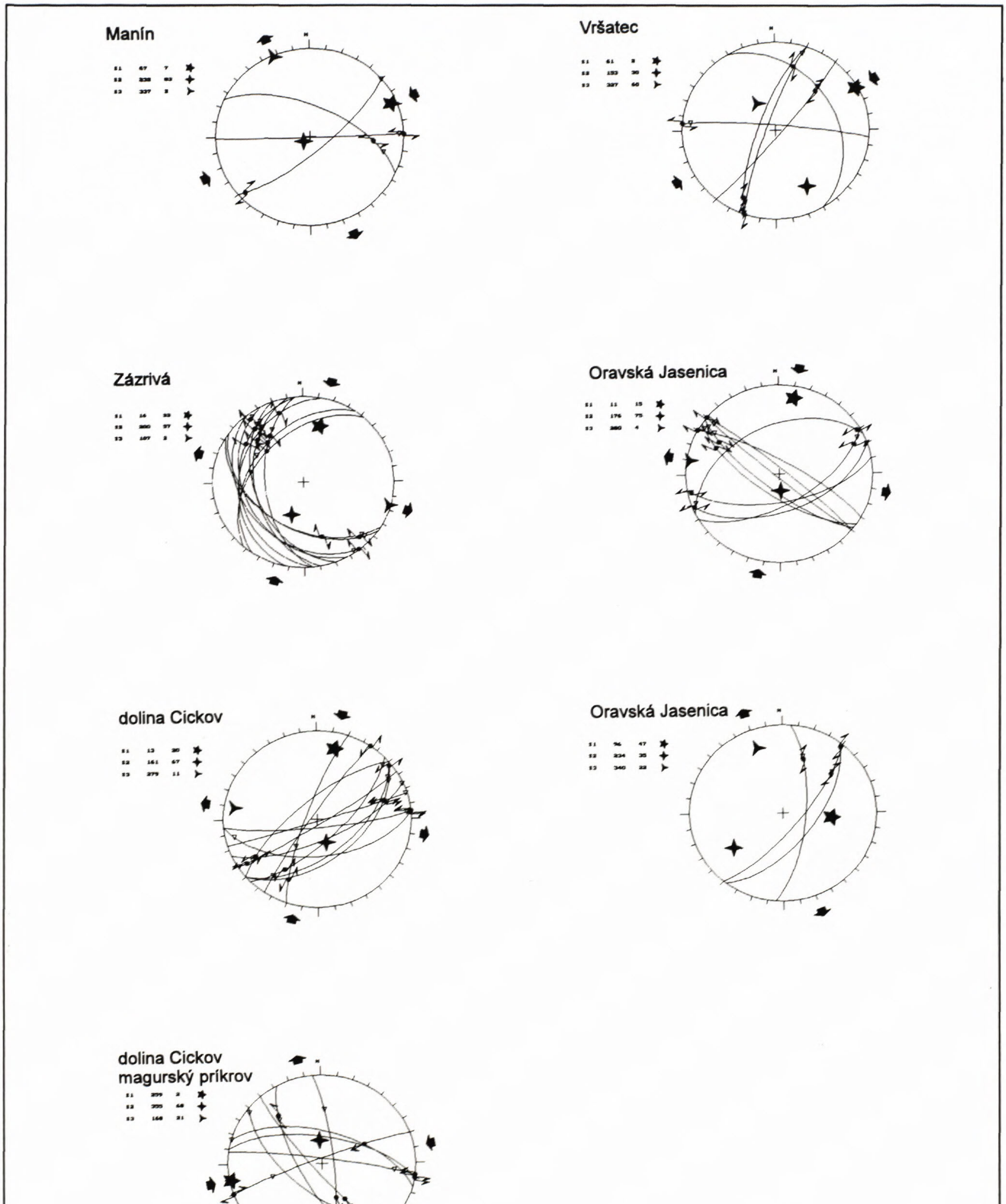


Table 3. Structural measurements in the area of Klippen belt and Magura Unit Cickov valley, Cickov valley Magura nappe

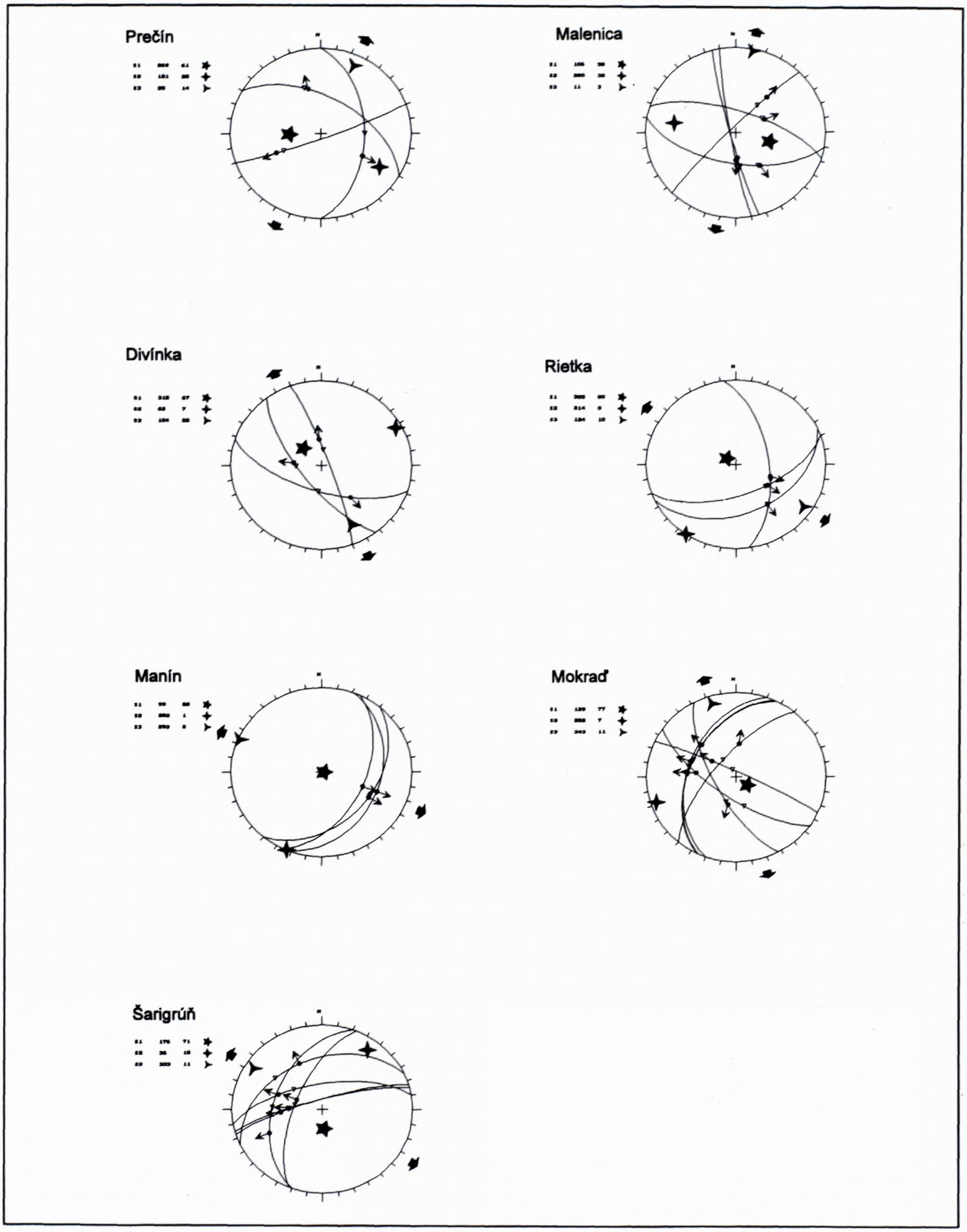


Table 4. Structural measurements in the area of Klippen belt and surrounding units

Discussion

Present shape of the Klippen belt is a result of its long term, continuous deformation brought about by convergence and later collision of the Inner Western Carpathians with the European platform (Fig. 7).

Structural analysis made in the western section of the Klippen belt allows to characterise Tertiary stage and its deformational development. The whole expanse of Klippen belt displays a very complicated internal structure. The bend gliding type folds observed as well in the rocks of the Klippen belt proper as in the rocks of the Magura nappe (Alexandrowski, 1989) speak in favour of a compressional stage spanning the time from Eocene-Oligocene to Lower Miocene, characterised by spatial shortening oriented perpendicularly to its course. The then Klippen belt was probably situated more to the south-west relative to its recent position and it was oriented NW-SE (Oszczypko and Slaczka, 1985, Kováč et al 1994). Compressional regime is also evidenced by frequent south-vergent (recent situation) reverse faults. Gradual rotation of the western part of Klippen belt went on until the end of Lower Miocene (Krs et al. 1982,1991, Túnyi a Kováč, 1991, Kováč a Túnyi 1995). Transpresional regime, predominant in the western part of Klippen belt since Lower Miocene, have progressively gained the ground. A sinistral shear zone have formed. The orientation of maximum stress was generally NNE-SSW. The transition from compressional to transpressional regime was presumably diachronous, as substantiated by subsequent waves of overthrusting of east-vergent flysch nappes (Jiříček, 1979).

Timing of tectonic events in the area of Outer Carpathians is also evidenced by stratigraphic divergence of the foredeep's filling, composed in the Polish and Ukrainian parts of the Badenian and Sarmatian sediments, while in the Romanian side the sedimentation continued until Quaternary (Roure et al., 1995). The molasse sediments usually directly overlie the Mesozoic, or crystalline basement of the foreland, as evidenced by a distinct erosional event, which took place between Upper Cretaceous and Paleogene as a possible consequence of Laramian phase. In contrast to diachronous tectonic events, which occurred during Late Oligocene to Miocene, the records of Upper Cretaceous to Paleocene Laramian inversion tectonics indicate its synchronous course along the whole perimeter of the Klippen belt.

The above facts evoke a concept of a compact block of Inner Western Carpathians, whose mobility between Upper Cretaceous and Paleogene resulted in a collision

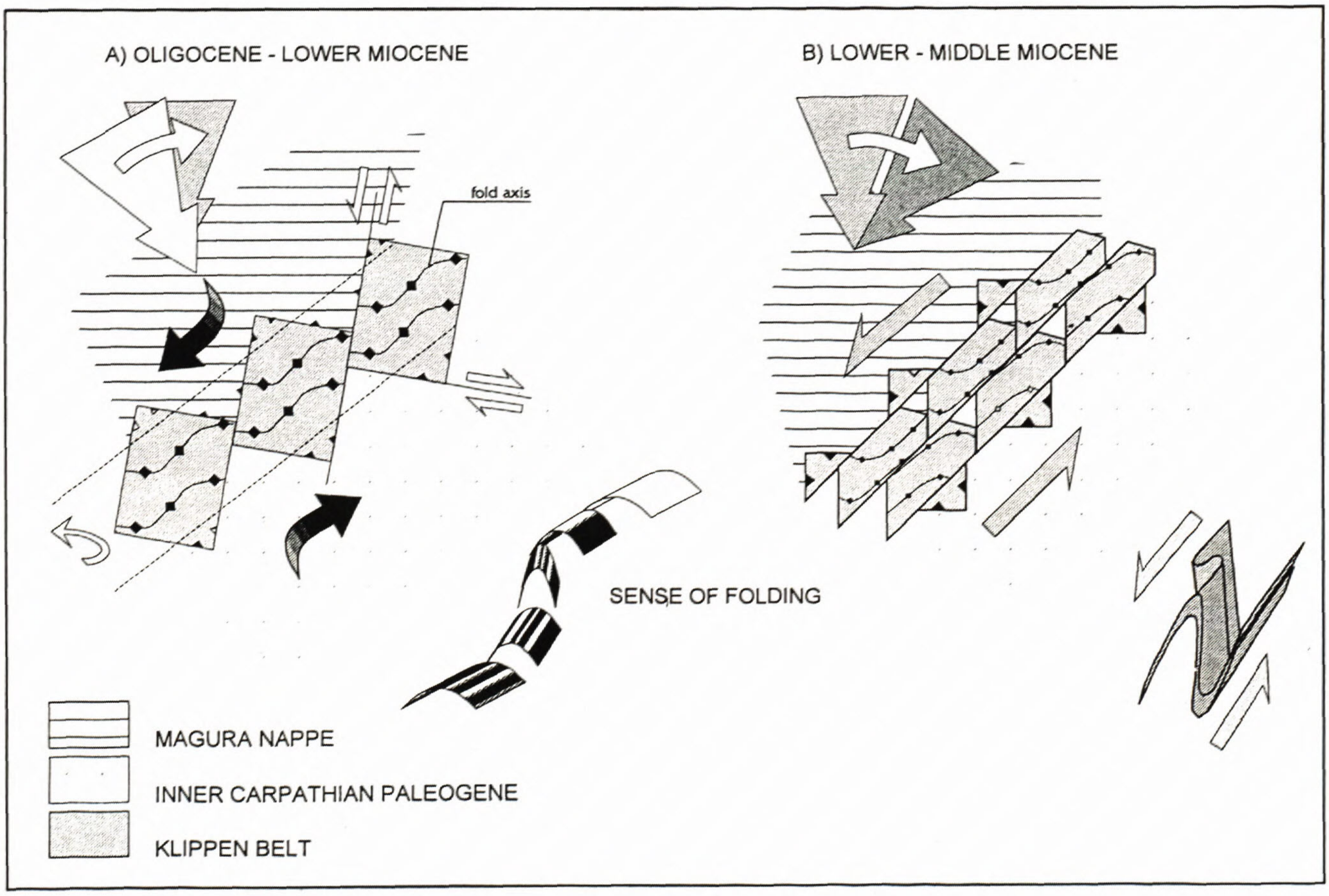
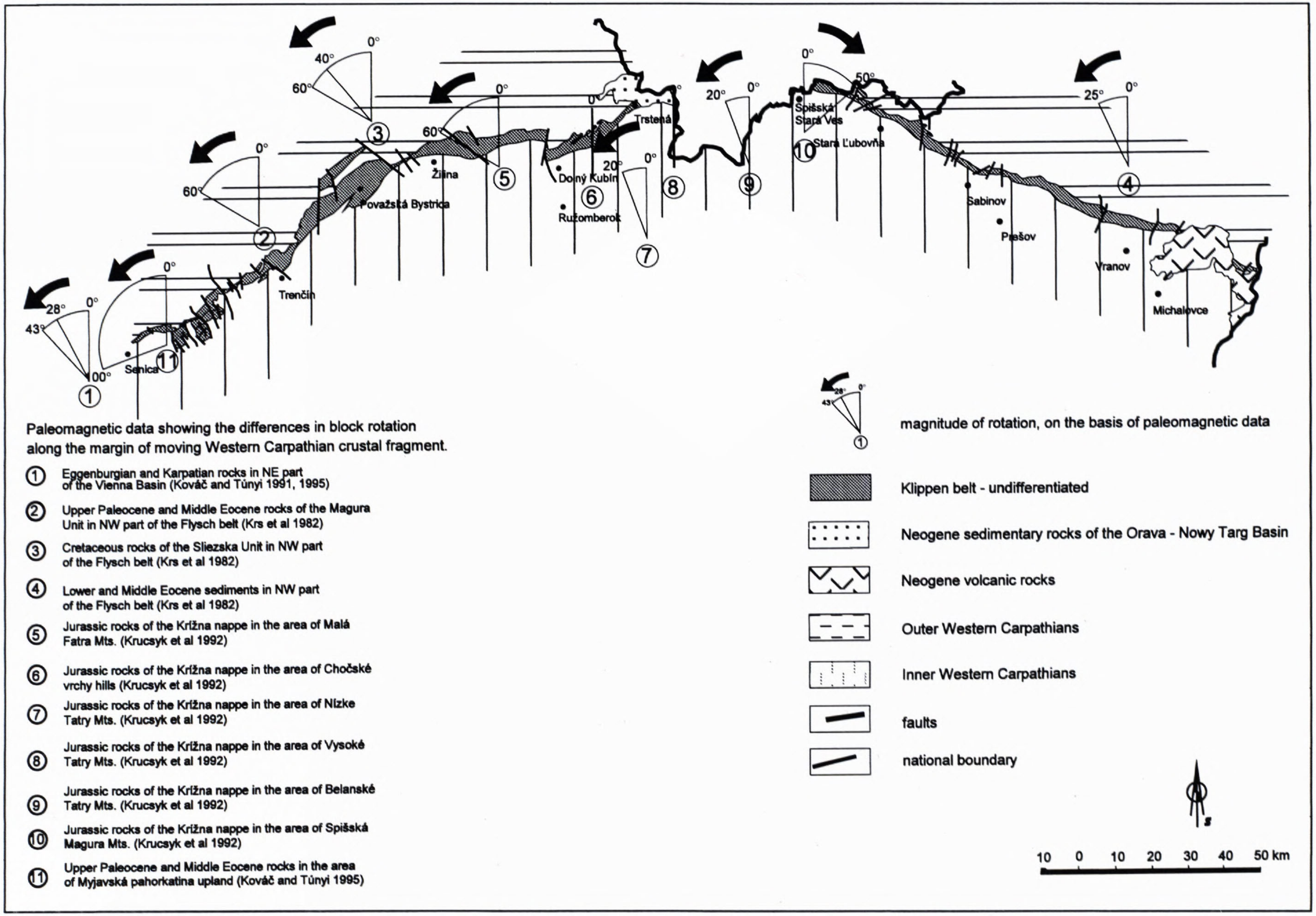


Fig. 5. Deduced kinematic development of the western part of Klippen belt



Paleomagnetic data showing the differences in block rotation along the margin of moving Western Carpathian crustal fragment.

① Eggenburgian and Karpatian rocks in NE part of the Vienna Basin (Kováč and Túnyi 1991, 1995)

② Upper Paleocene and Middle Eocene rocks of the Magura Unit in NW part of the Flysch belt (Krs et al 1982)

③ Cretaceous rocks of the Sliezska Unit in NW part of the Flysch belt (Krs et al 1982)

④ Lower and Middle Eocene sediments in NW part of the Flysch belt (Krs et al 1982)

⑤ Jurassic rocks of the Križna nappe in the area of Malá Fatra Mts. (Krucsyk et al 1992)

⑥ Jurassic rocks of the Križna nappe in the area of Chočské vrchy hills (Krucsyk et al 1992)

⑦ Jurassic rocks of the Križna nappe in the area of Nízke Tatry Mts. (Krucsyk et al 1992)

⑧ Jurassic rocks of the Križna nappe in the area of Vysoké Tatry Mts. (Krucsyk et al 1992)

⑨ Jurassic rocks of the Križna nappe in the area of Belanské Tatry Mts. (Krucsyk et al 1992)

⑩ Jurassic rocks of the Križna nappe in the area of Spišská Magura Mts. (Krucsyk et al 1992)

⑪ Upper Paleocene and Middle Eocene rocks in the area of Myjavská pahorkatina upland (Kováč and Túnyi 1995)

Fig. 6. Simplified map of the Klippen Belt with values with values of paleomagnetic measurements

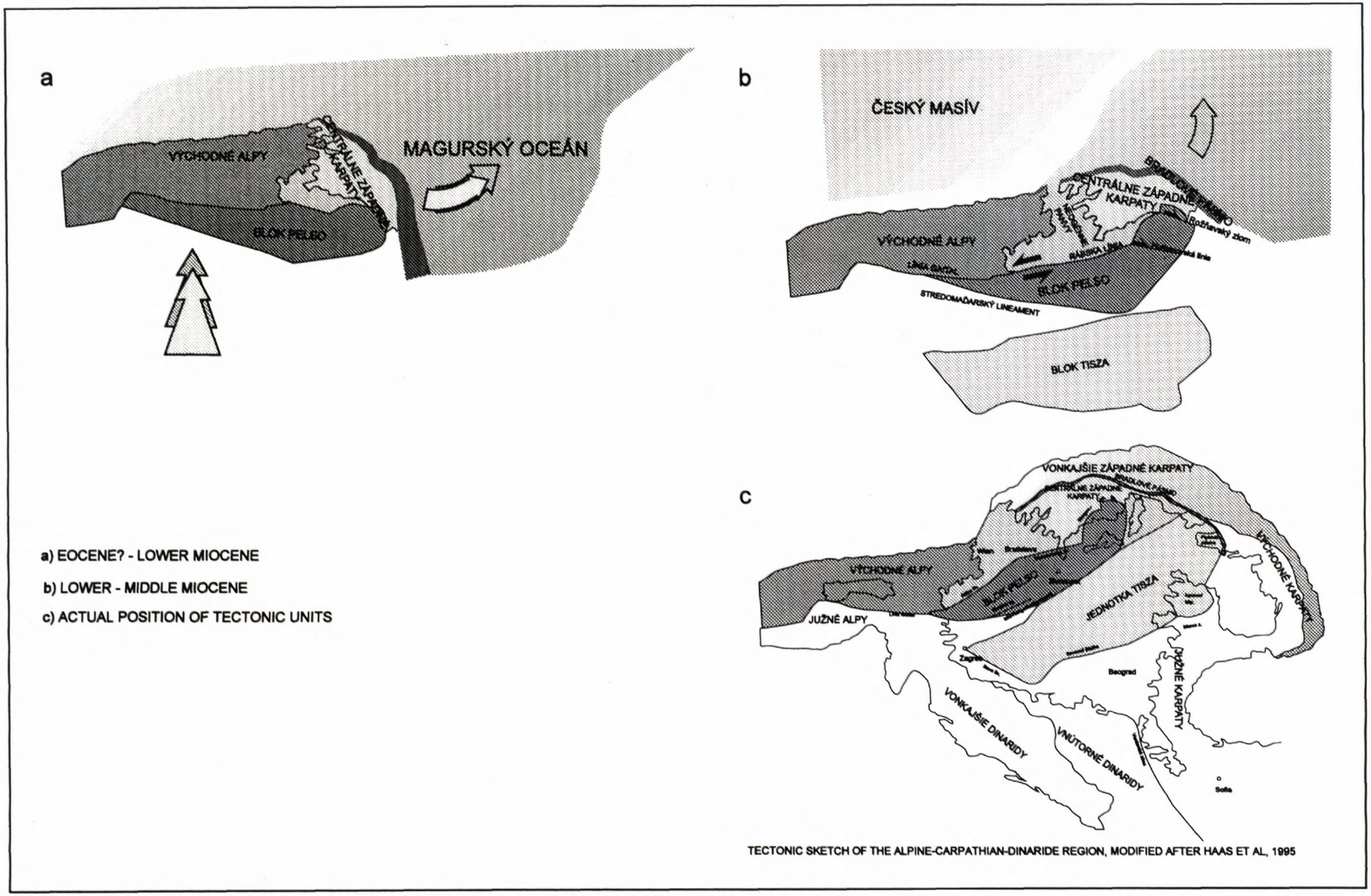


Fig. 7 A model of tertiary development of the Alpine-Carpathian-Pannonian region

along its western margin with the margin of the European platform at the end of Oligocene and during Lower Miocene (Fig. 7). The area of collision shifted gradually eastwards. In structural terms, the deformation process is expressed by gradual transition from compressional to transpressional regime.

The fact that the intensity of compression gradually decreased is vividly demonstrated by overall Post-Oligocene shortening of the Romanian part of the Flysch belt reduced between Badenian and Sarmatian by approximately 108 km, as compared to the reduction between Pliocene and Quaternary, which reached only 22 km (Roure et al. 1993). In the Polish and Ukrainian parts the compressional events were terminated at the end of Sarmatian.

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