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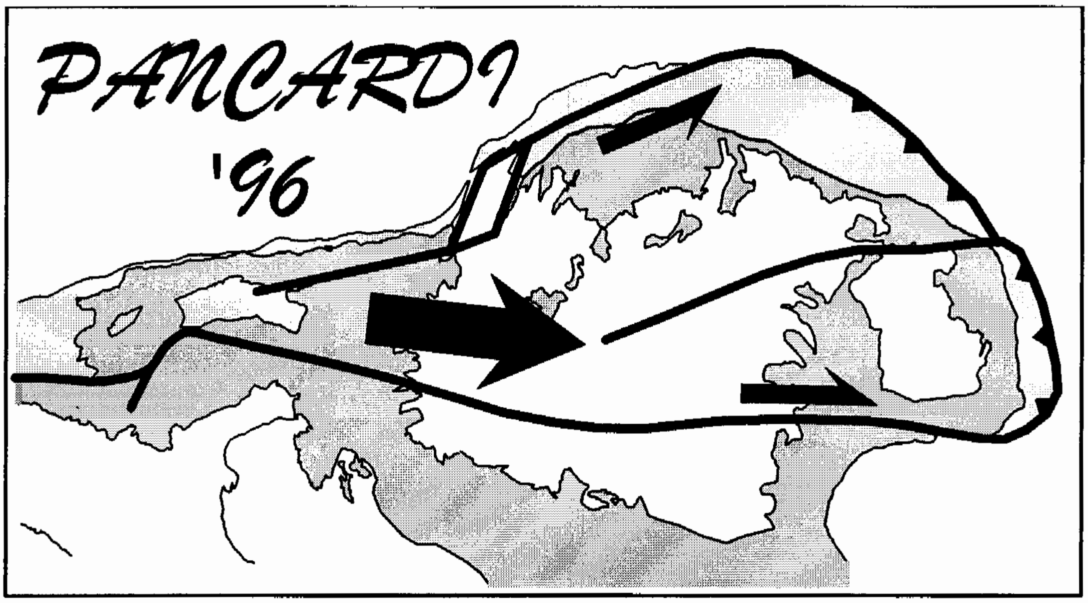

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A preliminary study of gravity field in the Eastern and Southern Carpathians and the narrow continental rifts in the Pannonian Basin

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Preliminary two-dimensional gravity models are presented along a Eastern Carpathian-Transylvanian basin-Pannonian basin transect and a Eastern Carpathian-Transylvanian basin-Southern Carpathian transect. The models are based on lithospheric cross-section on the Galati-Chisineu Cris profile, geological crustal cross-sections, published maps of crustal, lithosperic and sediment thisknesses, topography and detailed analysis of the long-wavelength Bouguer anomaly in Romania by local isostatic equilibrium study. The results show extensional lithosphere structures of the Transylvanian and Pannonian basin agree with the gravity field. Moreover, they indicate a crustal slab under the Eastern and Southern Carpathians.

The Pannonian basin is very suitable region for study of the image of the narrow continental rift as a mode of continental extension tectonics. In order to constrain the lithospheric structure of the B,k,s basin - the most available example of the narrow rift mode extension - gravimetric and magneto-telluric studies are presented. The study of the narrow rifts in the Pannonian basin suggets that an applied mode of continental extension tectonics from Buck for the B,k,s basin would be modified. The modification consists in consideration of intrusions of the high-density masses within the crust beneath the deep subbasin. The B,k,s basin is characterized by upwelling not only the Moho but also asthenosphere. In spite of significant thickness of the sedimentary basin fill the narrow rifts in the Pannonian basin are followed by relative gravity highs.

Alpine structure and geodynamic evolution of the Balkanides

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Recent plate tectonics concepts interprete the Alpine thrust belt on the Balkans as a mosaic of paleogeodynamic units, some of local and other of exotic origin, accreted to the Eurasian continent during the closure of the Tethys. The Balkanides, thrusted to the north over the foreland, form the external parts of the orogen.

The Alpine orogen is divided into two parts by the Vardar-Izmir-Ankara ophiolite suture - the main trace of the Tethys ocean which opened probably in the Middle Jurassic and closed during the Late Cretaceous or the Middle-Late Eocene. The northern part of the orogen includes mainly geodynamic units of the Eurasian continental margin and the southern one far-travelled fragments from Africa welded by sutures of different age and scale.

Parts of two first-order paleogeodynamic units are identified on the territory of Bulgaria: Moesian microcraton (foreland of the Alpine orogen) and deformed continental margin (the orogen itself).

The Moesian microcraton accreted to the Eurasian margin towards the end of the Paleozoic. It comprises a 3-5 km thick sequence of dominantly subhorizontal Mesozoic and Neozoic sediments overlying a pre-Paleozoic and Paleozoic folded basement. The cover rocks were deposited in shallow marine epicontinental basins with occasional and short continental depositional breaks. Major unconformities have been drilled at the base of the Triassic, Jurassic, Upper Cretaceous and the Neogene.

The deformed continental margin is a system of north vergent thrust sheets which contain fragments of the microcraton; of marginal flysch basin sediments formed during the Early-Middle Jurassic, Late Jurassic-Early Cretaceous and Late Cretaceous; of local, proximal and exotic tectonic units (or terranes) accreted to the continental margin during the Late Jurassic and the Early Cretaceous; of a Late Cretaceous volcanic island-arc system with recognisable frontal, axial and back-arc elements. A system of LateTertiary extensional basins is superimposed upon various units of the deformed continental margin.

Five stages may be recognised in the Alpine evolution of the continental margin: Triassic-Middle Jurassic (stage of passive continental margin in the northern periphery of the Paleotethys); Late Jurassic-Early Cretaceous (stage of passive continental margin in the northern periphery of the Neotethys); Late Cretaceous (stage Auf active continental margin and growth of the Srednogorie volcanic island-arc); Early Tertiary (collisional stage); Late Tertiary: (extensional stage).

The Vienna Basin: tectonics, subsidence and thermal evolution of a thin-skinned pull-apart

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The sediments of the Vienna pull-apart basin unconformably overly Alpine-Carpathian thrust sheets and sediments of an Early Miocene piggy-back basin which were thrust over the European (Bohemian) basement between the Eocene the early Miocene (c. 55 to 17 Ma). The formation of the pull-apart between the Karpatian (17 Ma) and the Pannonian stage (c. 8 Ma) coincides with the transition from post-collisional thrust shortening to the eastward lateral extrusion of the Alpine units. During extrusion, a sinistral transform system evolved which continued from the central Eastern Alps through the Vienna Basin into the Outer Carpathian Flysch nappes. The tectonics which led to Middle Miocene subsidence of the Vienna Basin between left-stepping segments of this transform fault can be described as divergent strike-slip duplexes. Rhomb-shaped duplexes from several hundred meters length up to the size of the entire basin are delimited by NE-striking sinistral faults and by connecting NNE-striking oblique-normal faults. Such duplexes were mapped along the basin margins and by 3D-seismic surveys of the OMV in the basin (Häusler et al., this vol.). Extension and strike-slip faulting was restricted to the Neogene sediments and the Alpine-Carpathian nappes overlying the European basement, i.e., to the uppermost 10-12 km of the crust.

Paleogegraphic maps show that the pull-apart basin acquired its outline in less than 1 Ma (within the Karpatian stage) and that the basin shape did not change during the Middle Miocene. High total basement subsidence, high subsidence rates (up to 5.8 km in 9 Ma), and comparably low finite extension (20-30%) characterise the duplex-shaped basin.

The basement subsidence of a divergent strike-slip duplex mainly is a function of the geometries and the kinematics of the basin boundary faults. Strain rate, duplex size, and depths to detachment determine amount and velocity of subsidence. Basement subsidence curves computed for a duplex of constant volume show that subsidence rates decrease with time, resembling subsidence curves of the McKenzie rifting/thermal cooling model. However, unlike in the McKenzie-model, this decrease is not due to thermal processes during cooling of the basin. Concave-up subsidence curves result from the strain geometry and from isostatic rebound effects.

The thermal evolution of a thin-skinned extensional basin which formed by extension of the uppermost crust has been modelled by finite difference algorithm. The model was set up for a 100 km thick lithosphere (30 km crustal thickness) with an initial steady-state geotherm and constant heat flux at the base of the crust as lower boundary condition. Crustal temperatures were computed for a 50 m grid which gives extremely good spatial resolution. Thin-skinned extension was modelled by a pure-shear velocity field applied to the uppermost 12 km of the crust. The resulting „basin" was continuously filled with sediments and a velocity field was constructed which accounted for synsedimentary deformation. Models were computed for 9 Ma subsidence, constant strain rate, 60% vertical thinning, and different sediment conductivities. The results show that thin-skinned extension hardly changes the initial thermal conditions and that only a very minor downbending of isotherms occurs. Advective downward transport of cool crust in the strained area overlaps and is nearly extinct by heat convection from the base of the lithosphere to the surface.

In sum it can be shown that subsidence of thin-skinned extensional basins is a function of strain geometries, deformation mechanisms, and isostatic rebound effects which result from the substitution of basement rocks by the unconsolidated basin-fill sediments. Thermal processes are not important for the subsidence of such basins. For the description of the Vienna pull-apart basin, the model of a divergent strike-slip duplex with a basal detachment which coincides with the floor thrust of the Alpine-Carpathian nappes seems to be most appropriate.

New geothermal measurements in Transylvanian Depression. Preliminary report on a joint cooperation between the Institute of Geodynamics - Bucharest, Romania, and the Geophysical Laboratory - Aarhus, Denmark

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From the heat flow point of view the Transylvanian Depression is well known as a remarkable low, in contrast to other Neogene basins in the Carpatho-Pannonian-Dinaride system. A joint cooperation between the Institute of Geodynamics - Bucharest and the Geophysical Laboratory - Aarhus on the heat flow and lithosphere evolution in the Transylvanian and Pannonian basins started in 1996 as a contribution to the subproject "Paleo Heat Flow and Fluid Flow in the Transylvanian and Pannonian Basins" of the PANCARDI Project of EUROPROBE. Funding is provided by the Romanian Academy and the Danish Natural Science Research Council.

A campaign of borehole temperature measurements was undertaken in August 1996 and the data from 12 thermally stabilized boreholes in unsampled areas of the Transylvanian Basin will be reported in this paper. The logging system built by the Geophysical Laboratory of Aarhus University consists of a quartz thermometer, a winch driven by an electric motor, a two conductor cable of length 1.5 km, a cable counter for depth measurement and a PC for data acquisition. The power is supplied by a generator. The temperature measurement system is based on the counting of the frequency of a quartz oscillator. The advantages of this system over a thermistor based four conductor system are high stability and the requirement of only a two conductor cable. The quartz crystal is cut to produce an almost linear temperature coefficient of about 1 kHz per degree. The frequency of the quartz crystal is about 9 MHz. Because such a high frequency leads to transmission problems over a long borehole cable the frequency is divided using a CMOS divider prior to transmission. At the surface the signal is filtered, amplified and multiplied to yield a frequency of about 28 MHz. The power requirements of the probe is 10 mA which is supplied from the surface via one of the two conductors. As the boreholes were only partially filled with water, the system was used in the continuous logging mode, with a few stops in the air column to obtain the parameters characteristic to the heat transfer from borehole to thermometer. A deconvolution procedure has been used to derive temperature and gradient variations with depth.

Neogene magmatism and tectonics in the Carpatho-Pannonian region

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Neogene magmatism in the CPR can be classified into (a) an earliest phase of highly siliceous acidic pyroclastic tuffs and ignimbrites, (b) slightly younger volcanism of calc-alkaline affinity, identical in its petrography and geochemistry to subduction-related magmatic rocks worldwide; and (c) a generally later phase of alkaline volcanism, similar to the late Tertiary/Quaternary intraplate activity elsewhere in Europe. An unsolved problem is the origin of the widespread early acidic magmatism which began in several regions 19 Ma ago. It may be linked with lithospheric delamination, in which hot asthenosphere was brought into direct contact with the base of the crust, heating it and causing melting. Such a hypothesis can be tested using isotopic and other geochemical methods.

The acid magmatism was followed by the formation of subduction-related andesitic stratovolcanoes along the West Carpathian arc at ca. 16 Ma. The majority of these calc-alkaline volcanoes were extinct by 10 Ma, an age which coincides with a major E-W compressional event in the region, possibly related to the entry of continental crust into the subduction zone. Thus, if oceanic subduction were responsible for the calc-alkaline magmatism, then the subducted slab first reached the required depth for magma generation of 100-120 km (the "magma generation window") simultaneously beneath the whole of the Western Carpathians around 16 Ma ago and ceased to generate calc-alkaline magma about 6 Ma later.

However, in the Eastern Carpathians there is significant calc-alkaline magmatism younger than 10 Ma, showing an age-progression along the chain from 10 Ma in the north to 0.2 Ma at the southern end of the chain. If an oceanic slab subducted beneath the East Carpathians then it must have reached the magma generation window at a progressively later and later time. It takes a finite time for a subducted slab of oceanic crust to reach the temperature and depth of the magma-generation window; this time-lag could account for the gap between the cessation of tectonism and the onset of magmatism. The time interval between the beginning of subduction and the arrival of the subducting slab in the magma generation window will be a function of the angle of subduction and the rate of subduction. In the East Carpathians the narrow volcanic zone and fast progressive movement of volcanism indicates that the period of time which the slab spent in the magma generation window was short. This in turn suggests that the piece of oceanic crust which was subducted was of small dimension and sank quickly. Slab detachment in the East Carpathians followed the arrival of unsubductible continental crust of the Tornquist zone or East European Platform at the trench around 10 Ma ago.

The oldest extension-related alkaline magmas are about 9-11 Ma old and were erupted just as the calc-alkaline magmatism was waning. This indicates a "switch" from a collisional tectonic regime to an extensional one. After this, alkali basalts occurred sporadically in time and place up to post-glacial times. These magmas may be related to a widespread upwelling of the asthenospheric mantle beneath Europe. They could not be erupted from the upwelling asthenosphere until after the subducting slab had become detached and had sunk into the asthenosphere. Such "slab window" alkali basalts have been observed in other regions of the world when a subducting slab has been detached.

Pre-Alpine and Alpine metamorphic history of the Sopron Hills (Burgenland, Austria)

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The Sopron Hills, in the borderland between Austria and Hungary, represent one of the easternmost occurrences of the Central Alps towards the Carpatians and in spite of the poor outcrop situation they play an important part in understanding the geology of this area. Andalusite (And) - bearing lithologies of presumed pre-Alpine age have been recognised in the Hungarian part of the Sopron Hills for several years. This work deals with the continuation of these rocks into the Austrian part of this crystalline massif. Petrological, geochronological and structural investigations of the partly well preserved pre-Alpine And-bearing rocks give major insights in the *pre-Alpine* metamorphic history, the *Alpine* overprint and the post-mid-cretaceous tectonic exhumation by normal faulting.

Lithologies with a relatively well preserved pre-Alpine mineralogy, which outcrop predominantly in the uppermost levels of the Sopron Hills, comprise the *Óbrennberg-Kaltes Bründl Series (ÓKB)* consisting of schists and feldspar-rich schists with varying amounts of kyanite, sillimanite, and locally preserved andalusite. The rest of the massif with strong Alpine metamorphic overprint comprise gneisses and monotonous diaphthoritic mica schists with varying quartz contents and numerous rectangular to rhomboic pseudomorphs after staurolite (Stau), which is called *Sopron Series (SS).*

Rb/Sr-mineral-ages in both series show partial Alpine resetting, although this was much more effective in the SS than in the ÓKB, where the oldest mineral-ages of the Sopron Hills are preserved.

The mica schists of both series are geochemically relatively similar. According to major- and traces discrimination diagrams, shales with an island-arc-signature are the most probable protolith for these rocks. Major- and trace-element discrimination diagrams for the amphibolites point to a protolith with ocean-floor-affinity, while the gneisses classify as peraluminous syn-collision granites.

The conditions of the pre-Alpine high-T metamorphism in the *ÓKB* are estimated at 650° C and 3-5 kbar. There is strong evidence for an Alpine metamorphism in the SS, with peak-conditions at 550 ± 30° C and 9.5 ± 1.5 kbar.

The SS in this area is believed to belong to the Lower Austroalpine "Grobgneis Unit", whereas the *ÓKB* show striking similarities to the Strallegger Gneisses and to the „Dist-Paramorphosenschiefer" (Koralpe), which are part of the Middle Austroalpine Units.

Although the present tectonic arrangement is supposed to be partly a result of the large scale nappe-transport during the Alpine orogeny the dominant ductile deformation within the mylonites and leucophyllites (shear bands, strain fringes, scc'-fabric, crystal preferred orientation and shape preferred orientation of dynamically recrystallised quartz) indicates a top-to-SE extension. These micro- and mesoscopic kinematic indicators as well as the geometric arrangement of the ductile to brittle deformation style and the Alpine metamorphic overprint suggests extensional exhumation along a SE-dipping normal fault.

Tertiary tectonic evolution of the Pannonian basin system and neighbouring orogens: a new synthesis of paleostress data

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The combination of a paleostress data base, borehole, gravity and seismic data, paleogeographic and stratigraphic information suggest that 7 major Tertiary tectonic episodes can be recognized in the Pannonian basin and surrounding orogens. The first two episodes affected two, separated major blocks, the East Alpine-Western Carpathian-North Pannonian (Alcapa) and the South Pannonian-Eastern Carpathian (Tisza-Dacia) blocks.

A Middle Eocene to Early Oligocene N-S compression is connected to contractional basin formation in the foreland and hinterland of the Alpine-Carpathian orogenic wedge. Due to the north-westward shift of the Adriatic promontory, the Alcapa terrane was separted from the Southern

Alps. This process probably started during latest Oligocene, and accelerated during the Early Miocene. The main dextral slip was accommodated along the Periadriatic and Mid-Hungarian shear zones. This dextral separation was associated with the lateral extrusion of the Alcapa wedge. During and/or after this tectonic episode, within the Ottnangian the eastern (Pannonian-Carpathian) part of the Alcapa suffered 50° CCW, the southern Tisza-Dacia block 60°-80° CW rotations.

The Pannonian basin system was born by rifting of back-arc style during the late Early and Middle Miocene time. The tension was oriented initially eastward, toward the free interface of the Carpathian subduction front. From the middle Badenian onward the direction of tension were controlled both by the retreating subducted slab and by the gradual cessation of thrusting in the Western Carpathians. The norheastward drag (NE-SW tension) was gradually replaced by E-W to SE-NW tension. After the cessation of thrusting along the northeastern segment, the whole basin was slightly compressed and some parts were inversted. During the Late Miocene, E-W to NE-SW tension renewed. From the latest Miocene the compressional tectonism has propagated from the Southern Alps gradually into the Pannonian basin and resulted in Pliocene through Quaternary inversion and uplift.

Miocene tectonic evolution of the Periadiatic Zone and surrounding area in Slovenia: repeated dextral transpression

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Dextral separation of the Periadriatic zone was postulated by several authors using divers criteria, but detailed kinematics and timing of movements were not yet investigated along its whole length. Stratigraphic and sedimentological study, structural and paleomagnetic measurements, mapping, borehole data analysis permitted to unravel the Miocene-Quaternary tectonic evolution of its Slovenian segment.

The brittle deformation was characterised by NNW-SSE (NW-SE to N-S) compression and perpendicular tension. The prominent style of deformation within the two main shear zones, the Periadriatic line-Sostanj fault system and the subparallel Sava-Celje fault zone is penetrative dextral strike-slip faulting associated with folding and verticalisation of beds. Such dextral transpression took place in the Early Miocene (Ottnangian), than during the Karpatian, and reoccurred several times during the Late Miocene and Pliocene and lasted up to the Quaternary. Between the two shear zones, the western Smrekovec area is characterised by sinistral transpression, while the eastern Savinja block was affected by dextral transtension.

The highly strained rocks within the dextral shear zones show mainly clockwise, sometimes counterclockwise rotations, variable in amount. The non-coaxial nature of faulting was detected by the comparison of paleomagnetic and stress data; NE-SW compression occurred in sites where important CW rotation took place. The area of sinistral transpression could be rotated slightly in clockwise direction, following domino-type rotation induced by the boundary dextral shear zones.

Relationship between tectonic zones of the Albanides, based on results of geophysical studies

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The Albanides link the Dinarides and the Helenides, with which they form the southern branch of the Mediterranean Alpine Belt. Our analysis of the Albanides and their extension into the Adriatic Sea integrates surface geological observations, well data and results of seismological, refraction and reflection seismic, gravity, magnetic and geoelectric surveys.

Evolution of the Albanides began with the Triassic subsidence of their Hercynian substratum under a tensional regime, culminating in crustal separation and opening of the Subpelagonian and Hellenic-Dinarid oceanic basins. The Alpine orogenic history of the Albanides spans Late Jurassic to Quaternary times and can be subdivided into a Late Jurassic-Early Cretaceous tectonic, a Mid-Cretaceous to Eocene main-tectonic, an Oligocene-Miocene late tectonic and Plio-Pleistocene neo-tectonic cycle.

The Albanides consists of two major paleogeographical domains. The Internal Albanides formed part of the oceanic Subpelagonian Trough, whereas the External Albanides developed out of the western passive margin and continental shelf of the Adriatic plate. During the early-tectonic phase, the ophiolitic Mirdita nape was obducted onto the margin of the Adriatic plate. This was accompanied by the development of a flexural foreland basin.

During the main-late and neo tectonic phases, progressive westward advance of the orogenic front was coupled with a westwards shift of the foredeep basin axis to its present location at the margin of Adriatic Sea. The External Albanides evolved out of the Ionian Mesozoic shelf sedimentary prism and the superimposed foredeep wedge. The Albanides are underlain by autochtonous continental basement was little deformed during their evolution.

The ophiolites of the Mirdita nape give rise to major gravity and magnetic anomalies, indicating that its thickness ranges between 2 and 14 km. Reflection seismic and gravity surveys carried out in the External Albanides and the Adriatic Sea define distinct structural belts which are related to different tectono-stratigraphic units.

Structuration of the Ionian and Sazani zones occurred during the late and neo-tectonic phases The carbonate dominated Late Triassic to Late Cretaceous series of the Ionian, Kruja and Krasta-Cukali zones contain several rich to very source rock intervals. In the Ionian zone Late Cretaceous, Paleocene and Eocene carbonates, Oligocene flysch type sandstone. The Tortonian Pliocene Molasse type clastics of the Periadriatic Depression.

Seismotectonic comparison of alpine collision structures: examples of recent extrusion in the Eastern Alps and in Turkey

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Introduction. The well known comparison of the movement of India towards the Himalyas with the deformation of an indenter against a plate, has allready been made by TAPONIER & MOLNAR twenty years ago. The fault pattern is similar in different parts of the Alpine chain. Two examples of „extrusion" are given:

(1) The movement of Arabia agaist Anatolia and Iran (we focus on the border zone of Arabia near the East Anatolian Fault and the extrusion of Anatolia).

(2) The movement of the African promonetory (Italy) against the Alps (In this part we focus on the interpretation of earthquake data in Austria and the Pannonian Basin).

As a consequence, an extrusion of crustal parts can be observed more or less normal to the maximum pressure axis. This movement continues until now.

The following features are discussed: (1) Earthquake data and length of seismic catalogues. (2) Faults from geologic investigation and from satellite images. Can the activity be checked properly? (3) Measurement of the velocity of plates. Magnitudes of velocity can be given by GPS and SLR measurement which indicate that Italy moves relative to Europe with 0.7 cm/year and that Arabia moves relative to Anatolia with 3-4 cm/year. (4) Fault plane solutions. Examples of fault plane solutions are given to characterize the kind of motion. The two types of earthquakes can be distinguished due to fault plane solution: strike slip movement and thrust-type movement.A tectonic interpretation is given.

The common inversion of the seismological and DSS data - New traveltime tomography method and results for Europe

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A new method of Taylor approximation of non-linearity of 3-D problems of seismics based on the wave equation and eikonal equation solution has been worked. It is shown that Taylor approximation of 3-D inverse traveltime problems has the following advantages over the linearization method. (1) It ensures a considerable gain as to the non-linearity approach accuracy. (2) It is valid with fewer constraints imposed on the velocity. (3) It is not need by the choice of reference velocity approach. (4) It does result in a problem correct by Tikhonov, instead of an essential incorrect one. (5) It involves significant reduction in the dimension of the problem for numerical inversion. (6) It is equally valid for the solution in Cartesian and spherical coordinates. The method is easily applied to interpret 3-D data of seismology and 2-D DSS data as well profile and spatial CMP data of seismic reflection and refraction wave exploration.

We describe processing and inversion of the observed seismic data by new method. The principled detailing of P-velocity model of the mantle obtained from the Bulletins of the ISC is only possible when using following additional data for every region: (a) the arrival and second times of the P-wave observed on long-range and DSS profiles, (b) data (absent in the Bulletins of the ISC) on the arrival and second times of the P-wave from a weak near earthquakes observed by seismic stations of the regional networks, (c) the second times of the P-wave in the range of epicentral distances of 12-25 degree determinate from records of major earthquakes, (d) the arrival times of the P-wave from the Bulletins of the ISC for teleseismic distances (these data in the theory of inversion that we use are similar to those of deep foci earthquakes or deep reflections). The employment of the data of points (a) and (b) enables detailing of the structure of lithosphere and asthenosphere and those of points (c) and (d) ensure specify the depth and the character of 410 and 670 km discontinuities. The new method provides common inversion of the main data (from Bulletins of ISC) and data of points (a)-(d) even in cases when crust and mantle contain low-velocity zones. The obtained 3-D P-velocity model of the mantle beneath Europe is considered.

Paleomagnetic constraints for paleogeographic position of Tatricum and Fatricum (Central West Carpathians) in the Late Mesozoic

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During last 10 years paleomagnetic data were obtained from the Mesozoic (Lower Jurassic - Lower Cretaceous) rocks in the Central West Carpathians of Poland and Slovakia (Kadzialko-Hofmokl and Kruczyk, 1987, Kruczyk et al., 1992, Grabowski, 1995). The samples were taken from the KriŸna unit (Fatricum) of the Tatra Mts., NiŸne Tatry, Choæ Mts., Spiœka Magura and Mala Fatra and from the Cover unit (Tatricum) of the Tatra Mts. All characteristic directions are of normal polarity, they reveal predominantly clockwise rotated declinations (except the directions from the Mala Fatra) and inclinations corresponding to the expected values for the European Platform. It is very likely that these directions represent a remagnetization of Early Cretaceous age. These data differ significantly from the Middle Jurassic - Early Cretaceous paleomagnetic directions from the Apulian realm (Marton & Marton, 1983, Channel, 1992). Comparison of declinations and inclinations from the Central West Carpathians and Apulia suggest that an oceanic separation between them existed at least in the early Cretaceous. Similarly as the Northern Calcareous Alps, the Central West Carpathians did not participate in the counter-clockwise rotation of Apulia.

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Thermal effects of the exhumation of metamorphic core complex on syn-rift sediments - an example from the Rechnitz Window (Austria)

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The Rechnitz Window is situated at the Alpine/Pannonian borderand represents the easternmost Penninc window of the Alps. During the Miocene the window was exhumed by tectonic denudation. The Austroalpine crystalline cover was removed by top-to-ENE normal faulting. This extension produced the Pannonian basin system where the earliest sediments of the this depositional cycle were formed in Middle Miocene. The sediments of the syn-rift stage are mainly conglomerates, fanglomerates and sandstones with thin coal bands. A high level of the organic maturation (Sachsenhofer, 1991) indicates that the bottom of the sedimentary sequence suffered a post-depositional thermal overprint. Heating was able to anneal the fission tracks (FT) in the detrital apatite grains of the sediments. The 13.6 million years average of the FT ages expresses the termination of the period of an increased heat flow. The aim of the presented two-dimensional numerical thermal model is a quantitative qualification of possible thermal surface heat flow within the hanging wall during the exhumation of the Rechnitz Window along normal faults.

As the chosen initial conditions as well as the boundary conditions clearly influence the results of such a mathematical model only such parameter configurations were used, where the program records of the cooling history fit the actual thermochronological measured data of the footwall of the Rechnitz Window (Dunkl and Demény, in press). During the model calculations a chosen sample within the footwall was exhumed with various faulting velocities (2.5 - 11.5 mm/a) along normal faults with various dip angles (10° - 50°). After each time step the temperature and the location of the sample were recorded resulting in a calculated cooling curve of the footwall. All model calculations reveal a typical convex-concave cooling curve and suggest an Early Miocene rapid exhumation of 2mm/a of the footwall followed by slow exhumation of 0.25mm/a. After this period of rapid faulting the near surface geothermal gradient is increased dramatically (>50°C/km). In order to investigate the theoretically possible surface heat flux a parameter map was calculated showing the surface heat flux in the hanging wall at a distance of 0-90km to the fault trace. This plot shows that within 10km to the fault trace the surface heat flux is increased distinclty for all faulting angles and faulting velocities. For high angled normal faults the lateral cooling effect considered in the two-dimensional model is too large and the surface heat flux near the fault trace is about 0.050W/m² less. An interesting feature is that low angled faults influence the surface heat flux in the hanging wall >100km distance to the fault trace, whereas the influence on the near surface thermal structure during high angled normal faulting is considerably reduced (<50km).

The presented model shows that rapid relative displacement during normal faulting produces a warming of the adjacent hanging wall and consequently an increased surface heat flow. This effect can easily provide the heat necessary for the resetting of the FT ages in the hanging wall of the Rechnitz Window without the assumption of a hidden volcanic body.

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Sachsenhofer, R.F., 1991. Maturität im Steirischen Tertiärbecken. Erdöl Erdgas Kohle, 107, 12-17.

Gondwana origin of the Tisza-Dacia Unit? Arguments from paleomagnetism

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The origin of the crustal units today forming the Intra-Carpathian area is still under debate (CSONTOS 1995). The so called Tisza -Dacia unit is built up by the Apuseni Mts., the South and the East Carpathians and is characterized by a common Tertiary tectonic evolution. The pre-Tertiary tectonic history of these blocks is hardly known. Middle Jurassic to Lower Cretaceous sediments from Piatra Craiului and Bucegi Mts. (SE Carpathians, Romania) were sampled for a paleomagnetic study. The sites are situated in the massifs of Piatra Craiului and Bucegi and in the strongly faulted area between them.

The Jurassic sediments lie on pre-alpine polymetamorphic crystalline basement of the Leaota massif which is part of the alpine Bukovinian nappe system. Facies development (fining up) and synsedimentary tectonics (normal faults) point to a scenario of extension tectonics presumably lasting from Middle Jurassic to Early Cretaceous.

At present we are able to isolate a common component for all sites with identical inclinations (≈ 62°) and declinations ranging from 20° to 160°. The scatter of the mean declinations are interpreted as the result of differential clockwise rotations.

In the Bucegi massif the common component (D 122°/I 62°) is better grouped in geographic than in stratigraphic co-ordinates pointing to a post-tectonic remagnetization. The steep inclination (actual geomagnetic field inclination ≈ 64°) indicates a remagnetization event which took place just before the Early Miocene large scale rotations.

Jurassic limestones reveal shallow reverse inclinations (≈ -30°) at high demagnetization temperatures additionally.

Clockwise rotations of the Apuseni Mts. and the South and East Carpathians (Tisza-Dacia unit) were already described by BAZHENOV et al. (1993) and PATRASCU et al. (1990,1994). Their investigations of Middle to Upper Cretaceous and Tertiary sedimentary and volcanic rocks reveal rotations of more than 80° and a timing of this movements prior to the Middle Miocene. PATRASCU et al. (1990) were able to give a well defined Upper Cretaceous (70-80 Ma) paleolatitude for the Apuseni Mts. of 21° N. The shallow reverse inclination from the Jurassic limestones corresponds to a paleolatitude of about 16°. Both the Cretaceous and the Jurassic paleolatitude are a convincing argument for the Gondwana origin of the Tisza-Dacia unit.

The ongoing project focuses on the detection of primary magnetic remanences of Middle Jurassic to Early Cretaceous age in the SE-Carpathians. The reconstruction of the plate tectonic puzzle in the Carpathian realm will greatly benefit from further paleomagnetic research.

Neogene magmatism at the Alpine-Pannonian transition zone

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Neogene alkaline volcanism developed in two main stages and formed two volcanic fields (Styrian Volcanic Field, SVF and Little Hungarian Plain Volcanic Field, LHPVF) at the Alpine-Pannonian transition zone. In the SVF, a Karpatian/Early Badenian trachyandesitic-latitic volcanism was followed by a Late Pliocene alkaline basaltic one, whereas in the LHPVF a Sarmatian/Early Pannonian bimodal trachyte-basalt magmatism preceded a Pliocene alkaline basaltic volcanic activity. This presentation focuses mainly on the LHPVF.

The Sarmatian trachytes have clear intraplate affinities and differ from the SVF trachyandesites and latites. The Early Pannonian basalts generated in the asthenosphere and show a remarkable similarity to the basalts of Oberpullendorf and Pauliberg (western LHPVF). Sr and Nd isotopic ratios of these volcanic products reflect more depleted character than the Pliocene alkali basalts of the central Pannonian Basin. Early Pliocene mafic volcanics of the southern LHPVF have dominantly primitive composition and show a wide variability in chemistry. Trace element and Sr and Nd isotopic signatures reflect different degrees of partial melting and a heterogeneous mantle source for the southern LHPVF magmas. Partial melting could have occurred either in the garnet stability field or in the garnet-spinel transition zone. A two-component mixing model is suggested for the generation of the LHPVF mafic volcanics. One of these components might be located in the asthenosphere or in the TBL (Thermal Boundary Layer) and has some features of St Helena-type mantle. The other component might be located at the lower part of the MBL (Mechanical Boundary Layer) and is considered to be the result of aqueous fluid metasomatism related to the Miocene subduction along the Carpathian arc.

Alkaline volcanism in the LHPVF postdated the main extensional phase of the Little Hungarian Plain and is supported predominantly by asthenosphere-derived melts. The trachytic volcanism occurred at the centre of the basin during the short-term aborted narrow-rift stage when β could have exceeded 2. The post-extensional basaltic volcanism might be related to the moderate raise of the mantle potential temperature due to an influence of a mantle plume ('thinspot' effect?).

Although geochemistry of the Badenian SVF latites shows some subduction influence, it cannot be stated that they have a direct subduction-related origin. Moreover, a recent study has pointed out a strong genetical relationship between the Gleichenberg latite and the ultrapotassic rocks of Balatonmária (central Pannonian Basin). They could be generated in a syn-rift phase when lithospheric extension reactivated K-rich metasomatic veins in the lower part of the MBL and caused decompressional partial melting.

Remote sensing, structural geology and 3D-seismic: an integrated approach to explore tectonic structures in the Vienna Basin

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Tectonic interpretations in the Vienna Basin and, likewise, in other prospective and hydrocarbon bearing sedimentary basins are substancially hindered by the very limited outcrop conditions in basin areas. The correct evaluation of the structural geometry and evolution of such basins, however, is of crucial importance for hydrocarbon exploration and production, e.g., for assessing reservoir geometries, for reconstructing fluid pathways through active or abandoned faults, and for evaluating the sealing capacity of faults. With kind permission, technical and finacial support of OMV, a detailled R&D study is carried out in the Vienna Basin and its surrounding which integrates the interpretation of multitemporal and multisensoral satellite imagery, 3D-seismic data, and structural geology.

Remote sensing interpretations use images of sensors showing different imaging geometries and spatial resolutions to rule out effects inherent in satellite data which lead to a suppression of lineaments parallel to the sensor look direction. Additionally to data of line scanners, mapping the visible and infrared electromagnetic spectrum (SPOT-Panchromatic, LANDSAT Thematic Mapper), Synthetic Aperture Radar Data (SAR) operating in the microwave range (ERS-1, Japanese ERS-1) are interpreted. Due to the high sensitivity of microwaves to surface roughness and soil moisture and their capability to penetrate the surface to a certain extent, they proved to be a useful tool for the mapping of morphology and lineaments. The data sets are geocoded using a digital elevation model (DEM) with a grid spacing of 50 meters to enable the overlay and the synoptic interpretation of the different data sets (sensor merge) and to correct for terrain induced geometric distortions (e.g., foreshortening and layover in radar scenes which hinder the thematic interpretation). DEM is also used to create perspective views to facilitate the extraction of lineaments. After the execution of atmospheric corretions in the case of Landsat TM and the suppression of the speckle noise in the radar scenes by the application of additive filters (e.g., Frost filter), different directional filter kernels have been used to enhance the edges in the scenes. A first evaluation of the resulting image products revealed that the Vienna Basin and the adjacent areas are characterised by lineaments which dominantly trend N-S, NE-SW and NW-SE.

OMV's 3D-seismic surveys offer the possibility to check the significance of lineaments and to correlate faults to lineaments derived from remote sensing data. Lineaments correlate to fault patterns which can be identified in 3D-seismic sections using advanced software packages for 3D-visualisation and interpretation. En-echelon N(NE)-striking faults and connecting NE-striking faults have been identified in time slices through Badenian to Pannonian strata (c. 2000 to 400 ms TWT) in the northern Vienna Basin. In cross section, faults display significant normal offsets. Synsedimentary faults are characterised by listric geometries and the stratigraphic patterns within fault-bounded blocks show growth strata and rollover geometries. Coverage of seismic data is limited to depths below 400 ms TWT (c. 400 m). To find possible tectonic surface expressions, faults are traced upwards to check for correlation to morphologic features and lineaments. By comparison to structures in surface outcrops, the fault patterns mapped in seismics were identified as oblique-sinistral faults which bound rhomb-shaped divergent fault duplexes. Arrays of several such duplexes define major sinistral shear zones within the basin which were active from the Karpatian to the Pannonian stage (c. 17-8 Ma). Microtectonic field observations show that the divergent sinistral shear zones are cut by conjugate NW-SE striking normal faults. Older faults were overprinted and moved as oblique-normal faults during correlate NE-SW directed extension. The NW-striking normal faults have a marked morphological expression in paralleling the dominant trend of the drainage system. They are correlated to NW-SE trending lineaments depicted by remote sensing data.

The detailed fault geometries revealed by remote sensing and seismic mapping are combined with results of structural geology surveys in order to acess timing and kinematics of faulting in the Vienna Basin area. Detailed tectonic analyses of surface outcrops allow to establish a deformational and paleostress history which, in turn, can be used to predict the timing and the direction of movements along subsurface faults.

The lateral extrusion of the Eastern Alps: fact or fiction?

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During the last decade, many models dealing with the Neogene tectonics of the Eastern Alps have postulated an eastward extrusion of the Central Alps towards the Pannonian Basin. One main requirement of these models is a large-scale sinistral displacement along major faults at the southern margin of the Northern Calcareous Alps. Such sinistral sense of movement has never been proven for the Salzach and Ennstal Faults. Because of the following arguments, even the opposite seems to be true:

(1) The hydrographical pattern of the Salzach and Enns fluvial systems is incompatible with a young sinistral displacement at the northern border of the Tauern Window.

(2) A hypothetic fault segment at the southern edge of the Mandling Wedge - as has been postulated by the extrusion models - does not exist in nature. Field investigations have shown that the eastward prolongation of the Salzach fault is situated exactly Nof that Mandling Wedge and not S of it. Therefore, the E-W trending Salzach and Ennstal Faults do not belong to one contious fault system.

(3) The Tertiary of Wagrain (lower Miocene) was subjected only to dextral sheer (WANG, pers. comm.). A post-depositonal sinistral displacement can be excluded.

(4) Extrusion tectonics should have caused a counterclockwise rotation of individual segments of the Northern Calcareous Alps with respect to the Central Alps. But palaeomagnetic investigations clearly show that just the opposite did happen.

(5) The assumption of a dextral displacement along the Salzach-Mandling Fault yields an explanation of the arcuate structure of Weyer (Weyerer Bögen) which then was created by an E-W convergence resulting from the opposite sense of movement along theSalzach-Mandling Fault to the W and the Mariazell-Puchberg and Trofaiach Lines to the E (dextral and sinistral, respectively).

Therefore, any tectonic models which require a sinistral Neogene displacement along the northern border of the Tauern Window are simply wrong. A continuous sinistral SEMP Line (Salzach- Ennstal-Mariazell-Puchberg) does not exist. If at all, a lateral extrusion of the Eastern Alps towards the Pannonian Basin could only occur previous to the deposition of the Miocene sediments of Wagrain.

Neotectonics of the Pannonian Basin

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New data and reinterpretation of old observations shed light on a very exciting and largely overlooked problem: the tectonic evolution of the Pannonian basin from the beginning of Pliocene to recent time. This period is distinct from the Miocene, which saw the extensional collapse of Alpine orogenic wedges, and the formation of the Pannonian basin system. We think that a new tectonic regime characterised by an increase of intraplate stress (neotectonic phase) was established at about 5 to 4 Ma and has continued up to the Present.

Our tentative model for the neotectonic evolution of the Pannonian basin suggest that desiccation of the Mediterranean sea during the Messinian caused a remarkable water level fall in the Pannonian Lake. It was associated with a tectonic uplift of the basin, and a hot-dry clima, which resulted in desert-like conditions in the former lake areas. Intensive erosion has started mostly in western part of the basin (Transdanubia) and continued up to the Recent. This led to a major erosional gap and tectonic discordance at the top of Pannonian strata, which is locally overlain by late Pleistocene to Holocene loess in a thickness of a few to less than 60 m. In contrast, at the western part of the basin (Great Hungarian Plain) subsidence renewed due to intraplate stress increase, and terrestrial red clays are interfingering with lacustrine and fluviatile deposits up to a thickness of 1000 m. Over here, the base of Quaternary is a paraconformity suggesting practically continuous sedimentary record with a cyclicity most probably controlled by the Milankovitch climatic cycles. High-resolution seismic data offer the first spectacular evidence that folding and/or faulting occurred during this neotectonic period, and locally faults active during the late Pleistocene and possibly even the Holocene can be present.

Contemporary stress partitioning in the Polish Western Carpathians

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In the Polish part of the Western Carpathians and the Carpathian Foredeep, recent horizontal stress direction was determined by mean of breakouts analysis method for four boreholes. Breakouts are compressive failures of the borehole wall which cause its elongation perpendicular to the maximum horizontal stress (S_{Hmax}). Long breakouts profiles give unique opportunity for continuos observation of stress direction changes with depth. Breakouts were detected with Six-Arm Dipmeter (SAD) and borehole televiewer (CAST) and processed with SPIDER program.

In the well PL 19 (located in the westernmost part of the Polish Carpathian Foredeep), S_{Hmax} direction changes from NNW for Devonian to NW for Precambrian basement. There are local deviations of stress direction in the vicinity of the fault zone which cuts Devonian rocks. NWN to NW direction of S_{Hmax} is corroborated by numerous breakouts analysis from neighbouring Czech side of the foredeep basin [Pavel Peska - WSMDB] but any stress partitioning has not been mentioned.

Borehole PL 35 is located in the Magura Nappe in the Carpathians, near Zywiec. Here, S_{Hmax} has different orientation for different structural levels. Mean breakouts direction within the flysch nappes indicates NNE S_{Hmax} orientation (similar stress direction was constrained by poor quality data from PL 32, located in the westernmost part of the same nappe). In the Miocene and Devonian autochthonous basement of PL 35 compression has NNW direction while within the short section of Precambrian metamorphic basement it changes towards NW. Therefore, three detached geodynamic levels could be differentiated in this well profile. Small scale deviations of stress orientation were also observed within Devonian interval. Tectonic examinations of the drill core shows, that the set of steeply dipping strike-slip faults is responsible for small scale stress reorientation.

In the well PL 34 which is located in the central part of the Polish Carpathians, and penetrated both Carpathian nappes and the autochthonous Permo-Mesozoic basement, S_{Hmax} trends N-S while in the deeper Carboniferous and Devonian fundament single breakouts indicate NW compression.

At the moment, three other boreholes from this region are under investigations.

Generally, in the westernmost part of the Polish Carpathians, from the deepest autochthonous basement upwards, S_{Hmax} direction rotates from

NW to NWN, respectively. Overthrusted nappes are compressed N-S or even towards NNE. S_{Hmax} orientation in the nappes is more or less similar with the last stage of folding compression in the Western Outer Carpathians. NW orientation of S_{Hmax} for metamorphic basement is characteristic for regional, „plate" compression characteristic for West European Stress Province.

Pre neogene terranes in the central part of the Balkan Peninsula

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At the end of Oligocene the geological framework of the central part of the Balkan peninsula was established. The preexisting terranes or composite terranes have already been in their recent position, and the last existing oceanic area, the Vardar ocean was closed.

The following units in this frame, from the east to the west, can be distinguished: (1) The composite terrane of the Carpatho-Balkanides (CBCT), composed of five terranes, docked together and to the Moesian plate at the East before the Middle Carboniferous; (2) The Serbian-Macedonian composite terrane (SMCT), which parts docked to the CBCT in Ordovician, but at its West new units were added during the Lower Paleozoic; (3) The Vardar Zone composite terrane (VZCT) representing the suture zone or a relict of the former Vardar Ocean, with a long and complex evolution, including different parts of this large oceanic area and incorporated crustal fragments. The largest and probably the last one among them was the Jadar block terrane, pushed into the Vardar zone oceanic area in Upper Cretaceous. This oceanic area was succesively closed from the East (during Upper Jurassic) to the West (in the Uppermost Cretaceous), but some parts were closed even earlier; (4) The five terranes belonging to the Dinarides: the Drina-Ivanjica terrane (DIT), the Dinaridic Ophiolite Belt terrane (DOBT), the East Bosnian-Durmitor terrane (EBDT), the Central Bosnian Mountains terrane (CBMT), and the Dalmatian-Herzegovinian composite terrane (DHCT). The DIT, the CBMT and the DHCT, or the basement of the Mesozoic carbonate platforms, merged together during Permian. The DOBT originated by Triassic rifting in that, during Permian (?) formed composite terrane, then was developed in an oceanic area and closed before the end of Jurassic, now are exposed only the remnants of this oceanic basin. The position of the EBDT terrane is not clear, it was probably pushed into the DOBT during (Middle/Upper ?) Jurassic.

At the end of Cretaceous this framework was established, during the Paleogene only movements along transcurrent faults, rotation and northwards movement of most units took place.

Neogene tectonics, basin formation and sedimentation at the Alpine-Carpathian-Pannonian junction zone

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During the neo-Alpine period, the basin forming processes led to the evolution of the Neogene basin system in the central and inner zones of the Alpine-Carpathian-Pannonian junction. The Vienna and Danube basins are the most extensive, filled by marine and lacustrine sediments attaining thickness from 5 to 8 km.

In the Early Miocene, during the initial stage of the collision between the Western Carpathians and North-European platform, basins of wrench fault furrow-type originated on the northern margin of the paleo-Alpine consolidated part of the orogene. In the latest Lower Miocene, during the Karpatian (culmination of the collision), the pull-apart basins were formed in the transpressional-transtensional regime in more external zones (Vienna Basin). In the hinterland of the orogene, mainly grabens originated. The basins in the frontal part of the Western Carpathians are characterized by thin-skinned tectonics, while the initial rifting of the back-arc basins were accompanied by whole-lithosphere extension.

An orogenic collapse took place during the Middle to Upper Miocene in a transtensional regime. Extensional basins of the syn-rift and post-rift back-arc types have been formed in the central zone; in the marginal parts the basins were formed by pull-apart mechanism. In the central part, the combination of normal faults and listric décollements took place (Danube basin).

The orogenic collapse attacked also inner zone. Neogene syn-rift and post-rift back-arc basins with graben-like features, superimposed on the Buda Paleogene Basin, were formed in the transtensional regime. Thickness of the Neogene sediments in the examined area reaches some 4-6 km.

During the Pliocene and Quaternary a partial relief inversion took place in the Central Western Carpathian area. The Pliocene compressional event is characterized by the stress-field with compression oriented perpendicular to the orogenic trend.

Principal geological and geophysical characteristic of the Alpine-Carpathian-Pannonian junction

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The map of general tectonic structure of the Western Carpathians and surrounding areas can be divided to following zones:

The outer zone, represented by the autochthonous sedimentary fill of the Carpathian foredeep and by allochthonous accretionary wedge of the Flysch Belt units overthrust on the slopes of the Bohemian Massif (part of the North European platform).

The suture zone between the outer and central zones is reflected on the surface by the Pieniny Klippen Belt. Southwards the closing of the South-Penninic ocean basin (Ligurian-Piemontais or Vahic ocean respectively) is supposed during the latest Cretaceous and earliest Paleogene.

The central zone is formed by the pre-Alpine and paleo-Alpine complexes of the Central Western Carpathians. The present nappe structural pattern of the zone has been formed during the Middle to Upper Cretaceous; the deformational structures reflect outward (northward) polarity. Besides the overthrusting of the superficial nappes (Hronicum, Fatricum and Silicicum) composed mainly of carbonate rocks, also the large basement nappes (Tatricum, Veporicum and Gemericum) have been formed. The Lower, Middle and Upper Austroalpine units in the Eastern Alps and in the pre-Neogene basement of the Vienna Basin represent the analogous units to the Carpathian nappes.

The inner zone was as a whole formed during the paleo-Alpine and/or Late Cimmerian (Late Jurassic - Early Cretaceous) tectonic movements; later its structure was modified by the Late Cretaceous and mainly by the Tertiary extensional and wrench tectonics. This crustal segment, named also the Pelso Unit, is bordered from the NW and N by the Rába-Hurbanovo-Diosjenö fault-lines, from the south by the mid-Hungarian lineament. Surficial part - the Transdanubian Central Range is in the nappe position with respect to the Austroalpine units.

Geophysical characteristics of the examined area reflect the processes connected with the Neogene development of the Eastern Alps, Western Carpathians and Pannonian Basin s.l. junction area.

Lithosphere thickness diminishes considerably from the west, from the Bohemian Massif and Eastern Alps, eastwards. Below the Transdanubian Central Range it reaches only about 60 km. This anomalous phenomenon can be explained as a result of the mantle upwelling in the back arc area.

Gravity minimum characteristic for the Alpine orogene as well as for the Eastern Carpathians is not so prononced in the Western Carpathians as is evident in the Bouguer gravity map. The origin of this anomaly is in the folded accretionary wedge complexes of the Flysch Belt and in the basement (Bohemian Massif) overriden by the Carpathians during the Neogene oblique collission.

Crustal thickness ranges within 34-26 km in the majority of the examined area. Considerable thinning is characteristic for the Pannonian region s.l., except the Transdanubian Range. The zone of thinned crust is situated in the centre of the Danube Basin.

The values of heat flow density are most expressive in the Slovak part of the Danube Basin, since the high thermal gradient area coincides with buried volcanic bodies. Outer Carpathians itself, as well as the majority of the Central Western Carpathians, are characteristic by a low thermal activity.

The pre-Tertiary basement contour map documents situation of depocentres in the central part of the Vienna and Danube basins, as well as in depocenters in the northern embayments of the Danube Basin (Blatné, Rišòovce and Komjatice depressions).

Geological evolution and hydrocarbon habitat of the External Albanides

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Albania is part of the Alpine-Mediterranean orogenic belt. Its Mesozoic and Tertiary evolution was controlled by relative movements between the Adriatic subplate and the European plate.

The External Albanides (Krasta-Cukali, Kruja, Ionian and Sazan Zones) are characterised by a thick series of mainly passive margin Triassic to Tertiary carbonates diachronously overlain by syntectonic Tertiary Flysch, Pre-Molasse and Molasse sediments.

Sediments of the Neogene Periadriatic Depression cover the north-western parts of the Ionian and Kruja Zone. Large scale northwest-southeast striking ramp anticlines characterise the internal structural style of those two zones.

Oil and Gas Plays in Albania: Oil and gas exploration and production has a long history in

Albania. The main oil play type are Ionian Carbonates of an Upper Cretaceous to Eocene age in a ramp anticline or imbricate structure. Porosity and permeability are mainly created by fractures in the crestal part of the anticline. In near platform or slope settings, dolomitisation is likely to enhance porosity and fracture density. Shaly and marly Oligocene Flysch sediments act as lateral and top seals. Sourcing is possible from a variety of Upper Triassic to Upper Cretaceous, moderate - high quality, high TOC, oil-prone source rocks within the individual imbricate or duplex.

A variety of structural and stratigraphic plays in the Neogene has been defined in the Periadriatic Depression. Reservoir rocks were deposited in shallow marine to deep water environments. Shaly intervals within the Neogene section act as lateral and top seals. Play types include lateral and up dip pinch-outs, four-way dip closed drapes, fault bounded sandbodies and four-way dip closed backthrust ramp anticlines.

Both oil and gas have been discovered in the Neogene. Gas is mainly of a biogenic origin from disseminated organic matter in the Neogene, with some admixture of thermogenic gas. Oil is sourced from source rocks in the carbonate section and migrates along carbonate structures and breached seals and fracture zones into the Neogene above.

Neogene superterranes of Dinarides and Carpatho-Balkanides in SR Yugoslavia

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Two regions of the Miocene lacustrine sedimentation on Balkan Peninsula are known for more than 100 years. Better studied is the Dinaridic realm of ancient K&K. The lacustrine Miocene between the Drina and Timok rivers were often, but unsuccessfully equalized to the Dinaridic one. After the recognition of the older terranes (Karamata et al., 1994) was possible to deliminate two large Neogene superterranes, one in the Dinarides and the other in the central Balkan Peninsula.

On the deep seismic profile (from Petrovac-na-Moru to Negotin) there is a sign of a dislocation in the region of Tutin delimiting, possibly, the two Neogene superterranes.

The sediments of the two lacustrine systems belong to two large sedimentary cycles, the single cyclotheme each. In SR Yugoslavia the older cyclotheme is developed in Northern Montenegro and, as a "gulf" (trench?), it cross from Pranjani, via Cacak and Trstenik to Alcksinac. In that area there is overlapping of the two cyclothemes. The younger cyclotheme covers all of Serbian area. ('Serbian Lake') reaching in some time portions to the Skopic surroundings in the South. It is in places ca. 1000 m thick; because of the great depth of burial the vitrinite reflectance is 0,77-0,91 for the Ibar coal (Ercegovac, 1991).

The age of the western Balkan lacustrine system was determined as Karpathian equivalents while covered by the marine Upper Karpathian and Badenien (Kochansky and Sliskovic, 1978) The age of the central Balkan lacustrine system ('Serbian Lake') is determinable by the findings of the ostracode genus *Mediocypris,* the key fossil for the lacustrine Middle Miocene for Eurasia (Kheil, 1968). Some controversy of the age determination by flora and mammals were caused by the great stratigraphical reach of these land fossils (Pavlovic, 1995).

Several thick tuff beds appear in the upper part of the Serbian Lake cyclotheme. Some of its measurements gave 15-16 Ma of age (Duraki, in press). The tuff was extruded from the few large volcanic centres like Kontlenik and Borac. That ancient volcanic activity, placed mostly in the Vardar Zone Composite Terrane, are the result of the collision and following relaxation (Cvetkovic et al., 1995). Differential neotectonic movement complicate present geological structure.

From compression through extension to inversion - Miocene tectonics of the Polish Carpathian Foredeep basin

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Polish Carpathian Foredeep (PCF) basin developed in Miocene times in front of the advancing Carpathian thrust belt (Oszczypko, Slaczka, 1989).

Recently completed structural interpretation of four regional, basin-wide seismic profiles located between Kraków and Przemyœl provided information on large-scale framework of Miocene tectonic development of this part of the PCF.

For the western part of the study area located between Kraków and Rzeszów it was concluded that only minor tectonic deformations of Miocene age can be observed within the PCFs' Mesozoic basement. They developed in form of normal faults located NW-SE. Immediately in front of the Carpathians, particularly between Bochnia and Tarnów, series of frontal thrusts developed within the foredeep sediments. Gentle flexure of basement in this part of the PCF suggests that bending of the lithosphere below the thrust belt was dominant process that has created present-day large-scale architecture of the PCF.

Very different results were obtained for the eastern part of the study area located between Rzeszów and Przemyœl. Seismic data revealed large amount of tectonic deformations present within the Palaeozoic and Precambrian basement of the PCF. They consist of either horst-and-graben structures related probably to strike-slip movements or systems of large normal faults and rotated blocks located NW-SE. Also, it was concluded that normal faults present in the easternmost part of PCF developed partly as a synsedimentary features and were slightly inverted during late Sarmatian. Moreover, maximum of extension controlled by these faults was located not immediately in front of the thrust belt but significantly further towards the north. This implies that extension was not only related to the lithosphere fracturing due to its flexure below the Carpathians but was also controlled by intense faulting related to Miocene reactivation of the Tornquist-Teisseyre tectonic line. Tectonic inversion of normal faults can be attributed to last stages of compression within the Carpathian thrust belt.

Oszczypko N., Slaczka A., 1989. The Evolution of the Miocene Basin in the Polish Outer Carpathians and Their Foreland. Geologica Carpathica, 40(1): 23-36.

Basin evolution of several sub-basins of the Pannonian Basin System - constraints from subsidence analyses and basin modelling

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Subsidence histories of the Vienna Basin, the Danube-Kisalfold Basin (Little Hungarian Plain Basin), the Styrian Basin and the East Slovakian Basin (Trans Carpathian Basin), in total based on over a hundred individual wells, are compared.

Striking is the contemporaneous onset of basin subsidence in all basins, together with the Karpatian maximum in subsidence rate for all basins. The Karpatian subsidence maximum indicates that Karpatian extension was the major feature governing basin evolution and all later phases are of lesser magnitude. In some cases aditional subsidence accelarations are observed, mainly for Pannonian times.

Uncertainties arize from the difficulties on excact quantification of age and paleowaterdepth. These problems are directly related to the time-transgressive character of the Pannoninan units. Karpatian and Badenian ages and paleowaterdepths are much better constrained.

Numerical absin modelling, adopting a modified McKenzie type extensional basin model is capable of explaining the observed subsidence reasonable well. Key features of the model are: (1) Karpatian extension only, (2) -Badenian-Pannonian postrift cooling, (3) relative small basins allow fast cooling, and (4) different amounts of crustal v.s. subcrustal extension.

Modelling also indicates that the Karpatian extension was the main basin forming process. However, there are numerous excellent documentations of later tectonics and changing stress fields. Apparently these are of a lesser magnitude with respect to basin subsidence.

Diversions from the postrift cooling trend in subsidence can be caused by: (1) uncertainties in data; (2) renewed extension phase in Pannonian times, with different impact; (3) lateral and temporal changes in rheology. Due to the problems age and waterdepth it was difficult to constrain the post-Karpatian evolution of the individual subbasins in detail.

Heat flow in the PANCARDI region and its geodynamic significance

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Heat flow is closely related to the structure and evolution of the Earth's lithosphere. More than 600 heat flow determinations and many thousands heat flow estimations were carried out in the PANCARDI region. The average heat flow in the Pannonian basin is about 90-100 mW/m^2, in contrast with a characteristic value of about 50-60 mW/m^2 in the surrounding region. The only exception is the central part of the Eastern Alps, where the heat flow is above 100 mW/m^2. Towards the Dinarides the heat flow is decreasing rapidly, and the Outer Dinarides is an extremely cold zone characterized by values of 30-40 mW/m^2. In the Inner Dinarides and in the transition zone towards the Pannonian basin geothermal highs occur. A large positive heat flow anomaly can be found at the southern part of the Pannonian basin, around Belgrade, which continues to the SE along the Vardar zone.

The heat flow is influenced by near surface geological processes, like groundwater flow and sedimentation and erosion. Intensive karstic water flow is the reason of the low heat flow in the Outer

Dinarides and in the Transdanubian Central Range. Simple heat balance calculation shows that the background conductive heat flux in the Transdanubian Central Range is the same as in its surroundings. The large scale groundwater flow occuring in the porous Neogene/Quaternary sediments does not alter the regional heat flow significantly.

Rapid Neogene sedimentation decreased the surface heat flow in the Pannonian basin. After correction the average background heat flow in the Pannonian basin increases to 100-110 mW/m^2.

The Pannonian basin is characterized by thin lithosphere and crust. In the surrounding region the lithosphere is thick and the Moho is deep. The overall correlation between the heat flow distribution and lithospheric structure is good. It was shown that the Neogene subsidence and high heat flow of the Pannonian basin can be explained by stretching of the lithosphere. However, the high post-rift subsidence rate and high present day heat flow can be explained only by assuming higher stretching of the mantle than the crust. This assumption means that extra heat was added to the lithosphere during basin evolution, thus deeper mantle processes were also involved in the formation of the basin. This assumption is supported by the widespread Neogene volcanism all over the basin. Better understanding of the nature of this mantle process requires more tectonic, geochemical/petrological and modelling investigations.

Kinematics of retreating subduction in the Carpathians

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The regional pattern of contraction directions and the evolution of the strain field from Paleogene to Neogene times enabled a stepwise reconstruction of the plate motions and the migration path of the Carpathian collision front. Brittle deformation structures in the Romanian Carpathians indicate three tectonic events related to major plate motions:

(1) Holocene to Pleistocene general E-W extension, N-S contraction in the Carpathian arc and local ESE-WNW contraction in the Vrancea area are related to the late roll-back stage and breakoff of the subducted slab in the bend area. The recent vertical position of the subducted slab below the Vrancea area of the Eastern Carpathians represents the final roll-back stage of a small fragment of oceanic lithosphere, formerly situated between the Moesian and East European plates.

(2) Pliocene to Middle Miocene fan-shaped orientations of contraction directions were caused by right-lateral oblique convergence in the Southern Carpathians, frontal convergence in the southern Eastern Carpathians and left-lateral convergence in the northern Eastern Carpathians. Kinematic axes and resultant vectors of displacement along the Carpathian arc and the Apuseni Mountains help to reconstruct the retreating subduction. The ages and locations of the eruption centers of the andesitic volcanic chain along the Carpathian arc in the overriding plate and the thrust directions are used as markers to reconstruct the roll-back area of the subducted slab between the Moesian and East European plates.

(3) Middle Miocene to Paleogene NE to ENE contraction caused right-lateral curved strike slip faults. The Carpathian nappes were thrust around the Moesian Plate during Paleogene and Early Neogene times and intruded into a small oceanic embayment between the Moesian and European plates. The suspected Jurassic oceanic crust was formed between the Moesian and European plates as the Penninic-Pieniny-Magura oceanic basins opened up. During Paleogene times, the Carpathian thrust-fold belt prograded from south to north.

The double-loop of the Carpathian fold and thrust belt was formed in Late Neogene times as a result of the eastward escaping Tisza-Dacia block, due to NE directed convergence of the Adriatic plate and the retreating subduction of an oceanic embayment between the Moesian and European plates.

Structural correlation between the Northern Calcareous Alps (Austria) and the Transdanubian Central Range (Hungary)

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In the East Alpine-Pannonian transitional area significant amount of syn-rift extension occurred during the Middle Miocene. In this recently defined Raba River extensional corridor a metamorphic core complex-style extensional period was shortly followed by and partly overlapped with a wide rift-style one. Based on the correlation of Eoalpine (Cretaceous) structural markers, about 80 km of ENE-WSW-directed extension can be documented for the Karpatian metamorphic core complex-style extension. The magnitude of Badenian wide-rift-style extension in a NW-SE direction is less constrained, but it is on the order of tens of kilometers (>40 km) based on preliminary cross-sectional balancing efforts. These findings have an important corollary for the relative, pre-extensional position of the Northern Calcareous Alps (NCA) and the Transdanubian Central Range (TCR). Taking also into account the displacement on Miocene strike-slip faults in the NCA, e.g. the Salzach-Ennstal-Mariazell-Puchberg fault with a sinistral displacement of about 60 km, the restoration of Neoalpine deformation brings the NCA and the TCR unexpectedly close to each other. In fact, some WNW-trending right-lateral strike-slip faults in the TCR (e.g. Telegdi-Roth line) are interpreted to be analogous to those described from the NCA (e.g. Wolfgangsee-, Windischgarsten- and Hochwart fault). These Cretaceous tear faults were reactivated during the Late Miocene as it can be documented by reflection seismic data in the subsurface of the Danube Basin and the NCA.

The structural correlation between the NCA and TCR based on the characteristic wrench fault pattern provides further evidence for the much debated interpretation of the TCR in terms of a Cretaceous nappe-system in an Upper Austroalpine (or "Ultrastyrian") structural position. Furthermore, the recognition of regional-scale right-lateral strike-slip faulting in these major Alpine units has a significant impact on the kinematic/dynamic reconstructions of the Alpine-Carpathian-Pannonian area during Cretaceous and Tertiary times.

Tectonomagmatic constraints on the dynamics of the final stages of subduction in the Eastern Carpathians

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Changes in volcanic activity can be related to variations in critical tectonic processes responsible for melt generation. A rigorous investigation of magmatism in the Carpathian arc may therefore more closely constrain the style and timing of subduction in the Carpatho-Pannonian region.

The East Carpathian volcanic arc constitutes the youngest and most voluminous segment of subduction-related magmatic rocks in Eastern Central Europe. A general age progression of the climax of magmatic activity is seen along the East Carpathians from older volcanic structures in the north-west to the youngest in the south-east, a feature which is particularly striking over the final 200km of volcanic structures in Romania. Magmatism continued into the Plio-Pleistocene, significantly later than the perceived end of subduction along the Inner Carpathian arc which took place during the Miocene.

Trace element ratios in magmatic rocks from the East Carpathians are typical for subduction-related magmas and suggest an input of fluids from a dehydrating subducting crustal slab. A simple model of upwelling of hot mantle due to slab delamination and subsequent mixing with lower and upper crust cannot explain the chemistry of the East Carpathian magmas. It is necessary to have subduction to produce the volcanism. However, the relationship between the timing of subduction and the climax of magmatism remains unclear.

The migration of magmatic activity from north to south may be explained by a corresponding migration of the magma generating zone along the arc. Oblique subduction of a narrow oceanic basin or slab roll-back could create the necessary tectonic conditions for migration. Continental crust may have initially entered the subduction system in the north whilst oceanic subduction continued in the south. Subducted lithosphere would thus initially delaminate and break-off in the north of the East Carpathian arc and progress southwards with time. As more buoyant continental crust entered the trench, a slower subduction rate would lead to slab breakoff at shallower depths. If the slab broke off at shallow levels (<50km) in the extreme south of the arc, it may account for some of the unusual geological features (e.g. the eruption of alkaline magmas).

Tertiary tectonic evolution of Southern Carpathians external area - reconstruction using kinematic and depth data

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The evolution of Southern Carpathians external area is analysed by means of paleostress determination, outcrop to regional scale structures, as well as depth interpreted data. The main latest Cretaceous - Tertiary deformations can be summarised as following:

After the middle and late Cretaceous orogenic phases, the Southern Carpathians - Moesian platform system was affected by strike-slip deformation with NE-SW oriented compression and NW-SE tension. During Paleogene - Early

Burdigalian pure tensional deformation is recorded, which opened a WSW - ENE oriented extensional basin. In late Burdigalian, NE-SW oriented contraction caused the oblique inversion of the older extensional structures. During the Sarmatian times the strike-slip regime was dominant. First NW-SE (middle Sarmatian), followed by N-S (late Sarmatian) trending compression direction produced mainly NW-SE dextral strike-slip faulting and thrusting in the frontal areas. The structural analysis suggest that the Sarmatian deformations which took place in the foreland areas along a roughly E-W oriented corridor represent the effect of the regional dextral movement between the Southern Carpathians in the north and the Moesian Platform in the south. Late Pliocene deformations recorded by small scale local folding and thrusting represent the final deformation stage recorded in the studied area.

Lateral variations in the mechanical properties of the Romanian Outer Carpathians: Inferences of flexure- and gravity modelling

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We present the results of two- dimensional flexure and gravity modelling of the subsidence of the Romanian Carpathian foreland based on twenty profiles through the Southern and Eastern Carpathians. The small distance between the profiles allows us to investigate the lateral variations in tectonic behavior along the profiles and along strike.

In general the topographic elevation of the Romanian Outer Carpathian mountain belt is modest and the minimum in the Bouguer gravity anomaly, characteristic for flexural control of subsidence in foreland basins, is located relatively far to the foreland in respect to the Outer Carpathian mountain belt. This implies that the contribution of topographic loading to the evolution of the Romanian Carpathian foreland system is small and, therefore, a subduction (underplating) dominated tectonic regime controlled the nappes emplacement and basin shortening in the external flysch and molasse basins during the Late Tertiary.

The modelling results infer important variations in effective elastic thicknesses (T_e) and plate boundary conditions. Especially in the western part of the Southern Outer Carpathians values for Te are low and increase to the east. High flexural bending stresses and changes in rheological properties of the Moesian Platform are proposed to explain this behavior. Furthermore, field observations indicate that variations in deflection along strike may also be related to basement unregularities, stress field rotations and strike- slip movement along lateral ramps during the Tertiary.

Continental collisioin and the ending phases of subduction in the Eastern and Southern Carpathians: incorporation of geophysical data from Romania

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The Eastern and Southern Carpathians in Romania have been interpreted as the final phases of closure of an oceanic embayment through subduction. The subduction is ending as overriding terranes collide with thicker crust along the continental margin of Europe. This project incorporates newly available geophysical data from Romania, as the gravity data, along with drillhole, seismic reflection and earthquake observation.

Previous work analysed similar geophysical data to study crustal and lithospheric structure associated with earlier collision in the Eastern Alps and Western Carpathians. High topography in the Eastern Alps, along with crust and a broad region of low Bouguer gravity anomalies, suggested approximately 200 km of continued convergence after oceanic closure. The Western Carpathians, in contrast, show low topography, thin crust and a narrow region of low Bouguer gravity anomalies, suggesting only about 50 km of convergence after oceanic closure; the continental margin of Europe is thought to be beneath the mountains.

The Eastern and Southern Carpathians present a unique opportunity to study structure at the time when the ocean basin has just barely closed.

When mountains just begin to develop as sediments are thrust over the continental margin. The current study may thus be important in appreciating the stage of continental collision development in new and ancient mountain belts world-wide.

The Southern Carpathians - wrench-fault corridor on the Western Margin of the Moesian Platform

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The Southern Carpathians mark the northwestern continuation of the Balkan orocline, forming an almost 100 km wide wrench fault corridor on the western margin of the Moesian platform. Their large-scale geometry proofs a transpressional nappe system due to collision in the Cretaceous and fragmentation due to dextral transpression since the Oligocene. Mylonites within the Danubian nappe show Late Cretaceous ductile shear, recording oblique collision and translation of the Transylvanian block towards the NE around Moesia (Ratschbacher et al. 1993).

Dextral strike slip movement on a NE trending fault system penetrates the Romanian Southern Carpathians. It was active at least since late Oligocene showing brittle deformation. A major tectonic lineament, the Cerna-Jiu-Cisnadie fault system, cuts convex across the Southern Carpathians from S to NE, showing a dextral offset of 35 km (Berza & Draganescu 1988). Along it's northern section the Petrosani basin was opened in Upper Oligocene as a negativ flower structure, whereas transpressional features are common west of the Godeanu massif. Southeast of the Cerna-Jiu fault the Mehedinti nappes were thrusted simultanously.

Due to the beginning of retreating subduction (Royden 1993) along the northern boundary of Moesia, NE directed motion of the Transylvanian block became E directed. The eastward movement was partially compensated by the E striking dextral Bistra-Lotru-Cozia fault system showing a dextral displacement of at least 10 km. Along this fault system the Hateg basin was opened as a pull apart basin showing mainly Sarmatian subsidence.

A re-organisation of tectonics in the western Southern Carpathians is proved during the Badenian due to extension in the Pannonian realm (~16.5 to ~14 Ma). Mostly along the contact between Danubian unit and Getic/Supragetic unit Sichevita-, Bozovici- and Caransebes-Mehadia basin subsided. The Getic/Supragetic block W of these intramontane basins was transported towards the Pannonian basin by at least 1 km. Subsidence dies out successively, starting with the Sichevita and Bozovici basin during the Sarmatian (~ 13 Ma) and ending with the Caransebes basin in the Pannonian (~8.5 Ma).

S of the Cerna-Jiu-Cisnadie fault strike slip tectonics were active throughout the Miocene and major displacement shifted from the Cerna-Jiu-Cisnadie fault to the dextral Baia de Arama-Severin-Timok fault system translating an paleozoic ophiolite 50km towards North. Along this major fault the Timok basin subsided (~ 16.5 Ma).

Tertiary subduction mechanism of the Carpathian-Pannonian region

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During the Late Cretaceous-Eocene, the future Karpathian orogen was part of the Alpine-Karpathian orogen formed by known southeastward subduction (135-55 Ma) of the Penninic realm and collision of European and Adriatic continents. While the Eocene Alps were at the converging (collisional) fronts, the remnant Eocene Karpathian Flysch Basin (rCFB) experienced subduction. The subduction in the Alpine region ended by delamination of subducting oceanic lithosphere from the light continental one and related magmatism (42-25 Ma).

During the Late Oligocene-Early Miocene, the rCFB was experiencing ongoing subduction, that formed the free interface for the East Alpine extrusion from the "Alpine collisional node". The oceanic plate underlying rCFB subducted southwestwards, later westwards while northeastward and eastward migration velocity of the accreting plate boundary was decreasing through the time. Slower subduction rates caused steeper dip of the subduction zone, Eggenburgian onset (22-19 Ma) and following duration of hinterland extension accompanied by asthenosphere elevation, onset of crustally derived volcanism above elevated asthenosphere and younger mantle-derived volcanism, progressively less contaminated by crustal material, all contemporaneous with shortening in frontal, accretionary, parts of the Carpathians.

Subduction of the rCFB led during the end of the Early Miocene to a collision with continental margin at the westernmost part of the present Carpathian arc. Northeastward, later eastward subduction roll-back of the subducting slab of the rCFB under the advancing Inner Carpathians, oblique closure of the basin, progressive change of subduction to collision from the west to the east along the Carpathian arc drove delamination of the remaining oceanic slab. Delamination has started in the west of the Carpathian Arc since Erly Miocene, ran along the arc to its present onset position in the bend area between the East and South Carpathians. The delamination lateral propagation rate had also decreasing trend in time. Delamination-related volcanism was synchronous with final stages of the collision, as it was in the case of Eocene-Oligocene "Alpine delamination".

Kinematics of the Periadriatic Fault in the Eastern Alps: evidence from paleostress analysis, fission track dating and basin modelling

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New kinematic data along the eastern part of the Periadriatic Fault (PF) in the Eastern Alps, show polyphase kinematic patterns due to a succession of distinct deformation phases. The PF and related structures mark a first order tectonic boundary between the Austro-Alpine and the South Alpine units that differ in style and timing of deformation in metamorphic conditions.

Initiation of the future PF may have been occurred during Oligocene break-off of the subducted lithosphere where tonalitic magmas intruded in a continuous belt along the future PF within a wrench zone controlling the location of the future PF.

Depth determinations using the Al-in hornblende barometry yielded c. 5-6 Kb. The deformed metamorphic basement units of the Gailtal metamorphic complex, Eisenkappel zone and Palaeozoic carbonate complexes of the Southern Alps (Eder unit, Devonian) show E-W striking mylonitic foliation and mineral stretching lineation gently plunging to the east. High ductile strain affected Periadriatic plutons after emplacement, as the PF acted as a „stretching fault" during transpressive N-S shortening, leading also to exhumation of the Periadriatic tonalites. Rheological and frictional properties and fluid pressure allowed a deformation on plutons that lengthen in the slip direction while strike-slip accumulated.

Subsequent brittle deformation led to changing convergence directions within a transpressive regime. These stages include:

(1) Early Miocene N-S directed contraction caused transpressional structures expressed by N-directed thrusts and S-directed backthrusts, NW-striking dextral faults (R faults), and NE-trending sinistral faults (R' faults).

(2) Late Miocene top-to-NW nappe stacking N of the PF (e_3 NW-SE, e_1 subhorizontal). The final overthrust of Karawanken Mountains during Miocene, which form a positive flower structure, also includes flexure of the northern foreland, and formation of a narrow Sarmatian to Quaternary foreland basin, the Klagenfurt Basin.The final NNW-directed overthrust of the Karawanken mountains onto the foreland is depicted by several NW-SE striking dextral tear faults and NW- to NNW-directed thrust planes in Upper Tertiary sediments.

2D-numerical modelling of crustal flexure and strength profile calculations were carried out in order to calculate the effective elastic thickness and shape of the Austro-Alpine crust underneath the basin using Bouguer anomaly data (Steinhauser et al., 1980, Meurers, pers. comm.). The best-fit models gave very low effective elastic thicknesses for the bending plate of between 1.7 and 0.9 km. Estimated bending moment and vertical shear forces alone create too shallow deflection, so additional horizontal forces (horizontal forces approx. -1.5 kbar) must be estimated.

The low effective elastic thicknesses indicate that only the a small part of the lithosphere supports the regional isostatic response to the load by the Karawanken Mountains. The lithosphere to north of the Karawanken Mountains is characterised by crustal thicknesses of between 40 and 45 km and elevated heat flows. Rheologic models for this lithospheric configuration indicate a strong decoupling of upper crust, lower crust and mantle and generally low strengths for the lower crust and mantle. This strength distribution suggests that only the upper crust elastically supports the topographic load and lower crust and perhaps mantle deformed by ductile flow. Ductile flow of the lower crust is also supported by the absence of a crustal root beneath the Karawanken chain (Steinhauser et al., 1980).

Data derived from apatite fission track dating on samples north and south of the PF show Miocene or Oligocene cooling ages. These range from 36.5 ± 1.5 to 31.7 ± 1.9 Ma for South Alpine Werfen Formation in Slovenia, and 12.8 ± 0.9 to 13.1 ± 1.4 Ma for tonalites between Lesach Valley, the Karawanken Mountains and the Pohorje massif north of the PF. Confined track length distributions from all samples indicate different cooling histories. Mean track lengths are confined to the range of 11,46 to 13,38 μm. The track length distribution from the South Alpine Werfen Fm. has shorter tracks which indicates that the sample spent a longer time in the upper part of the partial annealing zone (approx. 100° C).

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Multiple episodes of extension and contraction in the Eastern Alps

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The Alpine orogen of the Eastern Alps resulted from both multiple periods of extension and contraction. The following discussion mainly summarizes arguments for these from the Austro-Alpine and South-Alpine units.

The Variscan orogeny assembled various tectonic units to the future Austro-Alpine and South Alpine units that widely differed in style and tectonic significance before and during Late Variscan orogenic paroxysm. Widespread post-orogenic I-type granitoid intrusions are interpreted to result from post-Variscan equilibration of the thermal boundary layer in the thickened Variscan lithosphere. The heat input led to thermal weakening of these units resulting in localization of subsequent Permian extension that is thought to have resulted from general sinistral shear due to the specific site within the continent-scaled wrench zone between Laurussia and Gondwana. A pulse of Early to Middle Permian transtensive rifting led to formation of NNE- to NE-trending ductile and brittle normal faults, deposition of syn-rift sediments in half-grabens, gabbro intrusions, low-pressure/high temperature metamorphic overprint (within the stability field of andalusite), and localized melting of the continental crust and pegmatite intrusions within both Austro-Alpine and South-Alpine units. Late Permian to Triassic sequences are interpreted to represent post-rift sediments due to thermal subsidence. A second rifting pulse affected mainly higher Austro-Alpine and the South-Alpine units during early Middle Triassic and led to the formation of the Meliata oceanic domain along the southeastern margin of the Austro-Alpine units (sensu stricto). This rift event was also responsible for passive continental margin formation in both Bavaric/Tirolic units and Upper Juvavic units within the Northern Calcareous Alps. Some of present Middle Austroalpine and central Upper Austro-Alpine units may represent the originally northwestern rift shoulder to that event.

Rhaetian to Early Jurassic tectonic rifting led to the formation of the South Penninic ocean by separation of the Austro-Alpine realm from stable Europe. Evidence for this occurred within the Northern Calcareous Alps, and western Lower Austro-Alpine units.

The contraction history started with rapid Late Jurassic to Early Cretaceous subsidence of the Bavaric/Tirolic passive continental margin, emplacement of remnants of distal Meliata units und the opposite passive continental margin sequences that form now the Upper Juvavic tectonic klippe within the Northern Calcareous Alps. Nappe stacking within Austro-Alpine footwall units is a result of wedging of upper continental crust during a short-living period of A-subduction of Austroalpine units during the early Late Cretaceous, their entire consumation, and subsequent extension within a sinistral, transtensive wrench corridor. Burial and later thrusting resulted in a ramp-like structure of individual Austro-Alpine nappes. The Late Cretaceous sinistral wrenching appears to reflect differential plate motions in respect to the opening of the Atlantic ocean, and is partly responsible for iuaxtaposition of different Austro-Alpine and South-Alpine paleogeographic units. Another result of wrenching is the formation of a major sinistral shear corridor close to the present southern margin of Austro-Alpine units separating northern amphibolite facies metamorphic units from southern greenschist facies units by a transtensive ductile shear zones.

The Austro-Alpine units were affected by Eocene piggy back emplacement onto Penninic oceanic and units in extension of the European foreland. Brittle faults formed in the interior of Austro-Alpine units, and some major N-trending, sinistral strike-slip faults may be related to that event.

Final eastwards prograding shortening (Oligocene to Early Miocene) along the northern margin of the Eastern Alps led to displacement partitioning of contraction due to interferences of the geometry of the continental foreland and the geometry of the South Alpine rigid indenter. Several stages can be distinguished during this process: (1) Formation of a Oligocene, ENE-trending wrench corridor that continued into a (2) Early-Middle Oligocene wrench corridor where a conjugate dextral wrenching along started late in respect to the sinistral wrenching; and (3) final stages of extrusion towards east of a rigid Central Austro-Alpine block. Because of the wedge-like shape of the extrusionial wedge this started from areas with strong shortening (c. 40 % shortening), passed through a pre-Miocene neutrality to a stretching perpendicular to the extrusional displacement vector (with a N-S oriented stretching factor of c. 1.2) during extrusion. All these combined effects led to a strong complication of initial multiple rift configuration within Austro-Alpine paleogeo-graphic domains.

Middle Jurassic subduction-related volcanism and Cretaceous kinematics in Meliata units of the eastern Northern Calcareous Alps

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A sedimentological and structural study has been carried out on Meliata units of the eastern Northern Calcareous Alps (NCA). There, the Meliata units there comprise Middle/Late Triassic pelagic limestone and radiolarite, and the Doggerian Florianikogel Fm. with dark shale/slate and sandstones where the earlier formations are interpreted to represent olistolites within the Florianikogel Fm. (Mandl and Ondreijickova, 1991; Kozur and Mostler, 1992). Own field lithostratigraphic and structural investigations suggest that the Middle/Triassic and Doggerian formations represent a continuous sequence that is overlain by another tectonic unit with mainly greyish to colored pelagic limestones. The Florianikogel Fm. represents the well-preserved, finely laminated sequence with dark slate, cm-thick feldspar-rich tuffaceous layers, and several cm-thick, volcaogenic graywacke layers. Modal (using the Gazzi-Dickinson approach) and geochemical compositions (major, minor and trace elements following Bhatia & Crook, 1986) suggests a deposition of these graywackes in a arc-related geodynamic setting. Both the graywacke composition and the presence of tuffaceous layers indicate, therefore, provided correct biostratigraphy, the presence of a distal volcanic arc setting in an anoxic sedimentary basin in the Meliata ocean.

The thrusting of Meliata units onto the proximal Tirolic passive continental margin sequences of the NCA occurred under very low grade to low grade metamorphic conditions during pre-Gosau shortening and nappe stacking. Kinematic indicators display, similar to all underlying Austro-Alpine units, a top WNW emplacement of Meliata units under semi-ductile to ductile tectonic conditions. In portions, ductile fabrics were annealed (e.g. within a basal calcite marble), in hangingwall units overprinted by top-SE extensional fabrics.

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P- and S-wave tomography of the Vrancea seismogenic zone

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A set of 2782 P- and 2615 S-wave arrival times from 319 local earthquakes recorded at least at 7 stations were simultaneously inverted for 3-D P- and S-wave block velocity structures, hypocentral parameters and station corrections. The block dimension was 30 km x 30 km horizontally and the layer boundaries were at 20, 40, 60, 80, 100, 120, 150 and 180 km depth. A number of 248 blocks were modelled. The overall reduction in residual variance was 32%, leaving 0.46 s unexplained, mostly due the errors in S-wave picking. In the crustal domain, the results confirm the high velocities directly under the Carpathians and the low velocities in the foredeep region. In the subcrustal domain, the results confirm the seismic gap between 40 and 60 km depth, as well as the very narrow vertical region oriented SW-NE, with maximum 15 km in the SE-NW direction, containing the intermediate depth earthquake foci. There is a tendency of the foci between 60 and 150 km depth to lie in low velocity regions (v_P = 7.5-7.7 km/s). We tentatively explained the presence of these velocities in that depth range by a basalt to eclogit phase transition in the subducted oceanic crust. The foci lie in zones with $v_P/v_S \geq 1.7$ in the crust and between 1.6-1.7 below the depth of 60 km. Higher subcrustal velocities are found in NE (East European Platform) or in NW (Transylvanian Basin) in comparison with the southern regions belonging to the Moesian Platform.

Timing of basement reactivation in the Inner Western Carpathians

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Fault systems formed in the Austroalpine basement of the Inner Western Carpathians during Triassic-Jurassic rifting have been reactivated several times in a variety of tectonic regimes and metamorphic environments. The complex events recorded in the fault rocks of these systems have been locally obscured by overprinting, but the integration of structural data and the pattern of sediment deposition on a regional scale has helped to resolve local complexities into a regionally consistent model. The aim of this presentation is to discuss the significance of the observed repeated selective exploitation of ancient fractures and to speculate on its influence on the depositional pattern on the northern margin of the Pannonian basin.

Sets of steep E-W to NE-SW-trending extensional faults and NW-SE-trending transfer faults dissect the Austroalpine basement to form a system of blocks, which formed the floors of small (locally isolated) sedimentary basins from the Triassic onwards. Sedimentation was intermittent, controlled by reactivation of the bounding faults. As the availability of reliable slickenfibre data in this area is restricted (B.Sperner pers. comm. 1993), and sedimentary control on the timing of fault movements is poor, radiometric dating (Ar/Ar on white micas) proved an invaluable tool in determining the absolute timing of reactivation of the E-W to NE-SW-trending set as sinistral transtensional faults with varying amounts of dip-slip: ca. 85-82 Ma. Deformation was strongly partitioned into the fault zones, and the intervening blocks were only weakly deformed.

At least some of the E-W-trending set functioned sporadically as growth faults during rifting, with the largest sediment thicknesses on the southern i.e. downthrown side. This pattern is preserved as the thrusting related to the Lower Cretaceous compressional event was non-pervasive in the Inner Western Carpathians, in contrast to the Alpine-Pannonian transition zone, where coeval "corner effects" produced a more complex deformation pattern. It is speculated that the basement of the northern Pannonian basin to the south of the IWC similarly escaped major shortening, in which case the reactivated structures dominating the formation and development of Palaeogene and Neogene basins could be extensional faults of Triassic-Jurassic age, with coeval rift infill locally underlying the younger basins, rather than major thrust faults postulated in analogy to the transition zone further to the west. This implies that additional source and reservoir rocks may be preserved in the subsurface of the northern Pannonian basin.

Geodynamic evolution of the Central Dinarides

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As distinguished from the northwestern and southeastern Dinarides, the central parts are characterized by a zoned pattern in the distribution of the large lithostratigraphic units. From the southwest i.e., the Adriatic microplate to the northeast, six main lithological associations originating in different environments can be distinguished.

(1) The carbonate platform (CP) formations of the Alpine passive continental margin (the present External Dinarides) are underlain by Upper Paleozoic formations. Initial stages of CP evolution were predisposed by rifting accompanied by the magmatism of the continental crust origin, which finished in the Late Triassic. Afterwards monotonous carbonate sedimentation continued in stable environments and lasted, with a few hiatuses, unitil the Middle Eocene.

(2) The passive continental margin formations originated by continuous sedimentation on the slope of the CP and its foot. Two main units can be distinguished: (a) Jurassic to Turonian sandstones and limestones, only in some places with flysch signatures, and (b) Senonian - Paleogene (?) carbonate flysch sediments.

(3) The ophiolite formations originated in different environments: (a) Late Triassic to Early Cretaceous radiolarites with shales, micrites and basalts. (b) Graywackes and shales, i.e. an olistostrome melange with fragments of graywackes, basalts, diabases, gabbros, peridotites, cherts and exotic carbonate rocks; the age of the melange is presumably Jurassic to Early Cretaceous. (c) Ophiolites are represented by peridotites with subordinate gabbros, diabases and basalts; the radimetric ages of ophiolites range from 180 to 136 Ma. (d) Late Jurassic to Late Cretaceous overstep sequences represented mostly by clastic and carbonate rocks.

(4) The active continental margin formations, related to the subduction zone, are represented by (a) Upper Cretaceous-Paleogene trench sediments with blocks of blueschists; (b) Tectonized ophiolite melange in which exotic blocks of Upper Cretaceous and Paleocene limestones are also included; (c) Alpine medium-pressure metamorphic rocks originating from the surrounding Upper Cretaceous-Paleogene sediments, and (d) Alpine synkinematic granitoids.

The four formations marked by (2) to (4) are included in the Internal Dinarides.

(5) The allochthonous Paleozoic-Triassic formations are thrust onto the internal units but the frontal parts of the nappe overlie the northeastern margin of the CP. In some areas, below the Paleozoic-Triassic nappe tectonic windows composed of rocks of the ophiolite formations are found.

(6) Post-orogenic Oligocene and Neogene formations accumulated in marine to fresh-water environments in Oligocene intramontane basins, numerous Neogene depressions in the uplifted Dinarides, and in the Pannonian Basin.

Geodynamic evolution of the central Dinarides was related to a sequence of tectonic events which took place within the Alpine Wilson cycle. (1) Rifting processes of some 40-50 Ma duration which ended in the Late Triassic. (2) Opening of the Dinaridic Tethys which took place in Late Triassic/Early Jurassic time when a spreading center was set up. This made possible the generation of the oceanic crust during the period of 60-70 Ma. At that time there was probably also subsidence of the northeastern marginal parts of the CP composed of the Triassic formations with unconformably underlying Paleozoic formations, which were thus included in the basinal parts. (3) Subduction processes started in a subsequent Late Jurassic/Early Cretaceouc time as indicated by the first emplacement of ophiolites. By the end of these processes, the Paleozoic-Triassic formations overlain by the oceanic crust were probably detached and thrust onto the emplaced ophiolites and their country rocks. The emplacement of ophiolites and stocking of the Paleozoic-Triassic nappes was accompanied by the first strong Alpine metamorphism (120-110 Ma). (4) In the northern Dinarides, in the Late Cretaceous a magmatic arc has been already generated as indicated by the presence of trench sediments and igneous rocks characteristic for such a geotectonic setting. (5) The main deformational (compressional) event (about 40-50 Ma) and medium-pressure metamorphism accompanied by synkinematic granite plutonism took place after the Eocene termination of subduction processes. This deformation produced main NW-SE-trending fold, thrust and imbricate structures with the southwestern vergences. Only north of the presumed subduction zone, opposing northeastern vergences due to obduction were recognized. (6) Post-orogenic evolution started after the Eocene uplift of the Dinarides which gave rise to the separation of the Tethys into the Mediterranean and the Paratethys.

Which is the time of rotation? Review of paleomagnetic and K-Ar data from Romania

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Recent K-Ar data from Romania has changed or improved the age of some magmatic rocks sampled for paleomagnetic studies. A first important change concerns the age of basaltic andesites from Mures Valley (Apuseni and Poiana Rusca Mountains). These rocks, previous considered as Paleogene, have ages between 66 ma and 72 Ma. The second important contribution of the radiometric data concerns the ages of the two groups with different paleomagnetic directions from Miocene magmatic rocks of Apuseni Mountains. Two K-Ar data from the group with a declination around 70° suggest an age between 14.7 - 12.4 Ma. The K-Ar data from the group that show no rotation suggest an age around 11 Ma. The paleomagnetic data support the existence of a domain characterized by a large clockwise rotation in the eastern part of the Carpatho-Pannonian area. The amplitude of the rotation is variable from 70° in the Apuseni Mountains -Banat area to 120° in the Bucegi Mountains. Data from the Apuseni Mountains suggest a very fast rotation during Sarmatian. This rotation was coeval with the counterclockwise rotation of the Gutai Mountains, but took place after the end of the counterclockwise rotation of the North Pannonian Paleogene basin (around 16 Ma). This fast rotation was accommodated in the brittle layer by coeval trusts and strike-slip faults in the East and South Carpathians and extensional grabens and shear zones in the Great Hungarian Plain. These rotations reflect probably the continuously deforming lithosphere beneath the seimogenic upper crusts. K-Ar data from Pannonian-Quaternary volcanic rocks of East Carpathians show the migration of the volcanism along the arc and a short duration of volcanic activity in individual segments. Paleomagnetic rotations are absent in these magmatic rocks, but the migration is in the same sense as the previous clockwise rotation. The above features are all consistent with the slab breakoff model. Cinematic parameters derive from these data will be discussed with respect to the proposed tectonic models for this area.

Styles of Miocene thrusting, strike-slip faulting and extension in the eastern Calcareous Alps

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The final stage of collisional shortening in the Eastern Alps was characterized by intense brittle deformation of the Calcareous Alps during the Miocene. Thrusting over the European margin occurred until the Early Miocene (Karpatian stage, 17 Ma) as dated by overthrust Molasse sediments. Thrusting was generally directed northwards and exceeded 34 km since the Late Oligocene (Wessely, 1987). The irregular morphology of the overthrust European basement controlled deformation styles in the upper plate. From the

Early Miocene on continued shortening was accommodated by distributed sinistral shear during eastward lateral extrusion (Ratschbacher, 1991; Linzer et al., 1995) of the central Eastern Alps. Three stages of Miocene deformations can be distinguished in the Calcareous Alps.

(1) Early Miocene N-directed shortening during the onset of eastward lateral extrusion led to the formation of (N)NE-striking sinistral faults. Older NW-striking faults continued to move dextrally. N-directed shortening in the Calcareous Alps correlate to the N-directed translation of the Adriatic plate.

(2) Middle Miocene NE-directed shortening of thrust- and strike-slip type during the subsequent stage of extrusion caused sinistral movements along E-W to NE-SW striking faults which were partially linked with NE-directed thrusts. The Königsee-Lammertal-Traunsee fault shows spectacular examples of convergent strike-slip duplexes, flower structures and connected thrusts. Thrust distances along thrust planes connected to strike-slip faults locally exceeded 6 km (Warscheneck nappe). Sinistral offsets at strike-slip faults reached up 30 km (Pyhrn fault). Most of the sinistral displacement along the Salzach-Ennstal fault occurred during this stage leading to the formation of positive flower structures. Older NW-striking dextral faults were partially reactivated as high angle reverse faults. Deformation style changed east of the overthrust Bohemian basement spur, which formed a morphologic high of the lower plate and which can be traced up to 50 km behind the alpine deformation front (Wessely, 1987). West of this basement spur, NE-directed thrusts dominated, whereas east of it extensional deformation prevailed. At the eastern margin of the Calcareous Alps, increasing extensional strain marks the transition towards the Vienna Basin. NE-directed shortening in the Calcareous Alps resulted from the drag of the eastward extruding central Eastern Alps which added a component of sinistral simple shear to overall N-directed shortening.

(3) Middle Miocene E-directed extension led to the formation of E-directed normal faults and to normal-sinistral movement along NE-striking faults. Deformation at the Salzachtal-Ennstal shear zone changed from transpression to transtension. Extension in the Calcareous Alps was associated with orogen-parallel detachment faulting in the central Eastern Alps. There, E-directed extension paralleled the direction of mass transfer towards the Pannonian Basin during lateral extrusion. Extensional faulting was induced by reduced lateral confinement east of the Alps due to the eastward motion of the Pannonian lithospaeric wedges.

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Chronology of Cretaceous tectonic events in the Central Western Carpathians

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The Cretaceous stage was the main period of tectogenesis of units in the Central Western Carpathians (CWC, here considered as an area between the Penninic-Vahic and Meliata-Hallstatt oceanic sutures, i.e. corresponding to the Austroalpine system). The paleotectonic evolution encompasses preorogenic pelagic and synorogenic flysch sedimentation, magmatism and metamorphism of different types, subduction of zones floored by oceanic or attenuated continental crust, stacking of collisional thick-skinned crustal imbricates and emplacement of d,collement cover nappes, as well as superimposed transpressional and transtensional movements. All processes involved exhibit a forelandward (generally northward) progradation and vergency of dominant structures. The interpretation of relatively rich, sufficiently age-constrained material and structural rock records enables a sophisticated temporal-spatial reconstruction of Cretaceous orogenic processes within the CWC, partitioned into seven principal periods:

(1) Late Jurassic - Early Cretaceous (150-125 Ma). Closing of the Meliata ocean and collision of its margins, exhumation of some HP/LT metamorphosed Meliatic units, loading of the South Veporic basement and cover by the collisional stack, general crustal thickening in the southern CWC zones. In the northern CWC domains (Fatric-Tatric-Vahic) an extensional regime, lithospheric stretching and mostly pelagic sedimentation continued.

(2) Late Early Cretaceous (125-110 Ma). Shortening prograded to the southern margin of the Fatric basinal realm, cessation of sedimentation in the transitional Veporic-Fatric Velkì Bok domain, contraction is heralded by huge olistostromatic bodies in the Fatric Zliechov basin, extension-related submarine basanitic volcanism and resedimentation events in the Fatric-Tatric foreland, probably bulge-related shallowing of the South Tatric ridge with Urgonian carbonate platforms.

(3) Mid-Cretaceous (110-90 Ma). Gradual underthrusting of the thinned Fatric crust beneath the North Veporic thrust wedge, d,collement of the Zliechov basin infill to form an accretionary fold-and-thrust belt with coeval flysch deposition in forearc or piggyback basins. Shortening started also in the South Tatric domain. Thermal relaxation and compressional uplift of the ultra-Veporic thrust stack due to underplating of the Fatric crust.

(4) Late Turonian (around 90 Ma). After elimination of the Fatric basinal area and pushing-up of its detached and imbricated sedimentary filling over the South Tatric frontal ramp, an extensive overthrusting, narrowly age-constrained event occurred in the CWC. The Krizna (Fatric) and Choc (Hronic) nappes were gravitationally emplaced above the Tatric cover.

(5) Early Senonian (90-80 Ma). Shortening relocated to the outer Tatric margin facing the Penninic-Vahic ocean, where flysch coarsening-upward complexes deposited during underthrusting of the Vahic crust. Contemporaneously, the Veporic metamorphic core complex was rapidly exhumed by top-to-the east unroofing. Small anatectic granitic bodies intruded the Veporic basement.

(6) Middle Senonian (80-70 Ma). Deeply denuded Veporic units were overriden by the Silicic relief nappes. Transtension in the inner CWC zones, accretion along their outer edge with terrigenous and pelagic sedimentation.

(7) Late Senonian - Early Paleogene (70-60 Ma). Collision of the Tatric sheet and overlying nappes with the Oravic continental ribbon (Kysuca and Czorsztyn units of the later Pieniny Klippen Belt) after diminishing of the Vahic basin, followed by dextral transpression within the collisional zone and wrench faulting inside the CWC area.

The maps of tectonostratigraphic units and principal structures of the Western Carpathians and adjacent areas

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The first, tentative versions of two map sheets in the scale 1:1,000,000 have been compiled to demonstrate the present state of knowledge about the general tectonic structure of the Western Carpathians and surrounding areas.

The aim of the first map is to outline the dominant composition and regional distribution of the principal tectonostratigraphic units. The units are specified according to the paleogeographic and paleotectonic principles (e.g. the time of structuralization), less based on the lithostratigraphic and deformation criteria. In general, the map is stripped off the "post-tectonic" sedimentary and/or volcanic cover superimposed on the tectonic edifice formed during the main Alpidic compressive events. Thirty one items of the legend comprise superunits of the Alpine-Carpathian foreland and the orogenic zone itself.

The structural map depicts the most important macro- to megascopic structures, especially antiforms, synforms, large-scale recumbent folds, buried horsts, low-angle thrust faults, high-angle con-tractional (reverse) faults, extensional normal faults and strike-slip and/or oblique-slip contractional and extensional fault zones. Narrow spacing of reverse faults indicates imbricated tectonic style, the com-bination of reverse faults and synforms or antiforms defines fold-and-thrust belts. Coincidence of several kinematic types of faults in one line points to re-peated reactivations of a long living "lineaments" (usually former sutures) with changing kinematic role through time. Five temporal periods of formation of principal structures shown (Paleozoic-Middle Jurassic, Late Jurassic-Early Cretaceous, Late Cretaceous, Paleogene-Early Miocene and Neo-gene) are distinguished by different colours. Based on the age of the main phase of structuralization and dominating tectonic styles, two principal structural-tectonic provinces may be recognized in the map. These are the Alpine-Carpathian foreland (North European Platform) and the Alpine-Carpathian orogenic belt. The former obtained its fundamental structural features already in pre-Alpine times, the latter exhibits polyphase Alpidic evolution and a wide range of tectonic styles.

The Southern Alps - Dinarides relationship

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According to the classic division of the Alps, the area south of the Periadriatic line belongs to the Southern Alps. These in general include the Southern Karavanken and Carnic Alps, the Julian Alps and Dolomites and the Sava hills (Sava folds) of Central Slovenia.

The division of the Dinarides originates from the Kober's "bilateral orogen" that determines the External, Central and Internal zone. However, only the terms External and Internal Dinarides have been in common usage. The area to the south, i.e. the Adriatic basin bears different geotectonic names.

The cross-section from the Adriatic basin to the Periadriatic line, at least in Slovenia, shows a gradual paleogeographic transition between above mentioned units. Laterally from the Southern Alps to the Dinarides and vice versa, they express paleographic unity.

Starting from the south, the Istrian platform of the Adriatic basin transits normally to the External Dinarides, and they both form a unique Adriatic - Dinaric carbonate platform of Mezozoic to Paleogene age with non-significant paleogeographic differences. Their contact is a folded zone with a minor tectonic offset along reverse faults formed in post - Eocene age.

The transition of the External Dinarides to the Southern Alps and/or Internal Dinarides is also gradual. These last ones are represented here by a zone of Mesozoic deep water sediments known as the Slovene through. It was initiated in Middle Triassic, and had continuously progressed to the south. In post - Oligocene time, through sediments have been generally thrusted upon the Aridatic - Dinaric carbonate platform.

The northern rim of the Slovene basin is the Julian carbonate platform, that had desintegrated during Lower Jurassic and had been more or less covered by deep water sediments to the end of Mesozoic. In post-Oligocene, the Julian platform has been thrusted southward over the Slovene basin with undetermined amplitude of tectonic desplacement.

The Paleozoic basement of the Julian Alps is exposed to the north as the Southern Karavanken. The contact between these two units is mostly tectonical and it is determined by thrusts and normal faults of post-Oligocene age.

Laterally, starting from the northern Italy, the External Dinarides outcrop in the northern rim of the Po basin as the Trento platform, and they continue southeastward occupying the most part of southern Slovenia, Croatia and Bosnia. The deep water sediments of the Belluno through continue into the Slovene through and into the Central Bosnian zone of Internal Dinarides. The Julian platform together with its Karavanken basement could be followed east and northeastward into Transdanubian range of Central Hungary where they both emerge with the basinal sediments of the Southern Alps and/or Internal Dinarides.

Therefore the boundary between the Southern Alps and Dinarides, that is usually placed "somewhere" in Slovenia is artificial one, and it represents more geographical than geological division.

Subsidence analyis of reconstructed profiles of the Pienniny Klippen Belt Basin

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The area of research is Polish part of Pieniny Klippen Belt (PKB), for which twelve synthetic pre-orogenic 1-D profiles of individual zones of the basin were reconstructed. Profiles represent Czorsztyn-, Czertezik-, Niedzica and Branisko-Pieniny successions, and cover Pliensbachian-Early Campanian basin history. We applied subsidence analysis technique for analysing pre-orogenic history of tectonic vertical movements of the basin basement, which includes quantitative balancing of thicknesses, absolute ages, bathymetry and lithological data for individual lithofacial units, as well as calculating isostatic and decompaction effect of backstripping.

There is a good control on thicknesses of formations (small total thicknesses of profiles are characteristic: aprox. 200-500m) as well as on stratigraphy and lithology (last one has a minor influence on a model). Bathymetry estimations are based on lithofacial analysis, relations to CCD and ACD, and faunal indicators. Quantitative bathymetric control is poor, but relative changes are certain. Models for PKB basin strongly depend on bathymetry, what causes their error bars to be wide.

Our preliminary results (tectonic subsidence curves) show high dynamic of vertical tectonic movements of basin basement. Remarkable similarities exist in a general pattern of subsidence history over the whole PKB basin.

For Pliensbachian-Bajocian the curves show slow subsidence, which during Bathonian accelerated. Callovian-Oxfordian are characterised by very rapid subsidence, which might be attributed to tectonic event taking place across all the basin (more pronounced for Branisko and Pieniny successions). The subsidence character might be interpreted as extensional or transtensional. The second one is supported by high rate of subsidence, its short live span and sudden extinction, and lack of thermal cooling. The question is if lateral heat flow mechanism (characteristic for small transtensional basins) might be applied in a case of PKB basin, which was several tens of kilometres wide.

At the end of Oxfordian rapid uplift started, which lasted until Berriasian, ceasing with time. It is interpreted as a record of major modification of stress regime in the basin (possibly to transpressional regime?).

For Early Cretaceous subsidence curves are less reliable (mainly due to hiatuses), nevertheless they show higher diversity and the basin seems to behaved in a less uniform manner.

During Albian-Cenomanian slow subsidence appeared across all zones of the basin, and since Turonian rate of subsidence began to increase, creating a compressional type of curve. This is coincident in time with Turonian folding in Inner Carpathians to the South of PKB basin. The subsidence for Late Cretaceous might be thus explained by flexural bending mechanism in front of folding Inner Carpathians.

Pre-orogenic evolution of the Polish part of Outer Carpathians - quantitative subsidence and uplift analysis

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The Outer Carpathian flysch sequences in Poland are divided into several tectonic and facial units, related to primal sub-basins. Mainly Skole, Silesian and Subsilesian units are analysed here; for Magura and Dukla units results are very preliminary. Area of research is Middle and Eastern Polish Outer Carpathians. Synthetic reconstructed 1-D profiles for individual zones of sub-basins were prepared, covering Berriasian-Early Miocene basin history at most. For these profiles an input data (thicknesses, absolute ages, bathymetry, lithological parameters) were quantitatively balanced and profiles were backstripped in order to calculate tectonic component of the basement vertical movements. There is good control on thicknesses, lithology and stratigraphy of individual formations. Control on bathymetry is poor (error bars up to several hundreds meters) and was estimated using lithofacial and faunal indicators. Bathymetry is a key factor controlling curves character for Cretaceous-Early Oligocene.

Subsidence patterns similarities over the all basin suggest that geotectonic processes of regional scale controlled subsidence and uplift of sub-basins.

Relatively slow Berriasian-Hauterivian subsidence is interpreted as thermal cooling that followed possible earlier (Late Jurassic) extensional tectonic event (particularly in Silesian sub-basin).

Since Turonian-Coniacian until Maastrichtian-Paleocene an uplift of several hundreds meters over Skole, Subsilesian and Silesian sub-basins took place; it coincidented in time with Inner Carpathians folding. This uplift is interpreted as being a result of change in tectonic regime into compressional one. It is also suggested to be a part of geodynamic frame of Inner Carpathians foreland inversion, migrating in time to the North (e.g. Polish Trough). Our preliminary results show no presence of Late Cretaceous uplift in Magura and Dukla sub-basins. It might be an indicator of major rheological differences between crust of both mentioned parts of Outer Carpathian basin.

During Paleocene subsidence was re-established (in Magura and Dukla sub-basins increased in rate) and lasted until Middle-Late Eocene. Mechanism of subsidence could be an isostatic rebound after previous uplift, although the interpretation is very hypothetical.

During Late Eocene rapid uplift of a big magnitude (2000m?) started, which lasted until Early Oligocene. The uplift was followed by minor subsidence, being the last tectonic event in the basin. According to our interpretation, the uplift was a reaction to compressional stress which, due to general plate convergence background, increased after shortening processes to the South of Outer Carpathians had ceased. The increasing stress preceded shift of the locus of shortening to the North. Its final relocation and creation of main detachment surfaces resulted, in our opinion, in stress relaxation and Late Oligocene-Early Miocene limited subsidence. Further continuation of shortening introduced orogenic processes into analysed area.

Tectonical activity and facies distribution of the Neogene and Quaternary deposits in the Croatian part of the Pannonian Basin

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Recent structural relations and main tectonical movements in the north-western area of the Croatian part of the Pannonian Basin are presented. Relation; stress-deformational framework is explained. Transperssion of considered area is defined. Right wrench faults are pointed out. The most active faulted zones and different structural types are defined. The considered area is correlated with the adjacent region. Local structures and suitable traps for hydrocarbon accumulations are defined as well. Several typical examples of structural and lithofacies features are singled out. According to the well data as well as to the outcrop exploration and seismic profiling, regional litho-stratigraphical relations and facies distribution are explained. Due to the geochemical prospecting and correlation the most perspective zones are de-fined. All the data will be presented by the slides and/or transparency and on the posters.

A new model on the tectono-sedimentary evolution of southwestern Pannonian basin during the Late Miocene

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A new model on the tectono-sedimentary evolution of southernwestern Pannonian basin during the Late Miocene is presented. This was based on the interpretation of about 190 km of high-resolution, single-channel seismic profiles acquired on Lake Balaton and about 1700 km of multi-channel reflection seismics in SW Hungary.

Seismic stratigraphic interprertation has been calibrated by geologic mapping of selected areas and well logs. A magnetostratigraphic record was also available from a corehole in the study area, together with recent K/Ar dating of basaltic rocks from the Balaton highland.

The Late Neogene "post-rift" evolution of Pannonian basin was characterized, in a broad sense, by decreasing rates of subsidence (thermal subsidence), parallel with the increase of sedimentation rates. This resulted in a classic trangressive-regressive 2nd-order cycle, with general progradational patterns, followed by late-stage aggradation in the basin fill.

Our study showed that higher-order cyclicity can be also recognized at a regional scale in the Late Neogene "post-rift" sequence of south-western Pannonian basin. In particular, five 3rd-order sequence boundaries (Sar-1 and Pan-1 to Pan-4 Sequence Boundaries) can be documented on regional seismic profiles. Sequence Boundary Pan-2 has a magnetostratigraphic age of about 8.5 Ma and is associated with significant water-level drop in the Pannonian Lake and consequent exposure of basin margins that is widely recorded in the "marginal facies" of western Hungary.

The stratigraphic unit bounded by Pan-1 SB and Pan-4 SB is correlated with the Tortonian-Messinian 2nd-order cycle of the Mediterranean.

Following the Middle to Late Miocene extensional phase, the Pannonian area has experienced a tectonic reactivation during Late Pliocene and/or Quaternary. This is manifested by accelerated subsidence at the basin center and faulting associated with uplift and extensive erosion at the basin flanks. Erosional truncation of strata due to late-stage uplift of the Bakony mountains is best imaged by regional seismic profiles across southern Transdanubia and high-resolution seismic profiles of Lake Balaton.

The Neogene Styrian Basin

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The 100 km long, 60 km wide, and more than 4 km deep Styrian Basin is located at the eastern margin of the Alps and forms part of the Pannonian Basin System. It represents an extensional structure on top of a crustal wedge, which moved eastward during the final stages of the Alpine orogeny.

Basin evolution is subdivided into an early Miocene (Ottnangian to Karpatian) synrift and a middle to late Miocene postrift phase of subsidence. During the synrift phase thick clastic limnic/ fluviatile and marine sediments were deposited. The climax of extension during the synrift phase favoured the ascent of andesitic magmas. Today the voluminous shield volcanoes are nearly totally buried by younger sediments. An unconformity separates lower and middle Miocene sediments and is interpreted as the transition from the synrift to the postrift stage. During the postrift stage intercalations of sandy and shaly sediments and algal reefs were deposited. Basin inversion resulted in the erosion of a few hundred meters of sediment during the Pliocene and the Quaternary. Uplift was accompanied by a second volcanic phase producing basalts in Plio-/Pleistocene times.

The thermal history of the Styrian Basin was governed primarily by the Miocene magmatic event. Volcanic centers were characterized by extremely elevated heat flows (>300 mW/m^2) and heat flow decreased to background values (about 120 mW/m^2) at a distance of about 10 kilometers from the centers. After the early Badenian heat flows decreased and are in the range of 55 to 85 mW/m^2 since Sarmatian times. The volcanic activities in Plio-/Pleistocene times had only little influence on the regional heat flow pattern.

Subsidence analysis and the results of quantitative basin modelling suggest that the lithosphere beneath the Styrian Basin was extremely weak during Ottnangian-Karpatian times. This is probably due to high extension rates and high heat flows associated with Karpatian to early Badenian magmatic activity. Subsequent cooling enhanced the flexural rigidity. Depth dependant rheology models based on paleo-heat flow estimates, indicate a similar increase in lithospheric strength with time. The impact of Plio-/Pleistocene volcanism on rheology appears to be relatively modest, which can be explained by a deep position of the magma chamber for this event.

Tertiary Basins in Slovenia

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Tertiary basins in eastern Slovenia form part of the Pannonian Basin System. They are situated at the junction between the Eastern Alps, Southern Alps, Dinarides, and the Pannonian realm. Major WNW-ESE to E-W trending fault zones (Periadriatic and Donat shear zones, Sostanj and Sava-Celje faults) separate different tectonostratigraphic units.

North of the Donat Line (Units A1, A2) the oldest Tertiary sediments are Eocene (Paleocene?) in age. After a phase of major erosion, more than 5000 m thick sediments were deposited during Karpatian to late Miocene times. Oligocene and/or early Miocene magmatism (Pohorje tonalite) and early Miocene dacitic volcanism are important features of Unit A1 (north of the Periadriatic Lineament).

South of the Donat Line (Units B1, B2) the oldest Tertiary sediments including andesitic tuffs are of Oligocene and lowermost Miocene age. Badenian to late Miocene sediments follow after a stratigraphic gap.

Sediments of Unit A1 (north of the Periadriatic Line) exhibit consistent CCW rotation of about 30°. Unit B2 (Sava Folds) is characterized by moderate (20 to 30°) CW rotations. The rotations must be younger than Badenian. Units A2 und B1 are more complex and both CW and CCW rotations occur. However, CW rotations are far more frequent. These rotations must have occurred in post-Karpatian time, probably simultanously with movements in Units A1 and B2.

Brittle deformation of NE Slovenia was characterized by NNW-SSE (NW-SE to N-S) compression and perpendicular tension. The above fault zones were characterized by dextral strike-slip. This deformation was associated with folding and verticalisation of beds. Dextral transpression took place during the early Miocene (Ottnangian, Karpatian), reoccurred several times during the late Miocene and Pliocene, and lasted to the Quaternary. Situated between the major shear-zones, the Smrekovec area (Unit B1) is characterized by sinistral transpression, while the Savinja block was affected by dextral transtension. In the Mura depression NE-SW tension occurred, probably during the middle and late Miocene.

Several magmatic phases and high rates of vertical and horizontal movements resulted in a complicated thermal history. Early to middle Miocene thermal events occurred in Unit A1 (e.g. Pohorje and Gora Radgona areas). Coalification data indicate Paleogene and/or early Miocene thermal events along the Periadriatic Lineament in Units A1 and A2. Present-day heat flows are high (70 to 120 mW/m^2). This is a result of thinned crust.

Paleogeographic and orogenic evolution of the Alps

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The paleogeographic evolution of the Alps during the Mesozoic was controlled by three basins partly underlain by oceanic lithosphere: the Meliata-Hallstatt basin (opened in the Middle Triassic, closed in the Late Jurassic), the Piemont-Liguria basin (opened in the Middle Jurassic, closed in the Paleogene, and the Valais basin (opened in the Late Jurassic to Early Cretaceous, closed in the Eocene). Some paleogeographic domains cannot be traced all along the Alpine chain: There are no Austroalpine units (in the strict sense) in the Western Alps while there is no Briançonnais in the Eastern Alps, where Valais and Liguria-Piemont oceanic domains merge.

Cretaceous orogeny is the result of (1) collision between the Austroalpine continental crust and another continent further to the east (Eastern Alps) and of (2) subduction of oceanic crust and/or continental fragments (Sesia zone eclogites) under the Austroalpine-South Alpine margin (Western and Central Alps). Collision with the Briançonnais terrain and European distal margin is related to a second orogenic cycle during the Tertiary, also associated with eclogite facies metamorphism (Dora Maira-Adula-Tauern). Tertiary-aged N-S convergence amounts to 500 km in the Central Alps (and probably also the Eastern Alps) while E-W shortening in the Western Alps is essentially post-collisional, post-dating sinistral strike slip movement related to N-S-shortening in the Central and Eastern Alps. Post-collisional shortening in the

Central and Eastern Alps is characterized by strain partitioning into vertical thickening, orogen-parallel extension and lateral escape. The amount of "lateral extrusion", held responsible for the formation of the Carpathian arc by many workers, has been overestimated in our view.

The Alps-Dinarides superposition in NE Italy - observations and models from two interfering foldbelts

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The eastern Southern Alps are a complex, arcuate fold-and-thrust belt that developed at the north-eastern edge of the Adriatic (or Apulian) microplate. The present day, intricate architecture of this belt is the combined result of (1) Mesozoic rifting, basin and carbonate platform formation, (2) Cretaceous to ongoing plate convergence between Apulia and Europe with major changes in convergenc direction in the course of time, (3) the shape of the indenting Apulian microplate.

Rifting lead to swells with intermediate basins during early Liassic. Various high zones drowned during late Liassic, but the Friuli carbonate platform comprising the southernmost hills of Cadore and Carnia, and large parts of the Venetien plain remained high as long as to the Paleocene.

Flysch sequences date the Dinaric deformation as mainly late Paleocene to early Eocene. One of the peculiarities of the NW part of the Dinarides is the absence of metamorphism although some 250km of exposures exist across strike. This calls for a very low taper and long detachments along efficient decollement horizons. W to WSW-vergent Dinaric ramp-folds and ramp-flat thrust systems are well documented in the eastern and central Dolomites. In the Carnian Alps adjoining to the east they are less obvious, possibly due to the mentioned decollements. In the Mesozoic basinal sequences (N) the front of Dinaric thrusting advanced more to the west than in the Friuli platform (S), creating sinistral transverse zones following approximately the ancient paleogeography.

Alpine deformation began during late Miocene, extensive seismicity and folded Quaternary deposits indicate ongoing activity. The eastern South Alpine belt is located at the northern edge of the actual Adriatic microplate. It is a classical brittle fold-and-thrust belt with ramp-flat thrust trajectories and ramp-folds, three major thrust sheets with basement envolvement, and increasingly older sequences exposed towards the internal parts (N). Complex transverse patterns resulted from interferences with Paleogene (Dinaric) and Mesozoic structures. To the W, the belt ends at the Schio-Vicenza line (some 50km west of Venice) where the shortening is transferred southwards across the Po plain to the Apennines. To the E, the belt looses shortening (from some 55km in the eastern Dolomites to some 30km in western Slovenia) and gets gradually replaced by SE trending dextral strike-slip faults, that follow the NE Border of the Adriatic plate across Croatia and Bosnia towards Albania.

Miocene and Plio-Pleistocene volcanism of the Styrian and Klagenfurt Basins (Eastern Alps, Austria): geochemistry and geodynamic implications

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In the Neogene Styrian and Klagenfurt Basins, Alpine post-collisionextensional volcanic activity took place in Karpatian-early Badenian (K/Ar-ages: 16.8-14.9 Ma) and in late Pliocene-early Pleistocene (K/Ar ages: 3.8-1.7 Ma). The petrogenetic affinity changed from orogenic-type in the Miocene to anorogenic-type in the Plio-Pleistocene. Petrography, major (XRF) and trace (XRF, INAA) elements have been carried out on volcanics from numerous Miocene (outcrops and boreholes) and Plio-Pleistocene centres.

The Miocene lavas have a variable serial affinity, ranging from calkalkaline/high-K calk-alkaline (Kollnitz) to high-K calk-alkaline (Weitendorf, Mitterlabill) up to shoshonitic (Gleichenberg, Walkersdorf, Paldau). In the most voluminous Miocene volcano (Gleichenberg, 16.3-15.5 Ma) latites are the dominant lithotype; here trachytic and rhyolitic lavas locally occur. To the west, outcropping products are represented by relatively primitive (Mg# 66-70) basaltic andesites/high-K andesites (Kollnitz, 14.9 Ma) and high-K basaltic andesites (Weitendorf, 16.8-16.0 Ma). Boreholes samples are latites (Paldau and Walkersdorf) and high-K dacites (Mitterlabill). Incompatible trace element patterns of all the Miocene lavas, normalized to primitive mantle (Sun and McDonough, 1989), show a moderate negative Nb-, Ta- and Ti-anomaly and high LILE/HFSE ratios, typical of "subduction-related" magmas. On geochemical basis, three groups of rocks can been distinguished: the first, Gleichenberg latites-trachytes and Walkersdorf latites, have negative Ba-anomaly in respect to Rb and Th; the second, Weitendorf high-K basaltic andesites, Paldau latites and Mitterlabill high-K dacites show a small negative Ba-anomaly. Otherwise they share similar incompatible trace element patterns, including a significative negative Eu-anomaly in chondrite-normalized REE diagrams. The rocks of these two groups, all from the Styrian Basin, are geochemically clearly distinguishable from the Klagenfurt Basin volcanism, represented only by basaltic andesites and a high-K andesite from Kollnitz. These latter have a marked positive Th-anomaly and a steep chondrite normalized REE pattern with a strong LREE enrichment and no significative Eu-anomaly. The geochemical and petrological data so far obtained for the Miocene volcanism are compatible with a genesis by partial melting of a lithospheric mantle enriched by "subduction-related" components derived from the European lithosphere during the Paleogene N-S convergence which characterized the Eastern Alps/westernmost Carpathian transect. Such a delayed melting of a recently enriched lithospheric mantle is considered to be related to Miocene extensional collapse of the Eastern Alpine chain leading to the formation of the Pannonian Basin.

The studied Plio-Pleistocene volcanics are strongly silica-undersaturated and have a typical Na-alkaline affinity. They are mostly represented by lavas, except two vesiculated lava-like xenoliths within the pyroclastic rocks of Kalvarienberg and Riegersburg.

Their compositional variation roughly range from nephelinites (Wilhelmsdorf and Steinberg), to basanites (Steinberg, Klöch, Kindsbergkogel, Riegersburg).

The overall incompatible element pattern of the Plio-Pleistocene lavas is within the range of OIB; in respect to the OIB-average of Sun and McDonough (1989), they show an increasingly strong enrichment toward the most incompatible elements from P to Rb, which is in accordance with their strong silica-undersaturated character. In the Ba/Nb vs. K/Nb diagram these rocks plot in a narrow area, between the fields of Tristan da Cunha and St.Helena Islands. All these data are compatible with a derivation from low degrees of partial melting of an asthenospheric source.

Paleozoic evolution of the Tethyan domain

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Terranes now amalgamated in the Variscan orogen of southern Europe, formed a single ribbon like continent formerly attached to the northern side of Gondwana. This super-terrane detached from Gondwana in Silurian to form the northern margin of the Paleotethys. The western end of the super-terrane collided in late Devonian with the Laurentia-Baltica margin. The northern Paleotethyan elements are then incorporated into the Laurussian active margin as separate terranes: Mid and Central European and Intra-Alpine terranes.

Subsequently the Paleotethys started subducting northward under the accreted terranes. Terrane accretion and subduction of the Paleotethys have been responsible for the Variscan orogeny in Europe accompanied by crustal thickening up to a Cordillera stage in late Early Carboniferous. Then Gondwana and Laurussia are entering in a final continent-continent collision. The final closure of the oceanic domains is placed in Late Carboniferous. Crustal thickenning and arc magmatism during that period are rapidly followed by a general collapse of the Carboniferous active margin accelerating the closure of the remaining space between both super continents during the Late Carboniferous-Early Permian.

The northern orogenic areas have been affected by rifting since Carboniferous, starting with a major break-up along the Caledonian suture zone. In Late Carboniferous and Permian it is the Variscan accretionary complex which is affected by rifting. East of a paleo-Apulian promontory, this rifting graded into back-arc spreading (Hallstatt-Meliata marginal basin). The final closure of Paleotethys in these areas took place later between a migrating arc detached from Eurasia and a super-terrane derived from Gondwana, the Cimmerian continents.

On the Gondwana margin rifting took place first in Early Carboniferous certainly as a result of the partial collision with Laurussia at that time. But it is only when the Paleotethys engaged in an advanced stage of subduction that the Cimmerian blocks were removed from the Gondwana margin (inner Dinaro-Hellenides) to give birth to the Neotethys extending into the East-Mediterranean area.

The Cimmerian super-terrane comprises also a peri-Apulian plate domain: Tunisia, Sicily and southern Apulia and the Apulian elements from the Dinarides, Hellenides and Taurides. Due to a lack of space north of these elements they very quickly entered into collision with the collapsing European active margin during Late Carboniferous to Early Permian. Continuing translation of Gondwana westward provided some new space and a new rift appeared north of Tunisia-Sicily (the Sicanian-Lagonegro rift system connected to the Ionian sea-East Mediterranean basin). The western part of the Meliata back-arc rift (Southern Alps-Ivrea) aborted at that time, whilst its eastern part (Hallstatt-Meliata-Dobrogea) oceanised (e.g. Early Triassic MORB pillow lava of N-Dobrogea). During the Late Permian-Early Triassic collision of the detached inner Dinaro-Hellenides Variscan sliver with the Cimmerian elements.

Characteristics of the lithosphere reflected upon electromagnetic parameters along the magneto-telluric profiles in Romania

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Information carried out along the eight MT profiles crossing the Eastern Carpathians and Pannonian Basin - Romanian area are used to reveal the most important aspects related to the lithospheric structure insisting on the suture zone associated to the Carpathian Orogen and Tethyan one. Taking into account the magnetotelluric (MT) results referring to the lithospheric thickness variations, contact alignments and structural relations between the main tectonic units and placement of the enhanced conductivity zones (over 0.1S/m) an explanation of the link between the lithosphere dynamics and crustal deformation is to be attempted. By means of the geoelectrical cross-section elaborated for every profiles, a general spatial image was pursued to be achieved. The MT profiles bring into the light some characteristic aspects emphasizing the structural particularities of these two major tectonic units. A first problem is related to the thickness of the sedimentary cover (1000 - 3000 m in Pannonian Basin) and (13000 - 18000 m in the Eastern Carpathians's Foredeep). The transition zone from the crust to mantle, marked by a decrease of the resistivity (less than 10 ohm.m) and associated esspecialy to Orogenic areas stands for the interesting point to be clarified, as regarding its affiliation on the hand, by means of the electrical properties and of the assesed depth, and the causes which generated it, on the other hand. Obviously, owing to its involvement in revealing certain lithospheric aspects, the top of the asthenosphere (contact between tectonic plates of various thickness) was pointed out where it was possible.

East Carpathian-Pannonian connection according to geophysical data

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The geologic boundary between the East Carpathians and Pannonian Basin is eophysical data to be a part of the transcontinental Oder-Caucasian lineament separating the thick from thin lithosphere or hot from cold asthenosphere in Europe. Over this fault crustal thickness varies from 27-30 km in Pannonia to 56 km in East Carpathians. This boundary is very clearly seen in the geothermal field. The main thermal energy source is situated within Pannonia west of the Transcarpathian deep fault. The former caused lithosphere thinning and high-temperature asthenosphere formation under Pannonia at 60-65 km depth. Under the East Carpathians temperature decreases strikingly and the lithosphere thickens. The velocity, density and magnetic properties change. Here under the East Carpathians, the thin crust of the Pannonian basin is alternated by the thick lithospheric armour of the more than 65 km thick Cis-Carpathian through.

A rheological analysis of geophysical data enables us to express the following idea of the structure of this region. Under Pannonian basin the crust is thinned by high temperature to 28 km and thickens towards the Fold Carpathians. The sediments reach in the Transcarpathian through 5 km and rest on a young folded basement lying on plastic granites, which is demonstrated by high temperature (200° C) corresponding with granitoid creep. The plastic granitoids are underlained by 10-12 km thick brittle basites layer whose top is clearly traced by seismic data. The brittle-to-plastic basalts transition is not always a contrasting acoustic boundary and nearly coincides with the 520° C geotherm. The M-discontinuity separates in Pannonia basic from ultrabasic rocks which are in plastic state. The lithosphere thins to 60 km and has been destructed by high (to 1200° C) temperature.

In the East Carpathians bounded by deep faults crust thickens due to its doubling in granitoid and brittle basite layers. The M-discontinuity deepens even more in the Cis-Carpathian foredeep. This is due to sedimentary cover thickening and the appearance of a "crust-mantle mix" layer with 7.5-7.6 km/s longitudinal wave velocity. The large "crust-mantle mix" thickness is due to plunging of a layer of brittle basites ("basaltic plate") driven by high temperature from the Pannonian massif into the plastic upper mantle. Beyound the Cis-Carpathian through the temperature regime of the upper mantle is stabilized and the striking boundary between the lithosphere and asthenosphere vanishes.

A magnetotelluric study of the high-resistivity basement of the Carpathians

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Complex geological structure of the Carpathians and limited information available from boreholes make the interpretation of the orogen basement difficult. In this situation, geophysical survey plays the basic role in solving problems related to the structure and the genesis of the Carpathian orogen. The magnetotelluric investigations have been conducted in the Polish Carpathians for 20 years (Jankowski et al 1980, Molek and Klimkowski 1991, Stefaniuk 1995). Magnetotelluric data were interpreted by many geophysicists. This presentation is based on the author's own interpretation of magnetotelluric soundings made along seven profiles transverse to the orogen axis and crossing regions with different style of the geological structure. The results of interpretation are presented as depth cross-sections and, for a case of the eastern part of the study area, as generalized structural outline of the roof of the consolidated basement (Stefaniuk and Kuomierek 1986). The investigations enabled one to outline the morphology of the basement roof which was related to a high-resistivity magnetotelluric horizon. The morphology of the basement roof is much different in each profile, however in all cases four zones parallel to the orogen axis were separated. In the outermost zone the basement roof occurs at a relatively shallow depth. South to that zone the basement slopes steeply, then the most buried zone occurs. On the souhern margin of the area a zone of the elevated basement is observed. The results of magnetotelluric sounding interpretaton were subjected to tectonic interpretation.

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Geological structure of the West Carpathian Flysch Belt and its relation to the Eastern Alps

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The Flysch Belt of the West Carpathians in the eastern Czech Republic is a nappe complex formed by the polyphase Neoalpine orogeny during the Late Peleogene and Early Miocene. Based on lithofacies and tectonics the Flysch Belt is subdivided into the Outer (Krosno-Menilite) and Magura Groups of nappes. Sedimentary record of these units evidences the internal to external parts of the Flysch Belt. This trend results from the general movement of the African plate and the Pannonian block to the N and was manifested in the studied area in the NW and N trending thrusting during the last orogenic events.

The final movements of the Carpatho-Pannonian block system were controlled by an oblique collision with the North European Platform in the Miocene when the Flysch accretionary wedge formed. The collision mechanism diminished towards the E where the subduction process prevailed.

Typical tectonic features of structural types were characterized in cross-sections of the Flysch Belt. General fault pattern encompasses domains with the thrust faults, strike-slip faults, and normal faults.

Geodynamic evolution of the Flysch Belt is characterized using mapping data and analysis of the seismic, gravity, well log, petrophysical and geochemical measurements. Schematic cross-sections show the thrusting mechanism in selected orogenic phases. Subsidence, sedimentation, burial, erosion and thermal history are simulated using basin modeling software.

The frequency-characteristics of seismic and gravity data were processed using combined analysis of the derived gravity field reflectance image and the changes in the seismic echogenity. This technique makes it possible to identify structural-tectonic features from rather low-amplitude seismic and gravity data. It has been applied to draw density-balanced cross-sections of the upper crust layer along the selected seismic profiles with delineation of the tectonic elements.

From where the tectonic slices of the Cretaceous age could have been transported into the Magura Group of nappes?

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The Magura Group of nappes is the significant regional unit of the Outer Western Carpathians in which flysch sediments from the Lower Cretaceous up to the Oligocene are proved. In the front of the partial Raèa and Bílé Karpaty units tectonic slices of Cretaceous rocks occur that are from lithological and biofacial point of view distinctly different:

Raèa unit, Klippe of Kurovice: Kurovice Limestones are formed by grey micritic limestone of the Oxfordian-Tithonian up to Early Berriasian age. Nannofossils with dominant specimens of genera *Cyclagelosphaera* and *Watznaueria* give evidence of the Tethyan bioprovince.

Tlumaèov Marls (Berriasian-Valanginian) overlaying Kurovice Limestones are characteristic by grey marl and clayey limestone. Nannofossil assemblages with nannoconids and *Conusphaera mexicana* are of the Tethyan character. In the Valanginian (CC3 Zone) was observed rare *Micrantholithus speetonensis* that could indicate a minor influence from the Boreal bioprovince.

The Jurassic and Lower Cretaceous of the Klippe of Kurovice can be lithologically comparable to a degree with northern edge of the Alpine Flysch Zone (Eliáš et al., 1990).

Bílé Karpaty unit, Hluk development: Púchov Marls (Campanian-Maastrichtian) consist of red, highly calcareous claystone and marl. In the Late Campanian and Early Maastrichtian, nannofossils of genera *Ceratolithoides* and *Quadrum* support Tethyan bioprovince by evidence but in the Late Maastrichtian common occurrences of high- and low-latitude species document also some influence from the Boreal area. Sediments correspond to the Púchov Marls of the Pieniny Klippen Belt (Stráník et al., 1995). They could also represent slope sediments comparable with those of the Hauptklippen Zone of the Wienerwald (Bubík, 1995).

Antonínek Formation (Campanian-Maastrichtian) is characterised by turbidite rhythms formed by grey sandy-silty limestone and highly calcareous claystone and marlstone. Unlike Púchov Marls, the Early Maastrichtian nannofossil assemblages are rather of Boreal character documented by *Biscutum coronum* and *Prediscosphaera stoveri*. Equivalents of these sediments are unknown.

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Deformational sequence of a flysch sandstone: examples from Outer Carpathians (Poland)

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Deformation bands are widespread in Lower Eocene flysch sandstone of the Magura nappe (the innermost nappe in the Outer Carpathians in Poland). These structures were studied in detail at Gruszowiec and at Tylmanowa. Microscopic observations were combined with stress analysis. To our knowlege, this is the first attempt to trace and date a process of folding by studying the deformation bends.

At Gruszowiec, steeply dipping beds of the sandstone are cut by water escape sheets, deformation bands and minor brittle faults. The water escape sheets are oriented subpenpendicular to bedding and to the regional fold axis. Some of the water escape sheets pass laterally into the deformation bands. The latter present whole spectrum between the bands with no feldspar cataclasis occurring as (i) a single cross-fold set and (ii) several fold-parallel sets (the latter inclined under shallow angles to the bedding); and the bands with strong feldspar cataclasis forming several fold-parallel sets oriented under high angles to the bedding. The minor brittle faults form several fold-parallel and fold-oblique sets. These faults display cataclasis of feldspar and quartz and cataclasis of calcite cement. Orientation of the water escape sheets and deformation bands was controlled by regional stress field and these structures occurred progressively during regional folding. First, water escape sheets and deformation bands with no feldspar cataclasis were formed. The intensity of cataclasis increased during the folding, and the most recent deformation bands, which were formed close to the completing of the folding, display strong feldspar cataclasis. However, deformation bands display neither quartz cataclasis nor cataclasis of calcite cement. It appears therefore that all deformation bands pre-dated calcite cementation of the host sandstone. Brittle faulting, which involved quartz cataclasis and cataclasis of calcite cement, started after the regional folding was completed.

At Tylmanowa, two conjugate sets of deformation bands cut subvertically dipping sandstone beds. The linear acute bisector between the sets is horizontal and perpendicular to the regional fold axis. The bands accommodate dip-slip reverse movement. They were formed after regional folding was completed. The bands display feldspar cataclasis but do not display quartz cataclasis. They were formed before complete induration of the sandstone.

Summing up, it appears that the regional folding within the Magura nappe started no-later than during the deposition of the studied Lower Eocene sandstone. The folding was completed before calcite cementation and before complete induration of the sandstone.

The gravity field of the Pancardi Region and its geodynamic implications

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A new, unified Bouguer anomaly map of the Eastern Alps, Carpathian arc, Dinarides and the Pannonian basin has been compiled from previously prepared and recently published gravity maps and data. This map gives a general picture of the gravity field of the studied area and reveals several interesting features that are essential in understanding the geodynamics of the Pannonian basin and the surrounding mountains. In order to constrain the crustal structure and tectonic history of the region 2D gravity models are presented along a Western Carpathians-Pannonian basin-Southern Carpathians transect, and at the Alpine-Pannonian transition zone. These models are based on deep seismic lines, where available, and detailed geological sections. The results confirm that the whole territory of the Pannonian basin can be characterized with a wide rift mode extension, while some deep depressions show the characteristics of the narrow rift mode and the core complex mode extension combined with detachment faulting. Furthermore the modelling results and the Bouguer anomaly map suggest that the different parts of the Carpathian arc are at different stages of their evolution: the subducted oceanic slab under the Western Carpathians has already been detached and assimilated to the astehenosphere, while a lithospheric root is still present under the Eastern and Southern Carpathians. These findings are compatible with the observation that the last major phase of crustal shortening terminated at the early Middle Miocene in the Western Carpathians, but continued throughout the Pliocene in the Eastern and Southern Carpathians. In order to give an explanation we utilized the idea of strain partitioning which results from the oblique convergence and transpression between the European lithosphere and the different terranes that formed the Pannonian basin and the Carpathian arc.

Alpine tectonics in the East Carpathian/Pannonian transitional zone (Hungary/Romania)

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Based on the style of Miocene faulting observed on industry seismic reflection profiles and the characteristically retrograde metamorphism of the pre-Tertiary basement, a metamorphic core complex origin was predicted for some of the basement highs in the SE Pannonian basin. Indeed, recent apatite/zircon fission-track age-dating of amphibolite to greenschist facies basement rocks in this critical region verified this earlier speculation.

Similarly to the NW Pannonian Basin, the Middle Miocene syn-rift extension can be subdivided into an Karpatian metamorphic core complex style extension followed by a Badenian(?) wide rift style one. The earlier, ENE-WSW oriented extension is largely responsible for the formation of a regional detachment system which displays a distinctly down-to-the-ENE polarity. The probable breakaway zone for this system is located around Kelebia and the metamorphic core complex in lower plate position is represented by the Algyo basement high of Hungary. Outcropping basement highs in the Apuseni Mts. of Romania, such as the Codru-Moma, Padurea Craiului and Plopis ranges are bounded by antithetic, down-to-the-WSW normal faults and thus they are interpreted as large fault-block ranges in upper plate position.

The still continuing but diminishing continental extension during the Late Miocene could not advance to the localization of extension into a narrow rift zone in the Pannonian region, except some subbasins such as the Mako and Bekes basins. These basins are underlain by anomalously thin crust (20-22 km) and lithosphere (55-60 km) in a spatially coincident manner.

Two regional structure transect were constructed across the Hungarian and Romanian part of the Pannonian Basin and the Apuseni Mts. These perpendicularly oriented sections were also constrained by deep reflection seismic profiles (Pannonian Geotraverse 1 and 4) in order to gain insight into the lithospheric-scale structure of the region. These transects suggest large-magnitude extension during the Neogene, mostly due to the superimposed extensional styles.

Alpine tectonics in the East Alpine-Pannonian transition zone (Austria-Hungary)

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Structural interpretation of reflection seismic profiles combined with well data reveals distinct modes of upper crustal extension in the NW Pannonian Basin. As the first manifestation of extensional collapse at the beginning of the Middle Miocene (~17.5 Ma, Ottnangian/Karpatian boundary) the Rechnitz metamorphic core complex has been formed in the Raba River extensional corridor.This metamorphic core complex style, ENE-WSW trending extensional phase can be characterized by a minimum of 80 km horizontal extension. Shortly after, and partly overlapping with this period, the style of syn-rift extension changed to a wide-rift style one (16.5-13.8 Ma, Early and Middle Badenian) producing a minimum of 40 km extension in a NW-SE direction across the East Alpine/Pannonian transition zone.

The predominance of low-angle normal faults in the Neogene structure of the Danube Basin excludes its pull-apart basin origin proposed by many. The numerous Miocene detachment faults interacted with earlier Cretaceous decollement levels, although in a more complicated manner than previously thought.

Widespread Upper Badenian and Sarmatian strike-slip faulting has little to do with the formation of the Danube Basin but it belongs to the post-rift phase and records a basin-wide inversional stage. The still continuing, but gradually diminishing continental extension during the Late Miocene and Pliocene (12.5-5.5 Ma, Sarmatian-Lower Pannonian) could not advance to the localization of extension into a narrow rift zone in the NW Pannonian Basin, except perhaps the center of the Danube Basin (zone of Pasztori and Kolarovo).

Regarding the whole lithosphere of the NW Pannonian Basin gravity modeling indicates that the present-day thickness minima for the crust and the upper mantle do not coincide. The some 160 km lateral offset between them indicates the detachment of the the upper crust from the mantle lid along a rheologically weak lower crust during Miocene times.

Geodynamic evolution of the area adjoining the Pannonian Basin and Dinarides

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Almost all recent geodinamic interpretations of the evolution of the Pannonian Basin (PB) are related to the Carpathians. However, the Dinarides, especially its northernmost parts played very important role in their evolution.

The central part of the northernmost Dinarides is genetically related to an ancient magmatic arc, as indicated by following units: (1) Upper Cretaceous-Paleogene trench sediments, in lower parts interlayered by basalts, rhyolites and pyroclastics which overlie (2) Jurassic-Cretaceous ophiolites associated in places with blueschists, (3) Alpine medium-pressure metamorphics originating from the trench sediments and associated volcanics, and (4) Alpine synkinematic granitoids.

The western part of the northernmost Dinarides, west of the Zagreb-Zemplen fault zone is mostly covered by the Sava nappe, composed of Upper Palaeozoic metaclastic and carbonate rocks, Schytian clastics, and Middle and Upper Triassic limestones and dolomites. The tectonic windows composed of Jurassic-Cretaceous basinal sediments of Dinaridic affinity are exposed below the Sava overthrust. Further to the east in the area of Zagreb, the Sava nappe is thrust onto the ophiolites.

In the northern part of the Dinarides subduction processes terminated with the Eocene compressional event and the uplift of the Dinarides.

West of the Zagreb-Zemplen line numerous intramontane shallow-marine, fluviatil and lacustrine basins during the Oligocene were generated. Penecontemporaneous andesites can be compositionally correlated with the easternmost Periadriatic tonalites, but the andesites are also found along the Drava and Sava strike-slip faults.

The rift stage, induced by the upper mantle rise and attenuation of the "alpine" lithosphere with shallow necking, is marked by submarine Karpatian trachyandesites, Badenian basalts, andesites, dacites and rhyolites, and Pannonian alkali basalts. Extension gave rise to the escape tectonics, i.e., the displacement of the North Dinaridic units to the PB. The main trails for the large scale tectonic transport were the Periadriatic-Sava and Zagreb-Zemplen fault systems and their subparallel satellites.

The strong sin-rift unconformity is placed at the end of the Sarmatian, and break up unconformity at the end of the Pannonian. It is followed by a compressional event, regionally recognised all over the PB. Due to thermal subsidence in Pliocene the South PB was covered with more than 2.000 m of lacustrine fresh-water deposits. There is also some evidence of another, very recent compression phase, especially in the Sava and Mura domains.

Trace elements and isotope geochemistry of ultramafic xenoliths: constraints on the lithospheric mantle beneath the Graz Basin (Eastern Austria)

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The Plio-Pleistocene alkali basalt activity in the Carpatho-Pannonian Region (CPR) is characterised by the occurrence of a wide variety of ultramafic xenoliths, i.e. spinel lherzolites, clinopyroxenites, harzburgites, wehrlites, amphibole pyroxenites, etc. (Downes & Vaselli, 1995). They occur throughout the whole region from the Graz Basin (eastern Austria-northern Slovenia) to the Persani Mts. (Transylvania), from Nógrád-Gömör (southern Slovakia-Northern Hungary) to Balaton Highlands and Little Hungarian Plain (central-western Hungary).

Detailed isotopic and REE (Rare Earth Elements) and HFSE (High Field Strenght Elements) investigations have previously been performed in the above mentioned localities (Downes et al., 1992; Vaselli et al., 1995a), except for Nógrád-Gömör and Graz Basin. In this work, we present new isotopic and trace element data for 6 xenolith-bearing localities (Tobaj, Güssing, Grád, Kloch, Stradnerkogel, Neuhaus) in the Graz Basin where only the ultramafic xenoliths from Kapfenstein were previously studied (Vaselli et al., 1996). Güssing and Neuhaus can be regarded as new outcrops of mantle xenoliths since no mention of them has been found in literature.

The ultramafic xenoliths are mainly spinel peridotites although websterites, werhlites and pyroxenites have been found. Amphibole is always interstitial although discrete grains have found in Tobaj xenoliths. Textural features of the ultramafic xenoliths investigated indicate low to slight deformation, almost all the xenoliths being protogranular to porphyroclastic. The only exceptions are one xenolith from Neuhaus and one from Kloch which are equigranular and secondary, respectively.

Generally speaking, bulk-geochemistry and mineral chemistry of the single mineral phases indicate that most of the Graz Basin xenoliths seem to have suffered only a depletion by extraction of mafic melts at different degrees of partial melting because they have major and trace element contents which lie close to that of the Primitive Mantle as defined by McDonough (1990) or have lower contents but with the same trend (Vaselli et al., 1995b).

The REE and HFSE patterns for clinopyroxenes and amphiboles from the Graz Basin xenoliths are generally depleted in the more incompatible elements, most of the Ce_N/Yb_N ratios being from 0.23 to 0.65 and 0.23 to 0.57, respectively. Besides, Ti/Ti* and Zr/Zr* in clinopyroxenes and Zr/Zr* in amphiboles Ba, Nb, Sr and Ti contents indicate that mantle amphibole preferentially hosts these elements and their abundances are generally lower compared to amphibole megacrysts from CPR alkali basalts (Zanetti et al., 1995). Szabó et al. (1995) and Vaselli et al. (1995a) found similar values for interstitial amphiboles of ultramafic xenoliths from the Little Hungarian Plain and Persani Mts., respectively.

Sr and Nd isotopic composition for the clinopyroxenes are between 0.70210 and 0.70294 and 0.512960 and 0.51349 which indicate a depleted mantle and these ratios are strikingly similar to those observed in the ultramafic xenoliths from eastern margin of the CPR, i.e. Persani Mts. (Vaselli et al., 1995).

In conclusion, the REE and HFSE contents and the Sr and Nd isotopes for the ultramafic xenoliths from Graz Basin indicate that the lithospheric mantle beneath this region suffered enrichment/depletion processes very similar to those already observed for the xenolith suite from the Persani Mts. the two localities being situated at the peripheral parts of the mantle diapir which has been recognised by geophysical studies (e.g. Horváth, 1993; Lillie et al., 1994). Thus, the host magmas could have collected ultramafic xneoliths from a brittle-veined lithospheric mantle. No unequivocal evidence of subduction in the lithospheric mantle has been recorded in the Graz Basin ultramafic xenoliths and we may speculate that the processes which formed the interstitial amphiboles are related to metasomatic events.

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Results of deep seismic reflection profiling across the East Rhodopes, South Bulgaria

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According to recent plate tectonics concepts a probable collage zone is located south of the Moesian platform. This zone consists of terranes detached from Africa and accreted to Eurasia. The East Rhodope exotic terrane is one of them. It is composed of Proterozoic (?) amphibolite facies metamorphics, Mesozoic metamorphic rocks, sediments and basalts intruded by Late Cretaceous granites, all locally overlain by Paleogene sediments and volcanics. The East Rhodope terrane is a pile of thrusts, its deep structure and relations to the West Rhodope terrane being under debate.

According to the first deep seismic reflection profile Ardino-Ivailovgrad (ER1), the thickness of the Paleogene cover is up to 2.3 km. The crust is divided into four superlayers A, B, C and D. The main result is the discovery of a so far unknown tectonic zone imaged on the line ER1c by an about 10 km wide, SW dipping band of moderate to strong reflectors (superlayer D). It cross-cuts superlayers A, B and C and extends into the upper mantle. Superlayer D is interpreted as a pre-Late Cretaceous obduction zone (East Rhodope thrust front) marking the boundary.

Style of postsedimentary deformation in Plio-Quaternary Velenje basin, NE Slovenia

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Velenje basin is 10 km long elongate Plio-Quaternary intermontane depression, bounded by the Periadriatic line zone to the North and by the WNW-ESE trending Šoštanj fault to the South. Basin presumably originated in the regime of dextral transtension between these two fault systems. The basin fill is up to 1000 m thick and shows a typical fill-up sequence ranging from subaerial to lacustrine clastic sediments (Brezigar, 1986). The age of the sediments is poorly constrained except for the mammal remains and pollen content in the upper part of the stratigraphic succession, which indicate Upper Pliocene and Quaternary age (Brezigar et al., 1983), and the age of the basin is arbitrarily taken as Pliocene.

The main part of the basin is a 2 km wide trough-like structure between the Šoštanj fault and similarly WNW-ESE trending Velenje fault. In the basin area, Velenje fault is a boundary between major tectonic units of Kamnik-Savinja Alps to the South and Karavanke to the North (Mioè and nidarèiè, 1983, Brezigar, 1986) and is also a part of the Donat zone sensu Jelen (Jelen, 1994), which separates two major Tertiary tectono-stratigraphic units.

The largest part of data about the basin comes from the Velenje lignite mine. Borehole, seismic and other data show that lenticular, up to 160 m thick lignite seam has a synclinal shape, which is mostly due to the differential compaction of the basin fill. Lignite seam at the SE margin of the basin along the Šoštanj fault is cut by secondary faults and strongly segmented with up to several tens of meters of vertical offset between fault blocks, whereas above the Velenje fault the lignite seam is practically undeformed by faulting.

Using the data of more than 1000 boreholes, the geometry of the upper boundary of the lignite seam in the Šoštanj fault area was modeled and analyzed with various computer-aided techniques. The fault architecture and arrangement and geometry of minor tectonic blocks clearly indicate that the origin of structures is related to dextral movements along master fault(s) of the Šoštanj fault zone.

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Shift of basin subsidence due to oblique subduction along the Northern Austroalpine margin during the Late Cretaceous-Tertiary of the Eastern Alps and the Western Carpathians

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Subsidence within the Late Cretaceous to Early Tertiary basins at the northern margin of the Austroalpine microplate (Austroalpine Units of the Eastern Alps, Tatric and higher units of the Western Carpathians) shows a regular time shift from the West to the East. Rapid subsidence into bathyal depths within the northwesternmost part of the Northern Calcareous Alps (NCA) began already in the late Turonian. Other basins of the Gosau Group of the NCA (WAGREICH & FAUPL 1994) and the western part of the Inner Western Carpathians (WAGREICH & MARSCHALKO 1995) indicate a shift of this subsidence pulse predated by short uplift and deformation from the Santonian in the west to the Maastrichtian in the southeast. This eastward youngig in the beginning of major subsidence is continued within the Centralcarpathian Paleogene, e.g. the Sulov Conglomerates (Paleocene) and turbiditic formations of the Eocene/Oligocene, partly also early Miocene in eastern Slovakia (see also KOVÁC et al., 1994).

This time shift of subsidence can be interpreted as a result of diachronous oblique subduction processes to the north of the active leading margin of the Austroalpine microplate (including the NCA and the Tatric units of the Western Carpathians). This margin was characterized by southward subduction of the Penninic Ocean from the Cretaceous onwards The short deformation and following rapid subsidence may be due either to tectonic erosion or subduction roll-back, or a combination of both processes. Tectonic erosion due to collision and subduction of an oceanic asperity is more probable in the Eastern Alps based on structural evidence and sedimentological reasoning such as the elimination of an accretionary ridge north of the NCA (WAGREICH 1993, 1995). Within the Western Carpathians a combination of tectonic erosion and later subduction roll-back is more likely, especially for the subsidence of the Centralalpine Paleogene basins, which postdate accretion of the Pieniny Klippen Belt to the north.

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Alpine thrust and subthrust structures below the Vienna Basin and along its adjacent borders.

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The segment of the Alpine Carpathian belt, which passes the Vienna basin from one border to the other below the Neogene basin fill, are mainly the Flysch Zone, the Calcareous Alps with their Palaeozoic base, the Greywacke Zone and the Central Alps.

The Alpine structural style has been studied by detailed surface mapping and by deep wells situated at the borders and within the basin. In the area of the Matzen-Schönkirchen oil fields further information has been obtained by 3D seismic surveys. Correlation between the Austrian and the Slovakian part of the Vienna Basin and the Carpathians on surface show in general a continuation of the main elements and their stratigraphic characteristics from the Alps into the Carpathians but some changes in the structural arrangement.

The Semmering-Leithagebirge system representing the Lower/Middle Austroalpine units seems to be replaced by a more heterogeneous structural and facial complex in the Male Carpaty mountains.

The overriding of the deeper Carpathian and Central Alpine units by the Calcareous Alps is evident in the Alps and Carpathians as well as the overthrust of these units over the Flysch or Klippen Zones. The Greywacke Zone disappears in the Vienna Basin toward NE.

The structures of the Calcareous Alps are strongly compressed especially along their frontal part. Steeping, overturning and backthrustings are the consequence. The narrowing of the Calcareous Alpine Zone toward NE could be a tension effect, but the steep structures point to a stacking of tectonic elements because of subsiding conditions during overthrusting. The main nappe systems are from N to S the Bajuvaricum, Tirolicum and Juvavicum, mostly separated by Cretaceous to Palaeogene synclines, which are overthrust lateron, in the case of the Gießhübl syncline during Paleocene time.

In the Carpathians the tectonic subdivision is similar to that of the Calcareous Alps, but facial arguments suggest that the outcropping Krizna nappe system is the former frontal part of the Bajuvaricum, which has been left behind, whereas the main part has been thrust further toward NW, as the Slovakian drillings show. On surface the Tirolicum covers this northern part carrying a segment of Gosau at its frontal part (Brezova Gosau).

With the Neogene sediments in the Vienna Basin the nappe systems were also lowered down by faulting. In general no horizontal displacement along the faults is evident and the pull apart mechanism, which causes the tension is obviously caused by lateral slipping along the Alpine thrust planes either during or after thrusting.

Below the Alpine thrust complex the autochthonous subthrust floor is known by some deep wells. East of the Crystalline spur of the Bohemian massif Jurassic and Cretaceous sediments in a distinct facial arrangement are extending eastward, covered by Molasse.

The basement dips downward under the orogene in a moderate manner in the south of the basin and to a larger amount toward its northern part. Signs of a rifting within the Middle Jurassic are evident showing synsedimentary half graben tectonics, which ceased in the uppermost Middle Jurassic.

The geodynamic evolution of the Alpine-Mediterranean region: from structure to dynamics

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The geodynamical evolution of the Alpine-Mediterranean region is generally considered in the context of the interaction (convergence) of the Eurasian plate and the African plate. In analyses of this interaction the distribution of earthquake hypocentres and the focal mechanisms of earthquakes - in particular those occurring in subduction zones - have been an important source of data. New information concerning the nature of this interaction has been obtained by the application of seismic tomography techniques (Spakman, 1988, 1991; Spakman, Van der Lee, and Van der Hilst, 1993). The resulting three-dimensional seismic velocity structure provides insight into the history of plate convergence in the region on a time scale much beyond that contained in the distribution of present-day seismic activity. This new information allows for new ways of exploring the kinematics and dynamics of the geodynamical evolution of the region.

First, the 3D structure enables us to investigate the merits of various (published) regional aleogeographic/tectonic reconstructions. To this purpose we investigate the quantitative agreement between such reconstructions and the structure of the upper mantle, as obtained by seismic tomography. This is done by forward numerical modelling - on the basis of kinematic reconstructions - of the temperature distribution in the upper mantle, converting the calculated temperature distribution into seismic velocity structure and comparing these model results with the tomographic results (de Jonge, Wortel and Spakman, 1993,1994).

Secondly, from the seismic velocity structure we have inferred that - in the depth range of about 100 to 200 km - deeper parts of subducted slabs have become detached from lithosphere near the surface and we hypothesize that this detachment process has migrated laterally along the strike of the subduction zones. This process is referred to as: lateral migration of slab detachment (Wortel and Spakman, 1992; see also Yoshioka and Wortel, 1995). The process of lateral migration of slab detachment is envisaged to have geodynamical implications on a variety of scales. In particular, the formation and evolution of island arcs and their back-arc regions are adequately accounted for.

With slab detachment as a key element we presented a hypothesis for the Cenozoic evolution of the Alpine-Mediterranean region, with emphasis on the dynamical basis for observed kinematic patterns (Wortel and Spakman, 1992). On the basis of this hypothesis quantitative predictions can be derived for several areas in the Alpine-Mediterranean realm which can be tested against geological and geophysical data. Examples of some tests will be given. Of special interest in this respect are the spatial and temporal variations - implicit in the model of lateral migration of slab detachment - in state of stress, in vertical motions and in volcanic activity along the strike of convergent plate margins.

Analysis of pertinent observables (Miocene to recent) supports our hypothesis of slab detachment (including lateral migration) in the Hellenic and the Apenninic-Calabrian arcs and also in the Carpathian arc, and leads us to conclude that these three arcs are in different stages of evolution (Wortel and Spakman, 1993). The advancement of the slab detachment process and the associated processes increases in the given order: the Hellenic arc being the youngest and the Carpathian arc being the oldest (evolved) version. Finally, a very noteworthy result is that - for all three arcs - the migration patterns associated with the inferred lateral migration of slab detachment appear to originate in the region of the present-day Alps.

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The complex evolution of the Western Outer Carpathians: implications of flexure- and gravity modelling

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Vertical movements in the Western Outer Carpathian foreland system are investigated by lithospheric flexure- and gravity- models carried out along 5 profiles crossing the foredeep and thrust belt. Special attention is paid to the possible influence of pre- and post- orogenic processes on the deflection of the foredeep and thrust belt.

In the west the Neogene foredeep, resulting from the SE underthrusting or subduction of the North European plate under the Carpathian mountain belt, is very steep and narrow. This implies weak lithosphere and high bending stresses. Seismic observations of nearly horizontal Moho are explained with two possible scenarios: (1) a post- orogenic process of slab detachment and (2) the subduction of thinned lithosphere (pre-orogenic passive margin). Furthermore, post-orogenic regional scale uplift, about 150 to 300 m, is proposed for profiles crossing the Western and Central Carpathian foreland, in order to explain erosional surface, elevated distal foreland deposits and the low amplitude of the Bouguer gravity anomaly. A possible thermal uplift, associated with the Pannonian basin evolution is ruled out as possible explanation. Such uplift would imply a negative contribution to the gravity anomaly.

In the eastern part, the foredeep becomes more wider. Although the lithosphere is proposed to be slightly stronger, the effect of widening is explained by the interference of the East European plate, underthrusting or subducting the Carpathians to the SW.

Jointing in the Polish Outer Carpathians: hints for stress field reorientation

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The Polish segment of the Outer Carpathian fold-and-thrust belt is composed of a number of north-verging nappes. Studies of joint pattern within the different lithostratigraphical units of these nappes, as well as within the discordantly overlying younger strata, enable one to constrain the Late Cretaceous through Pliocene stress field of that region.

In the medial segment of the area studied, joints have been analyzed in several nappes, most of the data coming from the Magura nappe. In the last one, joint pattern reveals a clockwise rotation of the reconstructed maximum stress axis (s1) from the Late Cretaceous through the Middle Miocene strata. The maximum stress axis, inferred from the position of the acute bisector between conjugate Coulomb-shear or hybrid-shear fractures, is oriented N-S within the Turonian-Campanian strata, NNE-SSW in the Maastrichtian strata, ENE-WSW within the Palaeocene strata, and NNW-SSE within the Eocene through Middle Miocene strata. This gives 150° of clockwise rotation of s1 in the time-span considered. The maximum stress axes reconstructed for post-Cretaceous strata of other nappes are oriented NNE-SSW to NE-SW, being nearly perpendicular to fold axes.

On the other hand, the Pliocene molasses of the Podhale region display joint pattern indicating the N30-40°E oriented s1. This suggests a further clockwise rotation of the maximum stress axis by

60°. This orientation of s1 (NE-SW) coincides with that in the eastern segment of the Polish Outer Carpathians, both in the Palaeogene strata of Dukla and Silesian nappes and in the unconfortably overlying Middle Miocene molasses, as well as with the orientation of the present-day maximum horizontal stress axis, detected by breakout analysis.

Summing up, the stress field associated with jointing in the Magura nappe in the medial sector of the Polish Outer Carpathians has undergone clockwise rotation since the Late Cretaceous. The bulk of this rotation (130°) occurred during Palaeogene times, whereas Neogene rotation amounted to some 60°. No traces of this rotation have been found within other nappes.

The Miocene strata of the Carpathian Foredeep near Kraków display another picture. These strata are cut by four sets of joints and one set of gypsum veins. These structures appear to result from four successive deformation stages, including N-S extension of Langhian age, and three stages of subsequent compression (N-S, NE-SW and NW-SE). The last compressional episode appears to have been active during Pliocene-Quaternary times.

Jointing in the Skiba (Skole) Unit, Ukrainian Carpathians: preliminary results

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The Skiba (Skole) nappe is one of the outermost flysch nappes in the Outer Ukrainian Carpathians fold-and-thrust belt. The nappe is composed of a number of imbricated slices thrust one upon another in the middle-late Miocene times. In a SW-NE oriented profile, these are Slavsko, Rozhanka, Zelemianka, Parashka, Skole, Orovska and marginal slices, whose lithostratigraphic inventory includes: Upper Cretaceous thin- to medium-bedded Stryi beds, Palaeocene thick-bedded Jamna sandstones, Palaeocene-Eocene variegated shales and thin- to medium-bedded turbidites of Maniava, Pasiechna, Vyhoda and Bystritsa beds, Oligocene Menilitic beds and calcareous Holovets beds, as well as Oligocene-Miocene thin- to medium-bedded sandstone-shale complexes of Verkhovina beds. Joints and shear/hybrid shear fractures have been measured at some 40 localities equally spaced throughout all but the marginal slices of the Skiba nappe along the Opir river section.

The fractures are mostly kathetal and cluster into two to three cross-fold sets. The axes of maximum compression associated with jointing usually trend NE-SW to W-E, as far as Paleogene and Miocene strata are concerned, being subperpendicular to the overall strike of thrusts and fold axes. In the Upper Cretaceous strata, however, the axes in question strike N-S to NNE-SSW. These results are fairly coincident with those obtained by microtectonic studies of Kopyst'iansky and Kryzhevich (1985) on orientation of optical axes of deformed quartz crystals, and suggest that jointing must have been
coeval with folding and thrusting of the rocks studied.

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The Outer Eastern Carpathians record continuous convergence since the late Cretaceous.

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Convergence and resulting folding and nappe stacking of the Eastern Carpathian Moldavides nappe complex have traditionally (e.g. Sandulescu 1984) been interpreted to have occurred in two main phases: in late Cretaceous and in Miocene times. This separation was enforced by the pre-vious view of the internally conformable Maast-richtian to Eggenburgian Gura Beliei unit as the sedimentary cover of the folded, but not yet stacked area of the future Teleajen and Macla nappes in the front of the Ceahlau nappe complex. Strong deformation of the base of the Gura Beliei unit (Maastrichtian Gura Beliei Marls) suggests that large parts of this unit represent an out-of-sequence nappe. Its emplacement age is constrained to be Eggenburgian to Ottnangian, because lower Eggenburgian strata are a conformable member of the pile (Sandulescu et al. 1981) and the Ottnangian-Karpatian Doftana Molasse (Stefanescu & Marunteanu 1980) covers the folded pile sedimentary. This re-interpretation allows foreland propagating, in-sequence emplacement of the Teleajen, Macla, and Audia nappes between the Senonian (youngest sedi-ments in Teleajen nappe) and the Lower Miocene (sedimentary onlap of the later folded Doftana Molasse on an already deformed nappe edifice). The progressive eastward shift of sedimentary facies and depocenter especially in the structurally lower Tarcau nappe (Sandulescu 1984) reflects the propagating deformation front in this interval. Prograding upper age limits of conformable sedimentation and successively younger ages of sediments covering the folded pile of the outer part of the Moldavides nappe complex demon-strate continued advancing of the deformation front from Lower Miocene in the Tarcau Nappe to at least Sarmatian in the deformed foreland. Re-interpretation of the top of the frontal wedge of the Subcarpathian nappe as roof backthrust of a triangle zone (as indicated by folded overlying Sarmatian to Pleistocene strata) indicates con-tinuing deformation to sub-Recent times. Recent earthquakes (Oncescu 1984) below the bend region and results of geodetic surveys (Schmitt et al 1990) document ongoing tectonic activity.

Therefore, the structural evolution of the outer Eastern Carpathians took place between late Cretaceous and Recent times and reflects continuous, but punctuated convergence during this timespan. Deformation rates peaked during Early and Middle Miocene which is a result of possibly accelerated convergence rates in the Early Miocene, and Middle Miocene continental collision following preceding subduction of oceanic or thinned continental crust.

Dating the rotation of the Tisza-Dacia block by paleomagnetic analysis of Tertiary sedimen-tary rocks.

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Clockwise rotation of the Tisza-Dacia block (TDB) by ca. 90° has been demonstrated by a number of studies, but the precise dating of this rotation is still lacking. Published analyses of rotated Late Cretaceous magmatites ('Banatites') from the Apuseni Mts. and the Southern Carpathians constrain the rotation to be post-Cretaceous, and non-rotated Late Miocene magmatites from the Eastern Carpathians yield a lower age bracket. In contrast to previous paleomagnetic determinations of the rotation of the romanian parts of the Tisza-Dacia block which were based on usually poorly dated magmatic rocks, our study will be based mainly on paleomagnetic analyses of well-dated sedimentary rocks.

The Transylvanian Basin is situated in the stable center of the Tisza-Dacia block and paleomagnetic vectors documented in its sedimentary filling will therefore be a good representation for the time-evolution of the block's rotational movement. This study will concentrate on sediments of the western part of the Transylvanian Basin which document almost all the time-span from Late Cretaceous to Late Miocene times and did not undergo any significant deformation since they were deposited. In addition, we will analyse magmatic and sedi-mentary samples from the Southern Carpathians to constrain the areal extent of the TDB in pre- and syn-rotation times. This part of the project is designed as a test for the hypothesis that the eastern and central parts of the Southern Carpa-thians are integral parts of the rotated TDB, whereas the western Southern Carpathians consist of partly rotated slices of the TDB which were accreted to the Moesian plate during the block's rotation.

Our project, funded by NATO through its Linkage Grant scheme, is a cooperation between research groups from Tübingen, Cluj-Napoca, and Bucuresti and its participants bring together regional, sedimentologic, biostratigraphic, paleomagnetic, and tectonic expertise. A pilot study has been started this year and we will present preliminary results of it.

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