3. Hrvatski geološki kongres
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Opatija, 29.09.-01.10.2005.

7th Workshop on Alpine Geological Studies

Abstracts Book

Editors:
Bruno Tomljenović, Dražen Balen & Igor Vlahović

Croatian Geological Society

Croatian Geological Survey
Faculty of Science
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ZAGREB, 2005

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ABSTRACTS BOOK

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Papers in this Abstract Book reflect the authors' views.

Editors have corrected only the obvious mistakes in the text and unified the final layout of papers.

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The North-Eastern Waschberg Zone and Adjacent Units: Accommodation of Transpression Between Alps and Carpathians

Clemens Astleithner, Andrea May, Franz Neubauer & Johann Genser

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Key Words: Accommodation zone, Blind thrust, Ramp anticline, Transpression, Extension, Balancing.

The Waschberg zone represents a folded, thin-skinned tectonic thrust sheet derived from Mesozoic–Tertiary cover units of the European plate at the transition between Eastern Alps and Western Carpathians. This nappe overthrusted the southeastern margin of the Molasse basin along the Fallbach thrust and was overthrusted by the Rhenodanubian Flysch nappe complex, which is nearly fully covered by the Miocene Vienna basin fill. Subsequent to thrusting, the Waschberg nappe was passively deformed by anticline formation of the Molasse basin fill due to a late-stage shortening by blind thrusting in the footwall. There is no doubt that the stratigraphic units of the Waschberg zone derived from the autochthonous Mesozoic–Tertiary cover of the European plate as similar stratigraphy and facies development suggest. Our rough balancing of the cross-section published first by BRIX et al. (1977) and later by BRIX & SCHULTZ (1993) indicates a minimum displacement of 23.3 km of the Waschberg nappe along the Fallbach thrust and an origin of the Ernstbrunn Limestone klippen from the southeastern area beneath the central part of the Vienna basin. The dominance of Malmian shallow water limestone (Ernstbrunn Limestone) indicates an origin of the Waschberg zone from – in the present-day coordinates – the southeastern margin of the Malmian graben structure, which is filled with thick marls. There, Malmian platform carbonates were originally drilled in Zistersdorf ÜT1 (e.g., BRIX in BRIX & SCHULTZ, 1993).

We suggest that folding of the Molasse basin formed after thrusting of the Waschberg nappe over the Molasse basin by footwall propagation of thrusting. Based on balancing techniques, we estimate a shortening of 845 meter in the Molasse anticline. In front of the anticline and of the Fallbach thrust, further anticlines were formed within the Molasse basin. These are arranged en echelon indicating a stage of oblique, sinistral motion during final shortening along the Fallbach thrust. Such structures are common at the Alpine front and indicate deformation partitioning into orthogonal shortening at the front of the Alpine nappe stack and some strike-slip displacement in the interior of the Alpine wedge. All major tectonic units of the study area (Molasse basin, Waschberg zone and Vienna basin) are covered by gravels and sandstones of the Pannonian–Pontian Hollabrunn–Mistelbach Formation, which represents, therefore, an overstep unit.

The data presented before and extensive new structural field data from the Waschberg zone and adjacent units argue for the following tectonic development of the Waschberg zone starting with initial overthrusting and wide transport of the Waschberg zone over the Molasse basin. In a first stage, Early Miocene in age and D_1 in our scheme, the Waschberg zone was transported over the flexurally downbended Molasse basin. Based on balancing of a well-controlled seismic section of BRIX & SCHULTZ (1993), a minimum thrust displacement of ca. 40 kilometer is estimated, when also the thrust of the Rhenodanubian Flysch nappe complex over the Molasse basin is considered. Also the widespread extension gashes with calcitic fillings within the Ernstbrunn Limestone can be interpreted to belong to the deformation event D_1.

In the subsequent stage D_2, sinistral strike-slip motion occurred along an orogen-parallel fault system during the late Early Miocene, which is part of the confining fault system of the extruding ALCAPA block. We assume that the fault including the entire Waschberg zone was later rotated in an anticlockwise manner as also palaeomagnetic data indicate (SCHOLGER & STINGL, 2004). Block rotation behind the Bohemian spur, a crustal-scale obstacle of the European plate, gradually led to subsequent normal faulting and extension. This deformation phase D_3 also opened the Vienna basin as a pull-apart basin during the Badenian. The Mistelbach halfgraben opened contemporaneously with sedimentation and the Mistelbach normal fault reactivated likely a thrust fault in the rear of the Waschberg zone. We found a good example for synsedimentary tilting from the Rannerdorf–Hauskirchen pit, where foreland-directed tilting and sedimentary transport argue for such a model. The normal fault system reactivated the older thrust systems, and progressively reached the European plate in the footwall, as the Mailberg normal fault in the external sectors of the Molasse basin indicates (BRIX & SCHULTZ, 1993). Based on balancing, D_3 extension is estimated to reach ca. 10 percent.

Finally, weak evidence suggests that basin inversion reactivated NE-trending faults as dextral strike-slip systems due to WNW–ESE compression (D_4). This system was well described further south in central sectors of the extruding wedge and is considered to represent collision of extruding wedge with the European foreland (PERESSON & DECKER, 1997). We tentatively assume that WNW–ESE strike-slip compression is subsequently overprinted by NE–SW compression (D_5). This would imply a rotation of principal stress axes and can be reasoned by reorganization of motion directions of the still extruding block (e.g., DECKER et al., 2005).

Locally, ca. N–S extension (deformation stage D_6) is observed in few examples of Upper Pannonian deposits covering the whole region. The exact age of these structures is uncertain. However, from the kinematic point of view, this is in accordance with a widespread Quaternary tectonic activity in the southern and central sectors of the Vienna basin.

References

BRIX, F., KRÖLL, A. & WESSELY, G. (1977): Die Molassezone und deren Untergrund in Niederösterreich.– Erdöl- und Erdgas-Zeitschrift, 93, 12–35.

BRIX, F. & SCHULTZ, O. (1993): Erdöl und Erdgas in Österreich.– Naturhistorisches Museum Wien und F. Berger, Horn.

DECKER, K., PERRESON, H. & HINSCH, R. (2005): Active tectonics and Quaternary basin formation along the Vienna Basin Transform fault.– Quaternary Science Reviews, 24, 307–322.

PERESSON, H. & DECKER, K. (1997); Far-field effects of Late Miocene subduction in the Eastern Carpathians: E–W compression and inversion of structures in the Alpine–Carpathian–Pannonian region.– Tectonics, 16, 38–56.

SCHOLGER, R & STINGL, K. (2004): New paleomagnetic from the Middle Miocene (Karpatian and Badenian) in northern Austria.– Geologica Carpathica, 55, 199–206.

The Late Jurassic Radiolaritic Breccia at the Northern Margin of the Dachstein Block (Bad Ischl, Salzkammergut): Radiolarian Dating, Microfacies of Components and Tectonic Significance

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Key Words: Northern Calcareous Alps, Dachstein Block, Jurassic Breccia, Radiolarians, Microfacies, Tauglboden Formation.

North of the Katrin–Sonntagskarkogel mountain ridge (northern Dachstein Block) an as yet undescribed occurrence of radiolaritic breccia has been found in an area, which was actually supposed to be made up of Dachstein limestone. The samples of this lithostratigraphic unit, gained during a first field campaign, were scrutinised mainly on their radiolarian fauna and the nature and origin of the breccia components.

Samples of the fine-grained rocks (breccia matrix, radiolarites, silicic limestones and marls) were solved in diluted hydroflouric acid for their content in radiolarians. Six of the samples yielded utilisable radiolarian-bearing residues; five of them enabled a biostratigrapic classification according to the Unitary Association Zonation for Tethyan radiolarians of BAUMGARTNER et al. (1995). The onset and extinction of different species constrain a Middle Callovian to Early Oxfordian stratigraphic age, corresponding to U.A.–Zone 8 sensu BAUMGARTNER et al. (1995) or the Protunuma lanosus to Williriedellum dierschei-Subzone within the Zhamoidellum ovum-Zone of SUZUKI & GAWLICK (2003).

Thin sections were analysed in order to determine the stratigraphic affiliations of the breccia components by means of their microfacies characteristics. The clasts show a large variety in lithology and age, however, originate all from the the same, local substratum of ´kalkvoralpin´ Tirolic affinity. The components have a primary stratigraphic age of Norian to Callovian/Oxfordian and could be assigned to the following stratigraphic units (Fig. 1): Norian and Rhaetian lagoonal Dachstein limestone, Norian/Rhaetian Kössen formation, limestones of the Kendlbach, Scheibelberg, Adnet and Klaus formations and silicic rocks of the Ruhpoldinger Radiolarite group some clasts of which are thought to represent the distal parts of the Strubberg formation. In addition, in the assumably higher part of the section fine-grained detritus of the Upper Jurassic Plassen carbonate platform could be proven, suggesting an age of the breccia at the upper limit of the timeframe given by the radiolarian biostratigraphy. Considering all data, the breccia is supposed to be of Lower Oxfordian age corresponding to the Williriedellum dierschei-Subzone within the Zhamoidellum ovum-Zone of SUZUKI & GAWLICK (2003, Fig. 1).

The age and the lithostratigraphic suite of the breccia components confirm the breccia to be part of the Tauglboden formation as known from the type region in the Osterhorn Block. The absence of components of the Tethys reefal platform rim, slope and basin margin excludes an affiliation of the breccias to the more southerly situated Lammer Basin with its Strubberg Formation Basin fill. The sediments of the even more southerly Sillenkopf Basin are generally younger in age and show a different lithostratigraphic spectrum. The stratigraphic age, the breccia components and the early occurrence of Upper Jurassic shallow water components indicate a paleogeographic position of the depositional area in the southern, proximal part of the Tauglboden Basin close to Trattberg Rise as the main source region. The stratigraphic results, on the one hand, prove the Dachstein Block as part of the Tirolic mega-unit as suggested by FRISCH & GAWLICK (2003), but, on the other hand, claim the need to subdivide the Dachstein Block into a southern Upper Tirolic and a northern Lower Tirolic part, to the latter of which the Tauglboden Basin belongs to by definition (FRISCH & GAWLICK, 2003) – the structural border between the Upper and Lower Tirolic unit is as yet unknown, however, must be located somewhere south of the investigated Tauglboden formation occurrence and north of the Plassen area with its Strubberg–Sillenkopf basin fill.

References

BAUMGARTNER, P.O., BARTOLINI, A., CARTER, E.S., CONTI, M., CORTESE, G., DANELIAN, T., DE WEVER, P., DUMITRICA, P., DUMITRICA-JUD, R., GORIČAN, Š., GUEX, J., HULL, D.M., KITO, N., MARCUCCI, M., MATSUOKA, A., MURCHEY, B., O´DOGHERTY, L., SAVARY, J., VISHNEVSKAYA, V., WIDZ, D. & YAO, A. (1995): Middle Jurassic to Early Cretaceous radiolarian biochronology of Tethys based on Unitary Associations.– Mém. de Géol., 23, 1013–1048, Lausanne.

FRISCH, W. & GAWLICK, H.J. (2003): The nappe structure of the central Northern Calcareous Alps and its disintegration during Miocene tectonic extrusion – a contribution to understanding the orogenic evolution of the Eastern Alps.– Int. Journ. Earth Sci., 92, 712–727, Berlin.

SUZUKI, H. & GAWLICK, H.J. (2003): Die jurassischen Radiolarienzonen der Nördlichen Kalkalpen.– Gmundner Geostud., 2, 115–122, Gmunden.

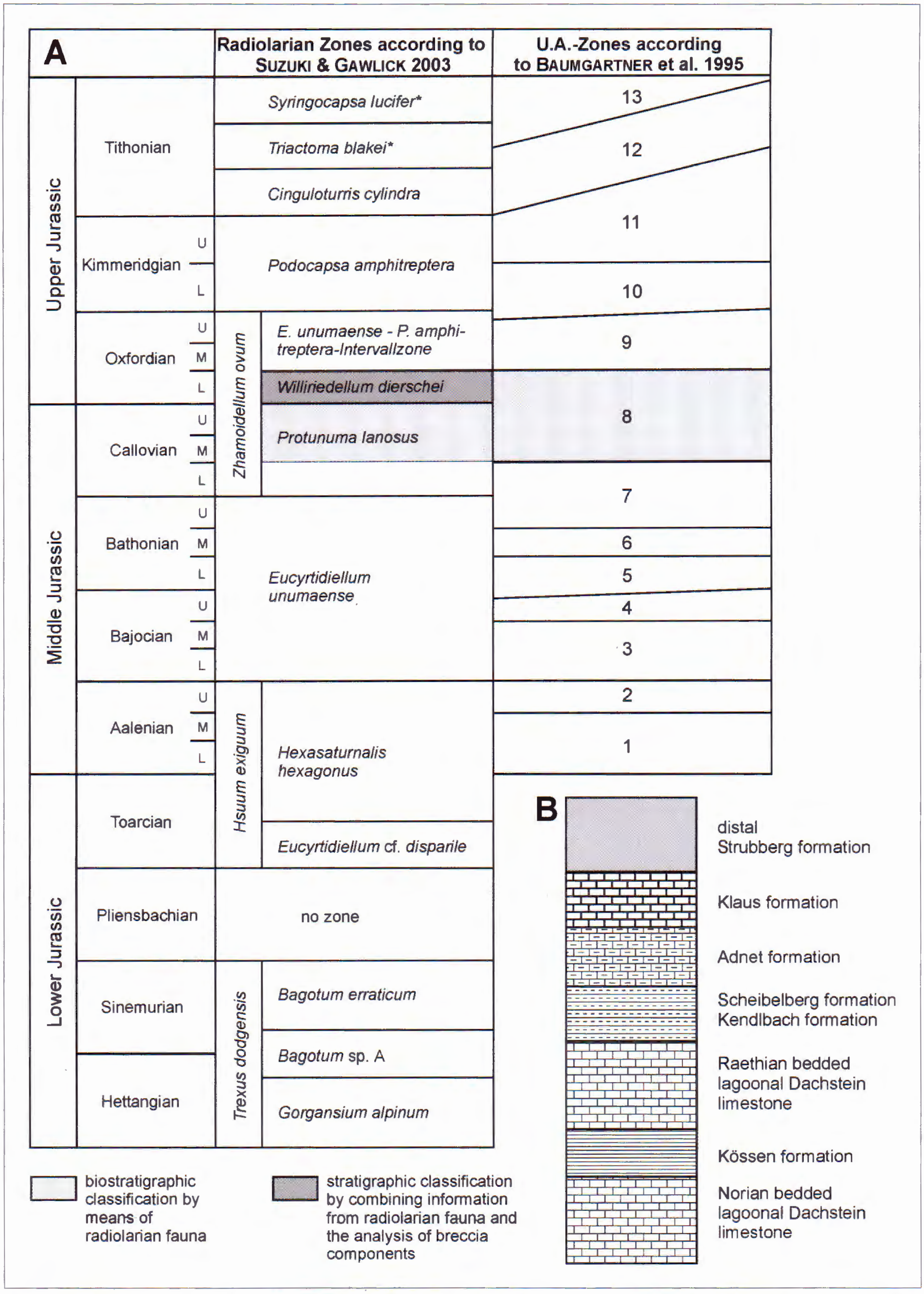

Fig. 1 (A) Biostratigraphic classification of the radiolarian fauna. Radiolarian zonation of the Northern Calcareous Alps according to SUZUKI & GAWLICK (2003). Unitary Association zonation for Tethyan radiolarians according to BAUMGARTNER et al. (1995). The combination of radiolarian dating, microfacies analysis of breccia components and comparisons to other occurrences of the Taugl-boden formation suggests the breccias to be Early Oxfordian in age. (B) Synthetic profile of the eroded source area derived from thin section analysis of the breccias. The reconstructed stratigraphic sequence is in good agreement with the succession met in the Trattberg Rise area.

Late Rhaetian to Jurassic Sedimentary Succession in the Environs of the Brinje Tunnel (Croatia – Outer Dinarides)

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Key Words: Outer Dinarides, Jurassic shallow-marine sedimentary succession.

The construction of the new Zagreb–Dubrovnik highway is an important part of the European transit corridor from the central Europe to Greece. During the construction work of the section from the tunnel of Mala Kapela South to Žuta Lokva, the surrounding mountain area of the tunnel Brinje has been investigated stratigraphically and microfacially by means of 200 thin-sections, including both outcrop samples (OT series) and samples from the tunnel itself (TM series). Palaeogeographically, the investigated sedimentary succession belongs to the Outer Dinarides of the Adriatic carbonate platform.

The Triassic/Jurassic boundary is not marked by a lithological change, but is characterized by a gradual transition. The Jurassic series of a shallow-marine facies has been evidenced stratigraphically by means of benthic foraminifera from the Late Sinemurian–Early Pliensbachian to the Kimmeridgian (? Tithonian).

While the reconstruction of the general facies evolution in this area is comparably well known, e.g. TIŠLJAR et al. (2002) and VELIĆ et al. (2002), including also stratigraphical, sedimentological and microfacies data, the palaeogeographical position, especially of the lower and middle–upper Jurassic series, needs further precision.

The studied sedimentary succession is composed as follows:

The oldest parts can be dated as uppermost Rhaetian with the occurrence of *Griphoporella curvata* (GÜMBEL) PIA and *Tetrataxis*? *inflata* KRISTAN and *Tetrataxis*? *nanus* KRISTAN-TOLLMANN. These are foraminifera-rich packstones containing also scattered remains of reef-building organisms. The early Liassic consists of packstones of reduced thickness and couldn´t be dated biostratigraphically. The upper parts comprise dark-brownish and slightly bituminous mudstones, partly showing brecciation, algal laminites, foraminifera wackestones with *Palaeomayncina termieri* (HOTTINGER) or *Amijiella amiji* (HENSON), poorly fossilized peloidal packstones of presumably faecal origin and *Favreina* wackestones. Other characteristic microfacies types are wackestones, almost exclusively or in a great abundance composed of the tubes of *Porferitubus buseri* SENOWBARI-DARYAN. The rare ooidal grainstones, sometimes with high abundance of oomoldic ooids, can be interpreted as tidal bar deposits since these are not in any connection to external platform facies. In conclusion, the Liassic sediments can be ascribed to a mud flat facies due to their microfacies characteristics. With the occurrence of *Palaeomayncina termieri* (HOTTINGER) they are of Late Sinemurian to Late Pliensbachian age (SEPTFONTAINE, 1988; BASSOULLET, 1997). The microproblematicum *Porferitubus buseri* was so far only known from Norium–Rhaetium reefal limestones (BERNECKER, 1996).

The Dogger couldn´t be dated stratigraphically, because of the lack of marker microfossils and partial dolomitization. In the area of Velika Kapela, a comparable Jurassic section with dolomitic parts in the Upper Liassic – Lower Dogger and the Oxfordian has been described by e.g. VELIĆ & SOKAČ (1978) and MATIČEC et al. (1997). In the Upper Jurassic part of our section there are also mudstones, but much less frequent than in the Liassic. There are wackestones partly containing *Alveosepta jaccardi* (SCHRODT) enriched in certain layers, indicating the time-span between the Late Oxfordian to the Early Kimmeridgian (BASSOULLET, 1997). Some kind of back-reef facies is represented by *Bacinella* bindstones with "Rivulariaceae" and also by biosparitic packstones with *Labyrinthina mirabilis* WEYNSCHENK and trocholinids. The occurring stromatoporoid–coral limestones and the laterally associated back-reef can be dated as Kimmeridgian with "*Kilianina*" *rahonensis* FOURY & VINCENT, *Labyrinthina mirabilis* WEYNSCHENK and *Conicokurnubia orbitoliniformis* SEPTFONTAINE. According to TIŠLJAR & VELIĆ (1993) *C. orbitoliniformis* occurs in the lower part of the Kimmeridgian (*Heteroporella anici* Zone) of the Gorski Kotar region. The most abundant stromatoporoid is *Actinostromina grossa* (GERMOVSEK). Other microfossils include *Mohlerina basiliensis* (MOHLER), *Thaumatoporella*, *Lithocodium–Bacinella* and fairly common *Nipponophycus ramosus* YABE & TOYAMA. Dasycladales are extremely rare in the whole investigated profile; in the Upper Jurassic we find rare *Salpingoporella* cf. *johnsoni* (DRAGASTAN) und *Dissocladella*? sp. For the reefal limestones VELIĆ et al. (2002) indicate a Middle Kimmeridgian/Tithonian age.

A carbonate slope/ramp facies is represented by fine-grained packstones with echinoid and sponge remains as well as tubiphyts. Noteworthy, that in this part also dolomites occur.

From the Oxfordian–Kimmeridgian boundary onwards the installation of a shallow-marine platform started first with lagoonal sediments. During the lower Kimmeridgian, after a regressional phase, the installation of a carbonate ramp took place correlated with a sea-level highstand, followed by a regressive–transgressive cycle leading also to the formation of the dolomites presumably under early-diagenetic (?evaporitic) conditions. These are followed by massive reefal limestones with a stromatoporoid–coral assemblage, representing a sea-level highstand and probably passing into the Tithonian as well. This succession mostly corresponds to the one described by VELIĆ et al. (2002). However, due to our new results some minor modifications of facies zones are necessary for the region of Brinje.

The studied shallow-marine Jurassic sedimentary succession is clearly distinguished from the Jurassic series known from the Southern Alps, Eastern Alps or from the Carpathians. This also accounts for the reconstructed thicknesses of different stratigraphic levels. In addition there are also differences in biofacies, e.g. the occurrence/absence of certain microfossils. For example, the larger benthic foraminifera *Conicokurnubia orbitoliniformis* SEPTFONTAINE so far known from Tunisia, Turkey (type-locality) and the Dinarides is missing in Kimmeridgian shallow water limestones of the Northern Calcareous Alps. Also in areas like in the Northern Calcareous Alps, the Dinarides or Morocco where the Triassic/Jurassic boundary is not marked by a carbonate platform drowning, certain microfossils that disappeared in the former persisted in the Liassic such as the tetrataxid foraminifera (e.g. BASSOULLET et al., 1999).

In conclusion, these observations clearly demonstrate that in the Early to early Late Jurassic times, the Eastern and Southern Alps were clearly palaeogeographically separated one from the Dinarides, whereas in the Rhaetian and the Late Jurassic times the sediments of both regions show a similar facies evolution. These results have to be proofed in a greater regional scale.

References

BASSOULLET, J.-P. (1997): Les Grands foraminifères.– In: CARIOU, E. & HANTZPERGUE, P. (coord.), Biostratigraphie du Jurassique ouest-européen et Méditerranéen.– Bull. Centres Rech. Explor.-Prod. Elf-Aquitaine, Mém., 17, 293–304, Pau.

BASSOULLET, J.-P., BOUTAKIOUT, M. & ECHARFAOUI, H. (1999): Deux nouveaux genres, Palaeocyclammina et Ijdranella, foraminifères (Textulariina) d´un niveau Liasique à Orbitopsella praecursor (Gümbel) du Moyen Atlas (Maroc).– Rev. Micropal., 42/3, 213–230, Paris.

BERNECKER, M. (1996): Upper Triassic reefs of Oman Mountains: Data from the South Tethyan Margin.– Facies, 34, 41–76, Erlangen.

MATIČEC, D., VLAHOVIĆ, I., FUČEK, L., OŠTRIĆ, N. & VELIĆ, I. (1997): Stratigraphy and tectonic relationships along the Senj–Ogulin Profile (Velika Kapela Mt., Croatia).– Geol. Croatica, 50/2, 261–268, Zagreb.

SEPTFONTAINE, M. (1988): Vers une classification évolutive des Lituolidés (Foraminiféres) jurassiques en milieu de plate-forme carbonatée.– Rev. de Paléobiol., vol. spec., 2, 229–256.

TIŠLJAR, J. & VELIĆ, I. (1993): Upper Jurassic (Malm) shallow-water carbonates in the Western Gorski Kotar area: Facies and depositional environments (Western Croatia).– Geol. Croat., 46/2, 263–279, Zagreb.

TIŠLJAR, J., VLAHOVIĆ, I., VELIĆ, I. & SOKAČ, B. (2002): Carbonate platform megafacies of the Jurassic and Cretaceous deposits of the Karts Dinarides.– Geol. Croatica, 55/2, 139–170, Zagreb.

VELIĆ, I. & SOKAČ, B. (1978): Biostratigraphic analysis of the Jurassic and Lower Cretaceous in wider region of Ogulin, central Croatia.– Geol. vjesnik, 30/1, 309–337, Zagreb.

VELIĆ, I., TIŠLJAR, J., VLAHOVIĆ, I., VELIĆ, J., KOCH, G. & MATIČEC, D. (2002): Palaeogeographic variability and depositional environments of the Upper Jurassic carbonate rocks of Velika Kapela Mt. (Gorski Kotar area, Adriatic Carbonate Platform, Croatia).– Geol. Croatica, 55/2, 121–138, Zagreb.

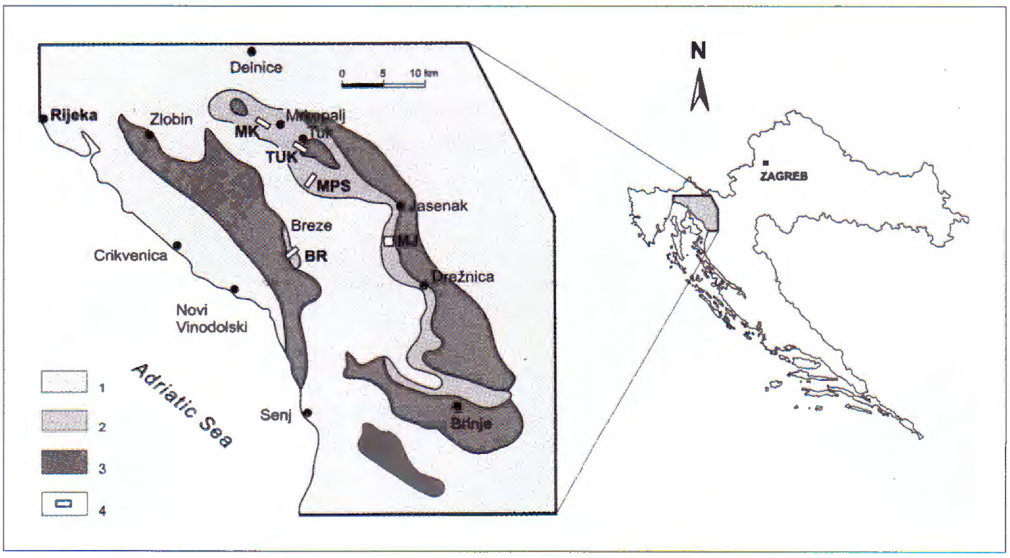

Fig. 1 Location map of the study area with the distribution of Upper Jurassic deposits of different palaeoenvironments (from VELIĆ et al., 2002). Legend: 1 – shallow water Oxfordian and Tithonian limestones; 2 – limestones with cherts; 3 – reefal - peri-reefal deposits; 4 – position of the studied geological columns by VELIĆ et al. (2002).

Tectonic Contacts Between the Alps, Dinarides and Hellenides

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Key Words: Alps, Dinarides, Hellenides, Cenozoic, Tectonics.

Constrained by the recent position of both the Dinarides and previously consolidated massifs in their hinterland, a reconstruction of the collisional kinematics between the Adriatic microplate with its segments and the sedimentary cover was done. Together with resistance of the massifs in direction of the movement, these segments play crucial role in formation of the Dinarides, Helenides and adequate parts of the Alps.

Without questioning the palaeogeographic integrity of geotectonic units mentioned above, especially during their Mesozoic–Eocene evolution, emphasis is given to tectonic elements that define the basis for their differentiation.

Time-sequence of the processes is not analysed. Only the most important changes are taken into account, i.e. (1) Eocene–Oligocene tectonics with formation of Dinaric structures and (2) post-Oligocene kinematics with formation of tectonic units of orthogonal restructuring (along the Hvar island strike direction and similar), compression of Oligocene–Miocene basins in Eastern Slovenia, and opening of depressions with Neogene–Quaternary sediments.

Variations in strike direction of structures and stratigraphic units that are characteristic for the Dinarides, Hellenides and Alps are concentrated in a narrower area and thus point to the fault contacts (Fig. 1), i.e. to the Skadar–

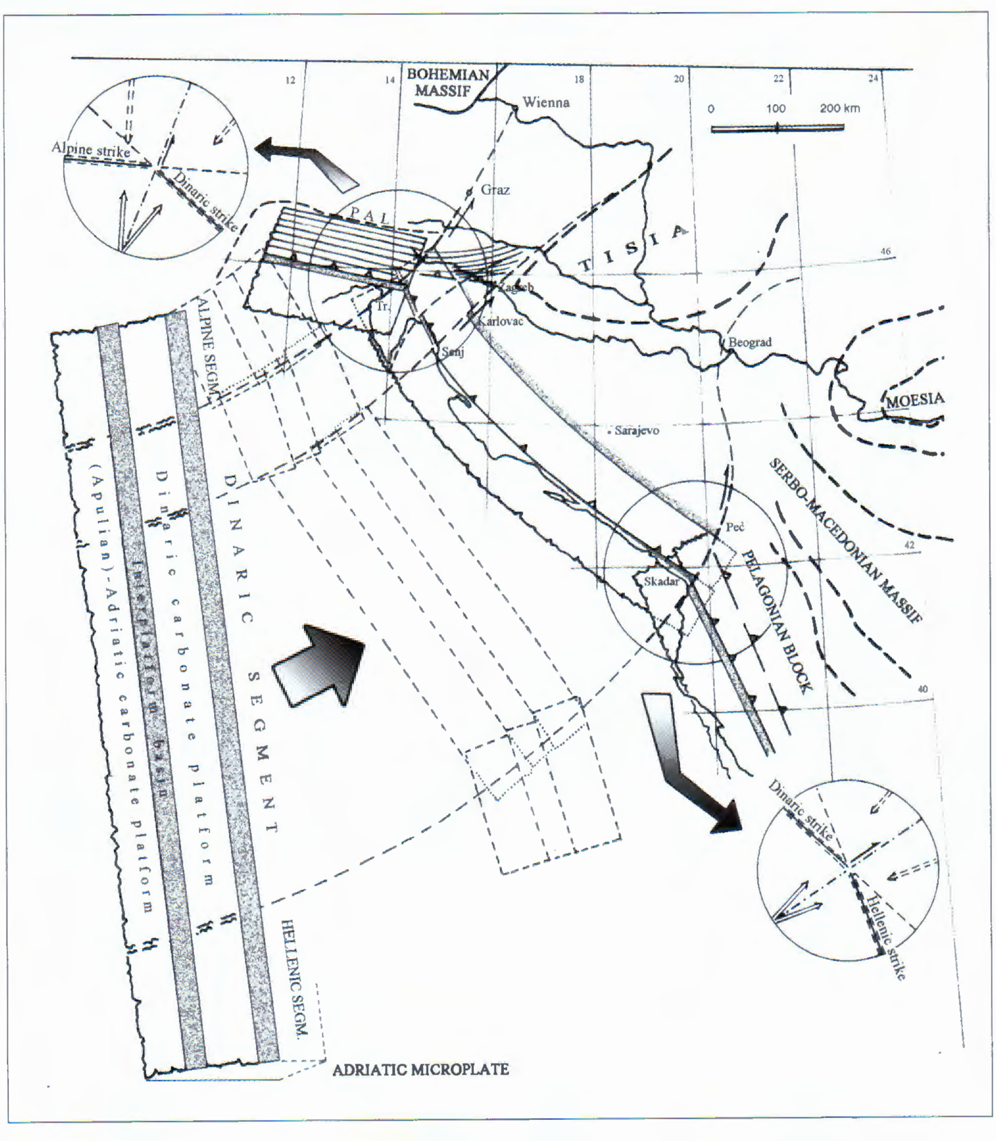

Fig. 1 Genesis of tectonic contacts between the Alps, Dinarides and Hellenides.

Peć and the Trieste–Postojna–Ljubljana fault zones. The former is interpreted as marking the contact between the Dinarides and the Hellenides, the later as acontact between the Dinarides and the Alps ("Alps" here refers to structures north of the Gorica–Postojna flysch zone together with the structures of the Sava folds).

Based on the mentioned fault zones, a model is constructed (Fig. 2) explaining the differences in magnitude and direction of movement of the Adriatic micro-plate segments, and formation of the transcurrent fault systems with specific manifestation at the surface. In direction of the collisional movement they are manifested by: (1) transpressional structures, conveying the relative continuity of strike of structural units at the surface and at the same time, due to the differences in intensity of displacement, cloaking the horizontal displacement, and (2) transtensional structures (depressions like rhombochasm, pull-apart basins etc.) where the transcurrent displacement becomes more marked.

The relatively simple application of the model to the Skadar–Peć fault system becomes more complicated along the Trieste–Postojna–Ljubljana transcurrent fault and its elongation all the way to the Vienna basin. It is with development of transtensional structures (the Styria and Vienna basins) that the area is opened for "extrusion" of the compressed Alpine units (Karavanke and Pohorje Mts.) towards the east, along sinistral and dextral transcurrent faults. The most important of these faults is the Periadriatic lineament (Fig. 3). In this way the function of the Trieste–Ljubljana–Vienna fault system is interrupted and movement is taken over by partly concordant systems of the Kvarner–Novo Mesto and the more important Senj–Karlovac–Zagreb–Koprivnica faults. These faults enabled collision and thrusting of the Dinaric segment into the area of the present-day Pannonian basin. The recent location of these faults is also partly influenced by the specific position and CCW rotation of the southwestern parts of Tisia towards NNE. Such a rotation of Tisia enables the assumption that oceanic rocks of the Inner Dinarides were primarily merged with the Meliata ocean. Additionally, the movement of Tisia explains tectonic relations in a narrow but crucial region of the Karlovac depression and the Hrvatsko Zagorje region.

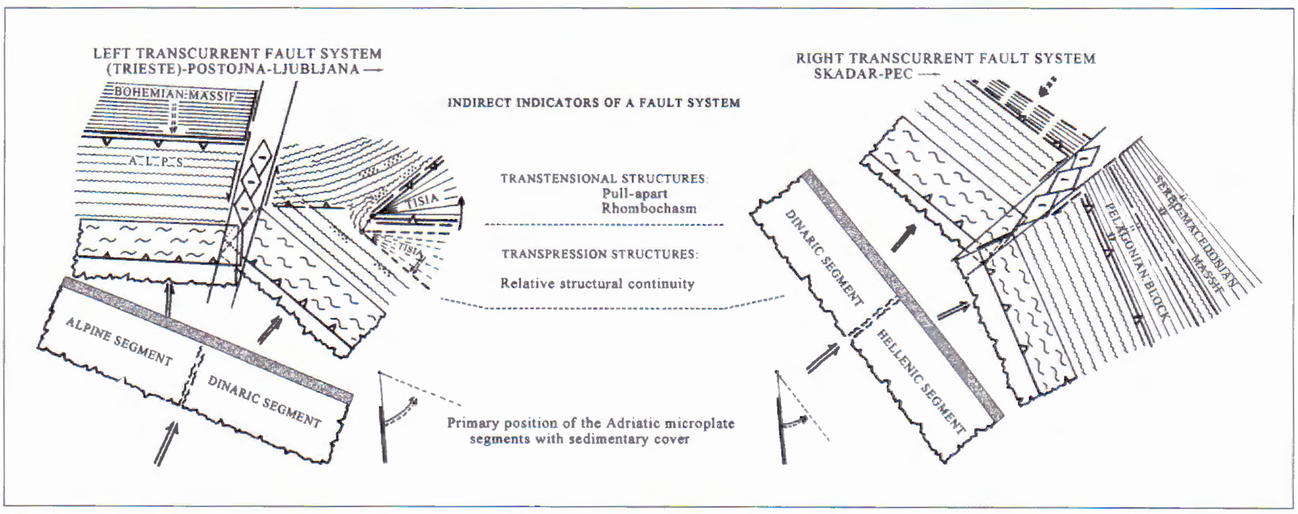

Fig. 2 Scheme of fault system kinematics.

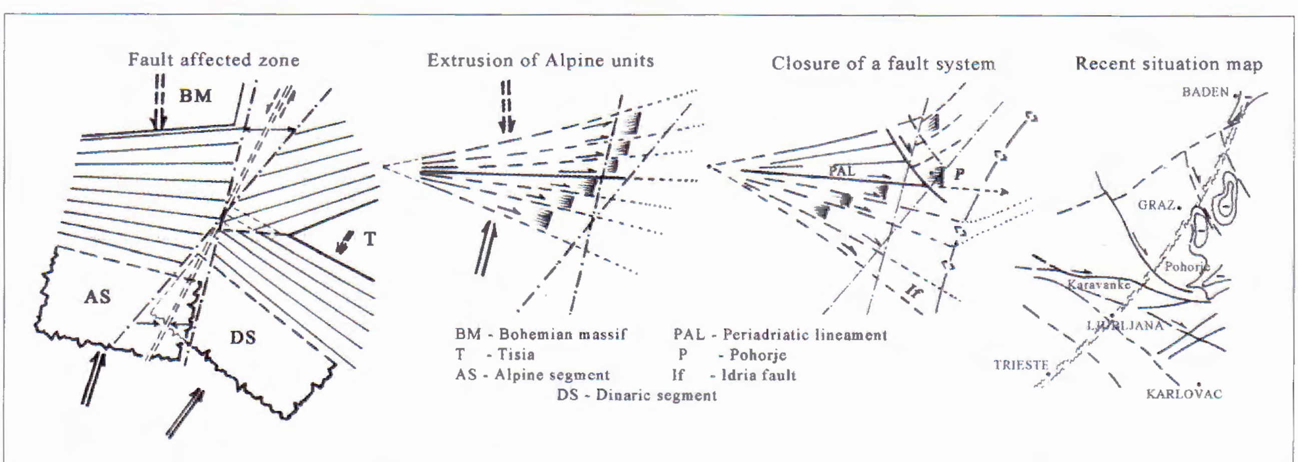

Fig. 3 Transcurrent fault system Trieste–Ljubljana–Vienna.

Tectonic Framework of the Dinarides and SW Part of the Pannonian Basin – Strait Area Formation Model

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Key Words: Dinarides, Pannonian Basin, Tectonics, Fault systems.

Defined transcurrent faults systems between the Dinarides and Alps, and the Dinarides and Hellenides extend along the NE direction, pre-determined by the position and resistance of earlier consolidated massifs. The Trieste–Ljubljana fault extends over Graz to Vienna basin, and the Skadar–Peć fault extends along the Serbo–Macedonian massif and Carpatho–Balkan chain into the Muresh fault west of Apuseni Mts.

These faults delimit a strait in which the structural changes of the Dinarides and SW parts of the Pannonian Basin took place during the Cenozoic collision. Especially marked tendency in this process was the length reduction of predominantly Dinaric structures. In a modified process, parallel to the formation of joined subduction zones, mostly in the Outer Dinarides, there was a discontinuous movement through the strait and certain structural changes happened due to the concave shape of the Skadar–Peć–Čačak fault zone. These changes can be described as a tendency of the (spiral) counter-clockwise rotation with a centre in the Sarajevo region. The marked increase in depth of disturbance is observed by formations of various ages at the surface. These structural changes include the formation of the Durmitor overthrust and the Sarajevo sigmoid, the NE vergence of compressional structures in the Vrbas region, the uplift of Palaeozoic rocks in the Jajce–Sarajevo–Konjic triangle, and also of the possibly younger Palaeozoic formations in the Lika region and at Mt. Velebit. In the Čačak–Kraljevo area, the continuity of the ophiolitic zone of Inner Dinarides is disturbed by the formation of Neogene sedimentary areas. On the other side, in the Konjic–Split–Primošten zone, there is the most significant reduction of the length of Dinaric units due to orthogonal restructuring and partial subduction of the already formed Dinaric compressional structures.

The tendency of spiral movement is also expressed in the formation of the Sava and Drava faults. Within the zone of marked collisional movement they follow the same pattern, especially in areas of the Trieste–Ljubljana–Graz fault system and the Senj–Zagreb–Koprivnica fault system (after the closure of the former by the extrusion of Alpine units, i.e. the Karawanken and the Pohorje Mts.).

The expression of collisional kinematics, but in a strait conditions, is especially marked by the oblique and transversal faults, mostly within the Sava–Drava area and in the mountains of northern Bosnia. By their strike these faults mimic the more closely located bordering faults of the strait, pertaining either to the dextral (Skadar–Peć–Belgrade–Muresh) or sinistral (Trieste–Ljubljana–Graz, later Senj–Zagreb–Koprivnica) transcurrent fault systems. It is by such transversal and oblique faults with various horizontal displacements that e.g. the tectonic transport of Psunj, Požeška gora and Dilj gora Mts., and the closure of the Požega Valley, the Sava and Drava depressions, and the Hrvatsko Zagorje area can be explained.

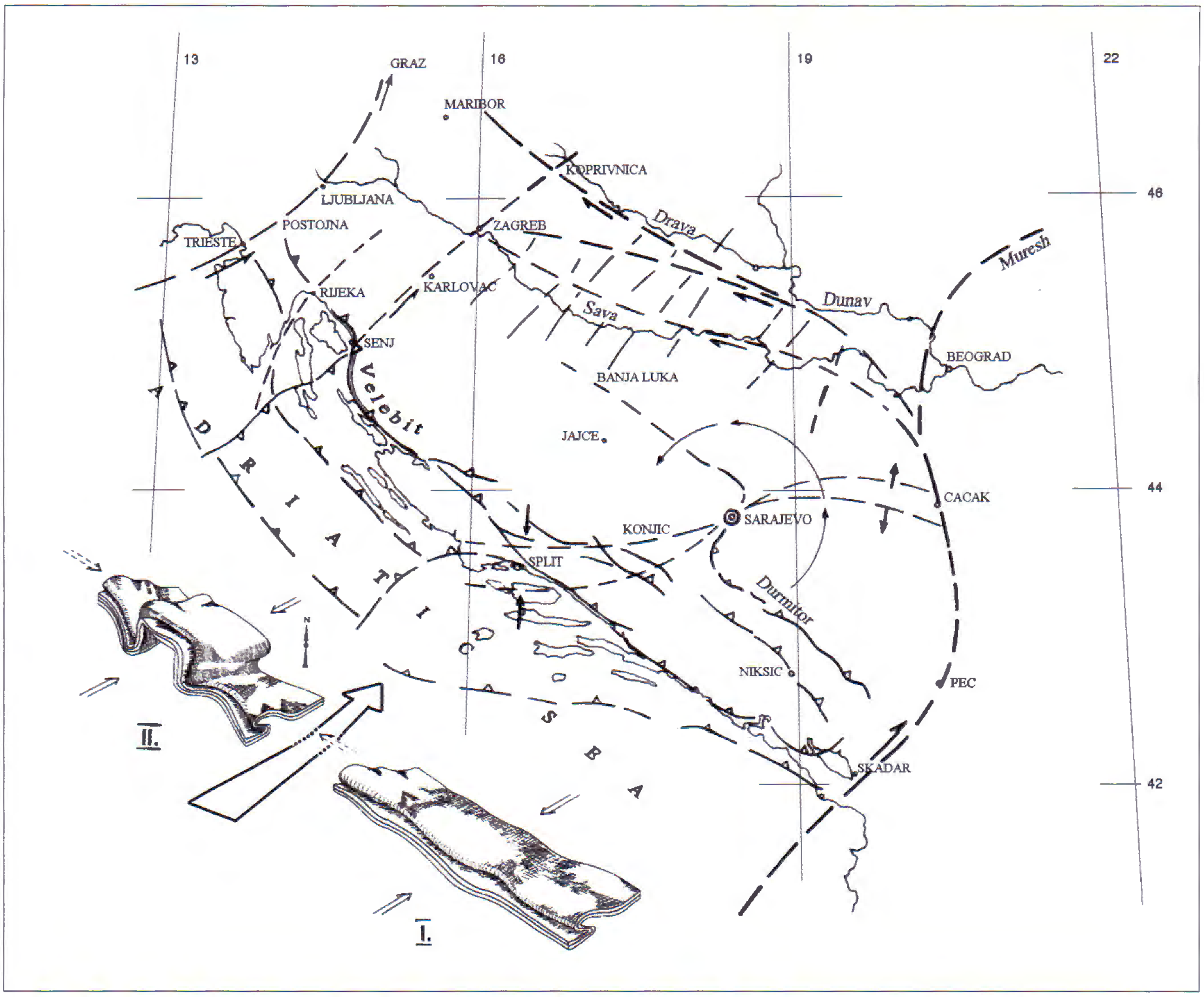

Fig. 1 The formation model for the structures of Dinaric strike and for the structures of orthogonal refolding.

Transcurrent Faulting in the Prealpes Klippen Belt

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Key Words: Prealpes, Recent tectonics, Transcurrent faulting, Stress analysis, Riedel model, Morphology.

The Prealpes klippen belt in Switzerland and France is formed by allochtonous tectonic nappes of which the Prealpes Medianes are the most important. They developed during the incorporation of the Briançonnais terrane in the Alpine accretionary prism after the Early Eocene. The Prealpes Medianes detached from their homeland and were subsequently emplaced into their present position in front of the Helvetic nappes and the External crystalline basements (syn–post Chattian). The fold-and-thrust development is rather well understood, but the more recent tectonic events (neotectonics; present tectonics) remain largely unknown. Besides some suspected reactivation of thrusting, there is also a "general feeling" that brittle faults (possibly transcurrent faults) are due to the recent tectonic activity. Indeed brittle faults are ubiquitous features throughout the Prealpine nappes.

We present the results of a systematic effort to investigate the nature and kinematics of observed faults and fractures. The areas of investigation are the western Prealpes Romandes, (Leman Lake to Jaun), and the Swiss Chablais Prealpes South of Leman Lake. We use a compilation of faults from geological maps (published and unpublished), and observations on faults and offsets in the field. These latter allow to compute the palaeostress estimates. A systematic investigation on lineaments seen on aerial photographs shows that they correspond mostly to vertical to subvertical tectonic faults observable in many instances in the field. Offsets are often difficult to document. There is a marked difference in the preferential orientation of faults from the geological maps (based on field observation) and faults mapped from the orthophotographies. The latter reflect a statistically more robust distribution of directions of faults. In the Swiss Chablais it is possible to show that many if not most of the faults have a strike-slip component of movement.

The kinematic interpretation of the observed faults shows that in both regions the fault orientation distribution and the senses of movement are governed by a transcurrent fault system, more specifically a Riedel shear system. Based on this it is possible to determine, for each investigation area, fault subgroups. In the Swiss Chablais the main orientation of the Riedel shear zone is NW–SE with a dextral movement, whereas in the Western Prealpes Romandes it strikes more or less E–W also with a dextral sense of movement. The faults with the highest frequency are the dextral R and P shear faults, while the R' and X are less frequent.

The main geomorphologic patterns (cliffs, crests and river valleys) follow two main structural trends: the major valleys follow the trend of the large-scale folds (for example the Sarine valley), but the smaller tributaries clearly follow the main, E–W oriented fracture pattern in the Prealpes Romandes. The drainage and fracture patterns observed in the Prealpes correlate well with those in the underlying Molasse (Fig. 1). This strongly suggests that the transcurrent tectonic fault system of the Prealpes is coincident with the transcurrent fault system in the Molasse and Jura foreland (Fig. 1). The overall E–W oriented dextral shear zones conjugate well with more meridional sinistral shear zones. Along strike of the Jurassic arc, the orientation of this conjugate fault system rotates according to the general stress field. This supports the idea that the fault systems are recent and postdate the nappe emplacement.

Reference

MOSAR, J. & BOREL, G. (1992): Paleostress from the Préalpes Médianes (Switzerland).– Annales Tectonicae, 6/2, 115–133.

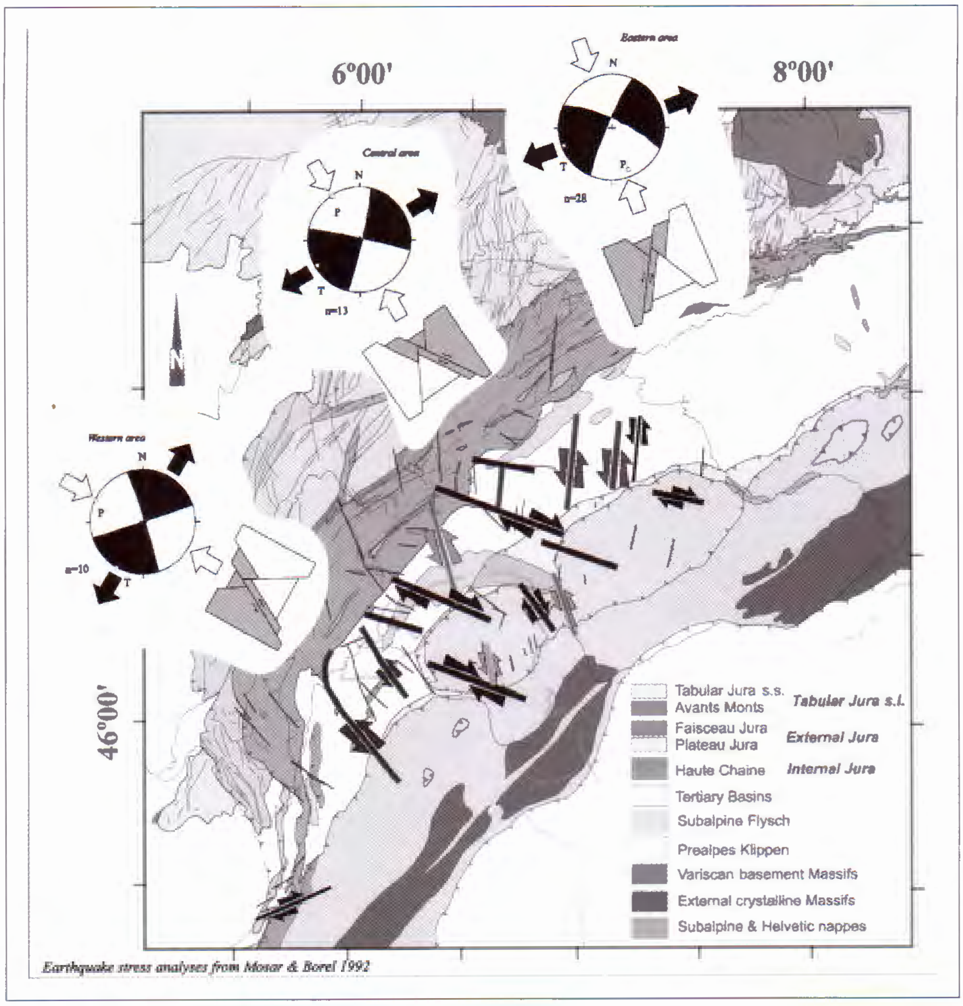

Fig. 1 Model for transcurrent faulting in the Prealpes and the Alpine foreland.

The Split–Karlovac–Wien Paleotransform and its Bearing in the Alpine Belts

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Key Words: Alps–Dinarides, Alps–Carpathian Connection, Transform.

The area between Split and Karlovac in the Dinarides is characterized by a perturbation in the regular arrangement of the NW–SE striking mountain ranges. On both sides of a tectonic line trending N–S and called the Split–Karlovac transverse (SKT; CHOROWICZ, 1975), the units differ in their stratigraphic successions, tectonic styles and are offset (Fig. 1).

While the Dalmatian and Outer High Karst zones are continuous, with only a sigmoid-shaped change in their strike, the typically carbonate platform High Karst zones are interrupted by faults linked to the occurrence of units including particular pelagic facies during the late Jurassic. The Prekarst zone, with transitional series to the more pelagic Bosnian zone to the NE, is offset by the SKT. The front of the Bosnian zone is much more offset over a distance of ~100 km. The ophiolitic bodies, belonging to the Serbian zone and which, like the other Dinaric units, verge SW-ward, disappear westward near Zagreb (Fig. 2). The Outer and Bosnian units of the Dinarides are continuous with the Southern Alps to the NW, but this is not the case for the Serbian zone. However, in the Eastern Alps units linked with ophiolites can be found in windows, and more to the west in the Swiss Alps, but they verge to the north, opposite to the vergence of the Serbian ophiolitic nappes.

This reversal in the vergence of the ophiolitic units on both sides of the northern continuation of the SKT suggests that a paleotransform fault zone existed during the Mesozoic between Karlovac and Wien (Fig. 2), in the transitional area between the Eastern Alps and the Western Carpathians (CHOROWICZ, 1977). The SKT is then the

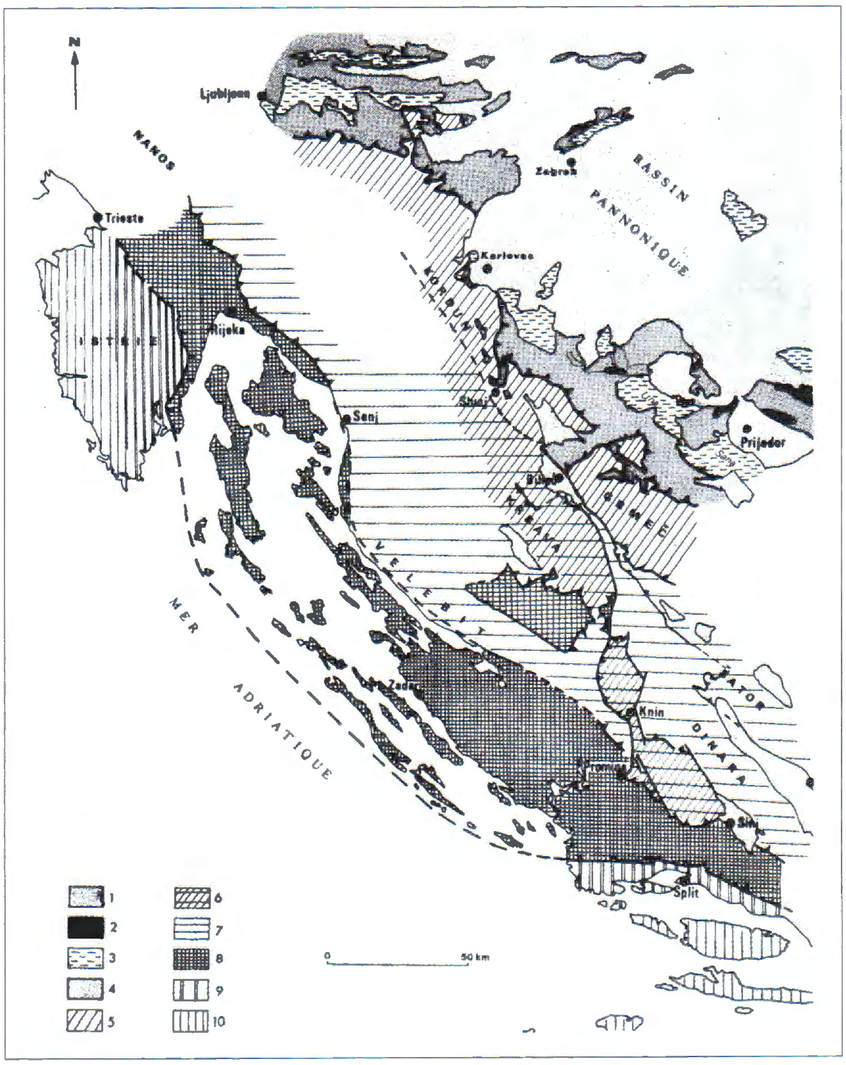

Fig. 1 Structural scheme of a part of the Dinarides along the Split–Karlovac transverse. Legend: 1 – Quaternary and Neogene; 2 – Ophiolites; 3 – Paleozoic; 4 – Inner zones; 5 – Prekarst; 6 – Inner Karst; 7 – High Karst; 8 – Outer Karst; 9 – Inner Dalmatian zone; 10 – Dalmatian zone.

transform direction forming the prolongation of this Split–Karlovac–Wien (SKW) oceanic paleotransform, progressively ending southward inside the Adriatic continental margin. The subsequent eastward lateral extrusion of the Inner Carpathian units, and the collapse of the Pannonian basin have made the SKW paleotransform partly hidden and complex. The present-day location of the missing part of the SKW transform seems to be the Pieniny Klippens at the boundary of the Inner and Outer Carpathians in the western part of this belt.

This major paleotransform in the Western Neotethys does not fit with most of the models used for explaining the formation of the Alpine belts in the Mediterranean area. However, it fits well with a model of CHOROWICZ & GEYSSANT (1976) that considers the ophiolites nappes to be derived from back-arc basins linked to the subduction of the main ocean (Fig. 3), which has completely disappeared, and which sutures in the Carpathians (east of the palaeotransform), and along the tonalitic line (west of it). In such a model, the paleo-slab of the main Neotethys was dipping SW in the Dinarides–Hellenides, and N (turning W) in the Alps.

References

CHOROWICZ, J. (1975): Le mécanisme de la structure transversale Split–Karlovac, dans les Dinarides yougoslaves.– C.R. Acad. Sc. (D), 280, 2313–2316.

CHOROWICZ, J. (1977): Etude géologique des Dinarides le long de la structure transversale Split–Karlovac (Yougoslavie).– Société Géologique du Nord, Publication 1, 331p.

CHOROWICZ, J. & GEYSSANT, J. (1976): La paléofaille transformante Split–Karlovac–Vienne. Introduction à un modèle d'évolution des chaînes alpines de l'Europe moyenne.– Rev. de Géog. Phys. et de Géol. Dyn. XVI, 1, 127–141.

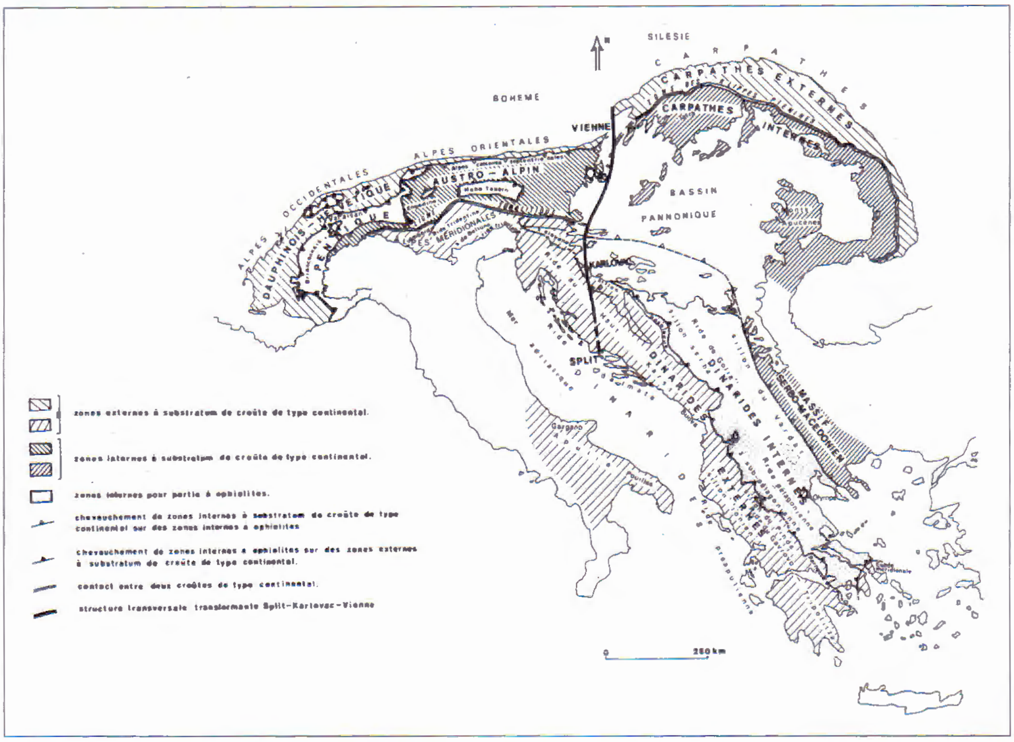

Fig. 2 Structural scheme on both sides of the Split–Karlovac–Wien paleotransform.

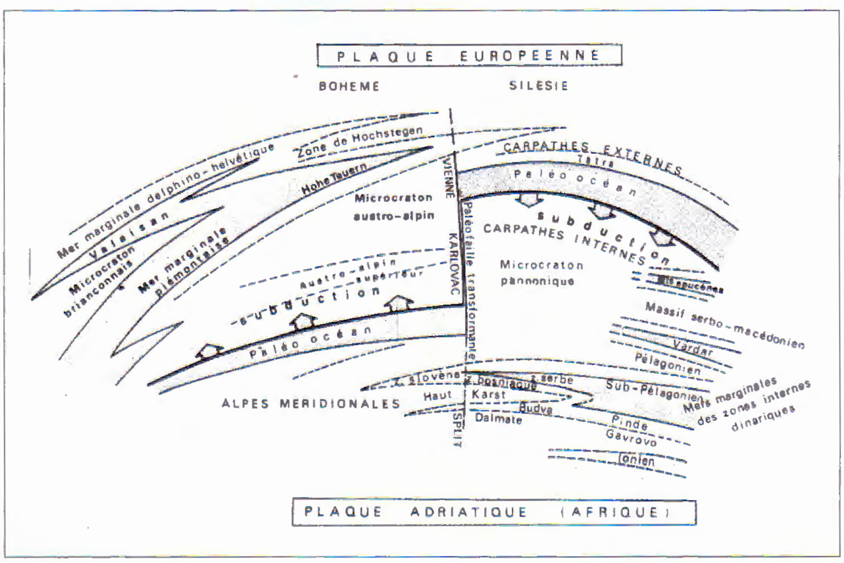

Fig. 3 Tentative sketch of the paleogeography during the Triassic–Jurassic transition time of the main isopic zones at Alps–Dinarides and Alps–Carpathian connections.

Mesozoic Plate Tectonic Reconstruction of the Carpathian Region

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Key Words: Plate-tectonics, Carpathians, Oroclinal bending, Tectonic transports, Palaeomagnetic data.

Palaeomagnetic, palaeobiogeographic and structural comparisons of different parts of the Alpine–Carpathian region suggest that four terranes comprise this area: the Alcapa, Tisza, Dacia and Adria terranes. These terranes are composed of different Mesozoic continental and oceanic fragments that were each assembled during a complex Late Jurassic–Cretaceous–Palaeogene history. Palaeomagnetic and tectonic data suggest that the Carpathians are built up by two major oroclinal bends. The Alcapa bend has the Meliata oceanic unit, correlated with the Dinaric Vardar ophiolite, in its core. It is composed of the Western Carpathians, Eastern Alps and Southern Alcapa units (Transdanubian Range, Bükk). This terrane finds its continuation in the High Karst margin of the Dinarides. Further elements of the Alcapa terrane are thought to be derived from collided microcontinents: Czorsztyn in the N and a carbonate unit (Tisza?) in the SE. The Tisza–Dacia bend has the Vardar oceanic unit in its core. It is composed of the Bihor and Getic microcontinents. This terrane finds its continuation in the Serbo-Macedonian Massif of the Balkans.

The Bihor–Getic microcontinent originally laid east of the Western Carpathians and filled the present Carpathian embayment in the Late Palaeozoic–Early Mesozoic. The Vardar ocean occupied an intermediate position between the Western Carpathian–Austroalpine–Transdanubian–High Karst margin and the Bihor–Getic–Serbo-Macedonian microcontinent. The Vardar and Pindos oceans were opened in the heart of the Mediterranean–Adriatic microcontinent in the Late Permian–Middle Triassic. Vardar subducted by the end of Jurassic, causing the Bihor–Getic–Serbo-Macedonian microcontinent to collide with the internal Dinaric–Western Carpathian margin.

An external Penninic–Váhic ocean tract began opening in the Early Jurassic, separating the Austroalpine–Western Carpathian microcontinent (and its fauna) from the European shelf. Further east, the Severin–Ceahlau–Magura also began opening in the Early Jurassic, but final separation of the Bihor–Getic ribbon (and its fauna) from the European shelf did not take place until the late Middle Jurassic.

The Alcapa and the Tisza–Dacia were bending during the Albian–Maastrichtian. The two oroclinal bends were finally opposed and pushed into the gates of the Carpathian embayment during the Palaeogene and Neogene. At that time the main N–S shortening in distant Alpine and Hellenic sectors was linked by a broader right-lateral shear zone along the former Vardar suture.

Late Jurassic–Early Cretaceous Alpine Deformation Events in the Light of Redeposited Sediments

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Key Words: Compressional tectonics, Redeposited sediments, Kimmerian nappes.

Sedimentologic and mapping work in the Salzkammergut, Austria (GAWLICK et al., 1999; MANDL, 2000; SCHWEIGL & NEUBAUER, 1997; FRISCH & GAWLICK, 2003) evidenced a Late Jurassic–Early Cretaceous compressional deformation event affecting the southern Upper Austroalpine realm. There a Triassic–Jurassic passive margin was sheared into a north-vergent (present directions) nappe system inducing large-scale slides, slumps and various sediment gravity flows. Since Alpine units in Hungary were in close proximity of the aforementioned units, any sign of these early deformations were aimed to be investigated. Study areas range from Bükk Mts (N Hungary) to Gerecse and Bakony Mts. (Transdanubian Range).

In Bükk Mts. there is a widespread, but thin olistostrome of micritic and radiolaritic matrix, incorporating different kinds of neritic and pelagic limestone clasts. The age of this formation is pre-Oxfordian and Oxfordian. Major olistoliths of hectometric size are mainly of Triassic Dachstein reef origin. This formation suffered subsequent latest Jurassic–earliest Cretaceous ductile deformation. It can be held as the equivalent of the earliest Salzkammergut redeposited sedimentary material.

In Gerecse Mts. Late Jurassic intra-basinal gravitational redeposition is common in several formations. Thin olistostromes of Kimmeridgian age contain reworked pelagic limestones and in some places big Dachstein limestone blocks. Sliding and/or slumping could have been initiated on still unconsolidated siliceous muds, resulting in erosion and short distance variation in thickness of Oxfordian radiolarite. Tithonian pelagic limestone hosts different extraclasts, including big blocks of Liassic limestones. In Berriasian a few meter thick blanket of deepwater redeposited conglomerate is widespread. The clast-supported, often imbricated conglomerate is mostly composed of Dachstein limestone clasts, but also contains rounded, weathered basalts and radiolarites. Changes in thickness, facies and observations on transport directions all suggest a source area from the present N–NE. The same transport directions were measured in the overlying slope deposits (FOGARASI, 1995; SZTANÓ, 1990). These latter are unanimously held as the equivalents of the Rossfeld formation of Salzkammergut.

In Bakony Mts. there are very weak indications of Oxfordian redeposition. In Tithonian, however, at a few localities, major olistoliths of Dachstein and shallow water Liassic limestones occur together with other pelagic limestone clasts in micritic matrix. The big boulders must have a nearby origin, possibly from the NE. Barremian is mostly represented by marls, which are thick in local depressions, but are entirely missing from regional highs or interfinger with crinoid limestones towards these highs. Apto–(lower) Albian is represented by crinoid limestones of two different facies. On the regional highs they are of shallow water origin, with a large-scale cross-bedding suggesting current pathways from the north. In deep basin segments between the regional highs breccia beds and turbidites comprised of redeposited crinoid sands were accumulated. Based on surface and subsurface data, folds of NW–SE axis could have existed prior to deposition of the Apto–Albian crinoid limestone. The different basement, the often abrupt changes in facies and thickness of the crinoid limestone are interpreted as a syn-tectonic feature: growing (uplifting), partly eroded anticlinal hinges host shallow water sedimentation, while the growing (subsiding) synclinal areas host deeper marine, better preserved sections and eventually deep sea fan breccia bodies. A major and sharp erosional unconformity of the Late Albian age tops the crinoid limestone. This part of the succession is better compared to the Southern Alps.

Structural, facies and paleomagnetic data and considerations constrain our Late Jurassic–Early Cretaceous reconstruction. Bükk, Gerecse and Bakony Mts. were all members of the Dinaric shelf of the Vardar–Meliata ocean. Bükk was in a more marginal, Bakony was in a more landward position. As the structural evolution of the Dinarides suggests, a large sheet of ophiolite nappe derived from the Vardar ocean obducted the Dinaric margin by the Late Jurassic. This event created a foredeep and imbrication, nappes in the overridden margin. Debris flows of Kallovian–Oxfordian age in the Bükk Mts. are interpreted as the first indicators of this compressive/transpressive nappe formation. Most of the clasts are derived from even more marginal parts, i.e. the equivalents of the Hallstatt zone of Salzkammergut. This early foredeep formation was soon overridden and deformed by the advancing ophiolite nappe. This position is somewhat analogous to the Austrian Lammer basin.

Synchronous deposits of the Gerecse Mts. (more landward in the reconstruction) show the first intra-basinal gravity driven redeposition in the Oxfordian. The upwards-increasing portion of older clasts (i.e. Triassic) in the Gerecse Late Jurassic/Early Cretaceous suggests a gradual emersion of nappes more to the NE, i.e. a more and more pronounced uplift due to thrusting and ramp folding. One member of this nappe system was made up of Dachstein limestone, i.e. local material (e.g. Buda Mts.), but the other was formed by an ophiolitic nappe (possibly that preserved in Bükk Mts.). An eventual third, crystalline nappe may be indicated by the heavy mineral spectrum of the Gerecse sediments (ÁRGYELÁN, 1996; CSÁSZÁR & ÁRGYELÁN, 1994). The position of this unit is somewhat analogous to the Tauglboden basin in Salzkammergut.

In the Bakony Mts. the Tithonian gravity flow deposits are interpreted as the distal indication of the foredeep propagation. A local thrust fault may be responsible for the large clasts and olistoliths in the deep marine setting. These local structural features seem to be reactivated in the Barremo–Aptian–Lower Albian, when syn-depositional compression and ramp-folding above SW vergent thrust faults is suggested. The resulting basin and high configuration can explain the facies changes in the Barremo–Aptian.

The three discussed areas all suggest that there is a SW-wards propagating compressional activity in the Late Jurassic–Early Cretaceous. This model is compatible with an active margin NNE from Bükk Mts. (present coordinates). The proposed nappe propagation is also compatible with the model set in Salzkammergut, but it expands its time limits until the Late Albian. It is proposed that the major Late Albian unconformity is due to a change in shortening directions.

Selected references

ÁRGYELÁN, G.B. (1996): Geochemical investigations of detrital chrome spinels as a tool to detect an ophiolitic source area (Gerecse mountains, Hungary).– Acta Geologica Hungarica, 39, 341–368.

CSÁSZÁR, G. & ÁRGYELÁN, G.B. (1994): Stratigraphic and micromineralogic investigations on Cretaceous Formations of the Gerecse Mountains, Hungary and their paleogeographic implications.– Cretaceous Research, 15, 417–434.

FRISCH, W. & GAWLICK, H.-J. (2003). The nappe structure of the central Northern Calcareous Alps and its disintegration during Miocene tectonic extrusion.– Int. J. Earth Sci., 92, 712–727.

GAWLICK, H.-J., FRISCH, W., VECSEI, A., STEIGER, T. & BÖHM, F. (1999): The change from rifting to thrusting in the northern Calcareous Alps as recorded in Jurassic sediments.– Geol Rundschau 87, 644–657.

MANDL, G.W. (2000): The Alpine sector of the Tethyan self – Examples of Triassic to Jurassic sedimentation and deformation from the Northern Calcareous Alps.– In: NEUBAUER, F. & HÖCK, V. (eds.): Aspects of Geology in Austria. Mitt. Österr. Geol. Ges., 92, 61–77.

SZTANÓ, O. (1990): Submarine fan-channel conglomerate of Lower Cretaceous, Gerecse Mts., Hungary.– N. Jb. Geol. Paläont. Mh., 7, 431–446.

Mafic Alkaline Metasomatism in East Serbian Mantle Xenoliths: Evidence of Paleogene Igneous Processes in the Lithosphere

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Key Words: Mantle xenoliths, Lithosphere, Metasomatism, Alkaline rocks, Carpatho–Balkanides.

Paleogene alkaline mafic magmatism occurred along the westernmost line of the East Serbian Carpatho–Balkanides. It produced fairly primitive basanites and respectively more evolved tephrites and tephriphonolites. These rocks show OIB-like, asthenospheric characteristics, similar to volcanic rocks of widespread Cenozoic European alkaline provinces (e.g. WEDEPOHL & BAUMANN, 1999). Study of xenoliths and xenocrysts entrained in these basalts provides important information about characteristics of East Serbian lithosphere (ESL). Low modal contents of clinopyroxene (cpx) and anomalously low-Al in orthopyroxene (opx) in the prevailing Type I peridotite xenoliths imply that the East Serbian lithosphere is more depleted than the lithosphere of adjacent regions. In this study we present evidence of lithospheric igneous processes that most likely occurred immediately before the entrapment of the xenoliths. These processes are related to a mafic alkaline metasomatism of the ESL.

Minerals and mineral associations, which resulted from modification of the ESL by alkaline metasomatism are usually regarded as Type II xenoliths/megacrysts (FREY & PRINZ, 1978). They are roughly divided into (a) clinopyroxene (±olivine) and olivine megacrysts, and (b) various reaction assemblages comprising cpx-rich lherzolite and spinel(sp)-rich olivine (ol) websterite xenoliths as well as numerous veins and pockets found in all types of xenoliths.

Cpx megacrysts have Mg#[MgO/(MgO+FeO)mol] <0.70, Al_2O_3>7 wt% and TiO_2 1–1.5 wt%. They show high Al^{VI}/Al^{IV} ranging 0.4–0.7, similar to cpx megacrysts found in alkali basalts of the Pannonian Basin (DOBOSI et al., 2003). Ol appears either accompanying cpx megacrysts or in form of its own megacrysts. Deformed and slightly recrystallized ol megacrysts may be mistaken for dunite xenoliths. In general, this olivine has distinctively lower Mg#s (~0.86) and slightly higher CaO (~0.2 wt%) than the olivine from Type I mantle xenoliths. The calculated primitive mantle–normalized trace element pattern for liquids in equilibrium with cpx megacrysts is similar but less enriched in Zr, Nb and LREE than the host basanites.

Cpx-lherzolite and sp-rich olivine websterite xenoliths are modally different but contain silicates of similar composition. They have Al-, Fe- and Ti-rich sp and cpx with low Mg# (0.86–0.89), and high Al_2O_3 (5–7 wt%) and TiO_2 (~0.8 wt%). Two-pyroxene geothermometres revealed uniform values of around 1100°C and are 100–150°C higher than temperature estimates based on mineral chemistry of East Serbian Type I xenoliths.

Numerous metasomatic assemblages are found in form of mm-sized irregular pocket-like patches and veins in all type of xenoliths. They are composed of cpx (both as euhedral crystals and irregular selvages around opx), severely altered glass or feldspar, sp (TiO_2 = 0.2–5 wt%), and more rare ol, apatite, ilmenite and carbonate. Very scarse relicts of phlogopite were also observed. Pocket cpx has Mg# 0.89–0.92, Al_2O_3=2–9 wt% and TiO_2=0.2–1.5 wt%. The textural relationships suggest the reaction between mantle opx and Cr–Al–sp and a CO_2-rich and SiO_2-poor melt and formation of cpx, feldspar/glass, Ti-rich sp and other minor minerals. In addition to patchy assemblages, where effects of incomplete reactions can be observed, there are also simplectitic associations of cpx, ol and sp. Silicates in these simplectites have similar composition to those appearing in patchy pockets and veins and that implies a similar origin.

The composition of cpx from the above described lithologies shows a trend targeted to the composition of the host cpx phenocrysts. Cpx megacrysts are nearest in composition to the host clinopyroxene and suggest similar origin, most likely by direct crystallization from magmatic melts. Cpx from cpx-rich lherzolites and sp-rich olivine websterites has slightly higher Mg# and lower Al_2O_3 and TiO_2 contents indicating that it is formed in reaction between metasomatic agents and pre-existing upper mantle wall-rocks. Liquids calculated to have been in equilibrium with these cpx's have very similar REE-pattern to the host rocks and that implies the reaction between percolating basanitic magma and wall-rock mantle peridotite. On the other hand, cpx and sp of pocket and vein assemblages display non-uniform compositions and calculated liquids in equilibrium with this cpx are more LREE-enriched than the host basanites.

The study of modifications of the ESL by mafic alkaline melts provides a better insight into petrogenesis of East

Serbian Paleogene mafic alkaline volcanic rocks. The first geochemical modelling based on REEs contents and ratios shows that the most primitive rocks have generally similar REE-pattern to primary magmas calculated as 5–10% melting of a MORB source enriched by 8% of melts derived from 0.3% melting of the same MORB source. However, even in this two-step melting model the calculated melts are still less LREE-enriched. A better fit of the REE-pattern is obtained when these two-step MORB partial melts are further mixed (up to 20%) with an end-member roughly corresponding in composition to metasomatic patches, i.e. to the liquid supposed to have been in equilibrium with metasomatic cpx. Although the model can serve only as the first approximation it indicates that the petrogenesis of East Serbian mafic alkaline rocks is related to complex enrichments of the lithospheric bottom and that the ultimate source of their primary melts was most likely within the thermal boundary layer. It can be concluded that no plume activation is required for the origin of this volcanism. It was entirely controlled by (i) a passive disruption of the whole lithospheric segment, (ii) infiltration of the lower lithosphere by very small partial melts of an asthenospheric mantle and formation of various metasomatic assemblages, (iii) melting of the lithosphere–asthenosphere boundary, and (iv) contamination/source mixing of these melts with such enriched lithospheric domains.

References

DOBOSI, G., DOWNES, H., EMBEY-ISZTIN, A. & JENNER, G. (2003): Origin of megacrysts and pyroxenite xenoliths from the Pliocene alkali basalts of the Pannonian Basin (Hungary).– Neues Jahrb. Mineral. Abh., 178, 217–237.

FREY, F.A. & PRINZ, M. (1978): Ultramafic inclusions form San Carlos, Arizona: petrologic and geochemical data bearing on their petrogenesis.– Earth Planet. Sci. Lett., 38, 129–176.

WEDEPOHL, K.H. & BAUMANN, A. (1999): Central European Cenozoic plume volcanism with OIB characteristics and indications of a lower mantle.– Contrib. Mineral. Petrol., 136, 225–239.

Plagioclase-Arenites from the Northern Apennines and Southern Alps: Record of a Paleogene Island Arc Related to Alpine Subduction

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Key Words: Alpine–Apenninic orogen, Eocene, Oligocene, Island arc volcanism, Plagioclase-arenites.

Peculiar plagioclase-arenites are exposed over a wide area in Northern Italy, extending from the Northern Apennines (Ranzano Basin–Montacuto, Moncasacco; Fig. 1) to the Southern Alps (central Brianza–Cibrone and Giudicarie belt–Molveno). They have drawn the attention of many researchers and have been described in several regional reports, but comparatively few papers have afforded a thorough interpretation of their palaeotectonic and palaeogeographic significance (among these RUFFINI, 1995; CIBIN et al., 1998; DI GIULIO et al., 2001).

The plagioclase-arenites occur as beds of variable thickness, from a few cm to over 1 m, interlayered to marly hemipelagic successions (Montepiano Marls in the Northern Apennines, "Gallare Marls" in central Brianza, Nago Lmst. in the Giudicarie belt) of Middle Eocene (Lutetian) to Early Oligocene age, or to turbidite successions of Early Oligocene age in the Northern Apennines (Ranzano Sandstones). They consist of prevailing fresh and euhedral plagioclase (24–54% of rock volume), commonly twinned and/or zoned; volcanic quartz (0–5%) and volcanic rock fragments (1–12%) are by far subordinate, while accessory ferromagnesian minerals (amphibole, biotite and opaques) occur in strongly variable abundance (2–30%). Other heavy minerals are restricted to zircon and apatite, but their abundance is negligible. Carbonate intrabasinal grains (mostly reworked tests of planktonic foraminifers, but also micrite intraclasts) are always present in variable amount (1–28%).

Such arenites are interpreted as reworked crystal tuffs rather than volcaniclastic sandstones as they consist of mostly neovolcanic sand-sized particles sensu ZUFFA (1987); zircon typology also reflects a single magmatic source (Fig. 2). Plagioclase composition (An_{55-85} at Cibrone, An_{50-70} at Montacuto; pervasively albitized al Molveno, but with labradorite preserved), mineralogy of the femic minerals, and interpretation of amphibole geochemistry suggest a basalt–andesite source rock.

Although not physically correlatable, the considered plagioclase-arenites display striking similarities as to composition, texture and facies in all their outcrop districts. The substantial absence of detritus from an ensialic crust induces us to interpreting the arenites as the product of island arc volcanism: actually, their oldest ages match well the radiometric dates for the metamorphic peak in blueschist–eclogite facies related to the climax of Alpine subduction of the Pennidic lithosphere underneath Adria, followed by continuing, even if still scarce, volcanic activity during the collisional stage associated to slab break-off. This frame led us to interpret the detected island arc volcanism as the result of poor magma production that began only during the final stages of alpine subduction and enhanced magma rise during collision and related slab detachment.

Preservation of the plagioclase-arenites is poor and commonly restricted to the cores of synclines; preservation of their feeder volcanic areas is even poorer, the only known remnant restricted to the Late Eocene Mortara volcano, presently buried underneath the Po Plain foredeep sediments. Early Oligocene (Rupelian) volcanoclastic sandstones (Val d'Aveto and Petrignacola Sandstone) in the Subligurian domain of the Northern Apennines are the surviving trace of calcalkaline volcanics related to a continental margin. Poor evidence for a Palaeogene subduction-related magmatism might have led to a widespread underestimate for the importance of subduction processes in the building of the Alpine Orogen.

References

CIBIN, U., TATEO, F., CATANZARITI, R., MARTELLI, L. & RIO, D. (1998): Composizione, origine ed etŕ del vulcanismo andesitico oligocenico inferiore dell'Appennino Settentrionale: le intercalazioni vulcano-derivate nella Formazione di Ranzano.– Boll. Soc. Geol. It., 117, 569–591, Roma.

DI GIULIO, A., CARRAPA, B., FANTONI, R., GORLA, L. & VALDISTURLO, A. (2001): Middle Eocene–Early Miocene sedimentary evolution of the Western Lombardy South Alpine foredeep (Italy).– Int. J. Earth Sci., 90, 534–548, Kiel.

RUFFINI, R., COSCA, M.A., D'ATRI, A., HUNZIKER, J.C. & POLINO, R. (1995): The volcanic supply of the Taveyanne turbidites (Savie, France): a ridde for the Tertiary Alpine volcanism.– In: POLINO, R. & SACCHI, R. (eds.): Rapporti Alpi–Appennino. Accademia della Scienze Scritti e Documenti, 15, 69–86, Roma.

ZUFFA, G.G. (1987): Unravelling hinterland and offshore paleogeography from deep water arenites.– In: LEGGET, J.K. & ZUFFA, G.G. (eds.): Marine clastic sedimentology, 39–61, London.

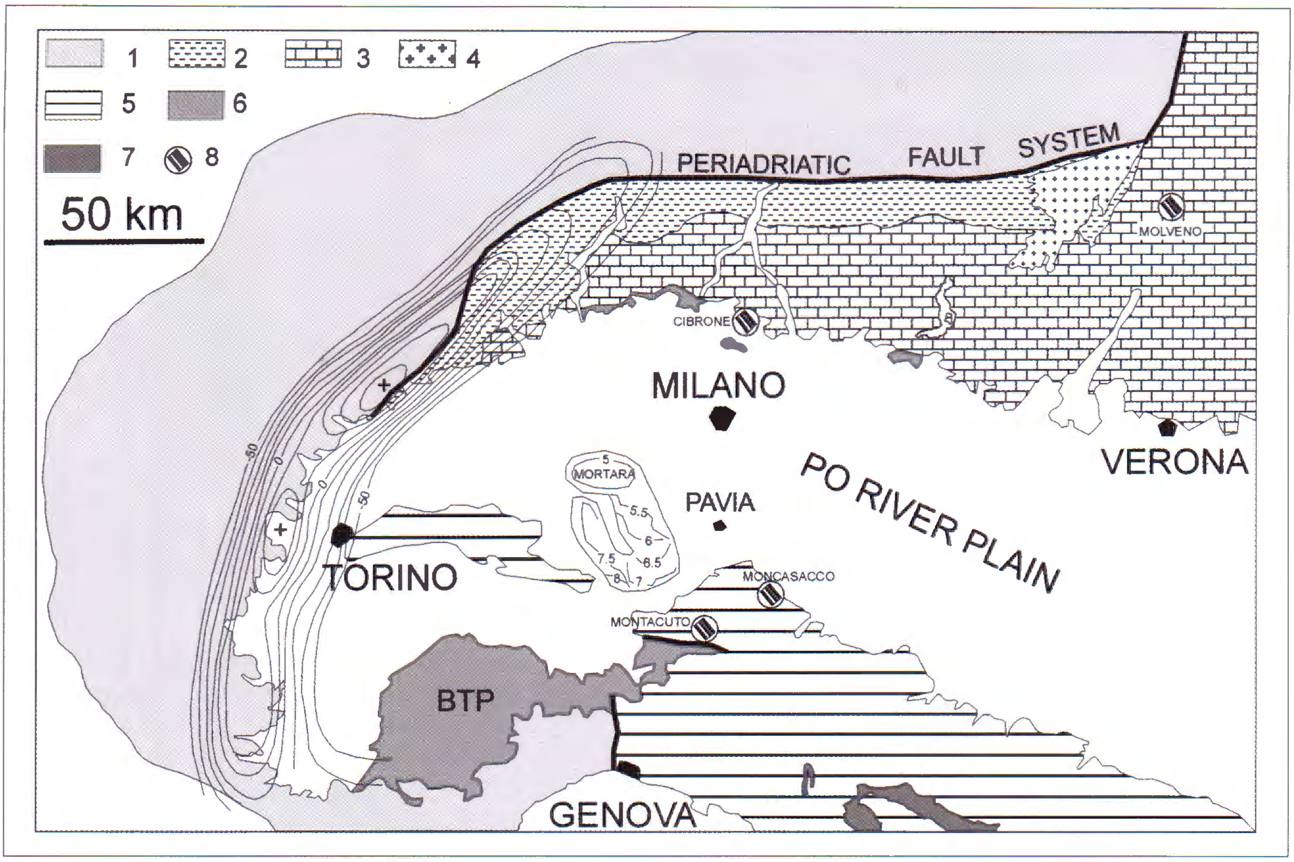

Fig. 1 Tectonic sketch map of the study area; gravity Bouguer anomaly (contour interval 10 mGal) in the Western Alps, and isodepth contour lines (in km b.s.l.) of the volcanic body drilled at Mortara, are also reported. 1 = Alps (Penninic–Austroalpine complexes); 2, 3 = Southern Alps (2 = crystalline basement, 3 = cover units); 4 = Adamello Batholith; 5 = Northern Apennines Ligurian units and Epiligurian sediments; 6 = Oligocene–Miocene molasses (BTP = Piedmont Tertiary Basin); 7 = Oligocene–Miocene Northern Apennines foredeep turbidites; 8 = location of studied outcrops.

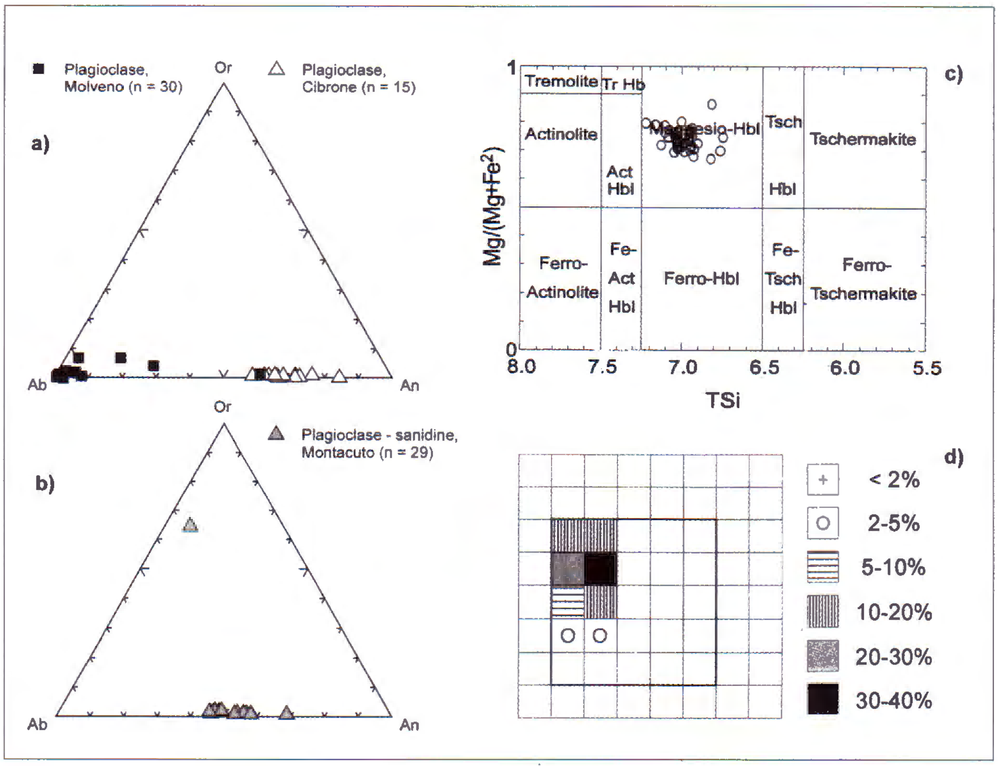

Fig. 2 Analytical data on the studied plagioclase-arenites. a), b) Plagioclase composition; c) amphibole geochemistry, Montacuto; d) zircon typology (Pupin diagram, Montacuto).

Norian Hallstatt Limestone from the Salzkammergut (Austria)

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Key Words: Hallstatt limestone, Fossil content, Norian, Northern Calcareous Alps.

During the late Triassic the Northern Calcareous Alps together with the Southern Alps and the Dinarides formed an up to 300 km wide and approximately 500 km long shelf area at the western Tethys (Fig. 1).

Beside the nearshore zone followed by the Dachstein formation the transition to the basin is represented by the Gosausee limestone, Pötšchen limestone and the condensed Hallstatt limestone (RASSER & SANDERS, 2003 cum. lit.).

Because of its content of fossils (macro as well as microfossils) and especially of its cephalopod record the Hallstatt limestone of the Salzkammergut got very famous. The macrofossil content may be stratabound or is concentrated as fissure deposits. The well-preserved fossil content of the fissure deposits is time dependent. The upper Norian Hallstatt limestone can be separated in grey coloured and red coloured limestones. According to encrustations (Mn, Fe_2O_3) the fossils of the red coloured type are better preserved. The degree of fossil deformation in fissure deposits is less then in stratiform ones.

Beside the cephalopods the hydrozoan genus Heterastridium is very common in the Sevatian part of the Hallstatt limestone. They are described as sphaeroidal organisms but the forms are very different and appear as discoidal to cylindrical till sphaeroidal even to polyaxial encrusting shapes. The internal structure of the Heterastriedians is very different. These differences are documented in the poster.

References

MANDL, G. W. (2000): The Alpine sector of the Tethyan shelf – Examples of Triassic to Jurassic sedimentation and deformation from the Northern Calcareous Alps.– In: NEUBAUER, F. & HÖCK, V. (eds.): Aspects of Geology in Austria. Mitt. Österr. Geol. Ges., 92, 61–77.

PILLER, W.E., DAXNER-HÖCK, G., DOMNING, D.P., FORKE, H.C., HARZHAUSER, M., HUBMANN, B., KOLLMAN, H.A., KOVAR-EDER, J., KRYSTIN, L., NAGEL, D., PERVESLER, P., RABEDER, G., ROETZEL, R., SANDERS, D. & SUMMESBERGER, H. (2000): Palaeontological Highlights of Austria.– In: NEUBAUER, F. & HÖCK, V. (eds.): Aspects of Geology in Austria. Mitt. Österr. Geol. Ges., 92, 195–233.

RASSER, W. E. & SANDERS, D. (2003): Field Guide to Mesozoic Carbonate Platforms and Reefs of the Northern Calcareous Alps.– Field Guide of the 9th International Symposium on Fossil Cnidaria and Porifera, Graz.

Fig. 1 Upper Triassic carbonate platform development in the Northern Calcareous Alps (from PILLER et al., 2000; after MANDL, 2000).

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Reconstructing Pre-Alpine Europe: The Significance of the Palaeozoic Granitic Rocks

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Key Words: Granitoid rocks, Palaeozoic, Variscides, Pre-Alpine European crust.

Variably deformed granitoid rocks constitute a large part of the remnant Palaeozoic crust preserved in the Alpine orogenic system. These granitoids carry important information regarding the geological history and structure of the pre-Alpine Europe (VON RAUMER, 1998; VON RAUMER et al., 2003). Based on formation ages and geochemical data, and by comparison with the situation in the (extra-Alpine) Variscides, distinct granite forming events and magmatic provinces can be defined, which in turn represent distinct geological/tectonic elements within the pre-Alpine crustal architecture:

I-type granitoids with ages of ca. 600–520 Ma represent remnants of the arc-type crust of the Avalonian–Cadomian Pacific-type orogenic belt (e.g. the older orthogneisses in the Silvretta crystalline complex; SCHALTEGGER et al., 1997).

Widespread granitic magmatism (dominantly S-type, but also I-type) characterises the Ordovician–Silurian time span and is generally interpreted in terms of (post-collisional, plume-induced or back-arc) crustal extension related to the Early Palaeozoic fragmentation of the Avalonian–Cadomian orogen at the northern Gondwana margin (e.g. granitoid rocks of the Ötztal crystalline basement; SCHINDLMAYR, 1999).

Within the Variscan orogenic cycle several distinct granite-forming events have occurred (FINGER et al., 1997):

Devonian to Lower Carboniferous I-type granitoids (mainly quartz–diorites, tonalites, granodiorites) with primitive chemical and isotope signatures formed along the early-Variscan active margins (e.g. the Cetic granitoid massif; FRASL & FINGER, 1988).

Chains of "Durbachite-plutons" (i.e. highly potassic, mostly coarse-grained melagranites with mafic enclaves) formed at ca. 330–340 Ma, probably as a result of slab-break-off processes, through mixing and mingling of crustal and enriched mantle magmas.

Lower Carboniferous S-type leucogranites and migmatites are indicative of fluid-present melting events along major Variscan thrust zones.

High-T melting of lower crust in post-collisional high-heat-flow zones generated large batholitic complexes consisting of S- and (mostly high-K_2O) I-type granitoids between ca. 320 and 350 Ma, e.g. in the western Carpathians (PETRIK et al., 1994; FINGER et al., 2003).

A distinct pulse of late-Carboniferous I-type plutonism (290–310 Ma) marks a zone of (back-arc?) extension north of the Palaeotethys subduction system (STAMPFLI et al., 2001) and is mainly seen in the Penninic unit and the Southern Alps (e.g. EICHHORN et al., 2000; CESARE et al., 2002).

Finally, I-, S- and A-type granitic plutons intruded along Permian rift zones (FINGER et al., 2003).

Present research has shown that single basement fragments in the Alpine chain are often well characterised by their particular granitoid inventory, and that on this basis efficient correlations can be obtained and pre-Alpine tectonic zones reconstructed (e.g. SCHERMAIER et al., 1997; VON RAUMER, 1998; VON RAUMER et al., 2003). With the increasing availability of modern geochronological methods, the information-potential of the granitic rocks can be better and better exploited.

The study of Palaeozoic granitic lithologies also plays a key role in the current research project "Correlation of Variscan crust in Austria and Croatia", which is a cooperation project between the mineralogical institutes of the universities of Zagreb and Salzburg. One task of this project is to compare the granite inventory of the Tisia block with that of the southern Bohemian Massif.

References

CESARE, B., RUBATTO, D., HERMANN, J. & BARZI, L. (2002): Evidence for Late Carboniferous subduction-type magmatism in mafic–ultramafic cumulates of the SW Tauern window (Eastern Alps).– Contrib. Mineral. Petrol., 42, 449–464.

EICHHORN, R., LOTH, G., HÖLL, R., FINGER, F., SCHERMAIER, A. & KENNEDY, A. (2000): Multistage Variscan magmatism in the central Tauern Window (Austria) unveiled by U/Pb SHRIMP zircon data.– Contrib. Mineral. Petrol., 139, 418–435.

FINGER, F., ROBERTS, M.P., HAUNSCHMID, B., SCHERMAIER, A. & STEYRER, H.P. (1997): Variscan granites of central Europe: their typology, potential sources and tectonothermal relations.– Mineralogy and Petrology, 61, 67–96.

FINGER, F., BROSKA, I., HAUNSCHMID, B., HRASKO, L., KOHÚT, M., KRENN, E., PETRÍK, I., RIEGLER, G. & UHER, P. (2003): Electron-microprobe dating of accessory monazites from Western Carpathian basement granitoids: Plutonic evidence for an important Permian rifting event subsequent to Variscan crustal anatexis.– Int. J. of Earth Sci. (Geol. Rundschau), 92, 86–98.

FRASL, G. & FINGER, F. (1988): The Cetic Massif below the Eastern Alps – characterized by its granitoids.– SMPM 68, 433–439.

PETRÍK, I., BROSKA, I. & UHER, P. (1994): Evolution of the Western Carpathian granite magmatism: age, source rocks, geotectonic setting and relation to the Variscan structure.– Geol. Carpath., 45, 365–371.

SCHALTEGGER, U., NÄGLER, T.F., CORFU, F., MAGGETTI, M., GALETTI, G. & STOSCH, H.G. (1997): A Cambrian island arc in the Silvretta nappe: constraints from geochemistry and geochronology.– SMPM, 77, 337–350.

SCHERMAIER, A., HAUNSCHMID, B. & FINGER, F. (1997): Distribution of Variscan I- and S-type granites in the Eastern Alps: a possible clue to unravel pre-Alpine basement structures.– Tectonophysics, 272, 315–333.

SCHINDLMAYR, A. (1999): Granitoids and Plutonic Evolution of the Ötztal–Stubai Massif – A Key for Understanding the Early Palaeozoic History of the Austroalpine Crystalline Basement in the Western Eastern Alps.– PhD thesis, University of Salzburg, 288 p.

STAMPFLI, G.M., VON RAUMER, J.F., BOREL, G.D. & BUSSY, F. (2001): Variscan and pre-Variscan evolution.– In: STAMPFLI G.M. (ed.): Geology of the Western Swiss Alps – a guide book. Mémoires de Géologie (Lausanne), 36, 28–41.

VON RAUMER, J.F. (1998): The Palaeozoic evolution in the Alps: from Gondwana to Pangea.– Geol. Rundsch., 87/3, 407–435.

VON RAUMER, J.F., STAMPFLI, G.A. & BUSSY, F. (2003): Gondwana-derived microcontinents – the constituents of the Variscan and Alpine collisional orogens.– Tectonophysics, 365/1–4, 7–22.

Structural Evolution of the Pennine Alps in the Monte Rosa Area

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Key Words: Pennine nappes, Monte Rosa nappe, Piemont–Ligurian ocean, Valais ocean, Shear zones, Continent collision.

The Pennine Alps in the Monte Rosa area represent the deep level of a collisional orogen where rock units derived from palaeogeographically far distant continental and oceanic sources were subducted to eclogite-facies depth, exhumed, and complexly deformed by several phases of folding and mylonitic shearing (Fig. 1). The different nappe units represent the following palaeogeographic domains, from originally NW to SE:

- *Monte Rosa nappe*: Distal continental margin of the European plate;
- *Antrona opiolites, Furgg zone ophiolites, Balma unit*: Valais ocean;
- *St. Bernard nappe system, Stolemberg unit*: Iberia–Briançonnais continent;
- *Zermatt–Saas ophiolite nappe*: NW basin of Piemont–Ligurian ocean;
- *Dent–Blanche, Sesia, and Cimes–Blanches nappe*: Cervinia continental fragment;
- *Tsaté nappe, Canavese ophiolite slivers (Levone)*: SE Piemont–Ligurian ocean basin;
- *Southern Alps (Ivrea zone)*: Adria continental margin.

Austroalpine units, characterized by Cretaceous deformation and metamorphism, do not occur in this area; the front of the Cretaceous Austroalpine orogen did probably not advance so far west. The oldest Alpine metamorphism determined in the area affected the Sesia nappe at Cretaceous–Tertiary boundary time (65 Ma), when Cervinia was subducted under Adria (RUBATTO et al., 1998). Early thrusting was directed towards the north, in a kinematic framework of southward subduction, but the nappe edifice has later been strongly modified by ductile out-of-sequence thrusting. In consequence, the same unit may occur at two different levels in the nappe stack, as is the case for Cervinia-derived nappes which occur both below the Tsaté nappe (Cimes–Blanches nappe, Etirol–Levaz basement sliver) and above (Sesia nappe, Dent–Blanche nappe). Three such ductile out-of-sequence thrusts occur which emplaced:

(1) the Monte–Rosa nappe on the originally higher Antrona ophiolites,

(2) the front of the Zermatt–Saas nappe on the originally higher Cimes–Blanches nappe,

(3) the Sesia/Dent–Blanche nappe on the originally higher Tsaté nappe.

In the southern part of the Monte Rosa nappe, the deformation phase that produced the out-of-sequence thrusting is the regional D1, a penetrative mylonitization with a top-north to –northwest shear sense, formed under greenschist-facies conditions (PLEUGER et al, in press). Older deformation structures are only preserved in eclogite boudins. This is followed by D2, recumbent folding and shearing with a top-southwest shear sense, probably related to

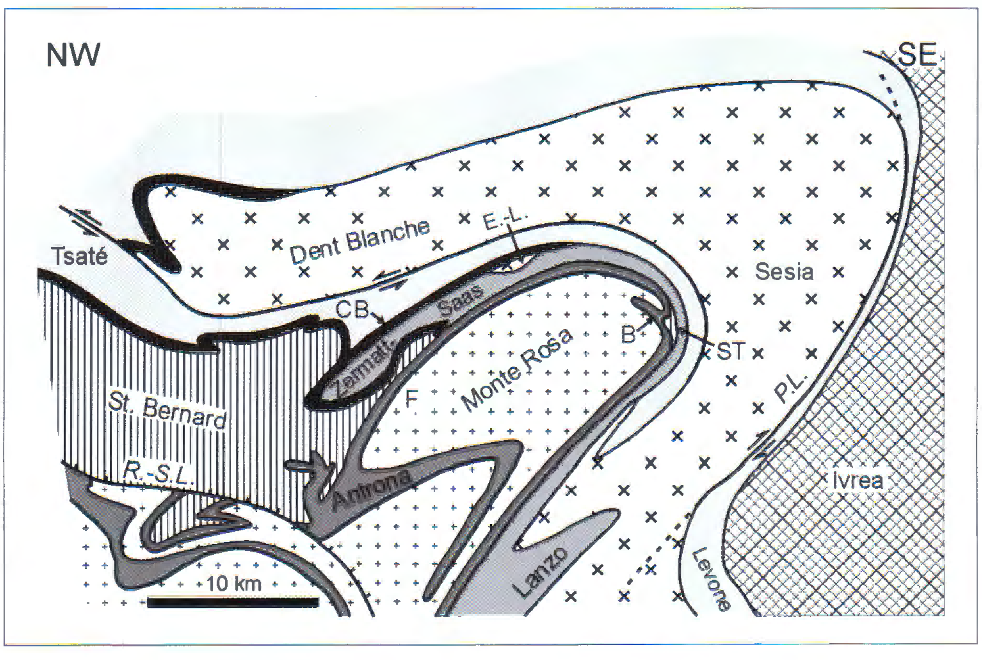

Fig. 1 Schematic cross section of the Pennine Alps in the Monte Rosa area. Eroded parts have been reconstructed and the thickness of some very thin units has been exaggerated. B – Balma unit; CB – Cimes–Blanches nappe; E.-L. – Etirol–Levaz basement sliver; F – Furgg zone; P.L. – Periadriatic line; R.-S.L. – Rhone–Simplon line; ST – Stolemberg unit.

orogen-parallel extension. D3 structures are backfolds and shear zones with a top-SE shear sense and extensional geometry (Gressoney shear zone, REDDY et al., 1999). D4 formed younger backfolds with NE–SW axes and steeply to moderately northwest-dipping axial planes. Radiometric data suggest that the entire sequence of D1 to D4 in the study area formed between 40 and 29 Ma.

We deduce from this study that deep levels of suture zones are not generally chaotic but, due to the ductile nature of the deformation, may be remarkably ordered, and therefore their geometry and kinematics can be clarified using the methods of structural geology, in combination with metamorphic petrology and geochronology. In the study area, ductile out-of-sequence thrusting considerably modified the structure of the nappe edifice.

References

PLEUGER, J., FROITZHEIM, N. & JANSEN, E. (in press): Folded continental and oceanic nappes on the southern side of Monte Rosa (Western Alps, Italy): anatomy of a double collision suture.– Tectonics.

REDDY, S.M., WHEELER, J. & CLIFF, R.A. (1999): The geometry and timing of orogenic extension: an example from the Western Italian Alps.– J. metamorphic Geol., 17, 573–589.

RUBATTO, D., GEBAUER, D. & COMPAGNONI, R. (1999): Dating of eclogite-facies zircons: the age of Alpine metamorphism in the Sesia–Lanzo Zone (Western Alps).– Earth and Planetary Science Letters, 167, 141–158.

The Simplon Fault Zone in the Western and Central Alps: The Mechanism of Neogene Faulting and Folding Revisited

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Key Words: Simplon fault zone, Western Alps, Tear fault.

The Neogene Simplon fault zone is commonly either considered as a transfer zone for dextral strike-slip movements during oblique convergence or as a core-complex-type normal fault leading to orogen parallel extension in the Alps. There is, however, evidence that the Simplon fault zone lacks a (south) eastward continuation and thus can not be considered neither as a transfer zone nor as a major extensional detachment.

MANCKTELOW (1992) convincingly demonstrated that normal faulting was coeval to backfolding in the central and northern parts of the Simplon fault zone (see also MANCKTELOW & PAVLIS, 1994). South of the Simplon fault zone and along the proposed eastern continuation of the Simplon fault zone a recent structural analysis (KELLER et al., 2005) traced the fold axial planes of major backfolds and thereby corroborated earlier propositions (MILNES et al., 1981; MANCKTELOW, 1992), which regarded backfolding to be coeval with normal faulting also in this southern and southeastern area. The en-echelon arrangement of backfolds is located south of the termination of the Simplon fault zone, in an area where a topological change of Adriatic Moho occurs and also in area where the Periadriatic line is markedly bended (SCHMI & KISSLING, 2000). These geometrical relationships suggest a genetic link between deep- and shallow- structural features. We thus relate the en-echelon arrangement of backfolds south of the Simplon fault zone to oblique indentation of a bended and asymmetric Adriatic indenter, defined by the Ivrea zone. During oblique indentation of this bended indenter extension occurs due to divergent block rotation around an indentation point. A counterclockwise rotation of the hangingwall block of the Simplon fault zone is considered to transfer the displacement by normal faulting into dextral slip along the Rhone line. According to this scenario, the displacements along the Simplon fault zone would cease towards the south, i.e. towards the tip of the indenter. The expected clockwise rotation of the footwall block, i.e. the Lepontine dome, is hindered because this part of the Alps is strongly pinched between the rigid indenter (i.e. the southern Alps) and the external massifs. Numerous late stage folds directly evidence pinching, a feature essentially missing in the hangingwall.

As evidenced by the recent fission track data (KELLER et al., 2005) the antiformal mega-fold wedge in the south shares a common cooling history with the Simplon fault zone footwall (i.e. the Lepontine dome) in the north.

In summary we propose that Neogene exhumation of the Lepontine dome is on the one hand related to updoming during the formation of antiformal fold structures and thus controlled by erosion. On the other hand, however, the Neogene Simplon fault zone, functioning as a tear-fault which links the differentially shortened blocks, allows for rather fast exhumation by tectonic unroofing.

References

KELLER, L. M., HESS, M., FÜGENSCHUH, B. & SCHMID, S.M. (2005): Structural and metamorphic evolution of the Camughera–Moncucco, Antrona and Monte Rosa units southwest of the Simplon line, western Alps.– Eclogae Geologicae Helvetiae, in press.

MANCKTELOW, N.S. (1992): Neogene lateral extension during convergence in the Central Alps: Evidence from interrelated faulting and backfolding around the Simplonpass (Switzerland).– Tectonophysics, 215, 295–317.

MANCKTELOW, N. S. & PAVLIS, T.L. (1994): Fold-fault relationships in low-angle detachment systemes.– Tectonics, 13, 668–685.

MILNES, A. G., GRELLER, M. & MÜLLER, R. (1981): Sequence and style of major post-nappe structures, Simplon–Pennine Alps.– J. Struct. Geol., 3, 411–420.

SCHMID, S. M. & KISSLING, E. (2000): The arc of the western Alps in the light of geophysical data on deep crustal structure.– Tectonics, 19, 62–85.

The Miraka Section in the Central Albanides – Middle Triassic Radiolarites as a Sedimentary Cover of the Mirdita Ophiolites

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Key Words: Albania, Albanides, Mirdita ophiolite, Triassic, Radiolarite, Radiolarians, Miraka section, Vardar Ocean.

Introduction

As a part of the Dinaride–Hellenide segment of the Alpine orogenic system the Albanian ophiolites represent the remnants of Mesozoic oceanic crust. These ophiolites were assumed due to former studies as Jurassic in age (ROBERTSON & SHALLO, 2000; SHALLO & DILEK, 2003), forming a small oceanic basin (Mirdita–Pindos oceanic basin).

A number of recent studies (e.g., ROBERTSON & SHALLO, 2000; SHALLO & DILEK, 2003) discern two different ophiolitic belts, although both are thought to derive from a single oceanic basin, namely the narrow Pindos–Mirdita Ocean. The Western Ophiolite Belt with lherzolite basement is interpreted as normal oceanic lithosphere, whereas the Eastern Ophiolite Belt shows harzburgitic basement and is interpreted partly as supra-subduction lithosphere above an intra-oceanic subduction zone. Formation of oceanic crust is thought to have started in late Early Jurassic time (ca. 185 Ma), east-dipping subduction in the Middle Jurassic. First flysch deposits are reported from Tithonian time (however, these are Maiolica-type deep-water carbonates), and coarse-grained Early Cretaceous flysch is described by several authors. Thrusting is therefore thought by some authors to have started in Tithonian times.

Radiolarites of the Miraka section: MiddleTriassic

Our study of the overlying cherty sediments (radiolarites, cherts shales) on top of the ophiolites in central Albania west of Librazhd (Miraka section) show a Middle Triassic (Illyrian to Late Ladinian) age of these ophiolites in contrast to formerly studies. These ophiolites were mapped as Middle to Late Jurassic in age according to the geological map of Albania (XHOMO et al., 2002). The ophiolites with the overlying cherty sediments occur as a big resedimented slide of nappe size in a Middle Jurassic matrix, which consists of radiolarites and cherty limestones. In the Miraka section directly on top of the ophiolites occur black, laminated cherty shales dated by the following radiolarians suggesting an Illyrian age: *Eptingium japonicum* (NAKASEKO & NISHIMURA), *Parasepsagon praetetracanthus* KOZUR & MOSTLER, *Pseudoertlispongus* cf. *hermi* (LAHM), *Pseudostylosphaera* cf. *longispinosa* KOZUR & MOSTLER, *Triassospongosphaera multispinosa* (KOZUR & MOSTLER). The overlying reddish radiolarian-rich laminated wackestones suggest a Late Illyrian to Early Ladinian age by means of radiolarians, although marker species are missing in this poor assemblage: *Anisicyrtis* sp., *Annulotriassocampe campanilis* KOZUR & MOSTLER, *Archaeocenosphaera* sp., *Pararuesticyrtium* (?) cf. *mediofassanicum* KOZUR & MOSTLER, *Pararuesticyrtium* sp., *Pseudostylosphaera* cf. *longispinosa* KOZUR & MOSTLER, *Welirella weveri* DUMITRICA, KOZUR & MOSTLER. The overlying more massif reddish-green radiolarites, mostly radiolarian-rich wackestones, are dated as Late Ladinian (*Muelleritortis cochleata* Zone, *Spongoserrula fluegeli* Subzone) by: *Annulotriassocampe baldii* KOZUR, *Archaeocenosphaera* sp., *Carinaheliosoma* sp., *Gomberellus* cf. *hircicornus* DUMITRICA, KOZUR & MOSTLER, *Muelleritortis cochleata* (NAKASEKO & NISHIMURA), *Muelleritortis expansa* KOZUR & MOSTLER, *Pseudostylosphaera* sp. (internal casts), *Spongoserrula fluegeli* KOZUR & MOSTLER. This Middle Triassic sedimentary succession reaches a maximum thickness of nearby 12 m. Most sedimentary rocks are bedded black to reddish radiolarites and cherty slates with poor preserved radiolarians. Most radiolarians occur as massif quartz strongly recrystallized.

On top of this succession occur red radiolarites with a mixture of Triassic, Middle Jurassic and early Late Jurassic radiolarians indicating the emplacement of the Triassic ophiolites in Late Middle Jurassic or Oxfordian. This can be confirmed by the dating of the ophiolitic Mélange underlying the ophiolites northeast of the Miraka section.

Middle Jurassic radiolarites – Mélange dating

North of Librazhd in the Zgosht area occur ophiolite blocks and pelagic carbonates in a cherty matrix. Component analysis of the mass flows indicates Late Triassic Hallstatt limestones by microfacies analysis, dated as Julian to Sevatian by means of conodonts. The matrix can be dated by radiolarians as Late Bajocian to Early Bathonian: *Archaeodictyomitra* sp., *Eucyrtidiellum dentatum* BAUMGARTNER, *Eucyrtidiellum unumaense* (YAO), *Gongylothorax* ? aff. *favosus* DUMITRICA, *Hexasaturnalis nakasekoi* DUMITRICA & DUMITRICA, *H. suboblongus*

(YAO), *Protunuma gorda* HULL, *Protunuma ochiensis* MATSUOKA, *Striatojaponocapsa conexa* (MATSUOKA), *Striatojaponocapsa plicara* (YAO), *Tethysetta aff. dhimenaensis* (BAUMGARTNER), *Tricolocapsa ? fusiformis* YAO, *Theocapsomma medvenicensis* GORICAN, *Transhsuum maxwelli* (PESSAGNO), *Williriedellum buekkense* (KOZUR), *Williriedellum yaoi* (KOZUR).

Results and conclusions

By our results the emplacement of these Triassic ophiolites must have start in the Middle Jurassic, nearly contemporaneous with the emplacement of the Hallstatt limestones (Late Bajocian to Early Bathonian). We interpret the whole sequence as a radiolaritic mélange and as a synorogenic flysch sequence formed simultaneously with the nappe emplacement and ophiolite obduction. The emplacement of the slides and blocks was sealed by Oxfordian radiolarites and later by a Kimmeridgian to Tithonian carbonate platform as determined in the Kurbnesh area. Our results therefore also imply that the Triassic ophiolites were transported over large distances, which means form the Vardar zone.

The actual controversial discussion about the tectonic interpretation of the ophiolites shows that a great number of stratigraphic data from all sediments in contact with the ophiolites and a detailed analysis of the mélange complexes are needed. The Mirdita ophiolite including the ophiolitic Mélange is much more complex than previously expected.

References

ROBERTSON, A. & SHALLO, M. (2000): Mesozoic–Tertiary tectonic evolution of Albania in its regional Eastern Mediterranean context.– Tectonophysics, 316, 197–254.

SHALLO, M. & DILEK, Y. (2003): Development of the ideas on the origin of Albanian ophiolites.– Geol. Soc. Amer. Spec. Pap., 373, 351–363.

XHOMO, A., KODRA, A., DIMO, L.L., XHAFA, Z., NAZAJ, S.H., NAKUCI, V., YZEIRAJ, D., LULA, F., SADUSHI, P., SHALLO, M., VRANAJ, A. & MELO, V. (2002): Geological Map of Albania 1: 200 000 scale.

The Triassic "Hallstatt limestone" Components and Slides in the Jurassic Radiolaritic Flysch Kcira–Komani–Porav Basin in the Central Albanides: Conodont Dating and CAI-Determination – New Implications for the Age and Emplacement of the Mirdita Ophiolites

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Key Words: Albania, Albanides, Mirdita ophiolite, Triassic, Jurassic, Conodonts, Radiolaritic flysch, Kcira–Komani–Porav Basin, Vardar Ocean.

Introduction

As a part of the Dinaride–Hellenide segment of the Alpine orogenic system the Albanian ophiolites should represent the remnants of Mesozoic oceanic crust. These ophiolites were assumed due to former studies as Jurassic in age (ROBERTSON & SHALLO, 2000; SHALLO & DILEK, 2003), forming a small oceanic basin (Mirdita–Pindos oceanic basin).

In the western to northwestern part in the Mirdita ophiolite zone in central Albania and its tectonic boundary to the Cukali zone in northern Albania a highly differentiated Mélange complex with different pelagic limestones ("Hallstatt limestones") and ophiolitic blocks occur. Formerly the Kcira–Komani–Porav zone was interpreted as an autochthonous Triassic to Jurassic sedimentary sequence separating the western and eastern Mirdita ophiolitic belt as attributed by several authors. Our recent study clearly shows the flysch character of this zone. In a Middle Jurassic radiolaritic matrix, as dated in the Perlat–Kurbnesh Mélange by means of radiolarians (GAWLICK et al., this volume) different "Hallstatt limestone" blocks and slides occur together with ophiolitic material. This implies the same source area of the pelagic limestones and the ophiolitic blocks.

Dating of the Hallstatt limestones and CAI-determination

Area south of Kcira – South of Kcira we determined different pelagic limestone ("Hallstatt limestones") slides in a radiolaritic matrix: 1) Middle Triassic cherty limestones with *Paragondolella* sp.; CAI 5.5–6.0; 2) Late Carnian to early Norian bedded cherty limestones with *M.* cf. *pseudodiebeli*; CAI >5.0; 3) Early Norian red cherty Hallstatt limestones with *E.* cf. *triangularis*; CAI 1.0–1.5; and 4) Late Alaunian to Sevatian bedded limestones with allodapic layers, partly chertified. Conodonts: *Gondolla steinbergensis, Epigondolla bidentata, Misikella hernsteini*. CAI 1.0–1.5.

Kcira village – In the Kcira village area and to the west we determined different pelagic limestone ("Hallstatt limestones") slides in a radiolaritic matrix: 1) Nopsca–Section: Olenekian to early Anisian with *Neospathodus homeri* at the base, *Neospathodus homeri* and *Chiosella timorensis* in the middle part of the section and *Gladigondolella budurovi, Chiosella timorensis, Neospathodus gondoilolides* and *Neogondolella* n. sp. near the top of the section. All samples show CAI 1.0–1.5; 2) Grey cherty bedded limestone of late Pelsonian with *Gladigondolella tethydis*–ME, *Gondolella* cf. *bulgarica, Gondolella* cf. *excelsa*. CAI low; 3) Early Carnian grey, partly allodapic, limestones with *Gladigondolella tethydis*–ME, *Gondolella foliata, Gondolella tadpole* and *Gondolella polygnathiformis*. CAI 5.0; 4) Late Alaunian to Sevatian/Rhaetian bedded limestones with allodapic layers, partly chertified. Conodonts: *Gondolla steinbergensis, Epigondolla bidentata, Misikella hernsteini* and *Hindeodella paucidentata*. CAI 1.0–1.5; and 5) Norian cherty limestone with *Gondolella steinbergensis*. CAI 5.0.

Area west of Qerret i Vogel (Dushi) – In the area west of Qerret i Vogel a lot of different pelagic limestone slides are incorporated in a radiolaritic matrix: 1) Condensed red limestones – late Pelsonian to early Illyrian with *Gondolella bulgarica, Gladigondolella tehydis*–ME and *Gondolella* cf. *bifurcata*; and 2) massif white to bedded grey limestones – late Ladinian to late Carnian. Conodonts: *Gladigondolella tethydis*–ME, *Gondolella foliata, Gondolella polygathiformis* and *Metapolygnathus nodosus*. All with low CAI-values.

Porav area – In the Porav area a very complex flysch sequence complex occur. Beside ophiolitic blocks and volcano-sedimentary material different pelagic limestone types ("Hallstatt limestones") are incorporated in a radiolaritic matrix: 1) Olenekian red cherty limestone with *Chiosella* cf. *timorensis* and *Neospathodus homeri*. CAI 3.0(–4.0); 2) ?Ladinian to Carnian bedded limestones with allodapic layers. Conodonts: *Gladigondolella tethydis*–ME, *Gondolella polygnathiformis, Gondolella* cf. *carpathica*. CAI 3.0; and 3) Late Triassic grey cherty bedded limestones with *Epigondolella* cf. *multidentata, Gondolella* sp., *Epigondolella* sp., some slides show CAI-values of CAI 3.0, others of CAI 1.5–2.0.

The matrix in all described areas consists of red and black radiolarites with turbidites consist of ophiolitic material. Different types of blocks of the ophiolithic sequence are common.

Results and conclusions

By our results the emplacement of these pelagic limestone blocks ("Hallstatt limestones") together with the ophiolites in the Kcira–Komani–Porav Basin must have started in the Middle Jurassic (Late Bajocian to Early Bathonian). The pelagic limestones with exception of the Early Triassic succession may be the original sedimentary sequence of the Mirdita ophiolites as shown in the Miraka section (GAWLICK et al., this volume) and therefore Triassic in age, but originated from different source areas due to facies characteristics. We interpret the whole sequence (= Kcira–Komani–Porav Basin) as a carbonate–clastic ophiolitic radiolaritic flysch basin and as a synorogenic sequence formed simultaneously with the ophiolite nappe emplacement. Some pelagic limestones show a high diagenetic overprint. These slides (pelagic "Hallstatt limestones", Early, Middle and Late Triassic) with a high diagenetic overprint up to CAI 6.0 float in a cherty (radiolaritic) Middle Jurassic matrix with low diagenetic overprint. This leads to the conclusion that the thermal overprint of the Triassic carbonates predates the emplacement of the slides into the radiolarian cherts and is therefore transported. The metamorphism is older than Bathonian, which is in clear conflict with the suggested late Early Jurassic opening of the Mirdita Ocean (see above), but would fit to published Middle Jurassic ages on ophiolithic metamorphic soles (around 170 Ma). Therefore, our results also imply that the ophiolites were transported over large distances together with the "Hallstatt limestones", which means from the Vardar zone, implying partly a Triassic age.

References

GAWLICK, H.-J., DUMITRICA, P., MISSONI, S. & HOXHA, L. (2005): The Miraka section in the central Albanides – Middle Triassic radiolarites as a sedimentary cover of the Mirdita ophiolites.– This volume, 31–32.

GAWLICK, H.-J., SCHLAGINTWEIT, F., HOXHA, L., DUMITRICA, P., MISSONI, S. & FRISCH, W. (2005): Reinterpretation of the Perlat–Kurbnesh ophiolitic melange in the central Albanides (Albania) as radiolaritic flysch – a result of component analysis and matrix dating on the base of radiolarians, detection of Late Jurassic reef carbonates and the determination of thermal overprint of Triassic carbonates by Conodont Colour Alteration Index (CAI) data.– This volume, 37–38.

GAWLICK, H.-J., SCHLAGINTWEIT, F., HOXHA, L., MISSONI, S. & FRISCH, W. (2004): Allochthonous Late Jurassic reefal carbonates on top of Serpentinites in the Albanides (Albania, Kurbnesh area) – new data for the development of the ideas on the origin of Albanian ophiolites.– Ber. Inst. Erdwissenschaft. Karl-Franzens-Universität Graz, Band 9, 136–138, Graz.

ROBERTSON, A. & SHALLO, M. (2000): Mesozoic–Tertiary tectonic evolution of Albania in its regional Eastern Mediterranean context.– Tectonophysics, 316, 197–254.

SHALLO, M. & DILEK, Y. (2003): Development of the ideas on the origin of Albanian ophiolites.– Geol. Soc. Amer. Spec. Pap., 373, 351–363.

New Stratigraphic, Facies, Structural and CAI Data of the Periadriatic Lineament Area – Analysis of the Polyphase Mega-Imbricate Zone South of Maria Elend (Karawanken Mountains, Carinthia)

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Key Words: Austria, Karawanken Mts., Periadriatic Lineament, Facies variations, Stratigraphy, Structural and thermal history, Conodont Colour Alteration Index (CCAI).

New investigations of an approximately 60 km wide area of the Karawanken Mountains around the Periadriatic Lineament (PL) south of Maria Elend (Carinthia, S Austria) have shown that the geology of this region is much more complex than previously assumed. The fairly recent official geological map of the Austrian Geological Survey (BAUER, 1985) strongly simplifies the stratigraphic and the structural situation. According to this map, there is only one major E–W-striking strike-slip fault. This fault is supposed to be the PL separating the Northern Karawanken Mountains (Eastern Alps) and the Southern Karawanken Mountains (Southern Alps). The latter are suggested to make up most of the area of interest and to be deformed in a rather simple manner. Younger structural investigations (POLINSKI, 1991; NEMES, 1996) showed that the Karawanken Mountains are laterally far less continuous but strongly segmented along high-angle faults of limited displacement, numerous of which displacing the PL also. However, after more detailed investigations of the stratigraphic successions it has become clear that the geological situation is even more complicated and tectonic processes different from the ones proposed must be considered.

In the investigation area a large number of individual imbricates could be proven – these tectonic lamellae show distinct variations in facies and stratigraphy, structural inventory and thermal history. By means of biostratigraphic methods wide regions formerly mapped as Bellerophon Fm., Werfen Fm., Alpiner Muschelkalk and Carnian sediments, being part of one tectonic unit (BAUER, 1985), could have been shown to be made up of numerous individual tectonic units with rocks of a remarkably larger range in stratigraphic age from the Upper Devonian/Lower Carboniferous (Hochwipfel Formation) to Middle/Upper Jurassic (Ruhpolding Radiolarite Group). Many of the Triassic and Jurassic rocks are directly comparable with the succession of the Tirolic unit of the Northern Calcareous Alps: Gutenstein and Steinalm formations; Reifling formation; Wetterstein and Raming formations; Leckkogel formation; Waxeneck formation and Wandaukalk. Most interestingly, a newly discovered Middle Jurassic radiolaritic breccia shows strong affinity to the Callovian–Oxfordian Strubberg formation. The Upper Triassic to Jurassic pelagic sedimentary sequence of the "intraplatform basin" on either side of the Karawanken tunnel, established by KRYSTYN et al. (1994), shows strong similarity to the pelagic succession of the Zlambach facies zone of the Northern Calcareous Alps, components of which are exclusively found in the form of slide blocks in the Hallstatt Mélange: Baca dolomite = Pötschendolomite; Frauenkogel formation = Pedata and Zlambach formations; Hahnkogel formation = Dürrnberg formation. This lithological suite looks quite the same like the coeval sequence of the Slovenian trough.

The geological structure of the Karawanken south of Maria Elend is dominated by E–W to ESE–WNW-striking high-angle faults separating from each other more than a dozen single imbricates of variable size and individual sedimentary characteristics. Some of the imbricates stretch across the whole area of interest in E–W-direction and have a maximum thickness of about 1.5 km. Others, however, are much smaller and pinch out laterally over short distances. Partly, coeval stratigraphic successions of specific imbricates not only show strong differences in lithology and facies but also in the diagenetic and thermal overprint tested by measurements of the Conodont Colour Alteration Index (CAI) ranging from CAI 1.0 to CAI 6.0. For that reason and since individual imbricates are derived from different paleogeographic positions of the European Triassic passive continental margin, showing affinities to the Triassic(–Jurassic) of the Northern Calcareous Alps, the Southern Alps and the Slovenian Trough, respectively, far tectonic transportation of crustal fragments must be taken into account as the most important tectonic process shaping the region. Differences in the internal structure of the imbricates indicate individual deformation possibly in different tectonic settings in far distance from each other before amalgamation to the present-day slice puzzle.

A surprising feature is the intensity of thermal overprint of some of the imbricates derived from the alteration of conodonts. To the very North and Northeast in late Carnian near-reef sediments of the Southern Karawanken Mountains (e.g., Waxeneck Fm.) the Conodont Colour Alteration Index reaches values as high as CAI 5.5 to 6.0, corresponding to lower to upper greenschist facies conditions. This metamorphic overprint is yet another argument for a reconsideration of the PL, since rocks are supposed to be unmetamorphosed south of the Southern limit of (Cretaceous) Alpine Metamorphism (SAM of HOINKES et al., 1999), which is located north of the PL or partly corresponds to it, respectively. So, in addition to the stratigraphical and facies constraints also the CAI data neglect an affiliation of the whole area south of the PL to the South Alpine realm. Instead, these high values of CAI 5.5 to 6.0 are comparable to facies-equivalent, thermally overprinted rocks of the

Northern Calcareous Alps, namely the Ultra Tirolic unit or the only rarely occurring metamorphosed slide blocks within the Upper Tirolic Hallstatt Mélange Zone (FRISCH & GAWLICK, 2003) – this metamorphism is supposed to have taken place in the framework of the Middle/Late Jurassic orogenic event.

Facing the complex structure of the Karawanken Mountains south of Maria Elend the model of the PL as a single strike-slip fault is not maintainable – instead it must be regarded as a subvertical, polyphase imbricate zone some kilometres wide across its strike. Generally, accretion of crustal slices is supposed to have propagated northerly since there are NE–SW-striking sinistral high-angle faults displacing the southern imbricates but terminating at E–W-faults of the central area. In contrast, dextral NW–SE-faults crosscut the whole imbricate zone, partly with offsets more than 1 km. However, absolute ages of faulting are difficult to assess due to the lack of sediments of Late Jurassic to Lower Miocene age – only east of the investigated area some faults could be proven to be as young as Late Miocene (BAUER, 1985). However, due to the geological complexity and the enormously large lateral transportation, an origin just in the framework of Oligocene/Miocene indentation and lateral extrusion tectonics is excluded. In contrast, it is assumed that an imbricate zone was already created in the period from mid-Cretaceous time, during which the Drau Range and the Transdanubian Range are supposed to have been transported towards the east along a sinistral fault zone whose overall location and extent is still unknown (e.g. LEIN et al., 1997). The Oligocene–Miocene dextral PL is suggested to have affected an area with a pre-existent complicated structure because of Jurassic and Cretaceous thrust tectonics und post-mid-Cretaceous strike-slip faulting. It is rather unlikely that it will be possible to quantify the large scale strike-slip fault movements and to assign them to specific tectonic phases with an exact age. However, future investigations along strike of the PL will hopefully lead to a better understanding of the border zone between the Eastern and Southern Alps, the escape of the Drau Range – Transdanubian units, and the general tectonic processes of and along large crustal fault zones.

References

BAUER, F.K. (1985): Geologische Karte der Karawanken 1: 25.000, Westteil.– Geol. B.-A., Wien.

HOINKES, G., KOLLER, F., HÖCK, V. NEUBAUER, F., RANTITSCH, G. & SCHUSTER, R. (1999): Alpine metamorphism of the Eastern Alps.– Schweiz. Mineral. Petrol. Mitt., 79, 155–181.

KRYSTYN, L., LEIN, R., SCHLAF, J. & BAUER, F.K. (1994): Über ein neues obertriadisch–jurassisches Intraplattformbecken in den Südkarawanken.– Jubiläumszeitschrift 20 Jahre Geologische Zusammenarbeit Österreich – Ungarn, Teil 2, 409–416, Wien.

LEIN, R., GAWLICK, H.-J. & KRYSTYN, L. (1997): Paläogeographie und tektonische Herkunft des Drauzuges – Eine Diskussion auf Basis von Fazies und Conodont Colour Alteration Index (CAI)-Untersuchungen.– Zbl. Geol. Paläont., Teil 1, 1996, H. 5/6, 471–483.

NEMES, F. (1996): Kinematics of the Periadriatic Fault in the Eastern Alps.– Unpubl. Diss. Univ. Salzburg, 1–225, Salzburg.

POLINSKI, R.(1991): Ein Modell der Tektonik der Karawanken, Südkärnten, Österreich.– Unpubl. Diss. Univ. Karlsruhe, 1–143, Karlsruhe.

Reinterpretation of the Perlat–Kurbnesh Ophiolitic Mélange in the Central Albanides (Albania) as Radiolaritic Flysch – A Result of Component Analysis and Matrix Dating on the Base of Radiolarians, Detection of Late Jurassic Reef Carbonates and the Determination of Thermal Overprint of Triassic Carbonates by Conodont Colour Alteration Index (CAI) Data

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Key Words: Albania, Albanides, Perlat–Kurbnesh ophiolitic mélange, Triassic, Jurassic, Component analysis, Mass flow deposits, Late Jurassic carbonate platform, Radiolarians, Conodont Colour Alteration Index (CAI).

Introduction

As a part of the Dinaride–Hellenide segment of the Alpine orogenic system the Albanian ophiolites represent the remnants of Mesozoic oceanic crust. A number of recent studies (e. g., ROBERTSON & SHALLO, 2000; SHALLO & DILEK, 2003) discern two different ophiolitic belts, although both are thought to derive from a single oceanic basin, namely the narrow Pindos–Mirdita Ocean. The Western Ophiolite Belt with lherzolite basement is interpreted as normal oceanic lithosphere, whereas the Eastern Ophiolite Belt shows harzburgitic basement and is interpreted partly as supra-subduction lithosphere above an intra-oceanaic subduction zone. Formation of oceanic crust is thought to have started in late Early Jurassic time (ca. 185 Ma), east-dipping subduction in the Middle Jurassic. According to the literature, the Perlat–Kurbnesh ophiolitic mélange in the central Eastern Ophiolite Belt is overlain by flysch sediments. First flysch deposits are reported from Tithonian time (however, these are Maiolica-type deep-water carbonates), and coarse-grained Early Cretaceous flysch is described by several authors. Thrusting is therefore thought by some authors to have started in Tithonian times.

Dating of the Perlat–Kurbnesh ophiolitic mélange and component analysis

Our study in the Kurbnesh area (central part of the Eastern Ophiolite Belt – XHOMO et al., 2002) shows that the Perlat–Kurbnesh mélange, which has a turbiditic–radiolaritic matrix and as such represents a flysch sequence, starts with radiolarian cherts without breccia components. In different localities, radiolarians in these basal cherts gave Late Bajocian to earliest Bathonian ages (e.g., *Protunuma quadriperforatus* O'DOGHERTY & GORIČAN, *Theocapsoma cordis* KOCHER (UAZ 5–8), *Stichocapsa magnipora* CHIARI, MARCUCCI & PRELA (UAZ 4–7). Radiolaritic sedimentation in the mélange continued until the Oxfordian, as is also shown by dating of radiolarians.

In the radiolaritic flysch (mélange) different components, which show the facies of Hallstatt limestones and cherts, are dated as Skythian to Norian by conodonts and radiolarians. We used the Conodont Colour Alteration Index (CAI) to determine the diagenetic or metamorphic overprint of the carbonates and found:

(a) Slide components (pelagic Hallstatt limestones, Early, Middle and Late Triassic) with a high diagenetic overprint up to CAI 6.0 float in a cherty (radiolaritic) Middle Jurassic matrix with low diagenetic overprint. This leads to the conclusion that the thermal overprint of the Triassic carbonates predates the emplacement of the slides into the radiolarian cherts and is therefore transported.

(b) The metamorphism is older than Bathonian, which is in clear conflict with the suggested late Early Jurassic opening of the Mirdita ocean (see above), but would fit to published Middle Jurassic ages on ophiolitic metamorphic soles (around 170 Ma – DIMO et al., 1998).

One key section for dating the Perlat–Kurbnesh mélange is located near the settlement of Kurbnesh. In this section we found evidence for the existence of an unknown Late Jurassic reef carbonate platform by component analysis of mass flow deposits in pelagic sediments. The shallow-water components are dated by fossils (calcareous algae, foraminifera, incertae sedis) as Kimmeridgian to Tithonian. The (now eroded) Late Jurassic shallow-water carbonate platform must have topped the ophiolites of the Eastern Belt and sealed the ophiolitic mélange below. The mélange appears to be contemporaneous with the oldest carbonate clastic radiolaritic flysch formation in the Northern Calcareous Alps, which is also sealed by a shallow-water carbonate platform of Kimmeridgian to Tithonian age. Both carbonate platforms were formed on an active continental margin due to the accretion of the Vardar/Tethys Ocean.

Conclusions

The Albanides have a polyphase thermal and stacking history, which is not sufficiently and exactly dated and understood at the moment. Eastward subduction must have started as early as Middle Jurassic. We interpret the radiolaritic mélange as a syn-orogenic flysch sequence formed simultaneously with a nappe emplacement and ophiolite obduction. This conforms with our new stratigraphic data and published metamorphism ages from the ophiolitic soles but conflicts with the assumption of late Early Jurassic opening of the oceanic basin. Our results therefore also imply that the ophiolites were transported from the east over large distances, which means form the Vardar zone.

The actual controversial discussion about the tectonic interpretation of the ophiolites shows that a great number of stratigraphic data from all sediments in contact with the ophiolites and a detailed analysis of the melange complexes are needed.

References

DIMO, A., MONIE, P., VERGELY, P., KODRA, A. & GJATA, K. (1998): Mosha radiometrike e shkembinjve te shtrojes metamorfike; te dhena te reja mbi mekanizmin e vendosjes se ofioliteve te zones Mirdita (Radiometric dating of metamorphic sole; new data on the mechanism of Mirdita ophiolite's emplacement).– Bul. i Shkenc. Gjeologj., N–1, 43–50, Tirana.

ROBERTSON, A. & SHALLO, M. (2000): Mesozoic–Tertiary tectonic evolution of Albania in its regional Eastern Mediterranean context.– Tectonophysics, 316, 197–254.

SHALLO, M. & DILEK, Y. (2003): Development of the ideas on the origin of Albanian ophiolites.– Geol. Soc. Amer. Spec. Pap., 373, 351–363.

XHOMO, A., KODRA, A., DIMO, L.L., XHAFA, Z., NAZAJ, S.H., NAKUCI, V., YZEIRAJ, D., LULA, F., SADUSHI, P., SHALLO, M., VRANAJ, A. & MELO, V. (2002): Geological Map of Albania 1: 200000 scale.

The Upper Triassic and Jurassic Sedimentary Rocks of the Sarsteinalm with Special References to the Radiolarian Biostratigraphy of Radiolarites and Limestones of the Plassen Carbonate Platform: Evidence for the Tectonic Configuration of the Upper Tirolic Dachstein Block (Salzkammergut Region, Northern Calcareous Alps, Austria)

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Key Words: Northern Calcareous Alps, Dachstein Block, Jurassic.

The new nappe concept of the Northern Calcareous Alps established by FRISCH & GAWLICK (2003), in which the Tirolic unit practically takes the whole area of the central Northern Calcareous Alps and is divided into three sub-units (nappes): Lower and Upper Tirolic sub-unit, separated by the Upper Jurassic Trattberg Thrust, and the metamorphic Ultra-Tirolic unit. The Hallstatt (Juvavic) nappe(s) formed the highest unit, but were completely destroyed by erosion after nappe stacking. Remnants of the Hallstatt nappes are only represented by components of up to kilometre-size in Middle/Upper Jurassic radiolaritic wildflysch sediments ("Hallstatt Mélange" belonging to the Upper Tirolic unit). Destruction of the continental margin started in the Middle to Upper Jurassic time and prograded from the oceanic side towards the shelf.

The Upper Tirolic Dachstein Block in the Salzkammergut area therefore is the basement of the Hallstatt Mélange and a key region for the reconstruction of the Triassic and Jurassic paleogeography. After the palinspastic restoration of the block movements, Mesozoic facies zones and tectonic features, which were shown to have formed during Upper Jurassic nappe thrusting, present a much more coherent picture than in actual coordinates. The Trattberg Rise, a ramp anticline during Upper Jurassic thrusting, and the related Trattberg Thrust form coherent and rather straight features. The arrangement of the Jurassic radiolaritic basins, which formed as flysch troughs in front of the advancing nappes, also shows a coherent picture. The good fit of all these sedimentary and tectonic features, which reflect the Upper Jurassic situation in the study area, are clear indication that, in the period between Upper Jurassic nappe stacking and Lower to Middle Miocene block movement during lateral tectonic extrusion, these features were not fundamentally distorted by tectonic processes.

The Sarsteinalm area is interpreted as the northernmost part of the Upper Tirolic Dachstein Block (former Juvavic Dachstein nappe – see FRISCH & GAWLICK, 2003 for explanations) south of the Hallstatt zone Bad Ischl–Bad Aussee. It belongs to the Callovian to Oxfordian radiolaritic carbonate clastic flysch basin in the Northern Calcareous Alps (= Lammer Basin). South of the Sarsteinalm area Hallstatt limestones occur and were interpreted as remnants of the Lammer Basin fill (MANDL, 2003). If these Hallstatt limestones belong to the Lammer Basin they should have a matrix of Callovian to Oxfordian radiolarites (GAWLICK & FRISCH, 2003). But in this area no radiolarites with mass-flow deposits of Hallstatt limestones exist. The pelagic Hallstatt-type rocks south of the Sarsteinalm area occur in fissures in between the bedded Dachstein limestone without radiolaritic matrix.

The Jurassic sedimentary rocks in the Sarsteinalm area in the Austrian Salzkammergut north of Mount Sarstein are poorly known so far with respect to facies and stratigraphy; also the attribution to certain formations is ambiguous. Rhaetian lagoonal Dachstein limestone is overlain by red nodular limestones of the Adnet and Klaus Formations (Liassic to ?Bathonian). These are followed by 1 m thick red radiolarites (Callovian to Oxfordian), thin black radiolarites (Callovian to Oxfordian), both dated by means of radiolarians (e.g., *Archaeodictyomitra* cf. *apiarium*, *Cingululturris carpatica*, *Eucyrtidiellum unumaense pustulatum*, *Eucyrtidiellum unumaense unumaense*, *Gongylothorax favosus*, *Gongylothorax* aff. *favosus*, *Williriedellum* sp. A, *Williriedellum carpathicum*, *Xitus magnus*, *Zhamoidellum* cf. *ventricosum*, *Zhamoidellum ovum* – *Protunuma lanosus*- and *Williriedellum dierschei-subzones* after SUZUKI & GAWLICK, 2003), mass-flow deposits with components of Late Jurassic shallow-water carbonates and finally, only preserved as small remnants, platform carbonates of the Plassen carbonate platform.

The components can be assigned to slope, platform margin with corals/stromatoporoids and occasionally also closed lagoonal facies with *Clypeina sulcata* (ALTH) of presumably Kimmeridgian age. The adjacent occurrence of different facies zones suggests an incomplete amalgamated sequence. Also the thickness of the slope and platform margin facies is too reduced for a continuous sequence. The transition from the basinal facies to the slope facies of the Plassen Formation is represented by wackestones to packstones with remains of Saccocoma together with resedimented shallow-water bioclasts. This observation indicates a shallowing-upward succession as was evidenced from other occurrences such as the Falkenstein at Lake Wolfgang, Mt. Plassen or Mt. Krahstein.

The sedimentary succession shows that no mass-flow deposits in between the Jurassic sedimentary series with components of Hallstatt limestones in the study area occur. Thus, it can be excluded, that slide masses of Hallstatt limestones were transported over the Sarsteinalm area during Callovian to Oxfordian. Therefore, the Sarsteinalm area can not belong to the upper Tirolic Dachstein Block s. str. In fact, it must be separated as an isolated block from the Dachstein Block by an east–west striking fault.

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References

GAWLICK, H.-J. & FRISCH, W. (2003): The Middle to Late Jurassic carbonate clastic radiolaritic flysch sediments in the Northern Calcareous Alps: sedimentology, basin evolution, and tectonics – an overview.– N. Jb. Geol. Pal. Abh., 230, 163–213, Stuttgart.

FRISCH, W. & GAWLICK, H.-J. (2003): The nappe structure of the central Northern Calcareous Alps and its disintegration during Miocene tectonic extrusion – a contribution to understanding the orogenic evolution of the Eastern Alps.– Int. Journ. Earth Sci., 92, 712–727.

MANDL, G.W. (2003): Hallstätter Kalke auf dem Sarstein? (Salzkammergut, Oberösterreich).– Jb. Geol. B.-A., 143, 213–220, Wien.

SUZUKI, H. & GAWLICK, H.-J. (2003): Die jurassischen Radiolarienzonen der Nördlichen Kalkalpen.– In: WEIDINGER, J.T., LOBITZER, H. & SPITZBART, I. (Eds.): Beiträge zur Geologie des Salzkammergutes. Gmundner Geostud., 2, 115–122; Gmunden.

Displaced Jurassic Foreslope and Basin Deposits of Dinaridic Origin in North Hungary

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Key Words: Jurassic, Redeposited carbonates, Foreslope, Basin, Foraminifera, Radiolarians.

The basement of the Pannonian basin is made up of tectonostratigraphic terranes of various origin. They gradually amalgamated to large composite terranes Alcapa and Tisza–Dacia that juxtaposed during the Tertiary (CSONTOS et al., 1992).

In North Hungary, in the basement of the Tertiary volcanic complex of the Mátra Mts. and in the western part of the Bükk Mts., remnants a Jurassic accretionary wedge i.e. the Darnó and Szarvaskő Complexes were encountered. The Szarvaskő Ophiolite Complex records a Jurassic backarc basin evolution (BALLA et al., 1983). In the Darnó Ophiolite Complex both Triassic and Jurassic constituents occur. They are overthrust onto the Bükk Parautochthon Unit that is made up of Variscan flysch in the Carboniferous, marine Permian to Triassic succession with Ladinian and Carnian volcanic suites and flysch-type Upper Jurassic representing the Eohellenic tectogenesis.

Ore exploration wells exposed several hundred-meter thick carbonate and radiolarite successions in the basement of the Mátra Mts. that can be assigned to the Darnó Complex. Based on detailed studies of core Recsk–109, the partially dolomitized limestone succession consists predominantly of grainstones with packstone–wackestone intercalations. Peloidal bioclastic grainstone is the most common texture type but sand-sized intraclasts and locally oncoid and ooid grains also occur. The most spectacular feature is the large amount of coarse to medium sand-sized fragments of reef builders (corals, sponges) microbial crusts and calcified cyanobacteria (*Girvanella*, *Ortonella*, *Cayeuxia*, *Tubiphytes*). Platform derived foraminifera are also common. Graded deposits were not found. Gravity flows may have transported the carbonate detritus to the site of deposition at the foreslope and proximal toe-of-slope. Based on foraminifera (*Gutnicella cayeuxi*, *Mesoendothyra croatica*, *Andersenolina palestiniensis*) the succession can be assigned to the Aalenian–Bathonian interval.

In the southern part of the Bükk Mts. fine-grained graded oolitic, peloidal grainstone with shale and radiolarite interlayers were encountered in surface exposures and cores (Bükkzsérc Limestone Formation) (PELIKÁN & DOSZTÁLY, 2000). These deposits were formed via turbidity currents in a basin relatively far from the carbonate producing carbonate platforms. Based on foraminifera (*Archaeosepta platierensis*, *Nautiloculina oolithica*) the age of the formation is Late Bajocian—Bathonian. The radiolarian fauna of the intercalating shale beds suggest Late Bajocian – Early Bathonian age (PELIKÁN & DOSZTÁLY, 2000).

In the wider region Middle to Late Jurassic carbonate platforms and reef facies are known only in the Dinarides in the area of the Adriatic Carbonate Platform (DRAGIČEVIĆ & VELIĆ, 2002). Coeval platform derived redeposited carbonates and intercalated pelagic basin deposits on the slopes of the Adriatic platform and in the periplatform basin of the Slovenian Trough and the Bosnian Flysch Zone (DRAGIČEVIĆ & VELIĆ, 2002; BUCKOVIĆ et al., 2004). These data confirmed the assumed paleogeographic connections between the Dinaridic units and the Darnó and Bükk units in the Jurassic (HAAS

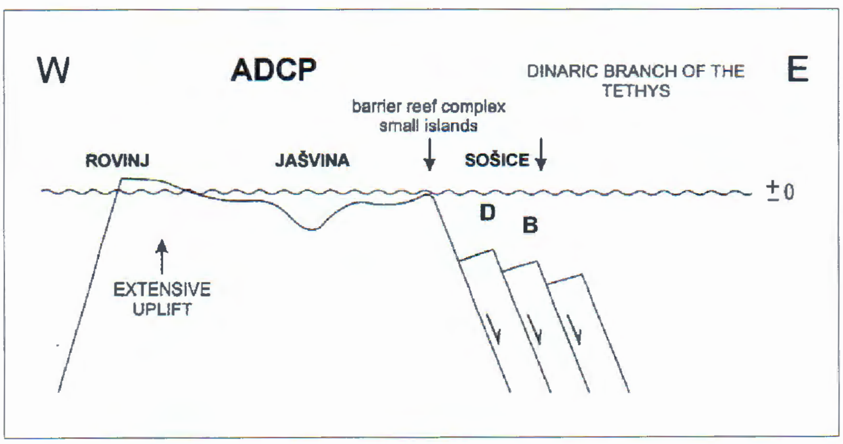

Fig. 1 Middle to Late Jurassic paleoenvironments of the Adriatic Carbonate Platform (ADCP) (after BUCKOVIĆ et al., 2004) and assumed paleogeographic setting of the studied carbonates in the Darnó Complex (D) and the Bükk Parautochthon Unit (B).

& KOVÁCS, 2001; PAMIĆ, 2003). The redeposited platform derived carbonates of the Darnó Complex may have been located during the Middle Jurassic in the vicinity of the NW part of the Adriatic Carbonate platform. Platform derived distal carbonate turbidites in the southern Bükk may have deposited farther from the platform in the periplatform basin (Fig. 1).

References

BALLA, Z., HOVORKA, D.M., KUZMIN, M. & VINOGRADOV, V. I. (1983): Mesozoic ophiolites of the Bükk Mountains (North Hungary).– Ofioliti, 8/1, 5–46, Bologna.

BUCKOVIĆ, D., CVETKO-TEŠOVIĆ, B. & GUŠIĆ, I. (2004): Late Jurassic paleoenvironmental evolution of the Western Dinarides (Croatia).– Geol. Carp., 55/1, 3–18.

CSONTOS, L., NAGYMAROSY, A., HORVÁTH, F., & KOVÁC, M. 1992: Tertiary evolution of the Intra-Carpathian area: a model.– Tectonophysics, 208, 221–241, Amsterdam.

DRAGIČEVIĆ, I. & VELIĆ, I. (2002): The northeastern margin of the Adriatic Carbonate Platform.– Geol. Croatica, 55/2, 185–232.

HAAS, J. & KOVÁCS, S. (2001): The Dinaridic—Alpine connection – as seen from Hungary.– Acta Geol. Hung., 44/2–3, 345–362.

PELIKÁN, P. & DOSZTÁLY, L. (2000): Jurassic formations of the Bükkzsérc boreholes (SW Bükk Mts., NE Hungary) and their structural setting.– Földtani Közlöny, 130/1, 25–46.

PAMIĆ, J. (2003): The allochthonous fragments of the Internal Dinaridic units in the western part of the South Pannonian Basin.– Acta Geol. Hung., 46/1, 41–62.

The Variscan and Permian Tectonometamorphic Imprint of the S Ötztal–Stubai Complex (Eastern Alps): Petrological, Geochronological and Structural Constraints

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Key Words: Permian, Sm–Nd, Pegmatite, Metapelite, Garnet composition, Ötztal–Stubai, Austroalpine.

The Ötztal–Stubai Complex (OSC) represents part of the Austroalpine Basement Units of the Eastern Alps situated W of the Tauern Window. Major parts of the OSC have a predominating Ordovician–Silurian and Carboniferous magmatic and metamorphic imprint, whereas a Cretaceous HP metamorphic overprint is confined to the SE part (FRANK et al., 1987; MILLER & THÖNI, 1995; SÖLVA et al., 2005). The SW section shows lithological similarities with the Campo Complex (CC) south of the Vinschgau Shear Zone(SCHMID & HAAS, 1989), as pegmatite-intercalations occur within hosting Sil-bearing Bt–Pl gneisses in the so called Matsch Unit. First new results provide constraints on the age of pegmatite-emplacement and the extent of related metamorphic processes in the pegmatite host rock of the Matsch Unit. Permian assemblages were distinguished from the Carboniferous by investigating phase relationships, mineral compositions and deformation structures as well as applying Grt Sm–Nd geochronology. Furthermore, Cretaceous deformation processes obviously played a major role for the current tectonic position of the Matsch Unit.

Lithologically the metasediments from the Matsch Unit are represented (from base to top) by Bt–Pl gneisses (± Sil, Grt, St, Ky, And), Grt–St micaschists (± And, Sil, Ky) and Grt–Ms schists (± St, Ctd). Both the Bt–Pl gneisses and Grt–St micaschists contain pegmatite-intercalations as well as And (± Sil, Ky)-bearing Qtz-veins. Relating stages of major mineral reactions with deformation stages (Dn), the following metamorphic evolution has been derived.

Within *Bt–Pl gneiss* and *Grt–St micaschists* Grt I grew syn- or postkinematically relative to D_1 and represents the earliest observed major mineral phase along with inclusions of Ilm. Grt I may show homogeneous alm–sps(–py–grs) composition or continuous growth zoning with decreasing Mn- and Ca-, increasing Mg/(Mg+Fe) from core to rim. In some places the Grt rim is affected by a retrograde Mn-increase and an inversion of the X_{Mg} zoning, which are probably related with later Grt resorption processes. First Sm–Nd analyses of a Grt–WR pair from And- and Ky-bearing Grt–St micaschist (sample HM07903) yielded 316±4 Ma (ε(t)Nd = -11.4) and thus evidences a Carboniferous age for the earliest metamorphism observed in the Matsch Unit. Grt I growth was followed by intense deformation (D_2), which produced a new major foliation. Postkinematically relative to D_2 St I + Ky I + Pl crystallized, which microstructurally resemble assemblages of the "kyanite-zone" OSC north of the Matsch Unit (PURTSCHELLER, 1969; TROPPER & HOINKES, 1996), where cooling below 300°C occurred at about 310–270 Ma (THÖNI, 1999 and references therein). In the Matsch Unit St I was then replaced by coarse-grained And, which is not only a product of metamorphic reaction, but also crystallized within Qtz veins. Synkinematically with respect to the subsequent deformation stage D_3 – which in some places produced a third intense foliation – And, Grt and the remaining St were decomposed to form Sil + Bt + Pl. The phase relations therefore require a heating stage following Carboniferous decompression, which is interpreted to relate with pegmatite emplacement. Still a reliable temporal correlation of metamorphic LP crystallization and pegmatite formation is confined to And-bearing samples, as Sil growth has also been described as a consequence of late Carboniferous decompression in the OSC further north (TROPPER & HOINKES, 1996).

Pegmatites from the Matsch Unit contain coarse-grained Ab, Ksp, Qtz, Ms, Tur, Grt and often cut the dominant foliation S_2 or S_3 of the metapelitic host rock discordantly. Within major parts of the Matsch unit, the syn- or post-magmatic deformation of the pegmatites is significantly weaker than the finite deformation of the host rocks. The first Sm–Nd data from pegmatite of the Matsch Unit (sample 03T41 containing magmatic Ab, Qtz, Ms, Grt, beryl and accessory apatite, Zn-spinel, sphalerite and zircon) gave a Grt–WR age of 255±8 Ma (ε(t)Nd = -10.8), thus constraining the Permian age of pegmatite emplacement. Pegmatite-garnet shows a homogeneous major element distribution (mol%: alm_{71-78}, sps_{21-28}, py_1), which is identical within both 1–2 mm sized grains and 10–50 micrometer sized garnet fragments. The possible presence of a second garnet growth stage, as well as any influence of post-magmatic (Cretaceous) thermal processes on the primary major element composition of Grt may therefore be excluded for sample 03T41. The metamorphic imprint postdating pegmatite-emplacement shows a gradient within the Matsch Unit and is related with the probably eo-Alpine greenschist facies shear deformation (D_4). In the eastern part fine-grained Grt II, St II, Ctd and a phengitic Ms-generation may occur, whereas in the westernmost part the Cretaceous imprint is confined to Chl and sericitic Ms formation.

Grt–Ms schists, which have a structurally higher position than the lithologies given above are characterized by medium to coarse grained Grt I cores containing inclusions of Ctd, Ilm, Tur, Ms and Gr-layers, which trace an older foliation (D_1). The Grt rim shows intergrowths with euhedral St I, which – in contrast with the lithologies described above – form an equilibrium assemblage. There are no unequivocal evidences of a Permian metamorphic and magmatic imprint due to the lack of pegmatite-intercalations and aluminosilicate phases.

Concerning the deformation stages, microstructures related with D_1 are confined to inclusion patterns in Grt (i.e. folded layers of Gr-pigment, Ilm and Qtz-trails). Intense folding and shearing during D_2 and D_3 pre-dated pegmatite-emplacement and mainly produced the major foliation in the pegmatite host rock. Micas, Qtz and Pl show medium-grained recrystallization and new growth within axial planes and mylonitic foliation planes. D_2 fold axes and intersection lineations trend NW–SE to E–W, whereas D_3 fold axes and stretching lineations trend SW–NE to E–W. Rarely, N–S trending intersection lineations have been observed. The major foliation planes S_2 and S_3 are subhorizontal or gently N dipping in the western and southern section of the Matsch Unit, whereas they are subvertical in the central and northern part. The current tectonic configuration of the described lithologies was established during lower greenschist facies shear deformation (D_4), which postdated pegmatite-emplacement. Very localized shear zones occur at the base of the Bt–Pl gneisses (i.e. the Vinschgau shear zone, (SCHMID & HAAS, 1989) and at the boundary of Bt–Pl gneisses with the overlying Grt–St micaschists. Top to W kinematics (LPO of Qtz, mica-fishes, σ-clasts, SCC' fabrics) were observed at the W and S margin of the Matsch Unit, sinistral kinematics occur at the N margin, where the mylonitic foliation subvertically trends E–W. A related internal shear zone presumably caused doubling of the pegmatite bearing lithologies due to Top W thrusting of the eastern over the western part of the Matsch Unit. Large scale (several 100 m wavelengths), tight to open folds (D_5) represent the final ductile deformation stage at lower greenschist facies conditions. E–W trending fold axes occur in the central and eastern Matsch Unit, whereas folds with NNE–SSW trending axes and ESE plunging axial planes refold D_4 shear zones in the W part. Consideration of the D_4 and D_5 structures is crucial for the reconstruction of the pre-Cretaceous tectonic evolution of the Matsch Unit, although the new data evidence already a Carboniferous common metamorphic evolution with the OSC.

References

FRANK, W., HOINKES, G., PURTSCHELLER, F. & THÖNI, M. (1987): The Austroalpine unit west of the Hohe Tauern: The Ötztal–Stubai Complex as an example for the Eoalpine metamorphic evolution.– In: FLÜGEL, H.W. & FAUPL, P. (eds.): Geodynamics of the Eastern Alps. Deuticke, 179–225, Vienna.

MILLER, C. & THÖNI, M. (1995): Origin of eclogites from the Austroalpine Ötztal basement (Tirol, Austria): geochemistry and Sm–Nd vs. Rb–Sr isotope systematics.– Chem. Geol., 122, 199–225.

PURTSCHELLER, F. (1969): Petrographische Untersuchungen an Alumosilikatgneisen des Oetztaler–Stubaier Altkristallins. (Petrographic study of aluminosilicate-bearing gneisses in the Oetztal–Stubai Alps).– Tscher. Miner. Petrogr. Mitt., 13, 35–54.

SCHMID, S.M. & HAAS, S. (1989): Transition from near-surface thrusting to intrabasement decollement, Schlinig thrust, Eastern Alps.– Tectonics, 8, 697–718.

SÖLVA, H., GRASEMANN, B., THÖNI, M., THIEDE, R.C. & HABLER, G. (2005): The Schneeberg Normal Fault Zone: Normal faulting associated with Cretaceous SE-directed extrusion in the Eastern Alps (Italy/Austria).– Tectonophysics, in press.

THÖNI, M. (1999): A review of geochronological data from the Eastern Alps.– Scweiz. Min. Petr. Mitt., 79, 209–230.

TROPPER, P. & HOINKES, G. (1996): Geothermobarometry of Al_2SiO_5 bearing metapelites in the western Austroalpine Ötztal basement.– Mineral. Petrol., 58, 145–170.

On the Dynamics of the Paratethys Sedimentary Area in Slovenia

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Key Words: Paratethys, Slovenia, Dynamic systems approach.

In order to understand the present-day organizational and structural pattern of the Cenozoic stratigraphic system in the area of Slovenia, it is necessary to see it as a manifestation of the underlying processes, including deformation. According to this view, inner geodynamics have been the main operator of the system concerned. Based on geodynamic information from the literature, information from our co-operation research, and from our own research, we have attempted to show how the area concerned has evolved along the evolutionary path of the six long-running behaviour of the system and the five discontinuous changes in behaviour.

The 1st long-running system state: We relate it to the collision process in the western Tethys ocean branches (the Pindos and Vardar branches, respectively) from about the end of the Lutetian to the Priabonian. It eventually terminated the Dinaric WSW thrusting related generation of foredeeps and flysch filling and uplifted the Dinarides. The recent finding of NE dipping of the Adria microplate lower lithospheric slab beneath the European plate in the Eastern Alps supports this idea. Today, only some small remnants of the flysch infilling are preserved north of Kočevje. As a result of this collision, a huge suture was formed between the Adria microplate and the Austroalpine orogenic lid, Tisia, the Serbo–Macedonian massif and Rodopes. Of the Austroalpine shallow sea deposits at the back of the forearc basin of the obliquely subducting Alpine Penninic–Magura Ocean, small remnants E of Mežica and W of Zreče are preserved north of the Periadriatic line.

The 1st discontinuous change: We relate it to a reduction in the sea-floor spreading rate on the central Atlantic ridge between North America and Africa. A reduced spreading rate between North America and Africa in the middle Priabonian (at around 35 Ma), but not between North America and Europe, caused a large displacement of the relative Africa–Europe rotation pole, and a change in the convergence direction and rate between Africa and Europe.

The 2nd long-running system state: In the Alpine Penninic–Magura Ocean an advancing subduction changed to a retreating subduction by about 35 Ma. Both processes resulted in an extension in the peri-Alpine and Alpine domain. The remnant deposits of the late NP 19–20 – early NP–23 (late middle Priabonian (~35 Ma) to early Rupelian (~32 Ma)) on the strongly tectonized Dinaric substratum of the present-day Southern Karavanke and Julian–Savinja Alps between the Periadriatic line and the Sava–Celje tectonic zone are, according to our tectonostratigraphical interpretation, related to this extensional event. The slab detachment process during the Rupelian produced melt generation of magmatic activity along the suture. The first tuff layers in the area have been dated to the early part of the NP 23 (~32 Ma). Effusive activity up to the beginning of the Egerian (~27 Ma) prevents an insight into further development of the extended area.

The 2nd discontinuous change: We correlate it with the beginning of the Adria microplate indentation, after 32 Ma. The Africa–Europe pole of rotation possibly started moving back to nearer its former position, i.e. back to convergence, earlier than proposed.

The 3rd long-running system state: Therefore, the convergence rate of the African plate shows acceleration before 20 Ma. The onsets of the bivergent Alpine orogen, and the thickening of Alpine nappes by internal deformation, are related to this acceleration. The 4D architecture of the Egerian sedimentary fill of the area in the eastern extension of the Savinja Alps and further to the east between the Donat transpression zone and the Sava–Celje tectonic zone, and in the Sava folds south of the Sava–Celje tectonic zone we interprete tectonostratigraphically as complex tectonic load-flexural basin sequences. The onlap near the tip of the inner thrust sheet load dated to the ~P 21/P 22 boundary (the Kiscellian/Egerian boundary) proves the contemporaneity of the flexural event in the area with the formation of a retro-wedge foredeep in the Italian Southern Alps as well as with a change from a flysch to a molasse type basin in the Alpine foreland. Further Adria microplate indentation triggered processes like lateral extrusion of the ALCAPA and gravitational collapse in the Eastern Alps. In the area of Slovenia it caused an inversion of basins and a huge right lateral dissection of the former assumed uniform Paleogene basin into the Slovenian and Hungarian Paleogene basins.

The 3rd discontinuous change: At ~20 Ma (the Eggenburgian) the subduction retreat in the Penninic–Magura Ocean reached the height of the Bohemian massif, and changed the direction of slab-pull from a N to E directions, following the arcuate outline of the Magura Ocean. The synchronicity of the fast rollback pull and the following slowing down of the sea-floor spreading on the central Atlantic ridge resulted in extension in the back arc position onto the Pannonian upper plate. It included the Styrian wedge between the Mur–Mürz fault and the Donat transpressive zone until the Karpatian (between 18 and 17.3 Ma).

The 4th long-running system state: Tectonic erosion of the crust by the ALCAPA extrusion and exhumation of the Pohorje high-grade metamorphic–batholithic complex were facilitated by the syn-rift extension and astenospheric diapirism. This Karpatian core complex mode of extension was followed by the Early to Middle Badenian wide-rift mode of extension, which then extended the whole area.

Our data confirm extensional collapse at the ~ Middle/Late Badenian boundary. Syn-rift extension and astenospheric diapirism caused the break-up of the extruding ALCAPA into the independent Eastern Alpine and the Western Carpathian–Northern Pannonian lithospheric units.

The 4th discontinuous change: We relate it to a time-progressive process of the detachment of the east-European lithospheric slab, to the associated colliding of the Western Carpathian–Northern Pannonian lithospheric unit against the east-European platform by the end of the Sarmatian, and to the associated change to active extension in the Pannonian basin at the beginning of the Pannonian s.s. Coarse clastic input, uplift and in places deep erosion indicate compression and a slight inversion in the area during the late Sarmatian. In the early Pannonian s.s., the change to subsidence and transgression affected the area.

The 5th long-running system state: It comprises the Pannonian s.s. syn-rift and the Pontian sensu Stevanović post-rift and compression stress-induced subsidence in the area, which accumulated over 2000 m of sediments. This compression is related to the beginning of the collision in the southeastern Carpathians at ~8 Ma, and to the beginning of the back arc extension in the northern Tyrrhenian Sea at ~9 Ma (~Pannonian s.s./Pontian sensu Stevanović boundary). The latter drove a CCW rotation of the stable Adriatic platform, which exerted compression in the Dinarides and in the locked Pannonian basin.

The 5th discontinuous change: The second stage of a fast subduction rollback extension in the Thyrrhenian Sea began at 6–5 Ma (~ Pontian/Dacian boundary). This gave new impetus to the stable Adriatic platform CCW rotation and to compression. By the end of the Pontian sensu Stevanović the whole Carpathian arc became fixed and the climax compression within the Pannonian basin began.

The 6th long-running system state: In the area of Slovenia the climax compression caused an overall inversion and transpression. This last deformation process, which is still going on, has significantly changed the organizational and structural pattern of the Cenozoic stratigraphic system of the area. According to GPS data, the horizontal surface crust movements in the SW corner of the area split into NW and NE directions. The third ESE direction is the continuation of the ALCAPA lateral extrusion along the Periadriatic line – Sava–Celje fault transpression belt. Strike-slip faulting in the three directions has created some small pull-apart/transtensional basins.

Due to space limitations, numerous references have been omitted. They will be given in the poster. Readers are kindly asked to send their comments.

New K–Ar Age Data on the Alpine, Low-temperature Regional Metamorphism of Mt. Medvednica (Croatia)

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Key Words: Alpine, Low-T metamorphism, K–Ar dating, K-white mica, Mt. Medvednica, Croatia, Bükk, Szendrő and Uppony Mts., NE-Hungary.

The systematic metamorphic petrogenetic investigation of three, major, pre-Neogene tectonostratigraphic units of Mt. Medvednica as one of the largest "inselbergs" of the major tectonic zone between the Eastern and the Southern Alps and the Dinarides i.e. the Zagorje–Mid-Transdanubian Zone (ZMTZ; PAMIĆ & TOMLJENOVIĆ, 1998) started in 2001. The results of the mineral paragenetic, microstructural, X-ray powder diffractometric and mineral chemical studies were summarised by JUDIK et al. (2004). The first K–Ar isotopic age data (122–110 Ma) obtained on the very low- to low-grade metamorphic complex of Mt. Medvednica were published by BELAK et al. (1995). These age values were mainly measured on whole rock samples from greenschists and syn-kinematic K-white mica separate from a quartz-rich vein.

In spite of the several constraints in isotopic dating of very low-grade metamorphic rock sequences, e.g., the critical importance of the accurate mineral separation and characterisation, the preferential loss of radiogenic isotopes due to the small grain size, the addition of radiogenic isotopes explained by the occurrence of detrital contaminants increasing the obtained isotopic ages, the K–Ar isotopic dating recently became a widely adopted method of age determination (e.g.: REUTER, 1987; ALTANER et al., 1987; CLAUER et al., 1995, ÁRKAI et al., 1995).

The aim of the present study was to obtain K–Ar isotopic age data on <2 μm size K-white-mica rich separates of various lithotypes of the very low- to low grade metamorphic complex, the diagenetic Jurassic Ophiolitic mélange and Cretaceous–Paleocene sequence of Mt. Medvednica. The K–Ar age data measured on rock types from very low- to low-grade metamorphic complex varied between 64 and 124 Ma. For the metapelite samples the average value corresponded to ca. 110 Ma, while it was significantly lower, ca. 80 Ma for the metavolcanic–volcanic–sedimentary rock types devoid of detrital K-white mica in the separates. Beside the Cretaceous, Alpine metamorphic age data, no isotopic evidence was found which would refer to an eventual Variscan metamorphic event. Similar conclusions were suggested by JUDIK et al. (2004) on the basis of mineral chemical investigation of selected slate samples from the very low- to low-grade metamorphic complex. The authors found mineral chemical homogeneity of K-white mica and chlorite grains situated parallel to S_{0-1} and S_2 foliation planes and the possible detrital ones. For this reason they suggested that the effect of a possible Variscan metamorphic event with temperature conditions not higher than the latest, Alpine one could not be directly proven.

In the matrix of the Jurassic Ophiolithic mélange and the Cretaceous–Paleocene sequence the diagenetic (in some cases low-temperature anchimetamorphic) conditions were probably not sufficient to reset the K–Ar system of the samples giving mixed isotopic ages.

The chronological correlation of the K–Ar age data measured on various rock types of the high-temperature anchizonal metamorphic complex of Mt. Medvednica with anchi-epizonal sequences of the Bükkia Composite Terrane, the Uppony and Szendrő Units (KOVÁCS et al., 2000) indicates that similarly to the orogenic metamorphism of the Bükk, Szendrő and Uppony Mts., the eo-Hellenic (160–120 Ma) and the Austrian (100–95 Ma) phases connected to the subduction–obduction of the Dinaridic Tethys and the further compressional thickening (ÁRKAI et al., 1995) could be responsible for tectono–metamorphic evolution of these units.

PAMIĆ et al. (2004) also obtained Cretaceous K–Ar whole rock age data on metarhyolite samples from the Mid-Bosnian Schist Mts. of the Internal Dinarides, explained by the Late Jurassic–Cretaceous subduction – obduction of the Dinaridic oceanic crust.

References

ALTANER, S.P., WHITNEY, G. & ARONSON J.L. (1984): Model for K-bentonite formation: evidence from zoned K-white mica bentonites in the disturbed belt, Montana.– Geology, 12, 412–415.

ÁRKAI, P., BALOGH, K. & DUNKL, I. (1995): Timing of low-temperature metamorphism and cooling of the Paleozoic and Mesozoic formations of the Bükkium, innermost Western Carpathians, Hungary.– Geol. Rundschau, 84, 334–344.

BELAK, M., PAMIĆ, J., KOLAR-JURKOVŠEK, T., PÉCSKAY, Z. & KARAN, D. (1995): Alpinski regionalno metamorfni kompleks Medvednice (sjeverozapadna Hrvatska).– In: VLA-

HOVIĆ, I., VELIĆ, I. & ŠPARICA, M. (eds.): 1st Croatian Geological Congress, Proceedings, 1, Inst. geol. istr., Zagreb, 67–70.

CLAUER, N., RAIS, N., SCHALTEGGER, U. & PIQUÉ, A. (1995): K–Ar systematics of clay-to-mica minerals in a multi-stage low-grade metamorphic evolution.– Chem. Geol., Isotope Geoscience Section, 124, 305–316.

JUDIK, K., ÁRKAI, P., HORVÁTH, P., DOBOSI, G., TIBLJAŠ, D., BALEN, D., TOMLJENOVIĆ, B. & PAMIĆ, J. (2004): Diagenesis and low-temperature metamorphism of Mt. Medvednica, Croatia: mineral assemblages and phyllosilicate characteristics.– Acta Geol. Hung., 47, 151–176.

KOVÁCS, S., SZEDERKÉNYI, T., HAAS, J., BUDA, Gy., CSÁSZÁR, G. & NAGYMAROSY, A. (2000): Tectonostratigraphic terranes in the pre-Neogene basement of the Pannonian area.– Acta Geol. Hung., 43, 225–329.

PAMIĆ, J. & TOMLJENOVIĆ, B. (1998): Basic geologic data from the Croatian part of the Zagorje Mid-Transdanubian Zone.– Acta Geol. Hung., 41, 389–400.

PAMIĆ, J., BALOGH, K., HRVATOVIĆ, H., BALEN, D., JURKOVIĆ, I. & PALINKAŠ, L. (2004): K–Ar and Ar–Ar dating of the Palaeozoic metamorphic complex from the Mid-Bosnian Schist Mts., Central Dinarides, Bosnia and Hercegovina.– Mineral. and Petrol., 82, 65–79.

REUTER, A. (1987): Implications of K–Ar ages of whole rock and grain-size fractions of metapelites and intercalated metatuffs within an anchizonal terrane.– Contrib. Mineral. Petrol., 97, 105–115.

Eoalpine Tectonometamorphic History of the Uppony and Szendrő Paleozoic (NE Hungary)

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Key Words: Eoalpine, Metamorphism, Ductile tectonics, Uppony and Szendrő Paleozoic, NE Hungary.

The Szendrő and Uppony Mountains in NE Hungary form two smaller, pre-Tertiary basement exposures in the so-called Gemer–Bükk region which comprises the innermost tectonic units of the Inner Western Carpathians and the neighbouring areas. The known stratigraphic range of these Early Paleozoic sequences extends from the Middle Devonian to the Middle Carboniferous including mostly platform and pelagic carbonates and a flysch-like sequence (Szendrő Mts.), furthermore clastic rocks of unknown age (Ordovician–Silurian?) and strongly altered, basic volcanics and volcano-sediments. For a more detailed stratigraphical and lithological description see KOVÁCS (1992).

The ductile tectonic evolution of these Lower Paleozoic sequences was studied by means of classical structural field methods and detailed microtectonic investigations. Structural investigations reveal that both units suffered a complex, polyphase folding. Regarding also available metamorphic petrological and geochronological data (ÁRKAI, 1977, 1983; ÁRKAI et al., 1981, 1995; KOROKNAI, 2004), the Cretaceous (Eoalpine) tectonometamorphic evolution of these units could be reconstructed as follows (Fig. 1):

D_1 – Formation of a bedding-parallel first foliation (S_{0-1}) associated with intensive flattening in the bedding plane as a consequence of an early tectonic event (F_1 folding and/or nappe thrusting?). Since this deformation is preserved mostly in small fabric-relics, its vergency and other structural characteristics are still unclear.

D_{2a} – Folding of the bedding-parallel foliation (S_{0-1}) into upright to moderately inclined, close to tight (locally isoclinal), subhorizontal to gently plunging, NW-vergent F_2 folds. A well-developed, generally SE-dipping, penetrative axial plane foliation (S_2) was formed during this event. Fold axes trend mostly to NE–SW, in the eastern part of the Szendrő Mts. to E–W, as indicated by the orientation of the intersection lineation of S_{0-1} and S_2 as well. The bedding-parallel foliation is heavily transposed into the "main" S_2 foliation in many outcrops, suggesting intensive flattening during progressive deformation. Structures connected to this phase of deformation are prevailing in both studied units.

The D_1 and D_{2a} events must have taken place on the prograde stage (at relatively high-temperature) of the Cretaceous metamorphism as indicated by the intensive crys-

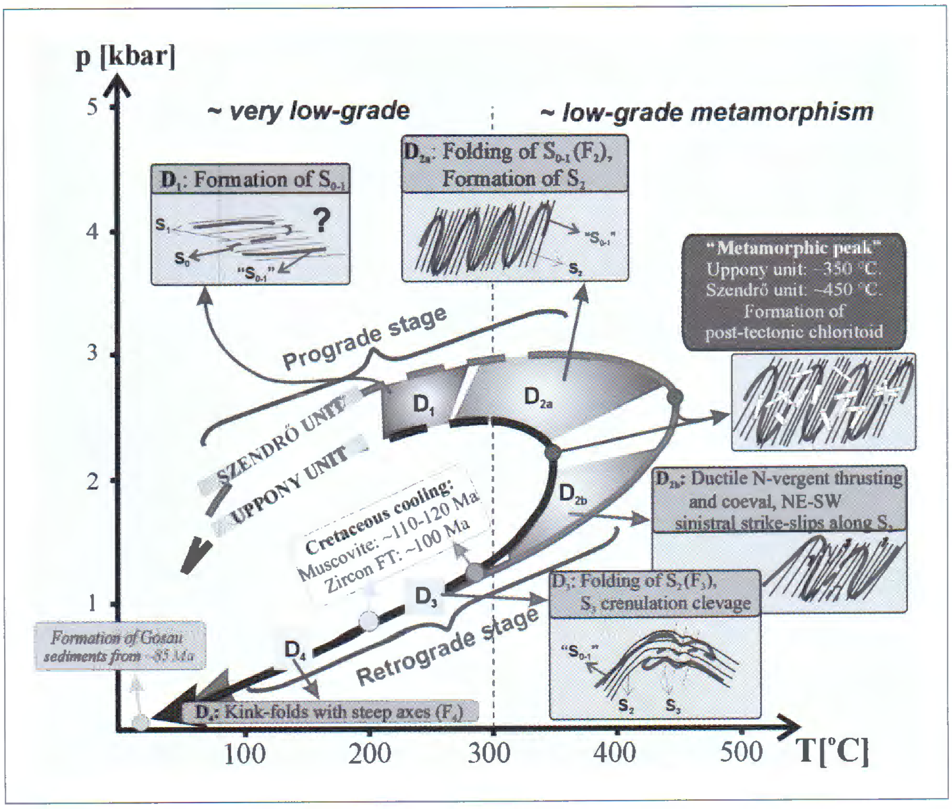

Fig. 1 Schematic sketch of the tectonometamorphic evolution of the Uppony and Szendrő Paleozoic units. Sources of the P–T–t–D data: ÁRKAI (1977, 1983), ÁRKAI et al. (1981, 1995), KOROKNAI (2004).

talplastic deformation of calcite and quartz associated with both S_{0-1} and S_2 foliations, and by posttectonic chloritoid (with respect both to S_{0-1} and S_2 foliations) which can be related to the thermal peak of metamorphism. Peak metamorphic conditions can be estimated at about 300–350°C in the Uppony unit (IC), and 400–450°C in the Szendrő unit (IC and chlorite–chloritoid thermometry). White mica cooling ages are in the range of ca. 110–120 Ma, while zircon FT data yielded ages about 100 Ma.

D_{2b} – Further flattening and ductile simple shear of limited amount occurred after/or at the late stage of F_2 folding. Shearing is resulted in the formation of a well-developed, either dip-slip or nearly horizontal, grain-scale stretching lineation, developed mainly in the carbonate rocks. The resulting N(W)-vergent thrusting (generally with a slight sinistral component) and the coeval NE–SW trending sinistral strike-slip movements suggest a transpressional tectonic regime. However, no large-scale mylonitic zones could be observed in the studied units.

D_3 – A second, less intense folding (F_3) produced locally a non-penetrative crenulation cleavage (S_3). F_3 fold axes are generally also NE–SW (E–W) trending, and gently to moderately plunging. This folding event is especially characteristic in the Szendrő unit where map-scale F_3 synforms and antiforms were also formed during this phase. This deformation occurred on the retrograde path of the metamorphic evolution, at significantly lower temperatures (<270–300°C) than the D_1–D_{2a-b} events, as indicated by the minor associated crystalplastic deformation of quartz and calcite.

D_4 – Lastly, steeply plunging F_4 kink folds were formed, related mostly to N–S or NW–SE trending, semi-brittle, steep shear zones accompanied frequently by calcite veins with en-echelone geometry. No foliation developed during this deformation phase, which indicates low deformation temperatures (≤200°C) on the retrograde path. The "anomalous" orientation of all previously formed structures in certain zones can be attributed to the passive rotation during this deformation, or – in certain cases – later Tertiary block rotations.

References

ÁRKAI, P. (1977): Low-grade metamorphism of Paleozoic sedimentary formations of the Szendrő Mountains (NE-Hungary).– Acta Geol. Acad. Sci. Hung., 21/1–3, 53–80.

ÁRKAI, P., HORVÁTH, Z. A. & TÓTH, M. (1981): Transitional very low- and low-grade regional metamorphism of the Paleozoic formations, Uppony Mountains, NE-Hungary: Mineral assemblages, illite-crystallinity, b_0 and vitrinite reflectance data.– Acta Geol. Acad. Sci. Hung., 24, 265–294.

ÁRKAI, P. (1983): Very low- and low-grade Alpine regional metamorphism of the Paleozoic and Mesozoic formations of the Bükkium.– Acta Geol. Hung., 26, 83–101.

ÁRKAI, P., BALOGH, K. & DUNKL, I. (1995): Timing of low-temperature metamorphism and cooling of the Paleozoic and Mesozoic formations of the Bükkium, innermost Western Carpathians, Hungary.– Geol. Rundsch., 84, 334–344.

KOROKNAI, B. (2004): Tectonometamorphic evolution of the Uppony and Szendrő Paleozoic.– PhD Thesis. Eötvös University, Budapest, 239 p.

KOVÁCS, S. (1992): Stratigraphy of the Szendrő–Uppony Paleozoic (Northeastern Hungary).– In: VOZÁR, J. (ed.): Special volume to the problems of the Paleozoic geodynamic domains. Western Carpathians, Eastern Alps, Dinarides. IGCP Project n° 276, Bratislava, 93–108.

Permo–Mesozoic Formations of the Darnó Hill Area, NE Hungary – A Displaced Fragment of the Inner Hellenidic–Inner Dinaridic Accretionary Complexes

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Key Words: Ophiolite, Abyssal, Slope, Carbonate turbidites, Sandstones, Radiolarians, Tectonics.

The Darnó Complex has been explored by three boreholes with continouos coring in the Darnó Hill area W of the Bükk Mts., each of them 1200 m deep: Rm–131, Rm–135 and Rm–136. They revealed, that the complex is built up by an upper, magmatic unit and a lower, sedimentary one.

The *upper unit* consists predominantly of pillow and massive basalts (in up to 100 m thick horizons) and subordinately of abyssal sediments penetrated in a few to max. tens of metres thickness: red radiolarites and mudstones, and bluish grey siliceous mudstones. Red radiolarites yielded alternatively Triassic (Ladinian–Carnian) or Jurassic (Bathonian–Callovian) radiolarians in the different horizons, whereas bluish grey silicites only Jurassic (Callovian) ones. The borehole Rm–135 explored also intrusive rocks (gabbros, microgabbros) in several hundred metres virtual thickness. Geochemically, these magmatic rocks show MORB-type, with high Ti-content. K–Ar radiometric dating did not provide unambigous results: although gabbros yielded Middle Jurassic (175–165 Ma) ages, basalts showed the age of a Middle Cretaceous tectonothermal event (110–95 Ma; DOSZTÁLY & JÓZSA, 1992). Megascopically, basalts are of two types. Amygdaloidal basalts, rich in pink and white calcite amygdals, as well as containing pink and reddish lime mud inclusions and inter-pillow void fillings, can be considered as early rift-type and as of Triassic age. They are often red or reddish colour, but can be green, as well. Basalts lacking calcite amygdals and lime mud inclusions are green coloured and appear similar to those of the Szarvaskő Complex. These may be of Jurassic age. Ultramafic rocks are not preserved, but former presence of a higher, ultramafic sheet is indicated by serpentinite pebbles in the Lower Miocene Darnó Conglomerate, and by serpentinite grains in Lower Miocene sandstones north of the Darnó area (SZTANÓ & JÓZSA, 1996).

The *lower*, sedimentary *unit* represents a lower slope and toe-of-slope setting, with three types of sediments transported by different types of gravity flows:

(1) Dark grey shales and bluish grey siliceous shales; in some horizons these appear as the "autochthonous" sediment, but in others have thin bedded, distal turbiditic character.

(2) Carbonate turbidites, often of fine laminated, distal character. These are of two types: grey, marly, micritic limestone (Oldal–völgy type of SW Bükk Mts.), and ligtht grey, oolitic–bioclastic limestone (Bükkzsérc-type of the SW Bükk Mts.). Dark grey to black chert layers or lenses may occur. Renewed sediment movements subsequent to the settling of turbidites resulted in slump structures, or, in more advanced stage, debris flows ("microolistostromes").

(3) In certain horizons a different type of debris flow deposits occur, with cm-sized micaceous sandstone lithoclasts. Of interest is the occurrence of plutonic (granite) and extrusive (dacite–rhyolite and andesite) rock fragments in the clasts, which may derive from a magmatic arc (B.-ÁRGYELÁN & GULÁCSI, 1997); however, their age is not yet determined.

Triassic deep water sediments (Bódvalenke-type, reddish-whitish siliceous limestones with red cherts) associated with reddish, amygdaloidal basalts occur as slide blocks (olistothrymmata) in the lower unit. The red cherts yielded Ladinian–Carnian radiolarians (DOSZTÁLY & JÓZSA, 1992; DOSZTÁLY, 1994). About 900 m below the surface, the borehole Rm 136 penetrated a block of fossiliferous Upper Permian Nagyvisnyó Limestone and evaporitic Middle Permian Szentlélek Fm. A surface occurrence of such an Upper Permian limestone block is known about 250 m from the location of the borehole (FÜLÖP, 1994).

This lower unit, both in its facies and composition, can be regarded as an equivalent of the Mónosbél Unit of the SW Bükk Mts. (cf. CSONTOS, 1999), which can be correlated with coeval parts of the Bosnian Flysch Zone (PAMIĆ et al., 2002). In the eastern neighbourhood of the Darnó Hill, close to the village Sirok (Kis–Vár–hegy Quarry) the lower sedimentary unit is exposed as a strongly folded sequence verging to the ESE. The direction and type of the deformation including stretching and boudinage formation along fold axes is also corresponding to that of the Bükk Mts.

With all these characteristics the Darnó Complex can be regarded as a displaced fragment of the Inner Hellenidic–Inner Dinaridic Neotethyan accretionary complexes ranging from Northern Greece to NW Croatia, with its nearest equivalent exposed in the Kalnik Mt. (kindly shown to Hungarian geologists by L. Palinkaš).

Selected References

DOSZTÁLY, L., JÓZSA, S., KOVÁCS, S., LESS, Gy., PELIKÁN, P. & PÉRÓ, Cs. (2002): 1st day programme, Post Congress Excursion C: North-east Hungary.– In: VOZÁR, J., VOJTKO, R. & SLIVA, L. (eds.): Guide to Geological Excursions, XVIIth Congress of the Carpatho–Balkan Geological Association, pp. 104–117, Bratislava.

KOVÁCS, S., JÓZSA, S., GULÁCSI, Z., DOSZTÁLY, L., B.-ÁRGYELÁN, G., FORIÁN-SZABÓ, M. & OZSVÁRT, P. (in press): Geological setting of Neotethyan ocean floor, trench and volcanic arc remnants in NE Hungary: a review. Part I: Bükk Mts. and Darnó Hill area.– Acta Geol. Hung., 48/3.

For other references see these two contributions.

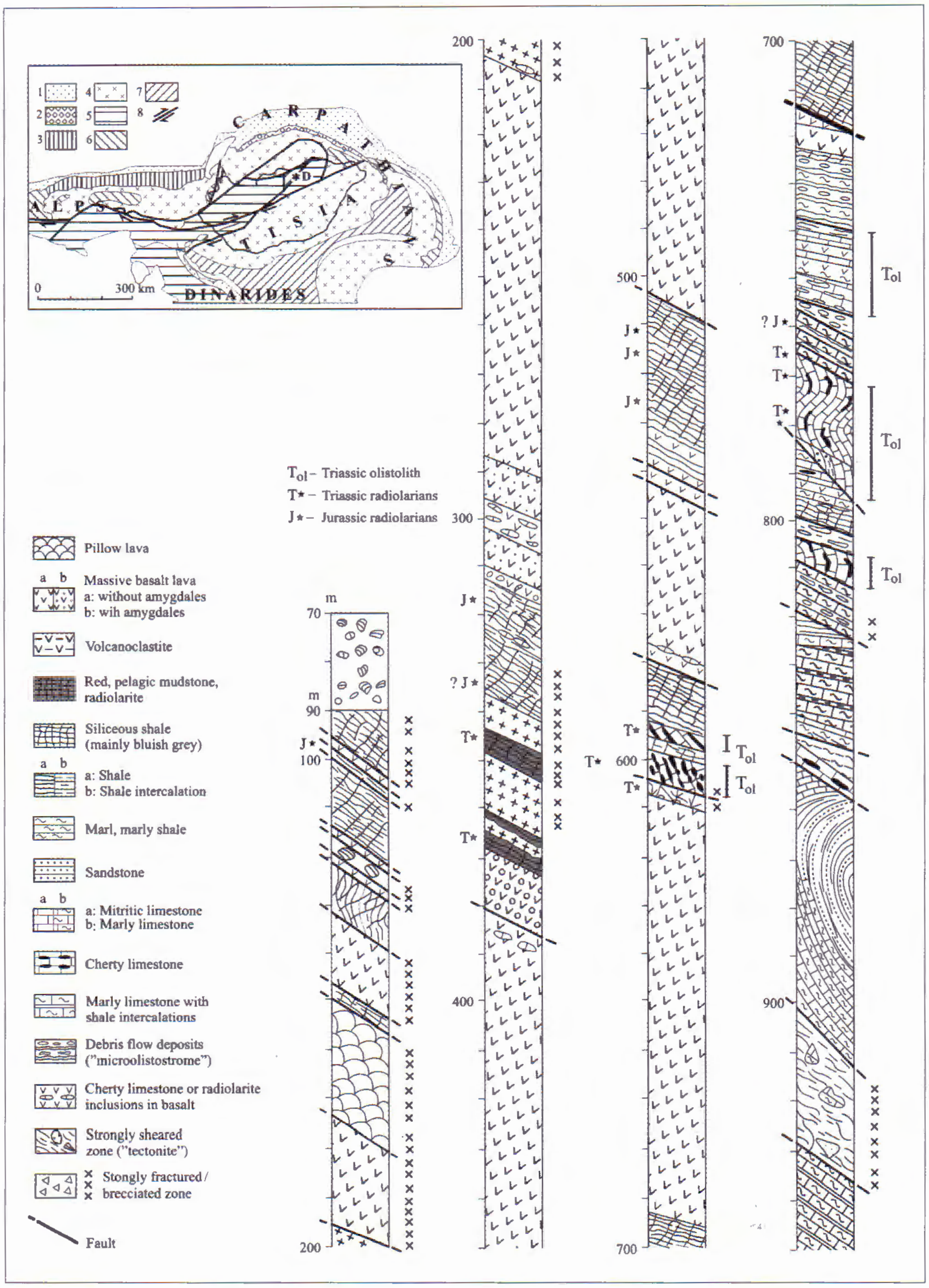

Fig. 1 Setting of the investigated region in the Circum-Pannonian region (marked with asterix) (after KOVÁCS et al., 2000) and part of the drill-core sequence of the borehole Rm–131 (after JÓZSA et al., 1996 and KOVÁCS et al., in press). Legend to the map in the upper left: 1) Outer Carpathian Flysch Belt; 2) Klippen Belt; 3) Northern Calcareous Alps; 4) Variscan granitoid–metamorphic complexes and Early Alpine shelf sequences related to the European margin of Neotethys; 5) Early Alpine shelf sequences related to the Apulian/Adriatic margin of Neotethys; 6) Penninic ophiolite complexes; 7) Neotethyan ophiolite complexes; 8) Major strike-slip zones; *D) marks the location of Darnó Hill on the figure.

Tectonic Position of Torna s.s. and Bódva Units in the Central Part of Rudabánya Hills, NE Hungary

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Key Words: Torna Unit, Bódva Unit, Metamorphic degree, Ductile deformation, Deformation phases.

We examined the structural settings of the Csipkés and Dunna-tető Hills, situated in Rudabánya Mts. (NE Hungary) between Perkupa and Szalonna villages.

According to the previous investigations the studied area is part of the Bódva Nappe, and was separated into two tectonic units (LESS et al., 1988). In the lower unit on the surface are explored only Jurassic rocks, containing black shale, marl and subvolcanic rhyolite bodies intercalations. The upper tectonic unit, which is built up by an overturned Bódva type Triassic sequence on Csipkés Hill and in the borehole Perkupa P–74, was thrusted upon the previously mentioned Jurassic rocks (PÉRÓ et al., 2003). The Triassic sequence represents the overturned limb of a recumbent fold, which is thrust over the Jurassic rocks (LESS et al., 1988; PÉRÓ et al., 2003). There is another Bódva type sequence on the Dunna-tető Hill, which is built up by the same formations as the overturned one, but here the stratigraphical younging is normal. The upper tectonic unit is represented as the member of a non-metamorphic Bódva Subunit on the geological maps (LESS et al., 1988).

According to new macroscopic, microscopic and conodont age investigations, there are two Triassic sequences on the slope of Dunna-tető Hill. One of them is the previously mentioned normal younging Bódva-type sequence (Dunnatető tectonic unit), with an age of Middle Anisian to Middle Carnian based on conodont investigations. The other one is an Upper Ladinian to Upper Norian Torna-type s. s. sequence (Martonyi tectonic unit).

The Jurassic rocks, appeared on the examined territory, have been separated into two formations (Telekesoldal and Telekesvölgy Formations) based on litological differences. I have described a new type of Jurassic sequence, named Csipkéshegy sequence, which can be the part of the Telekesvölgy Formation. The main characteristic of this development is containing a whole Bódva-type sequence from Steinalm Limestone to Szárhegy Radiolarite as redeposited pebbles. There is a big difference in the deformation degree of the two formations, too. The rocks of Telekesvölgy Formation are "healthy" and seems to be not deformed, those of Telekesoldal Formation are strongly deformed.

The metamorphic grade of some rocks from Martonyi Unit was investigated. According to the illite crystallinity and the Conodont Colour Alteration Index the samples have been anchimetamorphosed.

We set up several models on the structural settings of the area, based on field explorations and geological sections constructed. According to our investigations taken so far, the next one can be considered as the best. The Csipkés Hill is built up by an overturned, Middle Anisian to Jurassic sequence. These formations forms a synform (with an axis of ENE–WSW), with smaller scale parasitic folds. A normal younging sequence, containing Gutenstein Dolomite and Steinalm Limestone, is thrusted upon them. On the southern slope of Dunnatető Hill the Jurassic rocks of Telekesoldal Formation appear in lowermost position. A folded (with an axis of ENE–WSW) Bódva-type sequence (Dunnatető Unit) is thrusted upon them. The Martonyi Unit (Torna-type s.s. rocks) is above them in nappe position, preserved in a core of the syncline formed by the formations of Dunnatető Unit.

According to microtectonic observations, the most important deformational mechanisms of the samples from Martonyi Unit are the following ones: pressure solution, pressure twinning, and dynamic recrystallization. For the last mechanism, it is necessary to have at least 250°C (BURKHARD, 1993).

We detected 4 folding phases within 5 deformation phases, based on field investigations. Using them, we can reconstruct a part of the structural development of the examined area. The detected tectonic phases are the following ones:

D_1 deformation phase:

- development of layer-parallel foliation (S_1) in the rocks of Martonyi Unit and Telekesoldal Formation;
- the two units get in contact, while S_2 folds developed;
- perhaps some pressure solution, and calcite tails grown in pressure shadow are in connection with this phase.

D_2 deformation phase:

- anchimetamorpic event of the Martonyi Unit and Telekesoldal Formation, with F_2 folding phase and S_2 axis-plane schistosity;
- the following detected microstructures are in connection with this (D_2) phase: pressure solution, pressure twinning, and dynamic recrystallization, calcite tails grown in pressure shadows.

D_3 deformation phase:

- the Martonyi Unit and the rocks of Telekesoldal Formation thrust over the Dunnatető Unit with a vergency to the south–southeast.

D_4 deformation phase:

- the three units become folded together: F_3 folding phase;
- start to develop an axis-plane schistosity in the formations of Dunnatető Unit;
- after this folding phase, because of the continuation of compression become a thrusting event, with a vergency to the south–southeast. The Dunnatető Unit became the hanging wall of the Telekesoldal Formation;
- the shear bands measured in the Jurassic rocks of Telekesoldal Formation show moving top to the west. It can be interpreted as an observable sign of E–W tension formed by the vertical shortening of the footwall, generated by the overthrusting units from the north.

D_5 deformation phase:

- a normal younging sequence, containing Gutenstein Dolomite and Steinalm Limestone thrusts upon the previous existed structures;
- local development of folds (F_4) because of the dextral shear, generated by the side ramp of the thrust.

References

BURKHARD, M. (1993): Calcite-twins, their geometry, appearance and significance as stress-strain markers and indicators of tectonic regime: a review.– J. Struct. Geol., 15, 351–368.

LESS, GY. (1998): Földtani felépítés (Geology).– In: BAROSS, G. (ed.): Az Aggteleki Nemzeti Park (The Aggtelek National Park). Mezőgazda Kiadó, 26–66.

PÉRÓ, Cs., KOVÁCS, S., LESS, Gy. & FODOR, L. (2003): Geological setting of the Triassic "Hallstatt" (s.l.) facies in NE Hungary.– VI[th] Alpine Workshop, Sopron, Hungary, Annales Universitatis Scientiarum Budapestiensis de Rolando Eötvös Nominatae, 35, 58–59.

Late Neogene Counterclockwise Rotation in the SW Corner of the Pannonian Basin

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Key Words: Paleomagnetism, South Pannonian Basin, Neogene, Rotation.

Earlier paleomagnetic studies suggested that counterclockwise rotating Adriatic microplate could have triggered the youngest rotations in the Hrvatsko Zagorje area, in the area of Slavonian Mts. and in the Mura–Zala depression. Since the named areas are located quite far from the Eastern Adriatic coast, we decided to study the Krško and Karlovac basins, which are situated in-between (Fig. 1). From the collected 12 paleomagnetic localities (Badenian through Pontian sediments) ten yielded good paleomagnetic directions as a result of laboratory processing and statistical evaluation. They definitely point to the counterclockwise rotation of the area in post early Pontian times. The angle of the rotation is about 20° (D=337°, I=50°, k=48, α_{95}=10°). Thus, we have found a missing tectonic link from the Hrvatsko Zagorje, Slavonian Mts. and the Mura–Zala basins to the Adriatic microplate and collected further paleomagnetic evidence for the end of Miocene or even younger important tectonic movements in the South Pannonian basin.

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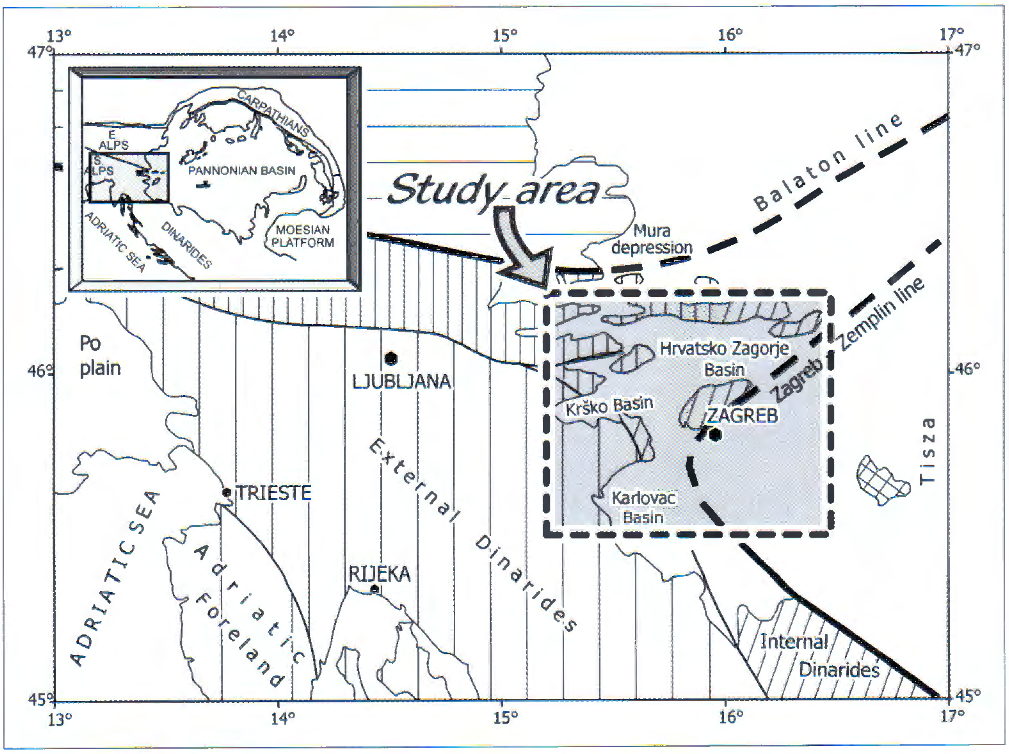

Fig. 1 The study area at the junction of the Alps, Dinarides and the Pannonian Basin.

Late Cretaceous Paleomagnetic Results from the Adriatic Foreland

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Key Words: Paleomagnetism, Adriatic plate, Cretaceous, Rotation.

The motion of Adria, the largest lithospheric fragment in the Central Mediterranean region have played a key role in the development of the surrounding mountain chains (Dinarides, Southern Alps, Apennines) and even of more distant areas (Eastern Alps, Pannonian Basin). In order to describe this motion in terms of rotations and latitudinal displacements paleomagnetic data are needed. The so far available data were inadequate to characterize the movements, except in a very general way. We are reporting new paleomagnetic results from two of the few areas, where stable Adria is accessible for taking oriented samples, from the foreland of the southern Alps (Colli Euganei and Berici Hills) and from Istria, the foreland of the NW Dinarides. In the former area pelagic limestones (Scaglia), from the latter, platform carbonates are the sources of the data. The new results will be analysed for possible relative movements between the foreland of the Southern Alps and Istria, and with respect to Africa. In addition, a comparison will be made between the late Cretaceous and the recently obtained Eocene results from the same areas in order to decide if Adria rotated during the latest Cretaceous–early Eocene.

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Geometry, Evolution and Kinematic Correlations of the Pre-Neogene Evolution of the Transylvania Basin

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Key Words: Pre-Neogene, Rifting, Continental collision, Transylvania, Tisza–Dacia.

The Transylvania basin represents an adequate example for the study of complex buried tectonic margins, superposed basins with poly-phase structural evolution and late-stage orogenic basins with no significant internal deformations. Although Transylvania has been considered for a long time a back-arc basin formed during Neogene contractional episodes of the Carpathians, it actually represents a complex system of basins with distinct geometries and kinematics. Due to the deep burial below thick and overall widespread Neogene sediments, the earlier basin evolution has been less studied and previous tectonic models are generally based on a wide range of assumptions and speculations in the absence of published detailed exploration data.

The first major extensional event is marked by the Triassic–Lower Cretaceous rifting, opening of the Transylvanides domain and subsequent evolution of an asymmetric passive margin system, locally superposed over the rifting structures. Our study reveals a presently NNE–SSW trending normal fault system and associated Jurassic–Lower Cretaceous sedimentary wedges. The inferred mechanism assumes a simple-shear asymmetric extension, with a master detachment fault dipping westwards at high depths near the South Apuseni Mountains. This detachment has abandoned, during shearing and upwelling, a portion of the main mobile area in the central–southern part, i.e. the Tarnave basin. Its southern border corresponds to a large, up to 100 km displacement transform fault, separating the extensional domain from the neighboring South Carpathians continental block. The main extensional area is partially preserved northwards in the Puini basin, as a direct continuation of the exposed South Apuseni Transylvanides, being made up of a thick sequence of Jurassic–Lower Cretaceous sediments deposited directly over oceanic crust. The structure furthermore is completely inverted in later tectonic episodes.

The first moment of basin inversion takes place in the Middle Cretaceous (Aptian) and corresponds to the coeval crustal shortening taking place in the adjacent orogens. This deformation is characterized by presently N–S oriented thrusts, accommodating the E-ward vergent nappe stacking of the Internal Dacides (North Apuseni Mountains) on top of the Transyilvanides. A first stage of thrusting of the ophiolites on top of the Middle Dacides (presently the East and South Carpathians basement) and their pre-Aptian cover is coevally recorded both in the Puini area, but also on randomly preserved Transylvanides patches across the entire eastern border of the basin, clearly recognised through basement thrusting on top of Lower Cretaceous sediments. In the south, only minor thrusts are recorded on the eastern flank of Tarnave basin, corresponding to lateral variations in the orogenic stacking.

The second moment of basin inversion is coeval with the main moment of continental collision between the Internal and Middle Dacides and final closure of the Transylvanides domain. In the Transylvania basin, the recorded age of this deformation event is Cenomanian–Turonian and mainly inverts the earlier normal detachment fault of the Tarnave basin, overthrusting ESE-ward the Triassic?–Albian basin fill. A large number of low-angle thrust faults pervasively affect the basement at the frontal contact between the Transylvanides and the Middle Dacides. The earlier southern transform fault was coevally reactivated along a large positive flower structure, accommodating a dextral displacement of the inverted basin in respect to the South Carpathians basement.

Localized Senonian subsidence interrupted the inversion episodes, small scale basins associated with minor normal faults trending N–S are preserved mostly in the same Jurassic–Lower Cretaceous (Puini) northern basin. This subsidence can be easily correlated with the Gosau-type basins and post-collisional subsidence widely observed in the adjacent South Carpathians and Apuseni Mountains.

Subsidence accelerated during Paleogene times, a thick package of Paleocene continental to Eocene marine deposits being still preserved at depth in the western Transylvania and exposed in the NW-most corner.

The third moment of basin inversion takes place during the Eocene, when mostly the Albian thrusts where re-activated in the NW Transylvania. Two basins are affected by these structures, Puini (north) and Sinmiclaus (west), a typical foredeep develops in the footwall of the main thrusts and syn-tectonic sedimentation is observed in the hanging-wall. This Eocene reactivation of presently NNE–SSW oriented thrusts is of regional significance, the thrusts being coeval and spatially juxtaposed over similar structures exposed in the South Apuseni Mountains. Thrusting in the Puini basin is also gradually decreasing southwards and gradually transferred to a domal-shaped structure in the South Apuseni Mountains. Thrusting reconstruction suggests a significant amount of rotation of the North Apuseni

Mountains in respect to the East and South Carpathians basement during the Eocene, coeval with the orogen-parallel extension, core-complex formation and rotation of the South Carpathians basement around the Moesian platform. In addition, Eocene rotation allowed the complete overthrusting of the Transylvanides domain northwards below the North Apuseni basement.

At the end of the Paleogene a large part of the basin is uplifted and subsequently eroded, earlier structures being preserved either in the two main sub-basins, or in randomly distributed isolated patches. During Upper Oligocene–Lower Miocene (Burdigalian), only the northern part of the Transylvania basin responded as an E–W oriented foredeep basin to shortening and southward thrust loading of the Piennides (senso largo) and footwall nappes. This basin has clear wedge-type geometry with small flexural normal faults. The study of the internal unconformities has enabled mapping of at least three thrusting moments during this time span, presently S-ward vergent. Following the Middle Miocene the entire Transylvania subsided, developing the juxtaposed Neogene basin, as a direct response to shortening and collision in the external part of the Carpathians.

The regional analysis of the pre-Neogene evolution of the Transylvania basin has outlined and clarified for the first time most of the previously missing key elements in the tectonic reconstructions, such as the kinematics of the basin opening and closure, correlations between the exposed margins of the Tisza, Rhodopian fragment, Piennides and Transylvanides. This has enabled a clear timing and geometry of internal deformations during the polyphase evolution of the Transylvania basin which took place during the Jurassic, Cretaceous, Eocene and Lower Miocene.

Significance of Ophiolitic and High-grade Metamorphic Detritus in the Tertiary External Dinaride Flysch Belt

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Key Words: External Dinarides, Flysch belt, Tertiary, Provenance study, Ophiolitic detritus, High-grade metamorphic detritus.

A nearly continuous belt of synorogenic Upper Cretaceous to Miocene flysch successions extends from the Southern Alps along the outer margin of the External Dinarides. Flysch formation is related to the large-scale compressional stress field that has affected the whole Adriatic realm since the Late Cretaceous, resulting in foreland basin evolution and deep marine sedimentation. The Dinaridic segment of the flysch belt has been traditionally considered as of Paleogene age. The evolution and major Tertiary deformation events of the External Dinarides need to be re-evaluated in the light of the new nannoplankton biostratigraphic data (see DE CAPOA et al., 1995; DE CAPOA & RADOIČIĆ, 2002) confidently indicating diachronous sedimentation younging towards SE with, at least, Serravallian ages in and SE of Central Dalmatia.

In this provenance study turbidite sandstones from the flysch belt were examined by means of petrography, whole-rock geochemistry (XRF analysis), heavy mineral analysis and single grain chemistry of detrital chrome spinel and garnet (electron microprobe analysis), so as to put constraints on the lithologies exposed to the surface during evolution of the Dinarides.

The medium to very fine grained turbidite sandstones exhibit low textural maturity, they are classified as lithic wackes, corresponding to a recycled orogenic provenance. Major element discrimination procedures according to BHATIA (1983) and ROSER & KORSCH (1988) indicate a mature, quartzose sedimentary provenance typical of passive continental margins. However, trace element compositional data (K_2O–Rb trend; Ni/La vs. Ti/La, Cr/V vs. Y/Ni ratio–ratio plots) signal mafic to ultramafic components, too, in the immediate sediment source. Upper continental crust normalized trace element distribution also shows striking positive Cr and Ni, and moderate positive V and Co anomalies. Cr/Ni values of 2 to 5 are slightly higher than the range of Dinaride ultramafics (1.1–1.7) but are in considerable overlap with Dinaride basalts and metabasalts.

Chrome spinel and small amounts of serpentinite and basaltic lithic fragments account for most of the observed whole-rock trace element features. Chrome spinel composition was used to constrain the ultimate ophiolitic sources. 70–90% of the analyzed grains is derived from peridotites. The smaller volcanic population is dominated by crystals of MORB affinity as indicated by their elevated Al_2O_3 and TiO_2 concentrations. The peridotitic population shows a wide range in petrological parameters (Cr#=0.13–0.89; Mg#=0.26–0.78; Fe^{2+}/Fe^{3+}=2.04–21.47; Al_2O_3=5.28–53.78) so a further classification was made according to the characteristic type of the host peridotites. Harzburgitic chrome spinel crystals predominate over the lherzolitic ones. In the entire flysch belt, the proportion of chrome spinels of lherzolitic affinity tends to increase from about 5–10% in the Southern Alps–Dinarides junction to about 30–50% towards SE, in central and southern Dalmatia and Montenegro. This trend is accompanied by increasing amounts of (a) unstable species of mainly metamorphic origin in the heavy mineral spectra and of (b) serpentine lithic fragments also towards SE, at the expense of rutile, tourmaline and especially zircon (WOLETZ, 1962; MIKES, 2003; PAVIČIĆ et al., 2003). Detrital garnet compositional spectra are either dominated by low-Mg, low-Ca or high-Mg, high-Ca type populations. These chemical groups identify Barrow-type, greenschist to amphibolite facies metamorphic rocks, and blueschist to eclogite facies metabasic rocks, respectively. Evidence for erosion of blueschist facies rocks also comes from ubiquitous occurrence of glaucophane in the flysch.

The new data presented above allow the following scenario to be proposed. Until Late Eocene–Early Oligocene in the Southern Alps–Dinarides junction mainly older sedimentary units in addition to granitoids and low to high grade metamorphics were exposed to erosion. Rather long (20–30 My) lag times in detrital zircon fission track data from this segment of the flysch belt preclude fast exhumation and erosion of the middle crust, implying that most ophiolitic detritus was also of reworked origin (MIKES et al., 2004). Very probably, by the Middle Miocene (Serravallian) the sedimentary cover of the Dinarides was largely removed, exhumation probably accelerated, and dominantly metamorphic rocks were eroded. The increasing contribution of first-cycle ophiolitic detritus of lherzolitic affinity, as indicated by serpentinite lithic fragments and chrome spinel chemistry, indicates direct erosion of the peridotites of the Dinaride Ophiolite Belt.

References

BHATIA, M. (1983): Plate tectonics and geochemical composition of sandstones.– Journal of Geology, 91, 611–627.

DE CAPOA, P. & RADOIČIĆ, R. (2002): Geological implications of biostratigraphic studies in the external and internal domains of the Central–Southern Dinarides. Memorie della Societŕ Geologica Italiana, 57: 185–191.

DE CAPOA, P., RADOIČIĆ, R. & D´ARGENIO, B. (1995): Late Miocene deformation of the External Dinarides (Montenegro and Dalmatia). New biostratigraphic evidence.– Memorie di Scienze Geologiche, 47, 157–172.

MIKES, T. (2003): Provenance analysis of Eocene flysch sandstones in the Northwestern External Dinarides.– M.Sc. Thesis, University of Tübingen, Tübingen, 75 pp.

MIKES, T., DUNKL, I. & FRISCH, W. (2004): Provenance mixing in a foreland basin as revealed by sandstone geochemistry and detrital zircon fission track analysis: the Eocene flysch of the NW Dinarides.– In: PENA DOS REIS, R., CALLAPEZ, P. & DINIS, P. (eds.): 23rd IAS Meeting of Sedimentology, Coimbra – September 15–17, 2004, Abstracts Book, p.199, Coimbra.

PAVIČIĆ, Lj., ZUPANIČ, J. & BABIĆ, Lj. (2003): Changing heavy mineral associations along the Outer Dinaric Eocene flysch belt: evidence for different structures along the rising Dinarides.– In: VLAHOVIĆ, I. (ed.): 22nd IAS Meeting of Sedimentology, Opatija – September 17–19, 2003, Abstracts Book, p. 149, Zagreb.

ROSER, B.P. & KORSCH, R.J. (1988): Provenance signatures of sandstone–mudstone suites determined using discriminant function analysis of major-element data.– Chemical Geology, 67, 119–139.

WOLETZ, G. (1962): Beobachtungen im Flysch von Istrien (Jugoslawien).– 8. Schwermineralanalysen von Flyschsandsteinen aus Istrien. Verhandlungen der Geologischen Bundesanstalt, 239–245.

The Berchtesgaden Block in the Berchtesgaden Calcareous Alps: A Key Area for the Reconstruction of the Polyphase Tectonic History of the Central Northern Calcareous Alps

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Key Words: Berchtesgaden Calcareous Alps, Polyphase tectonic history, Paleogeographic reconstructions, Lammer Basin, Trattberg Rise, Tauglboden Basin, Sillenkopf Basin, Berchtesgaden Block, Tirolic unit.

We present a new tectonic model for the Berchtesgaden Calcareous Alps contrasting all former tectonic and paleogeographic reconstructions (MISSONI et al., 2005). Biostratigraphy, facies analysis, and basin analysis of the sedimentary successions from Permian to Late Triassic resp. from Jurassic to Early Cretaceous allow to reconstruct the sedimentary and tectonic history in the Berchtesgaden Calcareous Alps. Triassic as well as Early and Middle Jurassic sediments were deposited in a rifted and drifted, transtensive continental margin setting. In the late Middle to Late Jurassic the geodynamic regime changed to an active continental margin and trenches with carbonate–clastic, radiolaritic flysch in front of advancing nappes were formed in sequence in the Triassic lagoonal area as a result of the partial closure of the Tethys Ocean: the older Lammer Basin (Early Callovian to middle Oxfordian) in the southern part of the Tirolic unit (lagoonal Dachstein limestone area), which belongs to the Upper Tirolic nappe sensu FRISCH & GAWLICK (2003) (e.g., Berchtesgaden Block, Dürrnberg Block, Berchtesgaden Hallstatt zone, Torrener–Joch-zone, Watzmann Block), contains mass-flows and slides originated in the former Hallstatt Zone; the younger Tauglboden Basin (Early Oxfordian to Early Tithonian) in the northern part of the Tirolic unit (partly lagoonal Hauptdolomite area), which belongs to the Lower Tirolic nappe sensu FRISCH & GAWLICK (2003) (e.g., northern parts of the Freieck–Göll–Kehlstein Block), contains mass-flows and slides originated from the nearby topographically high (= Trattberg Rise, e.g., Mt. Untersberg, Mt. Kehlstein). The Trattberg Rise, built of bedded Dachstein limestone, separate these two basins. The third radiolaritic basin, the Sillenkopf Basin (Early Kimmeridgian to Tithonian) partly with exotic clasts, is related to further tectonic shortening and is situated in the southern part of the Tirolic unit, which belongs to the southern Upper Tirolic nappe sensu FRISCH & GAWLICK (2003) (e.g., Steinernes Meer Block, Sillenkopf–Gotzen Block). A Late Jurassic (Kimmeridgian to Tithonian) shallow water carbonate platform (Plassen carbonate platform, e.g., Mt. Kehlstein, Mt. Untersberg) forms a post-tectonic cover and seals the Middle to Late Jurassic deep water basin evolution and is formed on an active continental margin.

A Cretaceous nappe stack as former interpreted cannot be confirmed. Only ongoing tectonic shortening and the increase of siliciclastic input, can be observed in the Kimmeridgian to Aptian sedimentary succession (Sillenkopf Formation, Schrambach Formation, Roßfeld Formation). Late Cretaceous to Eocene Gosauic sediments sealed this tectonic phase and were overthrusted due to Oligocene nappe stack, which is sealed by the Augenstein Formation Faults, mostly contemporanous to the miocene lateral tectonic extrusion, destroyed the Jurassic paleogeography and basin configuration and formed the modern block configuration.

The Berchtesgaden Block – a Tirolic and not a Juvavic unit

The Berchtesgaden Block, with the Mt. Reiteralpe, the Lattengebirge-massive, Mt. Untersberg, the Watzmann Block, destroyed by a polyphase thrust and fault generation, is situated nearly in its original paleogeographically position. The Upper Tirolic sedimentary succession of the Berchtesgaden Block starts in Early Triassic with greenish–grey Werfen beds, overlain by brownish limestones and dolomites of the Reichenhall Formation. These sediments are overlain by Anisian ramp deposits of the Gutenstein and the Steinalm Formations, which are overlain by Pelsonian pelagic dolomites. South of the Gschirrkopf a facial change of bright Steinalm dolomites to basal Reifling dolomites with a grey crinoidic limestone in a grey micritic matix is proved. Grey cherty and partly cataclastic dolomites, with the following conodont fauna occur: Fassanian 1 – *Gladigondolella tethydis* (HUCKRIEDE), *Gondolella excelsa* (MOSHER) and *Gondolella* cf. *pseudolonga* KOVÁCS, KOZUR & MIETTO; Langobardian 1 – *Gladigondolella tethydis* (HUCKRIEDE), *Gladigondolella tethydis*–ME sensu KOZUR & MOSTLER, *Neogondolella* sp., *Gondolella* cf. *pseudolonga* KOVÁCS, KOZUR & MIETTO and *Gondolella inclinata* KOVÁCS; Langobardian to Julian 1/1 – *Gladigondolella tethydis* (HUCKRIEDE), *Budurovignatus mungoensis* (DIEBEL). The stratigraphic and facial change from the Late Anisian to the Ladinian Reifling Formation to the reefal Wetterstein dolomite is for the moment not datable. This bright ?Late Ladinian to Lower Carnian Raming and Wetterstein Formations occur, only with the following conodont fauna: Ladinian to Early Carnian – *Gladigondolella tethydis*–ME sensu KOZUR & MOSTLER. Upsection followed sediments are limestones and dolomites of the the Wetterstein carbonate platform and proximal Cidaris beds with oolithic sandstones in the late Early Carnian Raibl Formation, with the following conodont fauna: Early Carnian – *Gladigondolella tethydis*–ME sensu KOZUR & MOSTLER, *Gondolella polygnathiformis* BUDUROV & STEFANOV. The Late Carnian dolomitic ramp deposits of the Opponitz Formation is followed by Norian lagoonal and the Rhaetian reefal Dachstein limestones, overlain by the Adnet and Klaus Formation and the Hallstatt Mélange (Strubberg Formation), sealed by the Plassen Formation.

Thrusting of the Berchtesgaden Block to the north is dated by Oligocene. Miocene lateral tectonic extrusion produce anticlockwise rotation. This can be determinated in the strike of facies zones, in the thermal contrast and in the displacement of the conodont alteration index value zones bothsides the Königssee-fault. Beside the facies and sedimentary evolution of the Berchtesgaden Block another argument for the parautochthonous character comes from breccia analysis: in the Berchtesgaden Calcareous Alps neither in the Lammer Basin nor in the Sillenkopf Basin occur Triassic lagoonal facies material from the Berchtesgaden Block in the mass-flow deposits or in breccias as slides. Material from the Berchtesgaden Block is also missing in the mass-flow deposits of the Lower Cretaceous Roßfeld Formation.

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References

FRISCH, W. & GAWLICK, H.-J. (2003): The nappe structure of the central Northern Calcareous Alps and its disintegration during Miocene tectonic extrusion – a contribution to understanding the orogenic evolution of the Eastern Alps.– Int. J. Earth Sci. (Geol. Rdsch.), 92, 712–727, Berlin.

MISSONI, S., GAWLICK, H.-J., SUZUKI, H. & DIERSCHE, V. (2005): Palaeogeography of the Watzmann Block (Berchtesgaden Calcareous Alps) – new results based on the analysis of the Triassic to Jurassic sedimentary succession.– Journal of Alpine Geology (Mitt. Ges. Geol. Bergbaustud. Österr.), 47, 169–209, Wien.

The Watzmann Block in the Berchtesgaden Calcareous Alps – A Palaeogeographic Reconstruction Based on the Analysis of the Triassic to Jurassic Sedimentary Succession

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Key Words: Berchtesgaden Calcareous Alps, Watzmann Block, Triassic, Jurassic, Palaeogeographic reconstruction, Mass-flow analysis, Radiolarian dating.

We present a new tectonic model for the Berchtesgaden Calcareous Alps contrasting all former tectonic and paleogeographic reconstructions (MISSONI et al., 2005). Biostratigraphy, facies analysis, and basin analysis of the sedimentary successions from Permian to Late Triassic resp. from Jurassic to Early Cretaceous allow to reconstruct the sedimentary and tectonic history in the Berchtesgaden Calcareous Alps. Triassic as well as Early and Middle Jurassic sediments were deposited in a rifted and drifted, transtensive continental margin setting. In the late Middle to Late Jurassic the geodynamic regime changed to an active continental margin and trenches with carbonate–clastic, radiolaritic flysch in front of advancing nappes were formed in sequence in the Triassic lagoonal area as a result of the partial closure of the Tethys Ocean: the older Lammer Basin (Early Callovian to middle Oxfordian) in the southern part of the Tirolic unit (lagoonal Dachstein limestone area), which belongs to the Upper Tirolic nappe sensu FRISCH & GAWLICK (2003) (e.g., Berchtesgaden Block, Dürrnberg Block, Berchtesgaden Hallstatt zone, Torrener–Joch-zone, Watzmann Block), contains mass-flows and slides originated in the former Hallstatt Zone; the younger Tauglboden Basin (Early Oxfordian to Early Tithonian) in the northern part of the Tirolic unit (partly lagoonal Hauptdolomite area), which belongs to the Lower Tirolic nappe sensu FRISCH & GAWLICK (2003) (e.g., northern parts of the Freieck–Göll–Kehlstein Block), contains mass-flows and slides originated from the nearby topographically high (= Trattberg Rise, e.g., Mt. Untersberg, Mt. Kehlstein). The Trattberg Rise, built of bedded Dachstein limestone, separate these two basins.

Stratigraphic, facies and sedimentological investigations on the Triassic and Jurassic sedimentary successions of the northern part of Mt. Watzmann and of the Herrenroint–Kühroint area show the following results (MISSONI et al., 2005):

1) For the first time described, late Sevatian Kössen beds and bedded lagoonal (Rhaetian) Dachstein limestone of the northern flank of Mt. Watzmann place the palaeogeographic position of Mt. Watzmann towards the southern rim of the Kössen basin in Rhaetian times, comparable to the palaeogeographic facies development at the northern Tennengebirge.
2) The resedimented composition of breccia components in the Herrenroint–Kühroint area contains breccia components in Zwieselalm facies, in Gosausee limestone facies and also in Dachstein reef limestone facies. The matrix of the mass-flow deposits are dated by means of radiolarians as Callovian to Oxfordian. This mobilizied sequence is mixed with allochthonous origin. Due to biostratigraphic dating of the cherty sediments and the palaeogeographic origin of the resedimented breccia components the Watzmann Block belongs to the western-most part of the Lammer Basin.
3) The Jurassic section of the Wimbachklamm, former the Jurassic-type section of Mt. Watzmann, can so far subdivided in two parts. The Early to ?Middle Jurassic sediments belong to Mt. Watzmann, whereas the late Middle to early Late Jurassic cherty sediments are separated by a fault.
4) These sedimentary succession show the Watzmann Block (with the Watzmann- and the Hochkalter-Mts.) as a tectonic isolated block, separated by ?Miocene strike-slipe faults from the Berchtesgaden Block to the north, the Roßfeld–Göll Block to the east, and the Sillenkopf–Gotzen Block to the southeast. The Berchtesgaden Block to the north show a rather similar Triassic to Jurassic sedimentary succession.

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References

FRISCH, W. & GAWLICK, H.-J. (2003): The nappe structure of the central Northern Calcareous Alps and its disintegration during Miocene tectonic extrusion – a contribution to understanding the orogenic evolution of the Eastern Alps.– Int. J. Earth Sci. (Geol. Rdsch.), 92, 712–727, Berlin.

MISSONI, S., GAWLICK, H.-J., SUZUKI, H. & DIERSCHE, V. (2005): Palaeogeography of the Watzmann Block (Berchtesgaden Calcareous Alps) – new results based on the analysis of the Triassic to Jurassic sedimentary succession.– Journal of Alpine Geology (Mitt. Ges. Geol. Bergbaustud. Österr.), 47, 169–209, Wien.

Pebble Petrology and Detrital Mica $^{40}Ar/^{39}Ar$ Geochronology from Tertiary Foreland Basins of SE France: Implications for Mountain Building and Exhumation in the Western Alps

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Key Words: Western Alps, Provenance, $^{40}Ar/^{39}Ar$ geochronology, Mineral chemistry, Exhumation.

During the Tertiary, syn-orogenic sediments were deposited in a series of foreland basins formed on the western foothills of the evolving Western Alpine orogen. Thus, the detritus contained within those basins is expected to store valuable information about the paleo-structures and the geodynamic evolution of the Alpine orogen. We conducted a provenance study, comprising electron-microprobe mineral geochemistry and single grain $^{40}Ar/^{39}Ar$ laser-probe geochronology, on detrital white micas (250–500 μm). The grains were separated from coarse-grained lithologies within the Tertiary basins of SE France: Middle to late Eocene sediments were sampled from Val du Guille flysch unit (Briançonnais nappe), St. Clément flysch (Sub-Briançonnais nappe) and the northern edge of Grès d'Annot flysch near Embrun (Digne nappe). Late Eocene–early Oligocene transitional sediments (Grès de Ville and La Poste conglomerate) were sampled in the Barręme basin (Digne nappe). Middle–late Oligocene molasse sediments were sampled in the Barręme basin (Grès Verts) and in the northern Valensole basin near Barlés (Molasse Rauge), along with middle Miocene marine molasse sediments.

Parallel to the single grain study we have studied the petrology and geochronology of several metamorphic rock pebbles detected in the Oligocene Barręme basin (La Poste conglomerate unit).

A total of 191 electron-microprobe analyses of detrital white mica grains separated from sandstone samples of all different deposition ages displayed relatively low Si content, with Si<3.25 p.f.u; only two individual grains with Si>3.35 p.f.u were found in samples of the Barręme Oligocene basin.

The La-Poste conglomerate unit of the Barręme Oligocene basin is composed predominately of Mesozoic carbonate clasts. Among the other types of lithologies comprising the rest of the clasts composition are rare bluschist pebbles (DE GRACIANSKY et al., 1971). Some of these pebbles, derived from an intermediate to a metabasic protolith, are comprised of garnet, glaucophane, epidote and Si-rich phengite (Si>3.35 p.f.u), our geothermobarometric investigation of these pebbles suggests their equilibration at P–T conditions of 10–12 kbar and 450 °C.

A total of 131 Total Laser-Fusion $^{40}Ar/^{39}Ar$ analyses yielded predominantly pre-Alpine ages, mostly 200–320 Ma, throughout the Tertiary foreland sedimentary sections. Alongside this age group, somewhat younger ages in the range of 160–180 Ma, were recorded in late Eocene sandstones of St. Clément and Grès d'Annot flysch units. A single Eo-Alpine, 96 Ma, grain was detected in middle Miocene sandy marine molasse of the northern Valensole basin. Alpine ages of 35±3 Ma, were recorded only by Si-rich phengites separated from a previously described garnet–blueschist pebble of early Oligocene depositional age.

As a whole, our study reveals the predominance of white micas characterized by pre-Alpine ages and relatively low Si content (Si<3.25 p.f.u) within the Tertiary sedimentary strata of the foreland basins of SE France. From a first look at these results it may be argued that detritus was derived almost exclusively from the Variscan igneous and metamorphic basement of the European plate, which was already exposed at that time in the External massifs of Maures Esterel and Pelvoux (FORD & LICKORISH, 2004). Nonetheless, the wide range of pre-Alpine ages and particularly the presence of ages in the range of 160–260 Ma, is not uniquely compatible with derivation from the Variscan basement of the European plate only. We suggest that a further contribution from higher structural levels of the Alpine edifice should be considered.

One of the unique features of the present western Alpine structure is the absence of an upper plate crustal lid such as the Austroalpine and Southalpine nappes of the Central and Eastern Alps. It seems plausible that the detritus within the late Eocene to early Oligocene basins record the existence of such units in the Western Alps at that time.

Although rare, the presence of blueschist-facies pebbles that yield Alpine ages (ca. 35 Ma) in the foreland basin of Barręme bear great significance, as they provide unequivocal evidence for the exposure of HP–LT metamorphic rock units of the inner Alpine orogen by early Oligocene time. This timing is in agreement with the first appearance of some individual high-Si white mica grains (Si>3.35 p.f.u) in the finer sediments and is further supported by the first appearance of glaucophane within the detrital heavy mineral assemblage of the early Oligocene Barręme basin reported by EVANS & MANGE-RAJETZKY (1991).

The relatively short time lag between the metamorphic event recorded by the blueschist pebble and the deposition age of their host conglomerate (30–32 Ma, according to EVANS & ELLIOTT, 1999) corresponds to high exhumation rate of at least 6 mm/year (assuming burial to HP–LT metamorphic conditions of 12 kbar by 35 Ma) for the internal Western Alps in the transition Eocene–Oligocene.

The data presented above appears to indicate that during the late Eocene, Oligocene and Miocene the inner metamorphic units of the Western Alps were blanketed to the west by low-pressure cover units and could not have contributed much detritus into the western foreland basins, although their exposure at the surface is well indicated by scarce HP–LT pebbles. This conclusion agrees well with the data obtained by CARRAPA et al. (2004) showing the common occurrence of high-Si and Alpine ages in detrital white micas in the Oligocene sediments of the Tertiary Piedmont basin on the eastern side of the orogen.

The proposed reconstructed early Oligocene structure beares much resemblance to the present day structure of the orogen, in which the internal high-grade metamorphic nappes (Acceglio Zone, Schists Lustrés, Monviso and the Dora–Maira Massif) are overlain to the west by the more external nappes (Briançonnais and Subbriançonnais) along SW directed backthrusts. It seems that the Western Alps structure was shaped during a short intensive exhumation event in the late Eocene to early Oligocene time and except from massive erosion of its upper structural units, had not changed much since.

References

CARRAPA, B., DI GIULIO, A. & WIJBRANS, J. (2004): The early stages of the Alpine collision: an image derived from the upper Eocene–lower Oligocene recode in the Alps–Apennines junction area.– Sedimentary geology, 171, 181–203.

DE GRACIANSKY, P.C., LEMOINE, M. & SALIOT, P. (1971): Remarques sur la presence de mineraux et de parageneses du metamorphisme alpine dans les galets des conglomerates oligocenes du syncline de Barreme (Alps de Haute–Provance).– C. R. Acad. Sci. Paris, 272D, 3243–3245.

EVANS, M.J. & MAGNE-RAJETZKY, M.A. (1991): The provenance of sediments in the Barreme thrust top basin, Haute–Provence, France.– In: MORTON, A.C., TODD, S.P. & HAUGHTON, P.D.W. (eds.): Developments in sedimentary provenance studies. Geol. Soc. London Spec. Publ., 57, 323–342.

EVANS, M.J. & ELLIOTT, T. (1999): Evolution of a thrust sheet top basin: the Tertiary Barręme Basin, Alpes-de-Haute–Provence, France.– GSA Bulletin, 111, 1617–1643.

FORD, M. & LICKORISH, W.H. (2004): Foreland basin evolution around the western Alpine Arc.– In: JOSEPH, P. & LOMAS, S.A. (eds.): Deep-Water sedimentation in the Alpine Basin of SE France: New perspective on the Grès d'Annot and related systems. Geol. Soc. London Spec. Publ., 221, 39–63.

Cretaceous Tectonic Evolution of the Alpine–Balkan–Carpathian–Dinaride Orogen

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Key Words: Cretaceous, Tectonic evolution, Alpine, Balkan, Carpathian, Dinaride, Orogen.

The Tertiary-aged Alpine–Balkan–Carpathian–Dinaride (ABCD) Orogen comprises two strands of a Cretaceous-aged precursor orogen: (1) Austroalpine units (ALCAPA block) and its eastward extension in Carpathians and Sred-nogorie zone of the Balkan area, and (2) Inner Dinarides with its extension into Apuseni Mountains (Tisia block), Southalpine units and Hellenides. Extensive new data and data taken from the literature allow establish some common features all over the area, which can be summarized as follows. In the Cretaceous-aged ABCD orogen, we distinguish between (1) pre-Late Cretaceous emplacement of Dinaric, Meliata, Mures and, possibly, Vardar ophiolites, (2) pre-Late Cretaceous collisional structures, mainly ductile thrusts, and (3) the Late Cretaceous formation of collapse sedimentary basins, likely due to retreat of the subduction zone of the Penninic ocean. These basins are associated with the so-called Banatite magmatism in south-eastern sectors of the Apuseni–Balkan strand, together with ductile low-angle normal and high-angle strike-slip faults that relate to the basin formation. The collisional structures constitute together a double-vergent early Late Cretaceous orogen, with Europe-directed ductile thrusts in the Austroalpine–Carpathian–Balkan strand, and Adria-directed thrusts in Inner Dinarides.

A reconstruction of the Late Cretaceous tectonic configuration is mainly based on palaeomagnetic data from Late Cretaceous units. This shows that the Upper Cretaceous units can be divided into several continental units including (1) the ALCAPA (ALpine–CArpathian–PAnnonian) block comprising the Austroalpine units in the Eastern Alps and Inner Western Carpathians, (2) the Tisia block extending from Zagreb in Croatia to the Apuseni Mountains, (3) the Dacia block which includes the Eastern und Southern Carpathians and the Balkan, (4) the Rhodope block and (5) the South-Alpine Dinaric block. The essential result of this restoration is that the ALCAPA, Tisia and Dacia blocks together formed an E–W-trending, straight orogen during the critical time at ca. 80 Ma when most of the so-called Banatite magmatism occurred. This view is also supported by palaeomagnetic data from Banatites, which call for post-Cretaceous bending and orocline formation of the Banatite belt during its invasion into the Carpathian arc. In some interpretations, the Balkan sector of the Dacia block was connected with the Moesian platform during the Late Cretaceous, and the Balkan block with the Rhodope block. Therefore, it is reasonable to assume that the Cretaceous orogen has separated a northern, South Penninic oceanic tract from remnants of the still open Tethys ocean in the east, whereas both continental orogenic strands merged in the northwest/west. There, the South Alpine–Dinaric belt was connected with the southern ALCAPA block when an open ocean was closed in a scissor-like manner due to convergence of the Dinarides towards the ALCAPA Tisia–Dacia–Rhodope continent. Note that early Late Cretaceous compressional structures show opposite vergency, Adria-directed in Inner Dinarides and Europa-directed in the Austroalpine–Carpathian–Balkan strand. In summary, reconstructions indicate open oceanic tracts, both to the north and southeast of the Late Cretaceous orogenic belt. This belt was attached to the Moesian platform in the east, and to the Adriatic microplate in the west. This leaves open the question as to which geodynamic process occurred within this belt during the Late Cretaceous, e.g. continuous subduction or collision along segments that are attached to continental blocks (Moesia/Europe) in the east, and the Adriatic block in the west. Orogenic polarity of the closure and nappe stacking was, respectively, to the N and NW rotating units back in the present-day position.

In detail, in the Austroalpine–Carpathian–Balkan strand, collision between Austroalpine units in a footwall position and emplacement of overlying Meliata/Juvavic/Silice units in a hangingwall position occurred during the early Late Cretaceous. Nappe stacking was directed towards the NW and W, and probably migrated from hangingwall to footwall. Upper plate Austroalpine units form klippen with very low- to low-grade metamorphic overprint during Cretaceous continent–continent collision. These juxtapose deeper Austroalpine units of the central sectors of the Eastern Alps with a metamorphic overprint that increases from greenschist facies conditions in the north to eclogite facies metamorphism in the south. At approximately the same time within the Cretaceous, similar ductile nappe structures were formed in the Apuseni, Southern and Eastern Carpathians. In the Southern Carpathians, the Severin oceanic rift was closed during the early Late Cretaceous. In the Apuseni Mountains, a ductile nappe stack formed at ca. 120–110 Ma, and the Mures ophiolite was subsequently emplaced onto the underlying basement-cover nappes during the Late Cretaceous. Each of these present-day isolated mountain groups represents basement-cover nappes that formed during ductile thrusting at very low-grade to low-grade metamorphic conditions. The Southern Carpathians include, from footwall to hangingwall, the Danubian basement-cover nappe stack, the Jurassic Severin ophiolite and the Getic–Supragetic nappe complexes. This suggests the presence of an oceanic tract between the Moesian platform and the Dacian units. The whole nappe stack formed at ca. 120 to 80 Ma, whilst post-orogenic collapse started slightly prior to ca. 80 Ma.

The Bulgarian Balkan region is linked by the Serbian Timok zone with the extension of the Danubian nappe complex of the Southern Carpathians. In Bulgaria, the Srednogorie zone comprises specific Upper Cretaceous sedimentary/volcanogenic basins. The Srednogorie zone extends to the Black Sea and there it is also superposed onto the southerly adjacent Strandja zone with mainly Late Jurassic tectonism. The basement of the Srednogorie zone experienced weak early Late Cretaceous deformation ca. at 102–100 Ma, which is post-dated by volcano–sedimentary basins.

Upper Cretaceous collapse basins sealed the ophiolite sutures (e.g. Meliata, Severin, Dinaric and Vardar sutures) and previously formed basement-cover nappe structures all over the area. Gosau-type basins can be traced from the Eastern Alps to the Srednogorie zone and represent a prominent feature of the region. The formation of the Gosau basins in the Eastern Alps was associated with sinistral wrenching along ca. ENE-trending faults, normal faulting at shallow crustal levels and exhumation of eclogite-bearing crust within Austroalpine units. This led to the juxtaposition of eclogite-/amphibolite-facies metamorphic rocks of lower tectonic units to very low-grade to low-grade metamorphic rocks of upper tectonic units along ductile low-angle normal faults in the Eastern Alps, Western Carpathians, Apuseni Mountains and the Balkan–Rhodope Mountains.

The Bulgarian Balkan region shows weak early Late Cretaceous deformation that is post-dated by volcano–sedimentary basins occurring within the Srednogorie Zone. The dextral Maritsa shear zone, which also in part includes sheared Late Cretaceous granites (78–80 Ma), separates the Srednogorie zone from the southerly adjacent Rhodope massif. In the Rhodope massif, the uppermost unit is a Cretaceous metamorphic unit that formed within Cretaceous amphibolite facies metamorphic conditions. The Srednogorie Zone shows subsidence and formation of local sedimentary basins, volcanism and shallow granitoid intrusions. Furthermore, ductile structures suggest that the NW-trending Maritsa shear zone and splays to the N (e.g. Iskar–Lavonitsa fault zone, Kamenitsa–Rakovitsa, etc.) can be regarded as a Late Cretaceous dextral wrench corridor that was active mainly under greenschist facies metamorphic conditions. Since igneous rocks (e.g. the Vitosha granite) intruded into the Maritsa shear zone were dated at ca. 80 Ma, initial exhumation and cooling of the uppermost tectonic units exposed within the Rhodope Mountains should also have an age of ca. 80 Ma, contemporaneous with main subsidence in the adjacent Srednogorie Basin.

In some areas, volcanic products are intercalated between fossil-bearing Late Cretaceous rocks, as in the Hateg basin of the Southern Carpathians and in the Srednogorie Zone. Biostratigraphic data indicate a Cenomanian to Maastrichtian age. Correlation of volcanics with nearby plutonic suites has not yet been carried out. It has also to be noted that beyond the present-day banatite belt, Late Cretaceous to earliest Palaeogene (sub-)volcanic rocks and granites were recently reported from the Dinarides in Croatia (part of the Tisia block) and Western Carpathians.

Banatite magmatism and mineralisation took place contemporaneously with the formation of the Gosau-type collapse basins, and may be interpreted to represent either a product of continuous northward subduction or post-collisional I-type magmatism due to break-off of the subducted lithosphere. Except the unique Rochovce granite, Cretaceous magmatism has not affected the ALCAPA block of the ABCD belt. The lack of magmatism in the Alpine sectors is an enigma until now. Possible explanations for this fact are: (1) the presence of only a small, subducting ocean but note the at least 500 km wide ocean, and (2) subduction of mainly water-poor carbonates which are not appropriate to trigger melting in the overlying lithospheric mantle wedge.

Subduction, Slab Detachment and Mineralization: the Neogene in the Apuseni Mountains and Carpathians

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Key Words: Subduction, Slab detachment, Mineralization, Neogene, Apuseni Mountains, Carpathians.

The Inner Carpathians comprise several distinct Neogene late-stage orogenic Pb–Zn–Cu–Ag–Au ore districts. The mineral deposits in these districts are closely related to volcanic and subvolcanic rocks, and represent mainly porphyry and epithermal vein deposits, which formed within short periods of time in each district. Here, we discuss possible geodynamic and structural controls that suggest why some of the Neogene volcanic districts within the Carpathians comprise abundant mineralization, while others are barren. The Neogene period has been characterized by an overall geodynamic regime of subduction, where primary roll-back of the subducted slab and secondary phenomena, like slab break-off and the development of slab windows, could have contributed to the evolution, location and type of volcanic activity. Structural features developing in the overlying lithosphere and visible in the Carpathian crust, such as transtensional wrench corridors, block rotation and relay structures due to extrusion tectonics, have probably acted in focusing hydrothermal activity. As a result of particular events in the geodynamic evolution and the development of specific structural features, mineralization formed during fluid channelling within transtensional wrench settings and during periods of extension related to block rotation.

In the Slovakian ore district of the Western Carpathians, Neogene volcanism and associated mineralization were localized by sinistral, NE-trending wrench corridors, which formed part of the extruding Alcapa block. The Baia Mare ore district, in the Eastern Carpathians, reflects a transtensional wrench setting on distributed oversteps close to the termination of the Dragos Voda fault. There, mineralization was spatially controlled by the transtensional Dragos Voda master fault and associated cross-fault systems. The Golden Quadrangle Cu–Au ore district of the Southern Apuseni Mountains reflects an unusual rotated transtensional/extensional setting close to the termination of a graben system. There, fluid flow was probably localized by fault propagation at the inner tip of the graben system.

The spatial and temporal evolution of the magmatism and its changing geochemical signature from (north)west to (south)east strongly suggests a link with the contemporaneous north-eastward roll-back of the subducted slab and a progressive south-eastward detachment during accelerating roll-back. This geodynamic evolution is further supported by the present-day overall and detailed mantle lithospheric density images, the present-day heat flow patterns, the crustal architecture and its interpreted evolu-

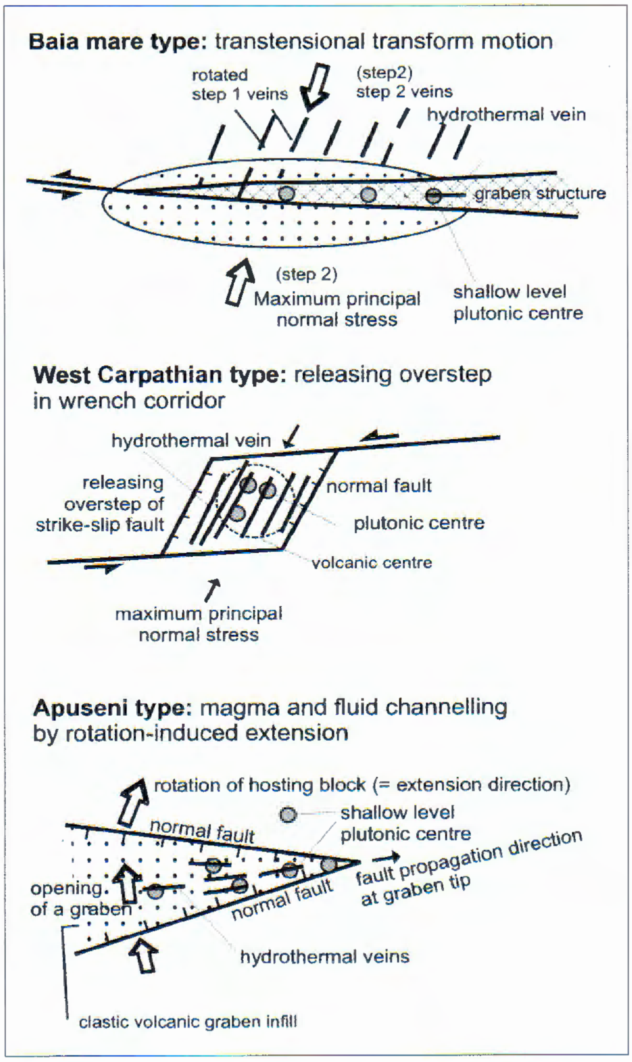

Fig. 1 Generalized models, shown in plan view, of the geodynamic control of late-stage orogenic systems, based on observations in the Inner Carpathians. Apuseni type – Slab window and extension. Baia Mare type – Magma and fluid channelling by intersection of a transform fault and volcanic chain. West Carpathians type – Wrench corridor type of magma and fluid channelling.

tion, and the spatial and temporal evolution of depocentres around the Carpathian arc.

In contrast to all these features, the mineral deposits in the West Carpathians, East Carpathians and Apuseni Mountains are too synchronous with respect to their individual volcanic history and contrast too much with younger volcanics of similar style, but barren, in south-eastern parts of the Carpathians to simply link them directly to the slab evolution. In all three districts, the presence of magmatic fluids released from shallow plutons and their mixing with meteoric water were critical for mineralization, requiring transtensional or extensional local regimes at the time of mineralization, possibly following initial compressional regimes.

These three systems show that mineralization was probably controlled by the superposition of favourable mantle lithospheric conditions and partly independent, evolving upper crustal deformation conditions.

In the 13 to 11 Ma period the dominant mineralization formed all across the Carpathians, and was superimposed on structurally favourable crustal areas with, at that time, volcanic–hydrothermal activity. The period may reflect the moment when the (upper part of the) crust failed under lithospheric extension imposed by the slab evolution. This crustal failure would have fragmented the overriding plate, possibly breaking up the thermal lid, to provoke intensive fluid flow in specific areas, and allowed subsequent accelerated tectonic development, block rotation and extrusion of a "family of sub-blocks" that are arbitrarily regarded as the Tisia–Dacia or Alcapa blocks, even though they have lost their internal entity.

Relationship Between Nappe Thrusting and Coeval Sedimentation: Application to Cretaceous Thrusting in the Northern Calcareous Alps

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Key Words: Synorogenic sediments, Thrust geometry, Eastern Alps.

In the western part of the Northern Calcareous Alps (NCA), all nappe units are exposed due to an overall eastward plunge of structures. The large nappe units are, from top to bottom, the Inntal, Lechtal and Allgäu nappes. The Allgäu and Inntal nappes are frontal and trailing imbricates of the Lechtal nappe, and the Cenomanrandschuppe (CRS) is a frontal imbricate of the Allgäu nappe (Fig. 1c). The thickness of the nappe units is in the range of 4 km (EISBACHER et al., 1990).

The switch from passive margin to synorogenic sedimentation in the western NCA took place under deep-water conditions and is documented by the transition from marly or siliceous carbonates to marls, sandy marls and coarse clastic deposits. Synorogenic sedimentation develops gradually and conformably from passive margin sedimentation in the CRS, the Allgäu and southern Lechtal nappes. In contrast, synorogenic sediments on the northern Lechtal nappe and the Inntal nappe record surface uplift and subsequent erosion, then transgression and subsidence. To interpret these contrasting histories of synorogenic sedimentation correctly, I first discuss the expected distribution of synorogenic sediments in relation to nappe thrusting.

The geometry of fault-bend folding has been used to construct retrodeformable cross sections of thin-skinned fold-and-thrust belts (e.g. DAHLSTROM, 1969). Assuming a ramp–flat geometry, thrusting in a deep marine environment has following consequences: As the frontal part of the thrust unit climbs up the ramp, water depth above the area of structural thickening decreases. An isolated carbonate platform develops on top of the evolving structure, or, if vertical growth is fast, short-lived carbonate buildups (Fig. 1a), which shed biogenic detritus into the surrounding deep marine areas. At the foreland and hinterland dipping panels of the structure, angular unconformities in synorogenic sediments will record growth if the structure (e.g. MEDWEDEFF, 1989). Continued growth will uplift the thrust unit above and behind the ramp above sea level. The thrust unit covers successively larger areas of the upper footwall flat and ends sedimentation in the overthrust areas.

The synorogenic sedimentary successions of the western NCA can be compared to specific positions in such a model (ORTNER, 2003):

Upper Footwall sedimentation: On the upper footwall flat (1 in Fig. 1a) below the thrusted units, conformable onset of synorogenic sedimentation probably records distant onset of contraction related to orogeny, and deposition of shallow water biogenic detritus shows the approaching of the thrust unit. The youngest sediments below the thrust record the minimum age of thrusting at the point of observation. This situation is comparable to Aptian–Albian synorogenic sedimentation of the Tannheim and Losenstein Fms. on top of the Allgäu nappe, which are overlain by the Lechtal nappe, and to Albian–Cenomanian synorogenic sedimentation of the Lech Fm. on top of the southern Lechtal nappe, which is overlain by the Inntal nappe. The uppermost Lech Fm. locally contains shallow water detritus transported by gravity flows (LEISS, 1992) and thereby records the destruction of carbonate buildups at the flanks of the approaching Inntal nappe.

Nappe-top sedimentation: On top of the thrust unit, where structural thickening has taken place, unconformable transgression of terrestric sediments on deeply eroded older rocks records surface uplift. The Branderfleck Fm. on top of the northern Lechtal nappe and of the Gosau Group on top of the Inntal nappe are found in this structural position (4 in Fig. 1a).

In the **foreland and the hinterland of the structure**, undisturbed synorogenic sedimentation will continue (1 and 2 in Fig. 1a, respectively). The CRS formed the northern continuation of the Allgäu nappe prior to the Campanian, when it was overthrust by the Lechtal nappe. The CRS has a conformable and continuous synorogenic sedimentary succession from the Aptian to the Campanian, overlapping both Upper Footwall sedimentation below and Nappe-top sedimentation on top of the Lechtal nappe. The CRS formed the foreland during thrusting of the northern Lechtal nappe. The hinterland in relation to the northern Lechtal nappe record conformable sedimentation up the Cenomanian, and was then overthrust by the Inntal nappe. It forms the upper footwall in relation to thrusting of the Inntal nappe.

Using such a model for synorogenic sedimentation and coeval thrusting has great predictive power, especially when working in poorly exposed areas, because it concentrates on simple geometric relationships between syntectonic sediments and their substratum.

References

DAHLSTROM, C.D.A. (1969): Balanced cross sections.– Can. J. Earth Sci., 6, 743–757, Toronto.

EISBACHER, G.H., LINZER, G. & MEIER, L. (1990): A Depth extrapolated Structural Transect Across the Northern Calcareous Alps of Western Tirol.– Ecl. Geol. Helv., 83, 711–725, Basel.

LEISS, O. (1992): Orogenically Controlled Sedimentation in the Lechtaler Kreideschiefer (Lechtal Shale; Cretaceous) and

Geodynamics of the Inner Western NCA (Northern Calcareous Alps; Lechtal Alps).– Geol. Rdsch., 81, 603–684, Stuttgart.

MEDWEDEFF, D.A. (1989): Growth fault-bend folding at southeast Lost Hills, San Joaquin valley, California.– AAPG Bull., 73, 54–67, Tulsa.

ORTNER, H. (2003): Cretaceous thrusting in the western part of the Northern Calcareous Alps (Austria) – evidences from synorogenic sedimentation and structural data.– Mitt. Österr. Geol. Ges., 94, 63–77, Wien.

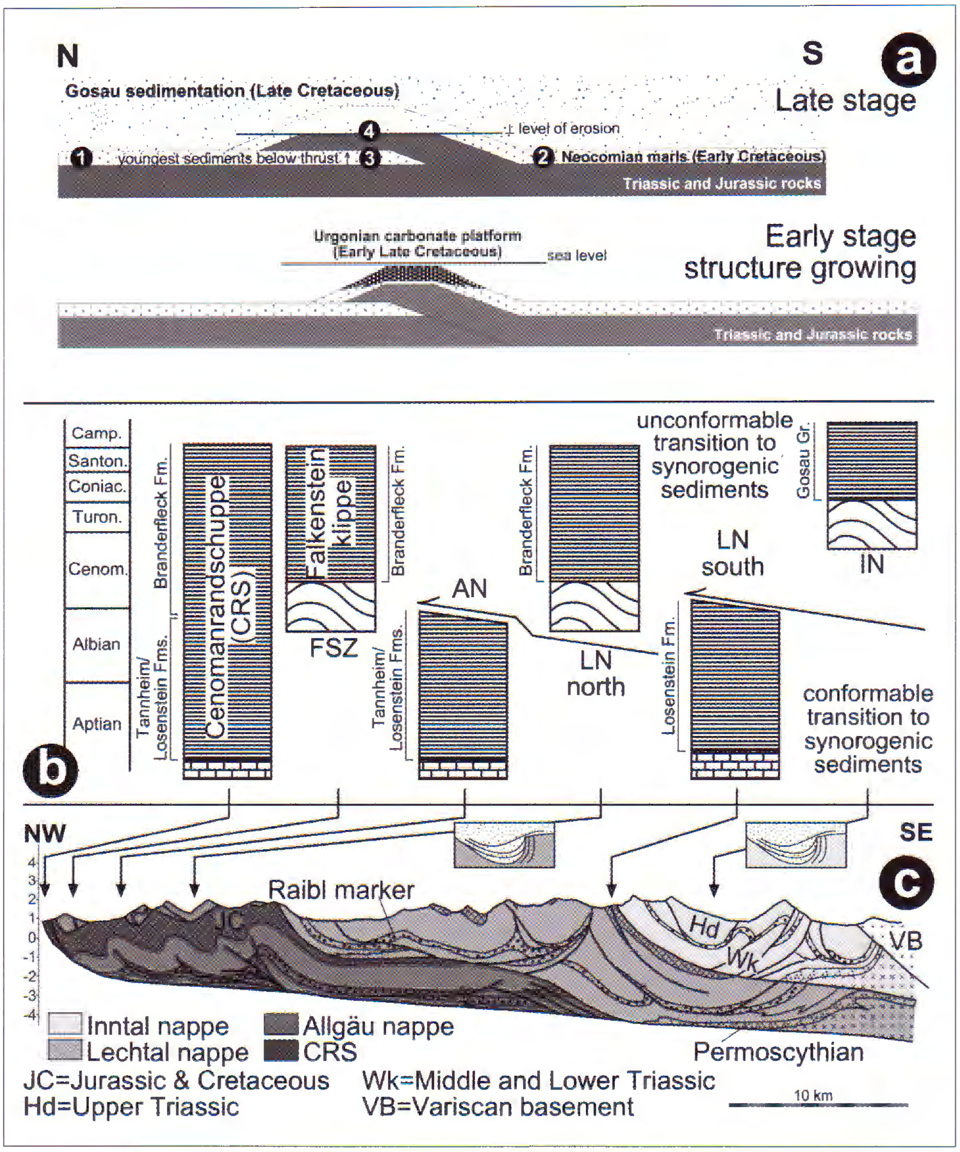

Fig. 1 For description see text.

3D-fold Geometry in the Rätikon Mountains, Vorarlberg: The Role of Superposed Folding

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Key Words: Polyphase folding, Nappe thrusting.

Our study of the nappe and fold structure of the area was motivated by the fact that the westernmost Northern Calcareous Alps (NCA) occupy the transitional zone between kinematically different blocks. Cretaceous shortening in the basement units to the southeast was top to the west (e.g. FROITZHEIM et al., 1994), whereas Cretaceous shortening in the NCA was top to northwest (e.g. EISBACHER & BRANDNER, 1996). We studied the structure of the eastern Rätikon mountains to establish an chronology of deformations based on superposed folding and brittle deformation.

In the westernmost part of the Northern Calcareous Alps, the deepest part of the nappe stack of the NCA is exposed. On a large scale, the "Schollen" as defined by early workers in the area (see TOLLMANN, 1976) can be seen as a hinterland-dipping duplex developed between the sole thrust on top of the Penninic Arosa zone, which is dragged into the NCA along thrust planes, and a roof thrust below an (unknown) higher tectonic unit. The Zimba–Schesaplana nappe, which occupies most of the investigated area, is has a simple northern part, which is dominated by an anticline–syncline system verging to NW with NE-trending fold axis, and a complex southern part. The continuation of the anticline–syncline system to the south is isoclinal, with a flat lying axial plane. It is refolded by a second generation of folds with ENE-trending axes and steep axial planes, resulting in a type 2 fold interference pattern. However, as we deal with brittle deformations, where folding occurs above detachments, the interference pattern is not fully developed. In all parts of the area, significant differences to the classic interference pattern is created by folding of Jurassic half graben structures, which are documented by dramatic changes in thickness and facies of Jurassic sediments.

A succession of deformations is as follows:

1) Jurassic normal faulting
2) Cretaceous folding associated to NW-directed thrusting after deposition of Turonian shales
3) Cenozoic folding associated to NNE-directed thrusting affecting Cretaceous folds

The present arrangement of nappes of different origin (Lower Austroalpine Mittagsspitzzone, Upper Austroalpine NCA, and Silvretta basement unit from bottom to top is most probably a result of Cenozoic out-of-sequence movements of the Silvretta basement unit, because this contact cuts all other contacts obliquely.

References

EISBACHER, G.H. & BRANDNER, R. (1996): Superposed fold thrust structures and high angle faults, northwestern Calcareous Alps, Austria.– Ecl. Geol. Helv., 89, 553–571, Basel.

FROITZHEIM, N., SCHMID, St. & CONTI, P. (1994): Repeated change from crustal shortening to orogen parallel extension in the Austroalpine units of Graubünden.– Ecl. Geol. Helv., 87, 559–612, Basel.

TOLLMANN, A. (1976): Der Bau der Nördlichen Kalkalpen.– Monographie der Nördlichen Kalkalpen, Teil III, Deuticke, Wien, 449 p.

Internal Deformation of the Monte Rosa Nappe Along the Stellihorn Shear Zone

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Key Words: Pennine Alps, Monte Rosa nappe, Shear zones, Neutron texture goniometry.

The Monte Rosa nappe in the Pennine Alps was subject to Tertiary eclogite-facies metamorphism during Alpine orogeny. During subsequent stages of exhumation, the nappe's southern boundary with the overlying Zermatt–Saas and Balma ophiolite units was sheared and folded in the course of four deformation phases (D_1 to D_4). Northwest-vergent shear movements (D_1) were followed by large-scale folding and (south)west-vergent shearing (D_2), and these in turn are postdated by another generation of large-scale folds and contemporaneous southeast-vergent shearing (D_3). Southeast-vergent shearing probably continued while the Pennine units were steepened along the Periadriatic line in the southern limb of the Vanzone antiform (D_4).

Within the Monte Rosa nappe, D_1 to D_3 produced relatively little and unevenly distributed strain with the exception of the Stellihorn shear zone where considerable shear deformation was localized. This shear zone runs in north–south direction from the upper Saas valley (Valais, Switzerland) through the Anzasca valley into the northernmost part of the Sesia valley (Piemonte, Italy) (Fig. 1). It divides the nappe into an upper and lower part and a western and eastern part in cross section and map view, respectively. As works of BEARTH (1952, 1958) already implied, this shear zone also roughly corresponds to a petrological boundary separating oligoclase-bearing rocks from albite-bearing ones in the footwall and hangingwall, respectively. The deformation in the shear zone took mainly place under greenschist-facies conditions.

Although in largest parts of the Stellihorn shear zone the mylonitic foliation is composite (D_1 to D_3) and the relative age of the deformation phases cannot be recognized with certainty, fold overprinting relations at the southern border of the Monte Rosa nappe (Sesia valley) and overprinting minor shear zones branching off from the major Stellihorn shear zone at the northern border (Mattmark area, Saas valley) yield a regionally consistent deformation history for transport directions of D_1 to D_3 as described above. The Stellihorn mylonites in many cases reveal this polyphase deformation in that the foliation plane bears two or more stretching lineations. Pole figures of quartz {c}, {m}, and {a} obtained by neutron texture goniometry document the three deformation phases and according shear senses by mostly „monoclinic" symmetries, i.e. oblique girdles and point maxima rotated from the pole to the foliation (in case of {c}) and the stretching lineation ({m}, {a}) (Fig. 1). However, in some cases (MR160, MR173, MR174, MR190) the pole figures had to be rotaded around the pole to the foliation until the strongest {a} maximum lay at the edge of the projection close to the E–W direction (reconstructed stretching lineation) and c-axes within the foliation plane lay in the centre of the projection. Assumed that a texture was formed by monophase shearing, the resulting geometries are then in accord with intracrystalline deformation by slip systems with slip direction <a>, and no other slip system is supposed to be active under greenschist-facies conditions. Although the deformation of the Stellihorn shear zone was polyphase, the stretching lineations reconstructed by this procedure are weakly preserved in the according hand specimens in case of MR160 and MR173. Moreover, in another sample (MR186) the texture fits well to the main stretching lineation but seems unaffected by strain increments that produced another lineation visible in the hand specimen. Compared to the regional kinematic history, the textures of the above-mentioned samples correspond to the stretching lineation which is supposed to be older than the other visible one(s). Therefore we conclude, that the textures tended to adjust more slowly to changing kinematic regimes than the macroscopic structures and may therefore archive information about strain which is otherwise erased. Notably the northwest-vergent D_1 movements seem to have had a stronger impact than now reported by macroscopic structures.

Two considerations suggest that the Stellihorn shear zone was originally a normal fault: (1) During D_1 the Monte Rosa nappe was exhumed from eclogite- to greenschist-facies conditions. This is rather in line with normal faulting than with reverse faulting. (2) If it was not a normal fault, it should not separate greenschist-facies rocks above from amphibolite-facies rocks below (provided, that this zonation really is the result of transport along the shear zone). However, a more detailed model of the structural evolution and significance of the Stellihorn shear zone is still to be developed.

References

BEARTH, P. (1952): Geologie und Petrographie des Monte Rosa.– Beitr. geol. Karte Schweiz 96, 94 pp.

BEARTH, P. (1958): Über einen Wechsel der Mineralfazies in der Wurzelzone des Penninikums.– Schweiz. Mineral. Petrogr. Mitt., 38, 363–373.

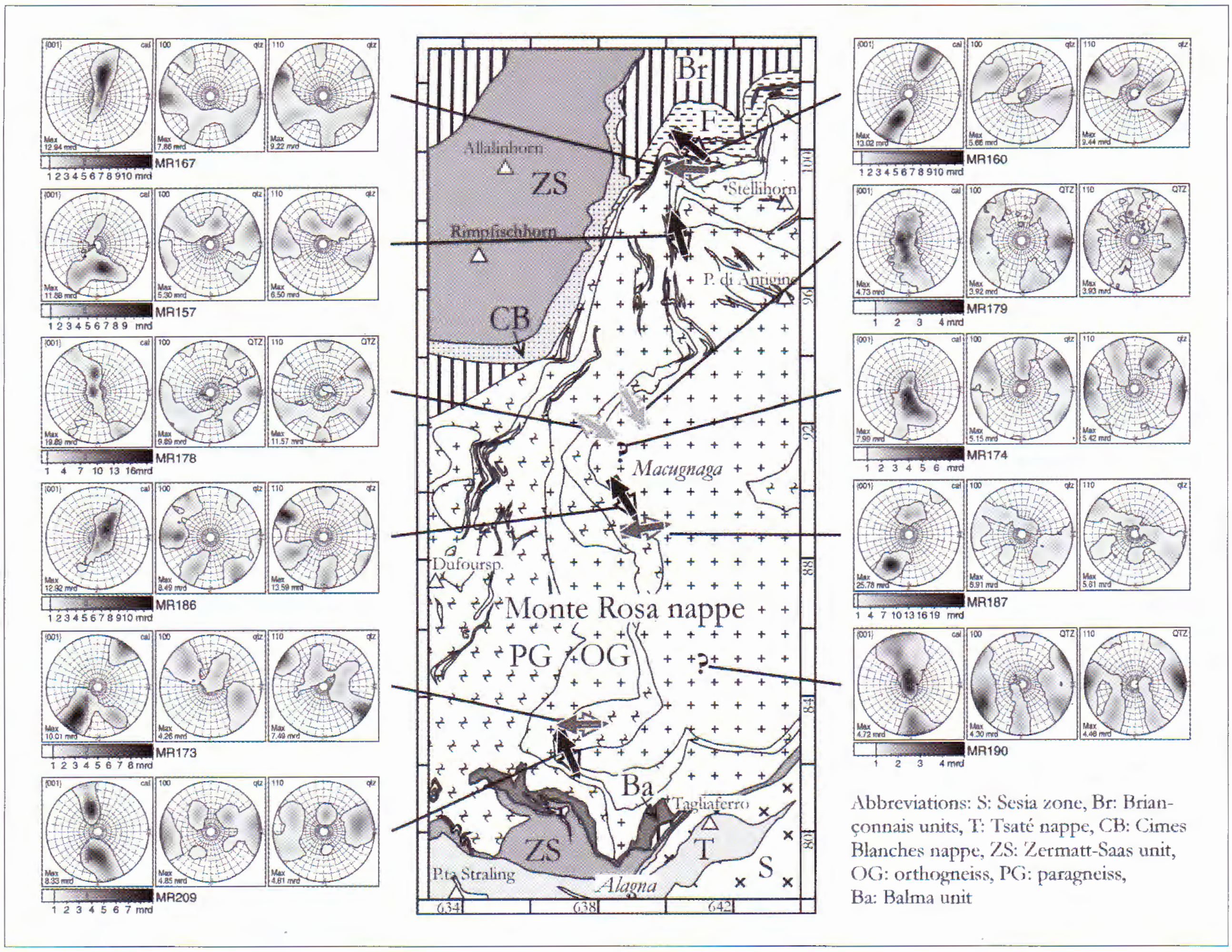

Fig. 1 Pole figures (upper-hemisphere Wulff projection) of quartzite textures obtained by neutron texture goniometry and infered shear senses along the Stellihorn shear zone. Black, middle grey, and light grey arrows in the map denote D_1 (top-to-the-northwest), D_2 (top-to-the-west), and D_3 (top-to-the-southeast) shearing. Kilometric coordinates in the map frame refer to the Swiss national coordinate system.

Integration of Geophysical and Geological Data in a Foreland Fold and Thrust Belt – Middle Adriatic (South Croatia)

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Key Words: Mesozoic carbonats, Synsedimentary kinematics, Tectonics.

Based on the interpretation of seismic profiles taken in the off-shore and near-shore areas of the Adriatic carbonate platform (AdCP), a map of depths to the basement of the carbonate complex and a map of depths to the hanging wall of the carbonate complex have been made. These two planes delimit the Mesozoic carbonate complex, with variously thick Eocene carbonates in its topmost part. The total thickness of the carbonates has been computed on the basis of the velocity law and thickness of individual lithostratigraphic units measured on the surface and in the boreholes. Thus were separated the belts in which the Mesozoic, particularly the Late Cretaceous, synsedimentary tectonics has produced considerable subsidence, resulting in increased thickness of the Mesozoic carbonate complex. On the other hand, sedimentological and structural research in the near-shore and island areas of the AdCP has revealed a pronounced lithological diversification of facies, associated with synsedimentary kinematic indicators (PRTOLJAN et al., 2004). Correlation of surface and subsurface data enabled the definition of main kinematic epochs and their corresponding geomorphological structures. It has been observed, that, in addition to varying thickness of the carbonate complex, in some parts there are kilometer-sized, subsurface structures. They are often asymmetrical and/or overturned, SW verging, with frequent bioclastic limestones of the packstone–grainstone type in their limbs. These anticlinal/synclinal structures reflect local structural deformations that correspond, by their dimensions and tectonic style, to the surface structures developed on a regional scale. The subsurface structures are buried (conserved) under younger lithostratigraphic units, which are characterized by very variable thickness all over the AdCP. This is particularly well expressed in the Sveti Duh, Dol, and Pučišća formations (GUŠIĆ & JELASKA, 1990). In some parts of the area investigated these formations may reach a thickness of hundred and more meters, whereas in other, paleomorphologically more outstanding, regions may be reduced to several meters or even completely lacking, in which case they are substituted by other lithotypes (reefal or bioclastic w–p–g, turbiditic limestones, etc.).

In that context we considered the reduced thicknesses and/or total absence of Upper Cretaceous deposits in the northeastern (continental) belt of the AdCP, and, on the other hand, in the extreme southwestern part, i.e., in the Eastern Adriatic slope (GRANDIĆ et al., 1997a, b). Thus, it may be concluded that the increasingly large thickness of the Mesozoic carbonate complex in the central archipelago area is the direct result of synsedimentary tectonics. The accumulation of sediments in the deeper part of the basin was produced by re-deposition of packages of semi-lithified deposits but also by longer duration of sedimentation. Most pronounced were the depressions south of Šolta Island, where the maximum thickness of the carbonate complex amounts to ca. 9500 m, and south of the mountains Biokovo and Mosor (9500 m), Brač Island (8600 m), western part of Hvar Island (7500 m), eastern part of Hvar Island (7450 m), and in the depression between the Šćedro and Korčula islands (7200 m). In the same zones, also the Tertiary and Quaternary siliciclastic–carbonate and clastic deposits, that overlie the carbonate complex, have the greatest thickness. Thus, the clastic deposits have the greatest thickness in the syncline north of Čiovo Island (5600 m), south of Mosor and Biokovo mountains (2030 m), and in elongated, compressed synclines situated southeast of Brač (2840 m) and Hvar islands (3440 m).

The present-day geological relations in the AdCP area are the result of several tectonic–sedimentary cycles, each of which built onto the preceding one and added successive structural elements, eventually producing the present-day structural–geomorphologic makeup.

The first epoch of the Mesozoic kinematic cycle, with recognizable influence on structural and paleomorphologic relations all over the AdCP, is associated with the Ladinian rifting processes (BERNOULLI & JENKYNS, 1974). During that time, an expressed paleomorphologic differentiation came into being, accompanied by magmatic activity, and producing large emerged surfaces with graben and half-graben structures, separated by labile (fault) zones. From the Late Triassic to the Middle Jurassic persisted a relatively peaceful situation, characterized by platform sedimentation. At the middle of the Late Jurassic (Kimmeridgian) a kinematic epoch occurs, during which large parts of the AdCP were affected, resulting in a paleoenvironmental differentiation ranging from sedimentary environments with pelagic (basinal) sedimentation (the so-called Lemeš Deposits) and to those with emerged surfaces with bauxites.

The Early Cretaceous is characterized by kinematic activity of lesser intensity and in restricted areas, so that a relatively quiet sedimentation was only periodically disrupted by inputs of non-carbonate clastics, but without significant plicative deformations. By the beginning of the Late Cretaceous, new stress led to the re-activation of previous geomorphologic structures but also to the formation of new ones. The initial movements can be recognized all over the

AdCP affecting the Middle and Upper Cenomanian deposits. These movements resulted in structural changes that had significant influence on paleoenvironmental relations, associated with deformations of semi-lithified deposits (slumps, synsedimentary faults, etc.). On one side, we have deepening of the trough with pelagic deposition, whereas on the other side segments of the platform were uptrown and/or tilted, being exposed to subaerial weathering (dessication cracks, breccias, caverns, bauxite pockets). After that, the platform was drowned by the pelagic deposits of the Sveti Duh Formation (Upper Cenomanian–Lower Turonian, which have covered (buried) the already existing structures (GUŠIĆ & JELASKA, 1990, 1993).

In the Santonian–Campanian, there occurred rather significant paleomorphologic changes associated with the general trend of the rise of the central Adriatic belt, initial beginnings of the present-day anticlines and synclines came to being (PRTOLJAN et al., 2003). In that epoch, kilometer- to tens-of-kilometer sized intra-platform troughs were formed, in some of which the pelagic deposition will uninterruptedly continue into the Paleocene.

References

BERNOULLI, D. & JENKYNS, H.C. (1974): Alpine, Mediterranean, and Central Atlantic Mesozoic facies in relation to the early evolution of the Tethys. In: DOTT, R.H. & SHAVER,R. H. (eds.): Modern and ancient geosynclinal sedimentation. SEPM Spec.publ., 19, 129–160, Tulsa.

GRANDIĆ, S., BOROMISA-BALAŠ, E. & ŠUŠTERČIĆ, M. (1997a): Exploration concept and characteristics of the stratigraphic and structural models of the Dinarides in Croatia offshore area.– Nafta, 48/4, 117–128.

GRANDIĆ, S., BOROMISA-BALAŠ, E. & ŠUŠTERČIĆ, M. (1997b): Exploration concept and characteristics of the stratigraphic and structural models of the Dinarides in Croatia offshore area.– Nafta, 48/8–9, 249–266.

GUŠIĆ, I. & JELASKA, V. (1990): Upper Cretaceous Stratigraphy of the Island of Brač.– Djela Jugoslavenske akademije znanosti i umjetnosti, 69, 1–160, Zagreb.

GUŠIĆ, I. & JELASKA, V. (1993): Upper Cenomanian–Lower Turonian sea-level rise and its consequences on the Adriatic carbonate platform.– Geologische Rundschau, 82, 678–686.

PRTOLJAN, B., KRATKOVIĆ, I. & MARKULIN, Ž. (2003): Tectonic control on Adriatic Carbonate Platform sedimentation (Late Cretaceous, South Adriatic).– In: VLAHOVIĆ, I. (ed.): Abstracts Book of 22nd IAS Meeting of Sedimentology, Opatija, Sept. 17–19, 2003, Institute of Geology, Zagreb.

PRTOLJAN, B., IVKOVIĆ, Ž., KRATKOVIĆ, I., MARKULIN, Ž. & GUŠIĆ, I. (2004): Cretaceous paleostress analysis of the Adriatic Carbonate Platform (AdCP).– In: PENA DOS REIS, R., CALLAPEZ, P. & DINIS, P. (eds.)): Abstracts Book of 23rd IAS Meeting of Sedimentology, Coimbra, Portugal, International Association of Sedimentologists, 225.

Transformation of Passive to Active Continental Margin – A Model for the Cretaceous Evolution of the Northern Internal Western Carpathians

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Key Words: Western Carpathians, Passive/active continental margin, Cretaceous.

The NW part of the internal Western Carpathians shows the nappe structure of **the Infratatric superunit (1–5)**, from bottom to top and from N to S: **(1) The Klape nappe**: Three sedimentary megacycles of Cretaceous flysch are observed: (a) prograding Middle Albian to Lower Cenomanian flysch with "exotic" pebbles (e.g. blueschists dated on glaucophane ca. 155 Ma; DAL PIAZ et al., 1995) and olistoliths (Triassic Schreyeralm, Raming/Wetterstein limestones and Hauptdolomit, Jurassic spotted limestones and marls, Jurassic sandy crinoidal limestones and Urgonian limestones) passing into Middle Cenomanian to Turonian marls, sandy marls to shallow-marine sandstones; (b) retrograding Coniacian to Santonian flyschoidal sediments with reefs of rudists and shallow-water organogenic limestones in conglomerates and olistostromes; (c) prograding Campanian/Maastrichtian to Eocene sequence with hemipelagic to pelagic marlstones in Lower Campanian, allodapic material (resedimented organic limestones, orbitoids, corals) in Upper Campanian/Maastrichtian flysch, sandy marls in the Maastrichtian to Eocene, tempestites in the Maastrichtian, olistoliths of Eocene reefs in the Lower Illerdian. **(2) The Manín nappe**: Triassic to Lower Jurassic shallow-water sediments, Middle Jurassic to Lower Cretaceous deep-water sediments, Barremian to Aptian "Urgonian" shallow-water limestones, followed, after a hiatus, by pelagic Lower Albian cherty limestones, Middle Albian to Middle Cenomanian marls (with blocks of Urgonian limestones), Upper Cenomanian to Santonian flysch with sandy–marly layers, Campanian hemipelagites and variegated marls (Couches Rouges) and Upper Campanian to Maastrichtian calcareous sandstones (SALAJ, 1997; MARSCHALKO & RAKÚS, 1997). **(3) The Belice nappe**: late Middle Jurassic to Lower Cretaceous clayee–cherty sediments, Cenomanian to Santonian marls, Santonian to Maastrichtian (?) flysch. **(4) The Humienec nappe**: remnants of micaschist basement, Permoscythian terrestrial and shallow-water siliciclastics, Middle to Upper (?) Triassic platform carbonates, early Lower Jurassic shallow-water, late Lower Jurassic to early Middle Jurassic pelagic sediments. **(5) The Inovec nappe**: micaschist basement, Upper Carboniferous and Permoscythian siliciclastics/volcanics, Middle Triassic platform carbonates. It is overlain by **(6) the Tatric Panská Javorina nappe**: gneiss–granite basement, Triassic to Lower Cretaceous shallow-water to pelagic sedimentary cover as well as **(7, 8) the Fatric and Hronic cover nappes**, sealed by the Central Carpathian Palaeogene sediments.

The nappes of the Infratatric superunit represent the attenuated continental margin after formation of the South Penninic Ocean in the late Early Jurassic. Sedimentary successions of the Humienec and Belice nappes are essential in understanding the Jurassic–Cretaceous dynamics of that margin. The Triassic carbonate platform environment was transformed into an intracontinental rift and a passive continental margin in the Early Jurassic times, which is reflected by pelagization and continued subsidence to deep-water conditions. The syn-rift sequence includes quartzitic sandstones, sandy crinoidal limestones and fine-grained breccias with shallow-water wackestones (all early Lower Jurassic), nodular limestones interlayered with resedimented sandy conglomerates containing allochthonous Triassic and Lower Jurassic clasts as well as unlithified limestones (middle Lower Jurassic). The post-rift sequence starts with pelagic reddish Adnet/Klaus nodular and *Bositra*-limestones, pale turbiditic crinoidal to cherty limestones (latest Lower to early Middle Jurassic).

Previous scenario is reconstructed from the Humienec nappe olistoliths contained in the Upper Cretaceous flysch sequence. It shows that breakup of the South-Penninic oceanic realm occurred in late Early Jurassic times, which conforms with recent radiometric age dating on Penninic oceanic crust by RATSCHBACHER et al. (2004) in the Eastern Alps.

The continuing passive margin succession is reconstructed from the Belice nappe. It starts with Middle Jurassic dark clayee–marly shales. These pass into late Middle to Upper Jurassic cherty shales containing a 4–5 m thick marker horizon of red radiolarite (Oxfordian; PLAŠIENKA et al., 1994) and turbidites with shallow-water carbonate clasts in the upper part (?Kimmeridgian/?Tithonian). They are followed by Maiolica-type limestone (Tithonian to Berriasian) overlain by cherty marly sediments containing a 0,8 m thick reddish radiolaritic shale layer changing with indistinct hiatus to the reddish marls of Couches Rouges type (Cenomanian to Santonian, with *Marginotruncata coronata* BOLLI), and a thick flysch sequence (Santonian to Maastrichtian?) with conglomerate beds, olistoliths, olistostromes and scarp breccia blocks.

The Inovec sedimentation area followed continentwards of the Belice and Humienec areas, on thicker crust. The advancing Humienec and Inovec nappes from the south was one source area for the flysch in the Belice forearc basin. Metamorphic conditions of the Infratatric Inovec nappe were 250–300°C and ca. 5 kbar.

The Jurassic to Lower Cretaceous passive margin sediments and thinned basement fragments of the Manín/Klape and Belice/Humienec areas became incorporated into the accretionary wedge, overlain (?) by the Meliata nappe. This new scenario was established in Albian times, which is, therefore, a good indicator for the start of subduction in the South Penninic realm. Sedimentation changes from cherty sediments to Middle Albian to Lower Cenomanian trench flysch in the Klape area, Middle Albian to Middle Cenomanian marls in the Manín area, or Cenomanian to Lower Santonian marls in the Belice fore-arc area. In the overlying Upper Santonian to Maastrichtian(?) Belice fore-arc basin flysch material was partly derived from the accretionary wedge to the north and partly from the Humienec and Inovec nappes to the south. The Coniacian to Santonian (in the Klape area), or Cenomanian to Santonian (in the Manín area) flysches changed to Campanian to Maastrichtian Couches Rouges marls. The latter formed a continuous sedimentation zone including the Manín, Klape

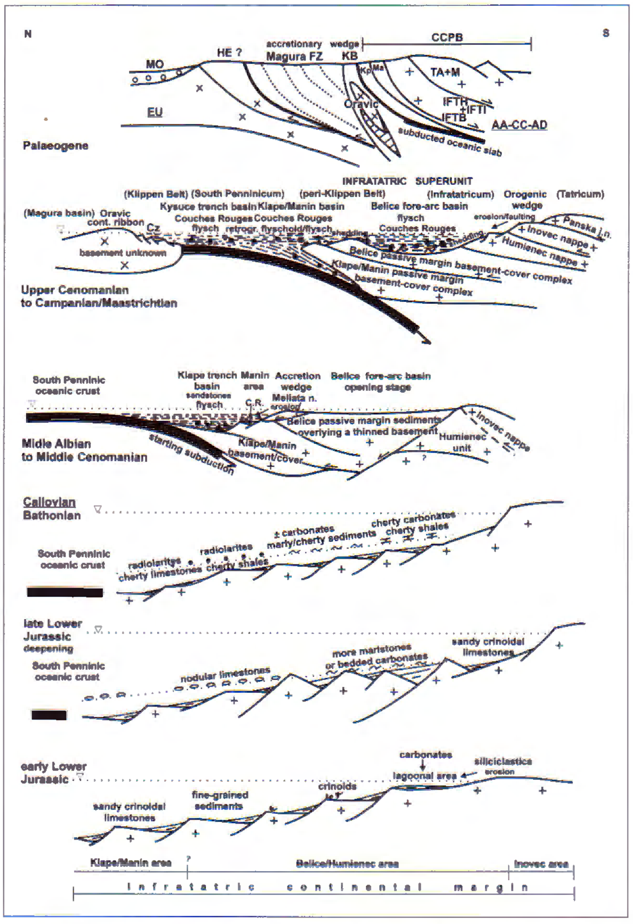

Fig. 1 Evolution scheme of the Infratatric continental margin. MO = Molasse sediments (Neogene); Nappe units: HE = Helvetic unit (Triassic to Palaeogene); FZ = (Magura) Flysch Zone (Upper Cretaceous–Palaeogene); KB = (Pieniny or Oravic) Klippen Belt divided into the Jurassic–Cretaceous pelagic Czorstyn (Cz) swell and basinal pelagic Jurassic–Cretaceous Kysuce units with Senonian to Palaeogene cover; Kp = Klape unit, Ma = Manin unit; Infratatric: Belice unit (IFTB), Humienec unit (IFTH) and Inovec unit (IFTI); TA = Tatric unit; M = Mesozoic cover nappes; EU = European Plate; AA–CC–AD = Austroalpine–Centrocarpathian–Adriatic Plate. Crosses = remnants of continental crust. Oblique lines = oceanic crust. Thick black points = olistoliths, olistostroms. CCPB = Central Carpathians Palaeogene Basin sediments.

and Kysuce areas (Fig.1). Findings of large blocks of Kimmeridgian to Tithonian limestones with special microfacies – microoncoids within the Coniacian flysch of the Kysuce and Klape areas and the Senonian flysch of the Belice area (MIŠÍK, 1997) – indicate juxtaposition of these units to the source area (the Albian/Cenomanian Infratatric accretionary wedge – Andrusov's ridge?) as late as in Coniacian time. These facts support the concept to place the sedimentation area of the Infratatric units (PUTIŠ, 1992) to the north of the Tatricum.

References

DAL PIAZ, G.V., MARTIN, S., VILLA, I., GOSSO, G. & MARSCHALKO, R. (1995): Late Jurassic blueschist facies pebbles from the western Carpathian orogenic wedge and paleostructural implications for western Tethys evolution.– Tectonics, 14, 874–885.

MARSCHALKO, R. & RAKÚS, M. (1997): Development of the Cretaceous flysch in the Klape unit and the recyclicity problem of the clastic material.– In: PLAŠIENKA, D. et al. (eds.): Alpine evolution of the W. Carpathians and related areas. Abstracts & introductory articles to the excursion. D. Štúr Publishers, Bratislava, 71–78.

MIŠÍK, M. (1997): Limestone clasts with microoncoids containing Globochaete and Saccocoma in Cretaceous conglomerate (Klippen and Peri-Klippen Belt) are they of exotic or non-exotic provenance?– In: PLAŠIENKA, D. et al. (eds.): Alpine evolution of the W. Carpathians and related areas. Abstracts & introductory articles to the excursion. D. Štúr Publishers, Bratislava, 33.

PLAŠIENKA, D., MARSCHALKO, R., SOTÁK, J., PETERČÁKOVÁ, M. & UHER, P. (1994): Origin and structural position of Upper Cretaceous sediments in the northern part of the Považský Inovec Mts. Part 1: Lithostratigraphy and sedimentology.– Mineralia Slovaca 26, 311–334.

PUTIŠ, M. (1992): Variscan and Alpidic nappe structures of the Western Carpathian crystalline basement.– Geol. Carp., 43, 369–380.

RATSCHBACHER, L., DINGELDEY, C., MILLER, C., HACKER, B.R. & McWILLIAMS, M.O. (2004): Formation, subduction and exhumation of Penninic oceanic crust in the E. Alps: time constraints from ^{40}Ar–^{39}Ar geochronology.– Tectonophysics, 394, 155–170.

SALAJ, J. (1997): Survey of Upper Cretaceous and Paleogene biostratigraphy of the Klippen and Periklippen Belts in the middle Váh valley.– In: PLAŠIENKA, D. et al. (eds.): Alpine evolution of the W. Carpathians and related areas. Abstracts & introductory articles to the excursion. D. Štúr Publishers, Bratislava, 99–117.

The Thermal History of the Alpine–Dinaric Transition Zone – Implications from Vitrinite Reflectance Data, Apatite Fission Track Dating and 1D Numerical Modelling

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Key Words: Alpine–Dinaric transition zone, Vitrinite reflectance data, Apatite fission track dating, 1D numerical modelling.

The Alpine–Dinaric transition zone is composed of several tectonostratigraphic units, including from N to S the Julian Swell, the Slovenian Basin, the Sava Folds and the Dinaric Carbonate Platform. No coalification break between pre-Variscan and post-Variscan sediments (across the Variscan discordance) can be recognized (e.g. RANTITSCH et al., 2000; RAINER, 2003). Consequently the post-Variscan thermal overprint reached at least the same intensity as the Variscan one.

Lateral and stratigraphical vitrinite reflectance (VR) trends and apatite fission track data (FT) of the Alpine (post-Variscan) sedimentary sequences reveal that the thermal history of these Carboniferous to Eocene sediments of the different tectonostratigraphic units is controlled by their former position within the Mesozoic Tethyan continental margin. The margin comprised platform areas (Dinaric Platform, Julian Swell) bordering graben-like structures (e.g. Slovenian Basin). This configuration was later on sealed by thick Upper Cretaceous to Paleogene flysch sediments in the foreland of the Dinaric orogen. The model for the thermal history of the Alpine–Dinaric Transition Zone, combining organic and anorganic temperature sensitive parameters, numerical modelling and Apatite Fission Track dating, is shown in Fig. 1.

The highest thermal overprint exists in the deep Slovenian Basin and the Sava Folds, where according to 1D numerical modelling results Upper Cretaceous to Middle Eocene flysch sediments more than 5 km thick caused VR values between 3 and 5% Rr in Triassic rocks. This corresponds to peak-paleotemperatures ranging from ~250 to >300°C. Less sedimentary overburden resulted in a lower thermal overprint in the shallow platform areas (0.8–2% Rr; ~150–220°C). The significant coalification-break in the Sava Folds – between erosional remnants of Upper Cretaceous (2.5% Rr; ~250°C) and overlying Middle Oligocene sediments of the Pannonian Basin (0.5% Rr; <90°C; SACHSENHOFER et al., 2001) – suggests a thermal overprint between Late Cretaceous and Middle Oligocene times.

The flysch deposition was followed by a rapid Late Eocene to Oligocene exhumation, when most of the flysch was eroded. The cooling below 110°C was recorded by Apatite Fission Track data. The ages from the southern part of the Sava Folds (Litija Anticline, Carboniferous conglomerates) indicate an exhumation between 48.2 and 34.7 Ma. Carboniferous rocks of the northern Sava Folds (Trojane Anticline) and the Trnovo Nappe (W of Ljubljana) show younger cooling ages (25.5–26.0 Ma). At least parts of the Julian Carbonate Platform were exhumed during the Middle Miocene (20 Ma; Cretaceous sandstones of the Bovec Basin), whereas the north-western slope of the Slovenian Basin (Cretaceous sandstones of the tectonic "window" near Lake Bohinj) suffered not enough thermal overprint for FT length reduction. According to these data the thrusting of the Julian Carbonate Platform (hanging wall) onto the Slovenian Basin (foot wall) occurred during the post Middle Miocene times (20.0 Ma). The early (Dinaric) and late Cenozoic (Alpidic) nappe stacking and strike-slip faulting dismembered the maturity patterns, but did not influence the maturity.

However, from the economic point of view, the erosion and complex compressional tectonic deformation may have destroyed most of the hydrocarbon reservoirs and traps. Therefore, the pre-tectonic hydrocarbon generation (during the Late Cretaceous–Early Cenozoic times) is the main limiting factor for the prospectivity of the northwestern Dinarides.

References

RAINER, T. (2003): Thermal history and hydrocarbon potential of the Alpine–Dinaric Transition Zone (Austria, Slovenia).– PhD Thesis, Mining University Leoben, 377p.

RANTITSCH, G., RAINER, T. & RUSSEGGER, B. (2000): Niedrigstgradige Metamorphose im Karbon der Südalpen (Kärnten, Österreich).– Carinthia II, 190/110, 537 – 542, Klagenfurt/Celovec.

SACHSENHOFER, R.F., JELEN, B., HASENHÜTTL, C., DUNKL, I. & RAINER, T. (2001): Thermal history of Tertiary basins in Slovenia (Alpine–Dinaride–Pannonian junction).– Tectonophysics, 334, 77–99.

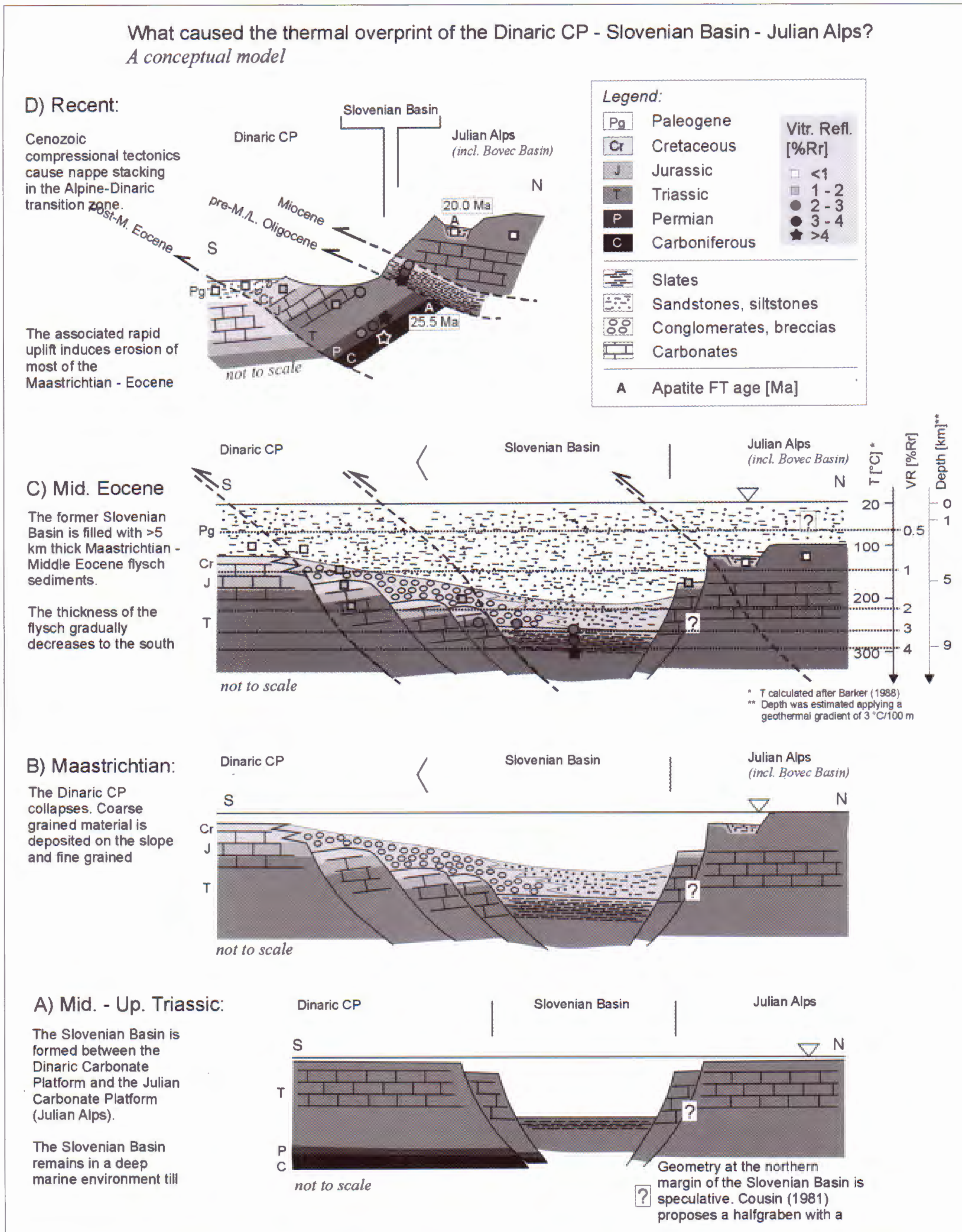

Fig. 1 Conceptual model for the sedimentary, tectonic and thermal history of the Alpine–Dinaric Transition Zone.

The Alps–Carpathians–Dinarides System: Major Tectonic Units and Deep Structure

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Key Words: Alps, Carpathians, Dinarides, Pannonian basin, Tectonics, Tomography.

In an attempt to understand the evolution of the Alps–Dinarides–Carpathian connection in time and space a tectonic map of the entire system is presented. This map was arrived at by compiling existing geological maps and by using subsurface information taken from the literature for those parts of the system that are covered by very thick Mio–Pliocene (in case of the Pannonian basin) or Mid-Cretaceous to Pliocene deposits (in case of the Transylvanian basin). Firstly, this map serves as a base map for a series of retro-deformations, following the pioneering work of BALLA (1987) and later work such as that by HAAS & PERO (2004) or CSONTOS & VÖRÖS (2004). Secondly, it is used for discussing the deep structure revealed by work on seismic tomography (BIJWAARD & SPAKMAN 2000; LIPPITSCH et al., 2003; SCHMID et al., 2004a). The map individualizes the following most important tectonic elements:

1. Miocene thrust belt: This thrust belt is the only feature that is common to Alps and Carpathians and which can be followed from the Alps all the way around the East Carpathians into the bending zone NW of Bucharest.

2. Europe-derived allochthons: These comprise, from external to internal, (a) the Helvetic and Subpenninic units of the Alps and the Danubian nappes of the South Carpathians, (b) the Briançonnais terrane of the Alps that terminates west of the Tauern window (SCHMID et al., 2004b), (c) the Rhodope unit of still uncertain position, (d) the Bukovinian–Getic–Sredna Gora nappe system, and (d) the Serbo–Macedonian unit.

3. The Tisza "block" with mixed European and Apulian affinities: This block broke off Europe during the middle Jurassic, i.e. at the same time as the Piedmont–Liguria ocean of the Alps opened. Hence it had European affinities before this opening, being positioned well north of Neotethys (Meliata). As a function of the opening of an ocean between Tisza and Europe, this block moved into a paleogeographic position that is comparable to that of the Austroalpine nappes, hence post-rift sediments such as late Jurassic Maiolica and/or radiolarites exhibit "Apulian" affinities.

4. Apulia-derived allochthons: In the Alps these elements are often referred to as being derived from the Apulian plate, encompassing all the elements originally positioned south of the Piedmont–Liguria ocean and being incorporated into the Alpine nappe stack (so-called Austroalpine nappes). This terminology, however, becomes problematic further to the east, where we distinguish between those parts of "Apulia" which were originally positioned south or north of the Meliata or Neotethys embayment, respectively. Hence, we distinguished (see SCHMID et al., 2004b), from external to internal (a) Lower Austroalpine nappes, Semmering nappe system and Tatricum, (b) Upper Austroalpine nappes originally positioned north of Meliata (as is the case for the Lower Austroalpine), such as for example the Northern Calcareous Alps, or the Veporicum and Gemericum of the West Carpathians, (c) an Eoalpine high-pressure belt that marks an eclogitic suture which represents the westernmost tip of the Neotethys embayment but which mostly consists of eclogitized continental crust (Koralpe–Wölz units of the Alps), and (d) the Upper Austroalpine nappes that mark the southern margin of Meliata and that occupy a paleogeographic position that is close to that of the easternmost Southern Alps.

5. Apulia-derived thrust sheets (Southern Alps and Dinarides): These consist of (a) the external Dinarides which are separated from the Southern Alps by the eastward continuation of a south-vergent dextrally transpressive Mio–Pliocene thrust front in northeatern Italy (Friuli) and Slovenia, (b) the Southern Alps that extend into Slovenia and westernmost Hungary (Julian South-Karawanken unit of HAAS et al. 2000), (c) the internal Dinarides, including the Bükk Mountains of Northern Hungary, and (d) the Jadar, Ivanjica, Korab and Pelogonian "massifs" or "blocks" that represent units positioned below the obducted Vardar and which are considered to be part of the distal Apulian margin, adjacent to the Meliata–Vardar-oceanic domain.

6. Ophiolites, suture zones and accretionary prisms with oceanic components: These comprise, from external to internal in respect to the Alps–Dinarides–Carpathian system (a) The Ceahlau–Severin ocean, (b) the Valais–Rhenodanubian or North Penninic ocean, (c) the Pieniny klippen belt, (d) the Piedmont–Liguria–Kriscevo–Solnok–Sava ocean whose scar we trace from the Alps eastwards all along the eastern tip of ALCAPA in northern Romania, where they cross the Carpathian mountains in order to join the Mid-Hungarian fault system that links them with that part of the Vardar ocean that stayed open until the Cretaceous–Tertiary boundary (Sava belt), (e) the Meliata–Darno–Szavarskő–western Vardar–Dinaridic–Mirdita ophiolites and Jurassic accretionary prisms, and (f) the Transylvanian–South Apuseni–eastern Vardar ocean.

High-resolution tomography in the Alps (LIPPITSCH et al., 2003) reveals the presence of a NE-dipping Dinaridic slab, positioned underneath the easternmost Alps, juxtaposed with the Alps at a late stage and during strike-slip movements along the Periadriatic–Balaton line. Although a direct comparison with the lower resolution tomography, based on ISC (International Seismological Center) data, but available for the entire Alps–Carpathians–Dinarides system (BIJWAARD & SPAKMAN, 2000), is difficult, it appears that the south-dipping European slab, still present underneath the Western Alps, broke off all along the Carpathian embayment during the last 20 Ma. Remnants of the NE-dipping Dinaridic slab visible in the easternmost Alps may also be discerned underneath the northern parts of the Dinarides. However, it appears that within the area of the Carpathian embayment most of the formerly subducted lithospheric slabs sunk to the deeper mantle, due to roll-back and slab detachment.

References

BALLA, Z. (1987): Tertiary paleomagnetic data for the Carpatho–Pannonian region in the light of Miocene rotation kinematics.– Tectonophysics, 139, 67–98.

BIJWAARD, H. & SPAKMAN, W. (2000): Nonlinear global P-wave tomography by iterated linearised inversion.– Geophys. J. Int., 141, 71–82.

CSONTOS, L. & VÖRÖS, A. (2004): Mesozoic plate tectonic reconstruction of the Carpathian region.– Paleogeography, Paleoclimatology, Paleoecology, 210, 1–56

HAAS, J. & PERO, S. (2004): Mesozoic evolution of the Tisza Mega-unit.– Int J Earth Sci, 93, 297–313.

HAAS, J., MIOČ, P., PAMIĆ, J., TOMLJENOVIĆ, B., ÁRKAI, P., BERCZI-MAKK, A., KOROKNAI, B., KOVACS, S., & FELGENHAUER, E.R. (2000): Complex structural pattern of the Alpine–Dinaridic–Pannonian triple junction.– Int. J. Earth Sci., 89, 377–389.

LIPPITSCH, R. KISSLING, E. & ANSORGE, J. (2003): Upper mantle structure beneath the Alpine orogen from high-resolution teleseismic tomography.– J. Geophys. Res. 108 (B8), 2376, doi:10.1029/2002JB002016.

SCHMID, S.M., FÜGENSCHUH, B., KISSLING, E. & SCHUSTER, R. (2004a): TRANSMED Transects IV, V and VI: Three lithospheric transects across the Alps and their forelands.– In: W. CAVAZZA, F.M. ROURE, W. SPAKMAN, G.M. STAMPFLI & P.A. ZIEGLER (eds.): The TRANSMED Atlas: The Mediterranean Region from Crust to Mantle. Springer, Berlin and Heidelberg,

SCHMID, S.M., FÜGENSCHUH, B., KISSLING, E. & SCHUSTER, R. (2004b): Tectonic map and overall architecture of the Alpine orogen.– Eclogae geologicae Helvetiae, 97, 93–117.

Tectonic and Stratigraphic Information on Greenschist to Eclogite Facies Metamorphic Austroalpine Units by a Sr–C–O Isotope Study on Marbles

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Key Words: Sr-isotopy, Marbles, Stratigraphy, Austroalpine, Eastern Alps.

Introduction

The Austroalpine is a major tectonic element in the Eastern Alps. It forms a complex nappe pile, consisting of unmetamorphosed to upper greenschist facies metamorphic Permomesozoic cover series, sub greenschist facies to upper greenschist facies Paleozoic sequences and amphibolite to eclogite facies, mostly polymetamorphic crystalline basement units. Large parts of the basement units consist of monotonous paragneisses and micaschists with intercalations of Neoproterozoic to Ordovician magmatic rocks. Other parts are characterised by variegated sequences of mostly garnet-bearing micaschists, quartzites, amphibolites and marbles. A Lower Paleozoic sedimentation age has been proposed for the latter units (e.g. SCHÖNLAUB, 1979). According to the nomenclature by SCHMID et al. (2004) most of the monotonous units belong to the Silvretta–Seckau and Ötztal–Bundschuh nappe system, whereas the proposed Lower Paleozoic units are parts of the Koralpe–Wölz or Drauzug–Gurktal nappe system.

In this study Sr, O and C-isotope ratios on marbles of different units are determined. The aims of the study are: (1) to try a characterisation of the marbles from the individual lithostratigraphic units by their isotopic signature, and (2) to compare the Sr-isotope ratios with the Sr-isotope seawater curve to get stratigraphic information. The available results show, that marbles of some lithostratigraphic units exhibit characteristic Sr-isotope ratios in a narrow range, which allow tracing these units over far distances. Furthermore the Sr-isotope ratios on some of the marbles make it possible to constrain their stratigraphic age to a few time intervals in Lower Paleozoic times.

Until now more than 30 samples of marbles from the Drauzug–Gurktal and Koralpe–Wölz nappe system have been investigated, including some samples of known stratigraphic age. As far as possible pure marbles from the centre of at least several meters thick layers were used for analyses to exclude secondary effects that may have shifted oxygen isotope compositions during metamorphism.

Results

Koralpe–Wölz nappe system: Marbles (Sölk marble) of the upper greenschist to amphibolite facies metamorphic Wölz Complex occur as meter to a few decameters thick layers, but in some localities they reach up to several 100 meters. Typical are coarse-grained, silicate-bearing calcitic marbles with white, grey, orange and greenish layers. Further pure white calcitic marbles and tremolite-bearing dolomitic marbles occur. The Sr-ratios scatter in a wide range and the values are high (0.70881–0.71024). The Rappold Complex experienced at least two amphibolite facies metamorphic overprints. Its marbles (Brettstein marble, Salla marble) reach up to more than 100 meters of thickness. Mainly they are coarse-grained and white coloured but there are also greyish types and silicate-bearing marbles. Low Sr-isotope ratios in a narrow range of 0.70800 to 0.70830 have been determined. The marbles (Gummern marbles) of the Millstatt Complex, and their equivalents in the "Laas Series" (South Tyrol, Italy) reach more than 100 meters in thickness. Both units experienced polymetamorphism and amphibolite facies conditions, in the southern part of the Millstatt Complex eclogite facies conditions have been demonstrated. Massive white calcitic marbles and minor greyish calcitic marbles occur. Further white, tremolite-bearing dolomitic marbles are present. The calcitic marbles are characterised by Sr-isotope ratios in a narrow range of 0.70862 to 0.70875.

Drauzug–Gurktal nappe system: In the lower greenschist facies metamorphic Goldeck Complex marbles (Martennock marble) are present as a continuous layer of several decametres in thickness. Frequent are fine-grained, layered types of white and greyish calcitic marble. Moreover brownish dolomitic marbles and silicate-bearing marbles occur. The calcitic marbles yielded Sr-isotope ratios of 0.70856 and 0.70876, whereas a very high value of 0.71257 was determined for a dolomitic marble. The marbles (Lind marbles) of the upper greenschist to amphibolite facies metamorphic Gaugen Complex show thicknesses of several decametres, but due to tectonics they form up to more than 100 meter thick bodies. They comprise fine to medium-grained calcitic marbles with a white or greyish colour, which are sometimes contaminated by silicate minerals. Further dolomitic marbles occur as layers. The calcitic marbles yielded Sr-isotope ratios in the range of 0.70854 to 0.70907. Only a few meters thick marble layers are present in the lower part of the amphibolite facies metamorphic Strieden Complex. They include medium-grained calcitic marbles and fine-grained dolomitic marbles with Sr-isotope values of 0.70886 and 0.70894.

A sample from the greenschist facies metamorphic, Middle Devonian Schöckelkalk Formation of the Graz Paleozoic yielded a Sr-isotope ratio of 0.70812, whereas 0.70814 and 0.70822 were determined for two samples of the also greenschist metamorphic, early Upper Carboniferous Triebenstein Formation of the Grauwackenzone. Other Devonian carbonates of the Grauwackenzone from the surrounding of metasomatic magnesite and siderite deposits yielded scattering and generally higher Sr-isotope ratios (FRIMMEL, 1988)

C- and O isotopy: The $\delta^{13}C$- and $\delta^{18}O$ ratios have just been measured, the results and an interpretation will be presented at the workshop.

Discussion and Conclusions

The marbles of all investigated units yielded values above 0.7085, except those of the Rappold Complex, which exhibit significantly lower values in a narrow range of 0.70800 to 0.70830. This allows tracing these marbles through the Austroalpine basement in the eastern part of the Eastern Alps.

In general the Sr-isotope ratio of a marble may bear stratigraphic information if the marble (1) formed in a marine environment and in equilibrium with the global seawater, (2) was not contaminated by Rb-bearing clastic detritus and (3) was not affected by later (e.g. metasomatic) processes disturbing the Sr-isotope system. On the other hand the influence of a metamorphic imprint is minor. The latter assumption is proved by the Sr-isotope ratios of the samples from upper greenschist facies metamorphic units with known stratigraphic age, which fit well with the expected ratios from the oceanic Sr-isotope seawater curve (HOWARTH, R.J. & McARTHUR, J.M., 1997): The value of the Schöckelkalk Formation corresponds to an age of 391±1 Ma, whereas those for the Triebenstein Formation show 315±1 Ma and 318±1 Ma. Most likely also the Sr-isotope ratios of the marbles from the Rappold and Millstatt Complex reflect primary seawater signatures: They were measured on thick layers of pure calcitic marbles and several results cluster within narrow ranges. Due to the fluctuation of the Sr-isotope seawater curve the measured ratios support several sedimentation ages for both groups of marbles. However, as both units experienced an amphibolite facies Variscan metamorphic imprint their sedimentation age has to be older than 320 Ma. On the other hand carbonate sediments with remarkable thicknesses and sedimentation ages older than the Upper Ordovician (465 Ma) are unknown from the Austroalpine unit. For this reasons the marbles of the Rappold Complex most likely have an age of 347–369 Ma (uppermost Devonian to Lower Carboniferous), 390–394 Ma (Middle Devonian) or 424–434 Ma (Lower Silurian), whereas for the marbles of the Millstatt Complex ages of 401–418 Ma (Lower Devonian) or 460–465 Ma (Upper Ordovician) are likely.

References

FRIMMEL, H. (1988): Strontium isotopic evidence for the origin of Siderite, ankerite and magnesite mineralisations in the Eastern Alps.– Mineral. Deposita, 23, 268–275.

HOWARTH, R.J. & McARTHUR, J.M. (1997): Statistics for strontium isotope stratigraphy. A robust LOWESS fit to the marine Sr-isotope curve for 0–206 Ma, with look-up table for the derivation of numerical age ("Look-Up Table Version 3:10 / 99").– J. Geol., 105, 441–456.

SCHMID, S.M., FÜGENSCHUH, B., KISSLING, E. & SCHUSTER, R. (2004): Tectonic map and overall architecture of the Alpine orogen.– Eclog. Geol. Helv., 97/1, 93–117.

SCHÖNLAUB, H. (1979): Das Paläozoikum in Österreich. Verbreitung, Stratigraphie, Korrelation, Entwicklung und Paläogeographie nicht metamorpher und metamorpher Abfolgen.– Abh. Geol. B.-A., 33, 124 p., Wien.

Zircon Typology in Crystalline Rocks of Moslavačka Gora (Croatia) – Preliminary Petrogenetic Insight from Transmitted Light (TL) and Scanning Electron Microscopy (SEM)

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Key Words: Zircon, Morphology, Typology, Moslavačka Gora, Croatia.

The mineral zircon is extremely variable both in terms of external morphology and internal textures. These features reflect the geologic history of the mineral crystallization and depend on many geological factors such as temperature and pressure of crystallization, chemistry, etc. Zircon has become one of the most widely used minerals for the extraction of information on the history and genesis of magmatic, metamorphic and sedimentary rocks. One of the major advantages of zircon is its ability to survive magmatic, metamorphic and erosional processes that destroy most other common minerals (CORFU et al., 2003). Systematic examination of zircon typology has led to the establishment of the widely used "Pupin diagram" in which zircon crystals are classified according to the relative development

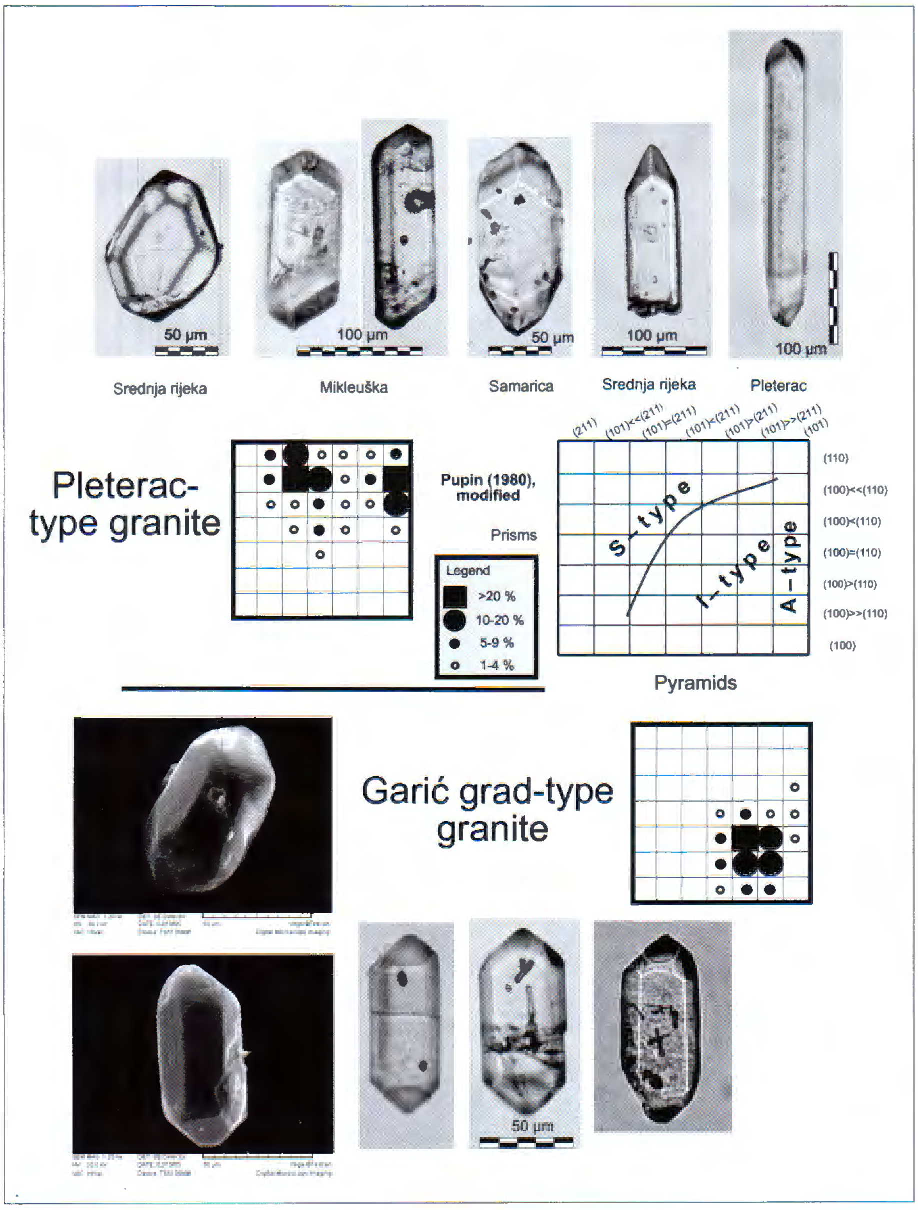

Fig. 1 TL and SEM images of zircons from Moslavačka Gora granites.

of the {100} vs. {110} prismatic forms and the {211} vs. {101} pyramidal crystal forms (PUPIN, 1980). The typologic study of zircon populations from granitic rocks lead to the proposition of a genetic classification with following divisions: (1) zircon grains from granites of mantle or mainly mantle origin (relatively dry alkaline and tholeiitic series granites) tend to be dominated by {100} and {101} forms; (2) granites of crustal or mainly crustal origin (aluminous to calc-alkaline rocks exhibit various combinations of forms with a prominent presence of {211} form; and (3) those from water-rich granites and pegmatites tend to have {110} and {101} as their dominant forms (PUPIN, 1980).

Here we describe zircons from the Moslavačka Gora granitoids, whose magmatic affinity has already been determined by petrological and geochemical studies (PAMIĆ, 1990). Recently, STARIJAŠ et al. (2004) distinguished two different groups of Cretaceous age fine-grained biotite-granites (biotite contents 4–10 vol.%), i.e. the Pleterac type and the Garić-grad type. The Pleterac type (PT) granites are mostly undeformed, chemically correspond to peraluminous S-type granite and comprise muscovite (2–4 vol.%). The Garić-grad type (GGT) granites often show a slight foliation and their chemistry point to igneous lower crustal sources.

Zircon from the two granite types (7 samples, each from different locality) was separated by conventional heavy-mineral separation technique (rock crushing, sieving, wet shaking table, bromoform separation, hand picking) from ca. 2 kg per sample. Zircon grains were analyzed with standard polarizing microscope (transmitted light) and additionally representative grains were analyzed with Tescan SEM. Figure 1 shows the main populations that have been recognized in the samples studied.

The euhedral prismatic PT zircons, with euhedral to subhedral mineral and fluid inclusions, are clear without evidence for the presence of older cores. The ratio length/width vary from ~1.5–3.5. The long-prismatic zircons show length/width ratio 6–7. Length of zircons varies from 50–100 μm to up to 300 μm for long-prismatic ones. The PT granites show unusual zircon morphology patterns with two maxima, one in the right upper corner of the Pupin diagram {101} combined with {110} i.e. I-type morphology, the other one showing steep {211} pyramides combined with the {110} prism. Such bimodal patterns may be indicative for felsic I-type granite melts that were chemically modified and driven towards S-type compositions through assimilation of meta-sedimentary material (HUMER et al., 2002).

The GGT granites have zircons with large {100} prisms and a dominant {101} pyramide, in accordance with their chemical I-type signatures. The zircon occurs as clear, unzoned, euhedral, sometimes fractured and unmetamict crystals with no overgrowth, their homogeneous morphology suggest a monogenic, igneous origin. Tiny and elongate inclusions of apatite are abundant. The GGT zircons have a length/width ratio of ~2.5 and a crystal size of ~100 μm. They appear to be of primary, igneous origin, with no evidence of metamorphic reworking.

References

CORFU, F., HANCHAR, J.M., HOSKIN, P.W.O. & KINNY, P. (2003): Atlas of Zircon Textures.– Reviews in Mineralogy and Geochemistry, 53, 469–500.

HUMER, B., GERDES, A. & FINGER, F. (2002): The Weitra Granite in north-western Lower Austria – a late-stage high-level I-Type intrusion associated with greisen in the Variscan South Bohemian Batolith.– Zbl. Geol. Palaeont. Teil I, 3/4, 213–235, Stuttgart.

PAMIĆ, J. (1990): Alpine granites, migmatites and metamorphic rocks from Mt. Moslavačka Gora and the surrounding basement of the Pannonian Basin (Northern Croatia, Yugoslavia).– Rad JAZU 10, 7–121, Zagreb.

PUPIN, J.P. (1980): Zircon and Granite Petrology.– Contrib. Mineral. Petrol., 73, 207–220.

STARIJAŠ, B., BALEN, D., TIBLJAŠ, D., SCHUSTER, R., HUMER, B. & FINGER, F. (2004): The Moslavačka Gora Massif in Croatia: part of a Late Cretaceous high-heat-flow zone in the Alpine–Balkan–Carpathian–Dinaride collision belt.– Ber. Inst. Erdwiss. K.-F.-Univ. Graz, 9, 453–454, Graz.

Geochemistry, Geochronology and Metamorphic Evolution of the Moslavačka Gora Massif (Croatia)

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Key Words: Cretaceous, Granites, Metamorphism, Geochemistry, Geochronology, Moslavačka Gora, Croatia

Introduction

The Moslavačka Gora Massif is located about 50 km east–south-east of Zagreb. It covers an area of about 180 km^2 and represents one of the major surface exposures of crystalline basement within the Tertiary sediments of the Pannonian Basin (PAMIĆ, 1990; PAMIĆ et al., 2002).

The central part of the massif is made up of different types of granites: the fine-grained undeformed Pleterac type and the slightly deformed Garić-grad type. The peripheral parts are mainly built up by migmatites and various types of metamorphic rocks (gneisses, amphibolites, metapelites).

Geochemistry of the granitoids

The Pleterac type (PT) granites are slightly more peraluminous than the Garić-grad type (GGT) granites, whereas the later have on average a slightly higher SiO_2 (70–75 vs. 73–76 wt.%). Clear chemical differences exist in the Ba, Y and Zr contents. The GGT granites are probably derived from metaigneous lower crustal sources. With reference to their high barium (543–788 ppm) and yttrium (44–94 ppm) contents, they resemble fractionated I-type granites (CHAPPELL, 1999). The PT granites correspond chemically rather to S-type than to I-type granites. They show A/CNK ratios slightly above 1.1 and much lower yttrium (15–30 ppm) and barium (201–444 ppm) at higher rubidium concentrations (184–323 ppm). The PT and the GGT granites can also be distinguished by their zircon morphologies (see STARIJAŠ et al., 2005, this vol.).

Geochronology

For a long time the Moslavačka Gora Massif has been considered as a major outcrop of Variscan crystalline basement of the South Tisia unit, like the Slavonian Mountains (Papuk, Psunj and Krndija). However, BALEN et al. (2001, 2003) reported Ar–Ar mica and amphibole cooling age < 90 Ma for various rocks of the massif. Also, a systematic electron-microprobe-based dating campaign on monazites from the granitic and the metamorphic rocks, which was carried out recently at Salzburg University, provided almost exclusively Cretaceous ages. Just in one sample of a metapelite, relics of monazites with a Permian age were found (STARIJAŠ et al., 2004).

Metamorphic evolution

The Cretaceous metamorphism in the Moslavačka Gora Massif was of the low-pressure type and reached, at least in places, granulite facies grade (ca. 700–750°C, 3–4 kb), with the formation of the paragenesis garnet + cordierite + K-feldspar + An-rich plagioclase + quartz (± sillimanite, ± biotite) in metapelitic lithologies. For a retrograde metamorphic event, which involves the growth of biotite at the expense of garnet, the replacement of cordierite by muscovite and biotite intergrowths, the replacement of sillimanite through muscovite + quartz symplectites, the growth of andalusite and the formation of a new, less calcic plagioclase, the thermobarometric estimates are ca. 550°C and 3 kb. This retrograde overprint may be related to the intrusion of the Pleterac granite.

Due to the large error of the electron-microprobe-based monazite dating method (ca. ±20 Ma), the precise timing of the different Cretaceous events (prograde low-P/high-T metamorphism, retrograde overprint, granitic plutonism) could not be resolved yet. Ar–Ar plateau ages of muscovites from a pegmatite and a deformed granite of around 75 Ma (BALEN et al., 2001) provide a lower age limit for the Cretaceous high-T metamorphism and the intrusion of the Moslavačka Gora granites, respectively.

In amphibolitic lithologies, mineral relics of a (possibly pre-Mesozoic?) Barrovian-type metamorphosis are preserved but are not yet dated.

A possible relationship with the Banatite magmatic belt?

Due to the newly discovered Cretaceous formation ages of the granitic rocks, a correlation of the Moslavačka Gora Massif with the Banatite magmatic belt of southeastern Europe may be possible. According to NEUBAUER (2002) the Banatite belt may have formed as a consequence of post-collisional slab break-off, representing a long but narrow zone, with increased heat input from the astenospheric mantle. The high-T/low-P metamorphism recorded in the Moslavačka Gora Massif indicates a position within a Late Cretaceous high-heat-flow zone, and thus would be compatible with such a model.

Chemical data indicate that the Moslavačka Gora granites are most likely derived from crustal sources, representing mainly slightly peraluminous, felsic granites (s.s.) to granodiorites. They may have formed as secondary magmas in the contact aureole of hot mafic mantle melts ponding at the base of the crust.

References

BALEN, D., SCHUSTER, R. & GARAŠIĆ, V. (2001): A new contribution to the geochronology of Mt. Moslavačka Gora (Croatia).– PANCARDI 2001 Abstracts, DP–2, Sopron.

BALEN, D., SCHUSTER, R., GARAŠIĆ, V. & MAJER, V. (2003): The Kamenjača olivine gabbro from Moslavačka Gora (South Tisia, Croatia).– Rad HAZU, 486, 27, 57–76.

CHAPPELL, B. (1999): Aluminium saturation in I- and S-type granites and the characterization of fractionated haplogranites.– Lithos, 46/3, 535–551.

NEUBAUER, F. (2002): Contrasting Late Cretaceous with Neogene ore provinces in the Alpine–Balkan–Carpathian–Dinaride collision belt.– Geol. Soc. Spec. Pub., 204, 81–102.

PAMIĆ, J. (1990): Alpine granites, migmatites and metamorphic rocks from Mt. Moslavačka Gora and the surrounding basement of the Pannonian Basin (Northern Croatia, Yugoslavia).– Rad JAZU 10, 7–121, Zagreb.

PAMIĆ J., BALEN D. & TIBLJAŠ D. (2002): Petrology and geochemistry of orthoamphibolite from the Variscan metamorphic sequences of the South Tisia in Croatia – an overview with geodynamic implications.– Int. J. Earth Sci. (Geol. Rundschau), 91, 787–798.

STARIJAŠ, B., BALEN, D., TIBLJAŠ, D., SCHUSTER, R., HUMER, B. & FINGER, F. (2004): The Moslavačka Gora Massif in Croatia: part of a Late Cretaceous high-heat-flow zone in the Alpine–Balkan–Carpathian–Dinaride collision belt.– Ber. Inst. Erdwiss. K.-F.-Univ. Graz, Band 9 Anhang, 453–454, Graz.

ALP 2002 – Two-dimensional Seismic Modelling on ALP01 and ALP02 Profiles

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Key Words: Refraction exploration, Seismic modelling, ALP 2002.

Introduction

The international scientific research project of deep refraction exploration of the lithosphere, ALP 2002, was conducted from the area of the Alps to the Dinarides (ALP 2002 Working Group, 2002). The research covered a large area, due to its enfolding of great depths: most part of Austria, western part of the Check Republic, border areas of Hungary and Italy, Slovenia and a part of Croatia. Seismic wave receivers (miniature seismographs) were placed at profiles, and shot points at adequate locations, which facilitated two-dimensional modelling and interpretation. Moreover, the geometry of recording and the registering of arrivals on all receivers of each shot point enabled tri-dimensional modelling and interpretation. After lengthy preparations, measurements were conducted following a strictly defined procedure during three nights, from the 2nd to 4th of July 2002, because of significantly lower environmental noise. The total length of the profile equalled 4,313 km, and contained 39 shots.

Two-dimensional Seismic Modelling

Two-dimensional modelling was carried out on the main profiles of the project: ALP01 and ALP02, as the first interpretation step. The profile ALP01 stretches in the north–south direction and perpendicularly crosses the Alpine mountain range. It starts at Bilin in the Check Republic, stretches over Plzen, Schladming in Austria and Gradin in Slovenia, and ends in Istria near Koromačno. The Profile ALP02 strikes in the northwest–southeast direction, diagonally transverses the Alps at Innsbruck, via Villach and Celje, enters into the Pannonian basin, and ends at Slavonski Brod.

The two-dimensional interpretation was carried out by software for Forward Modelling and Inversion. The Forward Modelling software is based on Ray Tracing, whereas the Inversion software on the method of Seismic Tomography. The programme packages were developed within the earlier projects of deep refraction research. An example of the recorded seismogram for the shot point at Ivanić Grad in Croatia (32070) on the Profile ALP02 is shown in Fig. 1. The seismogram shows arrivals of reflected and refracted waves for interfaces shown in the model interpreted in Figure 2.

Interpretation Results

Interpretation results are shown on the example of the ALP02 profile (Fig. 2). As input model, the four-layer model was used, i.e. the crust (the layer above the Mohorovičić discontinuity) is divided into two parts, the upper and lower crust. The first and shallowest layer is made of clastic deposits, particularly in the Pannonian basin. Already at the very beginning of the interpretation, it was discovered that the relief of the bedrock of clastic deposits and the applied velocities strongly influence the deepest horizons. For this reason, the boundary was determined on the basis of data obtained in petroleum-geological explorations (SAFTIĆ et al., 2003). The possibility of accurate definition of this boundary reduced the interpretation ambiguity considerably, i.e. enabled a more reliable determination of deeper boundaries.

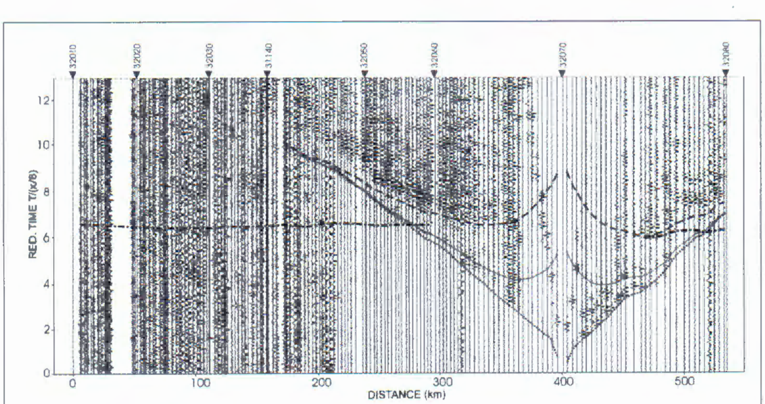

Fig. 1 Record section for the shot 32070 with theoretical arrivals for interpreted model shown in Fig. 2.

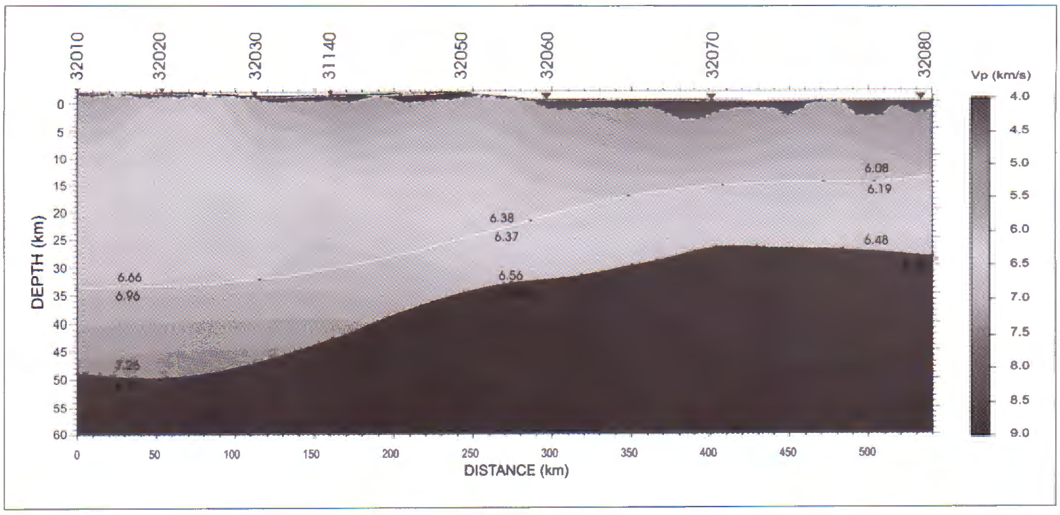

Fig. 2 Two-dimensional model of the ALP02 profile.

The depth of the Mohorovičić discontinuity is the highest in the Alpine area, approximately 50 km, and gradually decreases, while in area of the Pannonian basin in Croatia it reaches the depths of about 27 km. The velocities below the discontinuity exceed 8 km/s. The crust is divided into two parts; however, a large difference in seismic velocities is detected between the Alpine area and the Pannonian basin. In the Alpine area the velocities are generally higher, and the contrast at the boundary is clear, whereas in the area of the Pannonian basin the velocities are lower (5.8–6.4 km/s), the contrast at the boundary is very small, and for practical purposes it can be stated that there is no clear difference between the upper and the lower crust, which is also proven by preliminary interpretations of other refraction profiles.

Conclusions

Two-dimensional seismic modelling was carried out on the main profiles ALP01 and ALP02, and already the data from the first step of the interpretation offered new insights in the composition of the Earth's crust. The depth of the Mohorovičić discontinuity is about 50 km below the Alps, and about 27 km below the Pannonian basin. However, it should be definitely noted that the velocities on the crust in area of the Pannonian basin are low, with practically no clear division into two layers. Measurement data obtained by the ALP 2002 Project shall be, in a number of coming years, interpreted both by two-dimensional and three-dimensional interpretation methods.

Acknowledgements

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References

ALP 2002 WORKING GROUP, Reporter BRÜCKL, E. (2002): A Seismic Experiment to Explore the Alpine Lithosphere.– Eos Trans. AGU, 83 (47), Fall Meet. Suppl., Abstract, San Francisco.

SAFTIĆ, B., VELIĆ, J., SZTANO, O., JUHASZ, G. & IVKOVIĆ, Ž. (2003): Tertiary subsurface facies, source rocks and hydrocarbon reservoirs in the SW part of the Pannonian basin (Northern Croatia and Southwestern Hungary).– Geologia Croatica, 56, 101–122.

Do the Southern Alps Belong to the African/Adriatic Promontory During the Neogene? Preliminary Paleomagnetic Data from the Southern Alps

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Key Words: Neogene, Paleomagnetism, Southern Alps, African plate.

We present new paleomagnetic data from the Italian Southern Alps. In the dolomites a stratigraphic section in Upper Triassic to Upper Cretaceous carbonates (SAURO & MENEGHEL, 1995) at Alpe di Ra Stua (1) was sampled with 10 sites. An Upper Cretaceous magmatic sill at locality Corvara/Breida Freida (2) and an Eocene dyke at locality Val Fiscalina (3) were sampled. Both were dated radiometrically by LUCCHINI et al. (1983).

All components of the magnetizations we could isolate are overprints, which can be subdivided into two groups:

At locality (1) Doggerian/Malmian carbonates (Rosso Ammonitico) and red silty limestones (Barremian/Hauterivian) were thermally demagnetised. Two components could be isolated. The high temperature component (500–620°C) shows reverse polarity, SE directed declinations and demagnetization paths towards the origin during thermal demagnetisation, whereas the low temperature component (300–500°C) is characterized by normal polarity and NE directed declinations.

At locality (2) the magmatic sill, radiometrically dated to 68Ma (LUCCHINI et al., 1983) also showed two components. The higher coercive component, isolated between 25–50 mT was unblocking at T_{UB} = 550°C and was showing counterclockwise rotated declinations as well as demagnetization paths towards the origin. Both polarities are present. A lower coercive component, isolated between 15–40 mT was also characterized by T_{UB} = 400°C and clockwise rotated declinations. Again both polarities could be recognized.

At locality (3) an Eocene dyke that was radiometrically dated to 34Ma (LUCCHINI et al., 1983) was sampled. One component with reverse polarity and SW directed declination could be isolated. Thermal demagnetization showed stable decay of the ChRM between 400–550°C, AF-demagnetization was successful between 12–25 mT.

The new data from the Southern Alps compare well to results from the western part of the Northern Calcareous Alps and some data from the Central Alps (THÖNY et al., in review). Our results suggest two joined vertical axis rotations of the Northern Calcareous Alps, Central Alps and Southern Alps in the Cenozoic time.

The first event of clockwise rotation took place during the Early Oligocene. This rotation was probably caused by the collision and blocking of the Alpine wedge with the spur of the Bohemian massif in the eastern part of the Alps. With respect to the Cenozoic Alpine orogeny, clockwise rotation affected the upper plate units, which are the Austroalpine units and the Southern Alps, and lower plate units already accreted to the upper plate in the Early Oligocene. The second, counterclockwise rotation occurred in the Late Oligocene to Middle Miocene. In this stage of orogeny, the internal massifs of the Western Alps were already accreted to the upper plate and therefore included in the counterclockwise rotation (THOMAS et al., 1999; COLLOMBET et al., 2002). This rotation is contemporaneous with the counterclockwise rotation of Corcica/Sardinia (SPERANZA et al., 2002), the Apennines and the opening of the Balearic basin (MUTTONI et al., 2001) and a genetic relationship is suggested.

We define these units characterized by two vertical axis rotations, i.e. the Austroalpine nappe pile and the Southern Alps as *the Alpine–Adriatic Microplate.*

Due to the fact that the stable Adria is only characterized by NW directed declination directions, a fault zone has to limit the northern situated area, i.e. the Alpine–Adriatic Microplate to the south. A possible fault zone might be the Zagreb–Zemplin line that might prolongate to the west below the Po plain (BOSELLINI, 1981; VANDENBERG & WONDERS, 1976).

The main period of counterclockwise rotation of the African plate is dated into Jurassic times (BESSE & COURTILLOT, 2002), connected to the opening of the Central Atlantic Ocean. In the Neogene times no rotation can be detected (l.c.). Therefore, at least in the Neogene no joined geodynamics of the Southern Alps with the African plate can be assumed. The Southern Alps seem to show affinity to the geodynamics of the Austroalpine nappe pile and might not belong to the African/Adriatic promontory as proposed by CHANNELL & HORVÁTH (1976).

References

BESSE, J. & COURTILLOT, V. (2002): Apparent and true polar wander and the geometry of the geomagnetic field over the last 200 Myr.– J. Geophys. Res., 107(B11), 6-1–6-31.

BOSELLINI, A. (1981): The Emilia fault: a Jurassic fracture zone that evolved into a Cretaceous–Paleogene sinistral wrench fault.– Boll. Soc. Geol. It., 100, 161–169, Rome.

CHANNELL, J.E.T. & HORVÁTH, F. (1976): The African/Adriatic promontory as a paleogeographical premise for Alpine orogeny and plate movements in the Carpatho–Balkan region.– Tectonophysics, 35, 71–101.

COLLOMBET, M., THOMAS, J.C., CHAUVIN, A., TRICART, P., BOUILLIN, J.P. & GRATIER, J.P. (2002): Counterclockwise rotation of the western Alps since the Oligocene: New insights from paleomagnetic data.– Tectonics, 21, 14-1–14-15.

LUCCHINI, F., SIMBOLI, G., ZENATTI, A., BARBIERI, M., NICOLETTI, M. & PETRUCCHIANI, C. (1983): Petrochimica e dati radiometrici K/Ar e Rb/Sr dei "filoni basici" di Corvara in Badia e dei lamprofiri di Val Fiscalina (Dolomiti Orientali). Revisione classificata ed implicationi genetiche nel quadro del magmatismo filoniano delle Alpi.– Mineralogica Petrographica Acta, 27, 233–249, Bologna.

MUTTONI, G., LANCI, L., ARGNANI, A., HIRT, A.M., CIBIN, U., ABRAHAMSEN, N. & LOWRIE, W. (2001): Paleomagntic evidence for a Neogene two-phase counterclockwise tectonic rotation in the northern Apennines (Italy).– EPSL, 192, 159–174.

SAURO, U. & MENEGHEL, M. (eds.) (1995): Geologia e geomorfologia degli Altopiani Ampezzani.– Cortina d'Ampezzo, 158 p.

SPERANZA, F., VILLA, I.M., SAGNOTTI, L., FLORINDO F., COSENTINO, D., CIPOLLARI, P. & MATTEI, M. (2002): Age of the Corsica–Sardinia rotation and Liguro–Provencal basin spreading: new paleomagnetic and Ar/Ar evidence.– Tectonophysics, 347, 231–251.

THÖNY, W., ORTNER, H. & SCHOLGER, R. (in review): Paleomagnetic evidence for large en bloc rotations in the Eastern Alps during Neogene orogeny.

THOMAS, J.C., CLAUDEL, M.E., COLLOMBET, M., TRICART, P., CHAUVIN, A. & DUMONT, T. (1999): First paleomagnetic data from the sedimentary cover of the French Penninic Alps: evidence for Tertiary counterclockwise rotations in the Western Alps.– EPSL, 171, 561–574.

VANDENBERG, J. & WONDERS, A.A.H. (1976): Paleomagnetic evidence of large fault displacement around the Po-basin.– Tectonophysics, 33, 301–320.

Timing of Magmatism in the Pohorje Mts., Slovenia

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Key Words: K–Ar dating, Granodiorite, Dacite, Pohorje Mts, Slovenija, Eastern Alps.

Introduction

Age determination of the Pohorje magmatism and geochronologic relationships of particular igneous varieties have represented for decades a challenge to the researchers of this area. First published radiometric data of DELEON originate in the year 1969. A Miocene Rb–Sr age of 19.5 Ma was determined and as such used by other researchers practically until 1990-ies although other opinions occurred as well. In 1994 DOLENEC published some new determinations, indicating a Lower Miocene age of cezlakite (18.7±0.7 Ma) and bordering Lower to Middle Miocene age for the granodiorite (16.4±0.4 Ma). About five years ago more systematic work on this subject began. Some data linked to structural and paleomagnetic studies in the area were already presented (MÁRTON et al., 2002, 2004; FODOR et al., 2004).

On a regional scale the age estimations of the Pohorje pluton were based on the Rb/Sr dating of the Železna Kapla (Eisenkappel) intrusives (MIOČ & ŽNIDARČIĆ, 1978, 1989). They have used also superpositional evidence to support upper Paleogene age of the granodiorite magma emplacement. No evidence has been found for the Miocene sedimentary cover to be intruded and some granodiorite (at that time called tonalite) pebbles occur already in the upper Miocene (Helvetian) sedimentary rocks. First estimations by MIOČ & ŽNIDARČIĆ (1978) based on field observations consider cezlakite to be younger than granodiorite. Dacite was supposed to be of lower Miocene (Helvetian) age. The youngest are lamprophyre dykes.

Interpretation of the geodynamic setting of the Pohorje pluton is connected to the Periadriatic fault system along which most of the intrusions occur during the early Miocene. Granodiorite has been most frequently compared to the Adamello granitoid intrusion.

Lithology and age of magmatism

In the magmatic province of NE Slovenia most of intermediate to acidic plutonic and volcanic rocks consistently give an Oligocene to Miocene age. In the area of the Pohorje Mts. they intrude the medium to low-grade metamorphic basement. Their emplacement is related to the postcollisional decompression (ZUPANČIČ, 1994a). The main lithology is represented by medium to fine grained and porphyritic biotite granodiorite, with hornblende in somewhat deeper parts. The gabbroic rock cizlakite occurs at the SW side of the plutonic body. Numerous aplitic to pegmatitic veins are cross-cutting both of them. At the western part dacite locally intrudes granodiorite. The rocks are peraluminous close to metaluminous and have a typical calc-alcaline character (ZUPANČIČ, 1994b).

Nineteen new K–Ar ages are presented here for the Pohorje magmatic complex (PMC) comprising gabbroic to dacitic rocks. They have been determined on whole rock and on biotite, amphibole and feldspar monomineralic fractions, respectively. The ages range from 20.3±1.1 Ma to 15.09±0.58 Ma. There is systematic variation in age with the rock composition. The oldest ages were measured on cezlakite, and the youngest on dacitic rocks. No apparent younging direction was noticed within the studied area. Fabric pattern of the PMC rocks shows that complex geological events occur after the emplacement of the granodiorite. The analytical ages are slightly rejuvenated and the ages of all three magma series (granodiorite, transitional and dacite) overlap. According to the age pattern within the PMC the main episodes have occurred at 16.5 to 16.7 Ma, around the Karpathian/Badenian boundary. The latest changes dated in dacite occurred at around 15 Ma.

One sample from the Železna Kapla tonalite belt (E Karavanke) near Črna na Koroškem was dated, and it yielded the age of 32.4 Ma.

Conclusion

Systematic geochronological study carried out on the granitic rocks enable us to conclude that the formation of the PMC is Miocene in age. In Eggenburgian (around 20.3 Ma) a small body of cezlakite intruded into the hot metamorphic basement and was followed by the Ottnangian emplacement of big granodiorite mass at around 18 Ma. At the boundary Karpathian to lower Badenian at about 16.7 Ma a second phase of magmatism occurred together with rapid uplift and erosion. Dacite intruded at the NW part of the Pohorje Mts., partly rejuvenating still hot granodiorite and both cooled rapidly in quite shallow depths. The system seems to have been nearly closed after slight hydrothermal changes at around 15 Ma.

Magmatic activity in the Pohorje Mts. area is connected to the deep transtensional fractures related to the development of the Labot fault system north of the Periadriatic zone. It represents the westernmost intrusions along the extensional structures of the Pannonian basin and is contemporaneous with the acid calc-alkaline occurrences in Mecsek and Bükk Mts. (PECSKAY et al., 1995). Crystallization took place in an extensional stress field which continued also during the post-cooling brittle faulting. In contrary the Železna Kapla tonalite and tonalities buried in the Zala basin in Hungary are Oligocene in age and belong to the Periadriatic magmatic activity.

References

DELEON, G. (1969): Pregled rezultata određivanja absolutne geološke starosti granitoidnih stena u Jugoslaviji.– Rad. inst. geol-rud. istraž. ispit. nukl. min. sir., 6, 165–182, Beograd.

DOLENEC, T. (1994): Novi izotopski in radiometrični podatki o pohorskih magmatskih kamninah.– RMZ, 41, 147–152, Ljubljana.

FODOR, L., BALOGH, K., DUNKL, I., HORVÁTH, P., KOROKNAI, B., MÁRTON, E., PÉCSKAY, Z., TRAJANOVA, M., VRABEC, M., VRABEC, M. & ZUPANČIČ, N. (2004): Deformation and exhumation of magmatic and metamorphic rocks of the Pohorje–Kozjak Mts. (Slovenia): constraints from structural geology, geochronology, petrology, and paleomagnetism.– Geolines, 17, 31–32.

MÁRTON , E., ZUPANČIČ, N., PÉCSKAY, Z., TRAJANOVA, M. & JELEN, B. (2002): Paleomagnetism and new K–Ar ages of the Pohorje igneous rocks.– Geol. Carpathica, 53, Special issue.

MÁRTON, E., TRAJANOVA, M., FODOR, L., KOROKNAI, B., VRABEC, M., VRABEC, M., & ZUPANČIČ, N. (2004): Magnetic fabrics of the Pohorje igneous–metamorphic complex (Slovenia) related to deformation.– Contributions to Geophysics and Geodesy, Special issue.

MIOČ, P. & ŽNIDARČIČ, M. (1978): Tolmač za list Slovenj Gradec. Osnovna geološka karta SFRJ 1:100.000.– Zvezni geološki zavod, Beograd, 74p.

MIOČ, P. & ŽNIDARČIČ, M. (1989): Tolmač za lista Maribor in Leibnitz. Osnovna geološka karta SFRJ 1:100.000.– Zvezni geološki zavod, Beograd.

PECSKAY, Z., LEXA, J., SZAKACS, A., BALOGH, K., SEGHEDI, I., KONEČNY, V., KOVACS, M., MARTON, E., KALIČIAK, M., SZEKY-FUX, V., POKA, T., GYARMATI, P., EDELSTEIN, O., ROSU, E. & ŽEC, B. (1995): Space and time distribution of Neogene–Quarternary volcanism in the Carpato–Pannonian Region.– Acta Vulcanologica, 7/2, 15–28.

ZUPANČIČ, N. (1994a): Geokemične značilnosti in nastanek pohorskih magmatskih kamnin.– RMZ, 41, 113–128, Ljubljana.

ZUPANČIČ, N. (1994b): Petrografske značilnosti in klasifikacija pohorskih magmatskih kamnin.– RMZ, 41, 101–112, Ljubljana.

Investigating the Tisza–Dinarides Boundary: Structural and Petrological Features of the Inselbergs of Prosara, Motajica and Kozara (Northern Bosnia and Hercegovina)

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Key Words: Tisza, Dinarides, Sava Zone, Metamorphism, Collision, Ophiolites.

The aim of this structural, petrological and geochemical study is to define the kinematics and the age of collision between the Tisza block and the northernmost parts of the internal Dinarides along the south-western margin of the Pannonian Basin and before the onset of its rifting in the Mid-Miocene. The area investigated is situated in northernmost Bosnia–Hercegovina, where pre-Neogene rocks crop out only in the isolated hills of Kozara, Prosara and Motajica, immediately south of the Sava River. The hills of Prosara and Motajica, as well as the northern part of Kozara, are reported to be part of the so-called "Sava Zone" (PAMIĆ et al., 2002). This zone has been hitherto interpreted as a Mid-Cretaceous to Early Palaeogene accretionary prism, volcanic arc and back-arc basin that remained open until Mid-Eocene collision between the Tisza and the Dinarides (PAMIĆ et al., 2002).

The Sava Zone is dominated by Upper Cretaceous to Early Palaeogene flysch series. In Prosara and Motajica, this flysch is regionally metamorphosed, the grade increasing from non-metamorphic conditions in the S to low and medium grade (anchi- to epizonal conditions) in the N. The emplacement of granitoids in the Eo-/Oligocene (55–35 Ma; LANPHERE & PAMIĆ, 1992) produced a contact aureole that reached upper greenschist to amphibolite grade. Two deformation phases can be distinguished: an earlier deformation, concomitant with regional metamorphism, is related to N–S- to NE–SE-shortening, manifested in NW–SE-trending metric-scale folds in flysch sediments. Top-to-the-S transport directions in the western part of Prosara in greenschist-facies metasandstones and shales are presumably related to thrusting of Tisza onto the flysch series of the Sava Zone during collision. A second deformation phase is related to the emplacement of the plutons. In Motajica, this is evidenced by the development of a second foliation and its upwarping ("ballooning") with increasing proximity to the granitic pluton, as well as in a weak fo-

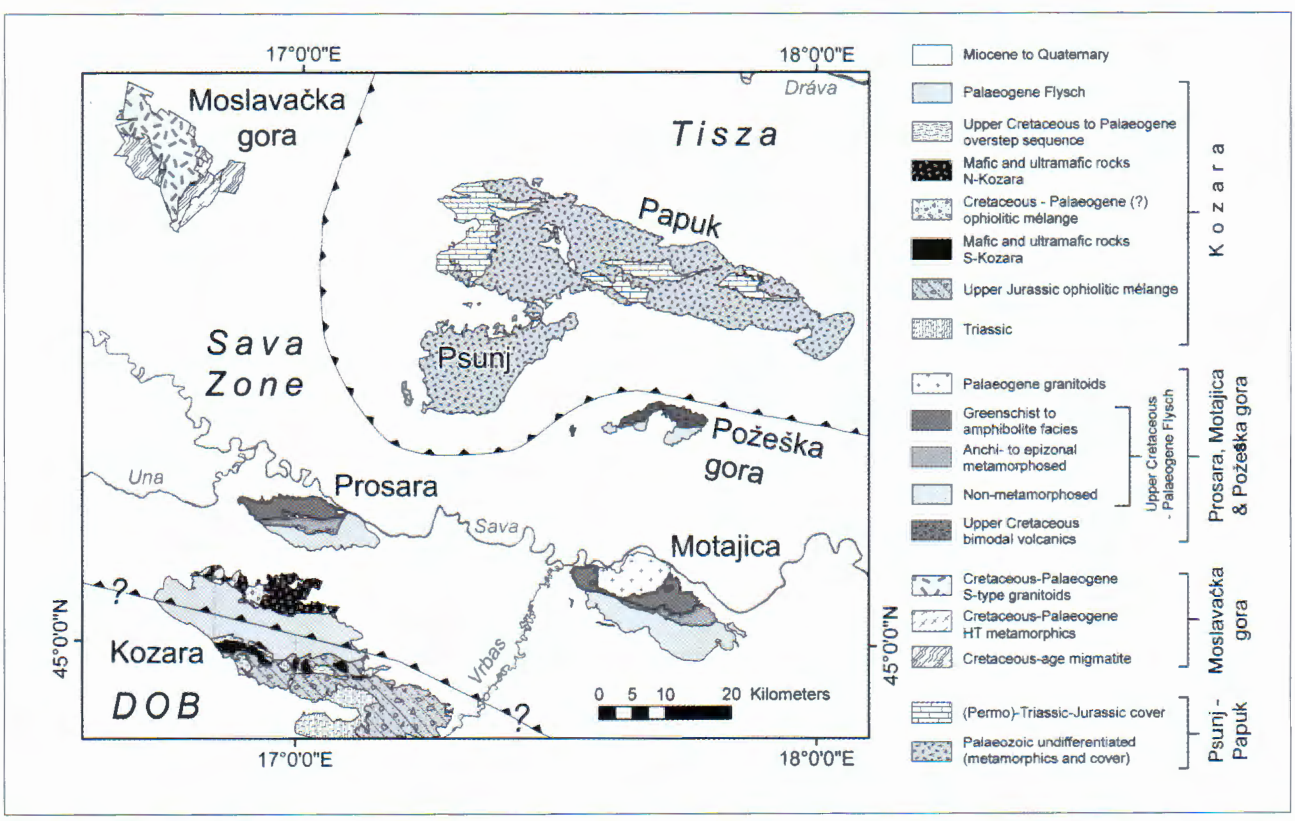

Fig 1. Simplified geological–tectonic map of the Slavonian and North-Bosnian inselbergs along the Sava River. The tectonic contacts refer to the presumed pre-Neogene situation, i.e. before the onset of Neogene to recent tectonics related to the Pannonian Basin. DOB = Dinaric ophiolite belt.

liation in the topmost part of the pluton itself. Associated stretching lineations are W–E- to NW–SE-oriented (i.e. parallel to the general strike) and indicate transport directions away from the pluton center (i.e. top-to-the-W and top-to-the-E west and east of the pluton, respectively).

The Sava Zone contains also ophiolites (exposed in N Kozara). They consist of gabbros and dolerites of yet unknown age, pillow basalts intercalated with red, pelagic limestones that yielded an Late Campanian to Early Maastrichtian microfauna (KARAMATA et al., 2000), of Late Cretaceous bimodal volcanics, as well as of a largely tectonised mélange (PAMIĆ, 2000). The ophiolite of N Kozara is juxtaposed against the Dinaric ophiolite zone (constituting the S part of Kozara), which was obducted already in the Late Jurassic. Geochemical analyses from the N and S ophiolites suggest differing magmatic origins, supporting the geologic evidence for a separation of the two ophiolite belts. Compared with samples from the S, dolerites and gabbros from N Kozara show lower Mg-contents and enrichment of incompatible elements like Ti and P, suggesting a more evolved magma source. Enrichment of LREE in samples from N Kozara suggests an island-arc or enriched MORB setting. The depletion of LREE in samples from the S, on the other hand, is more characteristic for N-MORB. However, the tectonic relationships between the two ophiolites (top-to-the-S thrust, sealed by unconformably overlying Tertiary flysch?) remain yet poorly understood. Despite uncertainties (particularly the lack of geochronological data), we propose that the N Kozara ophiolites could represent a remnant of the Vardar ocean that stayed open until the Late Cretaceous–Early Palaeogene.

References

KARAMATA, S., OLUJIĆ, J., PROTIĆ, L., MILOVANOVIĆ, D., VUJNOVIĆ, L., POPEVIĆ, A., MEMOVIĆ, E., RADOVANOVIĆ, Z. & RESIMIĆ-SARIĆ, K. (2000): The western belt of the Vardar Zone – the remnant of a marginal sea.– In: KARAMATA, S. & JANKOVIĆ, S. (eds.): Int. Symp. Geol. Metal. of the Dinarides and the Vardar zone, 1, 131–135, Banja Luka.

LANPHERE, M. & PAMIĆ, J. (1992): K–Ar and Rb–Sr ages of Alpine granite–metamorphic complexes in the northwestern Dinarides and the southwestern part of the Pannonian Basin in northern Croatia.– Acta Geologica, 22, 97–111.

PAMIĆ, J. (2000): Basic geological features of the Dinarides and South Tisia.– In: PAMIĆ, J. & TOMLJENOVIĆ, B. (eds.): Pancardi 2000 Fieldtrip Guidebook, Vijesti HGD, 37/2, 9–18.

PAMIĆ, J., BALEN, D. & HERAK M. (2002): Origin and geodynamic evolution of Late Paleogene magmatic associations along the Periadriatic–Sava–Vardar magmatic belt.– Geodinamica Acta, 15, 209–231.

Modelling of Sedimentation in the Pleistocene Mitterndorf Basin

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Key Words: Pleistocene, Mitterndorf basin, Modelling.

The software package WinGeol/SedTec (FABER & WAGREICH, in press) simulates erosion and deposition in dependency on topography, fault movements, lithological properties and sea level. Sediment transport such as mass and suspension flows are induced by elevation or concentration differences between neighbouring cells. Grain size reduction during sediment transport is included into the model. The spatial distribution of different rock types in the source area is used to model sediment composition. Rock types are characterized by their resistance to erosion and grain size reduction during sediment transport. Input data for simulation include elevation, lithology, fault data and tabular data from various data sets such as sea level curves and control points. Faults are defined by their geometry, geographic position, time interval of activity, and a displacement vector.

The Mitterndorf basin comprises a Pleistocene to recent depocentre of the larger Neogene Vienna Basin, situated at the junction of the Eastern Alps and the Western Carpathians. The Mitterndorf basin is a still active pull apart basin, about 50 km long and a maximum of 10 km wide. It formed along prominent sinistral strike-slip faults (e.g. the Leitha fault system – HINSCH et al., 2005; DECKER et al., 2005) during Pleistocene to recent times. The Mitterndorf basin is filled with up to 150 m of mainly (glacio-)fluvial gravels of mainly Late to Middle Pleistocene age. Sand layers and grey to red paleosoils are rarely observed.

Simulation of the Mitterndorf basin with WinGeol/SedTec incorporates a strongly simplified digital elevation model including the nearly flat Vienna Basin, a low relief eastern and southeastern mountainous metamorphic basement source area, and a western higher relief carbonate mountainous source area (Northern Calcareous Alps). The Mitterndorf basin was modeled by a simplified rhombic fault bounded subsidence area. The simulation concentrated mainly on the southern part of the basin, as sediment transport paths and sedimentation patterns were simpler in that area. Sediment input was mainly controlled by lateral paleovalleys, resulting in a fan-like sedimentation pattern of the Neunkirchen fan and the Wöllersdorf fan.

Simulation results indicate a complex interplay of erosion and sedimentation of different lithologies according to the chosen parameters for bedrock erodability and grain size reduction. The two fans have been successfully modeled by coarse channel sediment building fans from point sources where channel-like paleovalleys enter the basin. The internal sediment architecture of the fans displays some variations due to different lithologies and irregularities as a consequence of the coarse cell size (500 m), the large time steps (40,000 years) and the simple geometry used for this simulation. However, a clear cyclic trend in carbonate clasts can be recognized, indicating low sedimentation rates and low carbonate clast input during interglacial periods to high carbonate input during glacial times.

References

DECKER, K., PERESSON, H. & HINSCH, R. (2005): Active tectonics and Quaternary basin formation along the Vienna Basin Transform fault.– Quaternary Science Reviews, 24, 307–322.

HINSCH, R., DECKER, K. & WAGREICH, M. (2005): 3-D mapping of segmented active faults in the southern Vienna Basin.– Quaternary Science Reviews, 24, 321–336.

FABER, R. & WAGREICH, M. (in press): Modelling of topography and sedimentation along synsedimentary faults: WinGeol/SedTec.– Austrian Journal of Earth Sciences, 97.

Active Tectonics at the NE Corner of the Adria–Europe Collision Zone (Slovenia and Northern Croatia): GPS Constraints on Adria Motion and Deformation at the Alps–Dinarides–Pannonian Basin Junction

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Key Words: Adria microplate, Active tectonics, Collision zone, GPS measurements, Slovenia, Croatia.

Precisely quantifying the current motion of the Adria microplate, more simply termed Adria, remains one of the major challenges in Alpine–Mediterranean geodynamics. Knowing how Adria moves is critical for understanding the kinematic boundary conditions that drive circum-Adria active deformation in the Apennines (Italy), the western, central, eastern, and southern Alps (France, Switzerland, Italy, Slovenia, Austria), and in the Dinarides (Slovenia, Croatia, Bosnia–Herzegovina, Serbia and Montenegro, and Albania). More broadly, knowing how Adria moves should give some important basic constraints still required for developing a better understanding of the geodynamics in the complex Nubia (West Africa)–Europe collision zone.

We present results from our PIVO–2003 (PIVO = Periadriatic fault – Istria Velocity Observations) GPS experiment. We used decade-scale episodic GPS data from 36 sites distributed across Slovenia and northern Croatia (Fig. 1). We processed all GPS data using GIPSY (release 2.5) software and JPL precise satellite ephemeris and clock files. Data from 15 permanent GPS sites were used to define a stable Eurasia-ITRF-2000 reference frame.

We used data from 7 sites located in Adria's major aseismic outcrop, the Istria peninsula of Slovenia and Croatia, together with continuous GPS data from 2 permanent GPS sites on the Po Plain, to define the Adria–Europe pole of rotation. We formally inverted subsets of the Istria and Po Plain Eurasia-referenced GPS velocities for a series of Adria–Europe trial rotation poles; these did not vary significantly when we varied site combinations. We thus obtained a robust rotation pole (~46.7°N, 9.7°E, 0.4°/m.y. ccw). Our pole locates near the pole ANDERSON & JACKSON (1987) derived earlier by inverting a broadly distributed circum-Adria set of earthquake slip vectors (Fig. 2). Our mean rate residuals (0.53–1.09 mm/yr) average 0.88 mm/yr, suggesting that the northern Adria microplate is rigid to <1 mm/yr. The coincidence between our Istria/Po Plain pole and Anderson and Jackson's circum-Adria pole brings into question the recent hypothesis that Adria is actively fragmenting into two major sub-blocks (OLDOW et al., 2002).

Episodic decade-scale GPS data from additional 29 sites, distributed accross Slovenia and northern Croatia, were used to assess and quantify active deformation at the NE corner of the Adria–Europe collision zone. Predominant strain regime throughout most of the study region appears to be N–S to NNE–SSW shortening at the rate of up

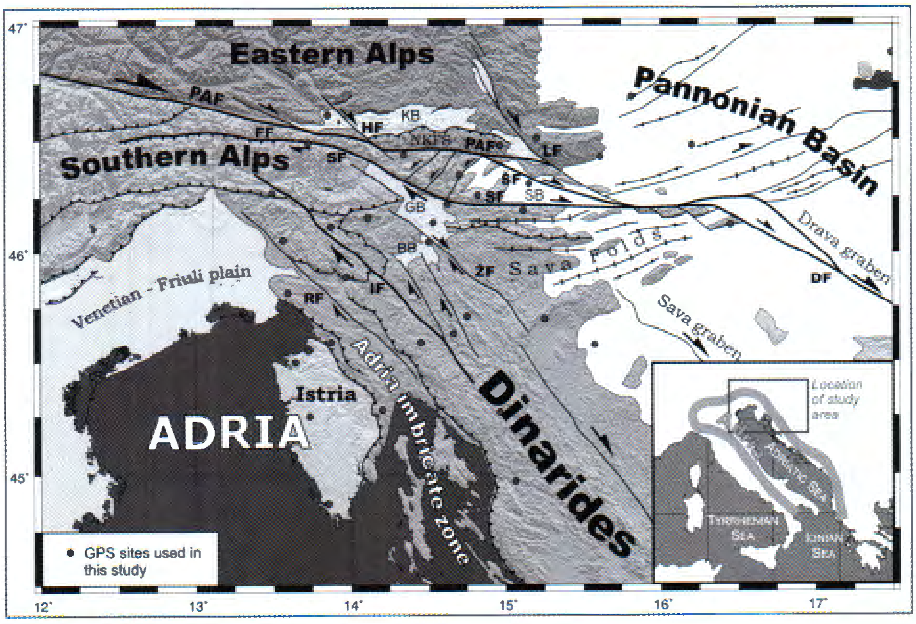

Fig. 1 Regional geological setting and the network of GPS sites used in this study. Neotectonically active faults: DF – Drava fault, HF – Hochstuhl fault, IF – Idrija fault, LF – Labot (Lavanttal) fault, PAF – Periadriatic fault, RF – Raša fault, SF – Sava fault, ŠF – Šoštanj fault, ŽF – Žužemberk fault. Plio–Quaternary basins: KB – Klagenfurt basin, GB – Gorenjska basin, BB – Barje basin, SB – Savinja basin.

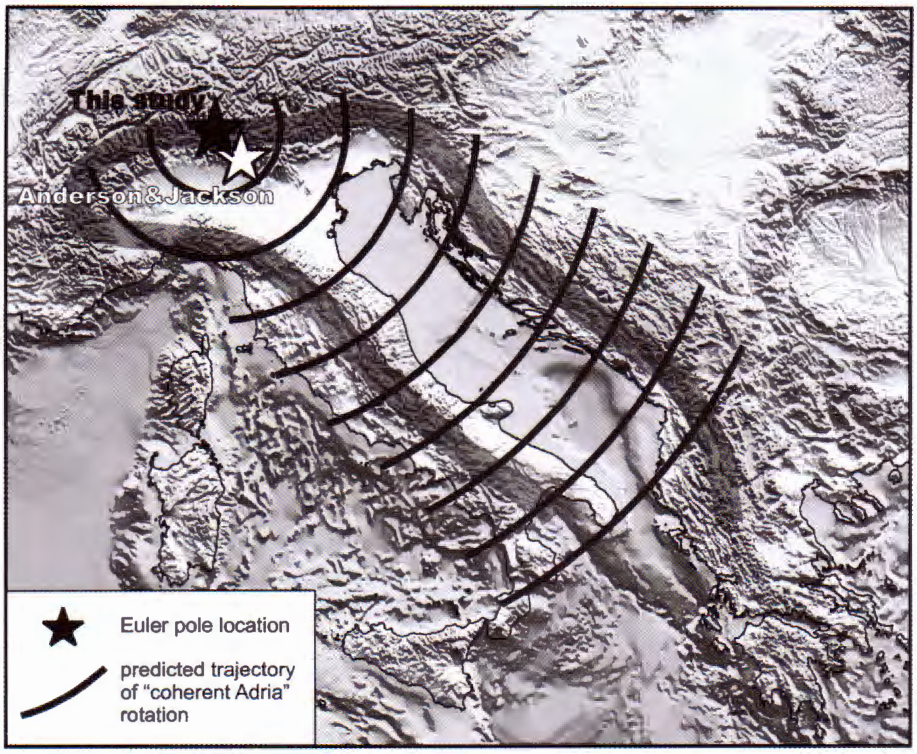

Fig. 2 Our average solution for Adria–Europe Euler pole compared to the result of ANDERSON & JACKSON (1987). Adria rotation trajectories calculated from our solution fit well with regional-scale strain data, like slip vectors of major earthquakes, suggesting that Adria behaves as a coherent block.

to several mm/yr. We observe a significant and sharp (few mm/yr) dextral (±transpressive) gradient in GPS velocities along the Periadriatic fault system, suggesting that lateral extrusion in the Eastern Alps is still active and being driven by the CCW rotation of Adria (cf. GRENERCZY et al., 2000). This motion appears to become more diffuse to the east where it is probably distributed across the Sava fold-belt.

References

ANDERSON, H. & JACKSON, J. (1987): Active tectonics of the Adriatic region.– Geophys. J. R. astr. Soc., 91, 937–983.

GRENERCZY, G., KENYERES, A. & FEJES, I. (2000): Present crustal movement and strain distribution in Central Europe inferred from GPS measurements.– J. Geophys. Res., 105(B9), 21835–21846.

OLDOW, J., FERRANTI, L., LEWIS, D., CAMPBELL, J., D'ARGENIO, B., CATALANO, R., PAPPONE, G., CARMIGNANI, L., CONYI, P. & AIKEN, C. (2002): Active fragmentation of Adria, the north African promontory, central Mediterranean orogen.– Geology, 30, 779–782.

$^{40}Ar/^{39}Ar$ Amphibole and Biotite Dating of Romanian Banatites

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Key Words: Banatites, Romania, $^{40}Ar/^{39}Ar$ dating, Amphibole, Biotite.

New $^{40}Ar/^{39}Ar$ amphibole and biotite ages have been obtained from the Upper Cretaceous belt, named by VON COTTA (1864) as "Banatites" associated by BERZA et al. (1998) into "Late Cretaceous Banatitic Magmatic and Metallogenic Belt" (BMMB). The Banatite belt stretches from Romania, Serbia to Bulgaria. Here we report results from two regions in Romania – the South Carpathians and the Apuseni Mountains (Fig. 1). Banatite magmatism occurred after early Late Cretaceous orogeny associated with orogenic collapse and Gosau sedimentation. This Cretaceous orogen was formed during an independent orogenic cycle due to consumption of oceanic tracts and subsequently early Late Cretaceous collision of continental blocks. The assembled terrane collage was heavily modified by Tertiary collision of continental, extrusional and oroclinal processes during incorporation of these units into the Carpathian arc and the indentation of the Moesian Block as the present-day arcuate mountain belt formed. Characteristic of this Cretaceous orogenic belt is a significant variation in intrusion ages along strike and from east to west. Romanian and Serbian banatites appear to be younger than the Bulgarian ones. That characteristic feature is underlined by our new data.

The Apuseni Mts. Province is a non-porphyry environment related to more evolved (granodioritic–granitic) magmatism. It is subdivided into three zones: Vladeasa, Gilau–Bihor and South Apuseni. These contrasts South Carpathian Banatites exposed in Serbia and Romania.

For our first patch of $^{40}Ar/^{39}Ar$ dating, volcanic and plutonic samples were chosen from selected sample locations in the Apuseni Mts. and South Carpathians Province (Fig. 1). Samples were prepared for stepwise heating experiments of amphiboles and biotites. Low temperature release yielded highly variable ages indicating extraneous argon. A gabbroic intrusion near Ciclova gave an amphibole plateau age of 68.75±0.38 Ma. Another amphibole spectrum of the Tincova intrusion yield a plateau age of 85.86±0.51 Ma. All over all the data cluster in three different age groups. The youngest ages range from 61.42±0.34 Ma to 71.59±0.40 Ma, the second group ranges from 77.65±0.29 Ma to 78.27±0.59, and the oldest age group from at 85.86±0.51 Ma to 89.48±0.35 Ma.

For a sample from Ciclova we calculated pressure and temperature from amphibole and plagioclase. The Ciclova intrusion, according to these results, equilibrated at a pressure of 750 bar at around 700°C. Rim components underline a subsequent hydrothermal influence on the intrusion body.

Our new $^{40}Ar/^{39}Ar$ ages from banatitic magmatic intrusions, especially the young ages do partly not confirm the data from the literature. The new data, together with reliable data from the literature, show a younging towards the Pannonian basin and a younging from south to north (south Carpathians to Apuseni Mts. They constrain three different geological events. One in Maastrichtian time, one during Campanian and the third one around Turonian–Santonian. We can draw the following conclusions from our primarily studies:

(1) The new $^{40}Ar/^{39}Ar$ data show three different age groups: a young one around 61–72 Ma, a second one around 78 Ma, and a third group at 86–89 Ma.

(2) The younger ages occur in the inner alignment, whereas the older ages occur more in the eastern, external sample locations, consistent with recent results in Romania and Bulgaria.

(3) P–T estimates show a later hydrothermal imprint in regard to the low equilibration temperature of 700°C and a very low intrusion level of 750 bar.

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References

BERZA, T., CONSTANTINESCU, E. & VLAD, S.N. (1998): Upper Cretaceous magmatic series and associated mineralisation in the Carpathian–Balkan Orogen.– Resource Geology, 48/4, 281–306, Tokyo.

VON COTTA, B. (1864): Erzlagerstätten in Banat und Serbien.– W. Braumüller, Vienna, 105 p.

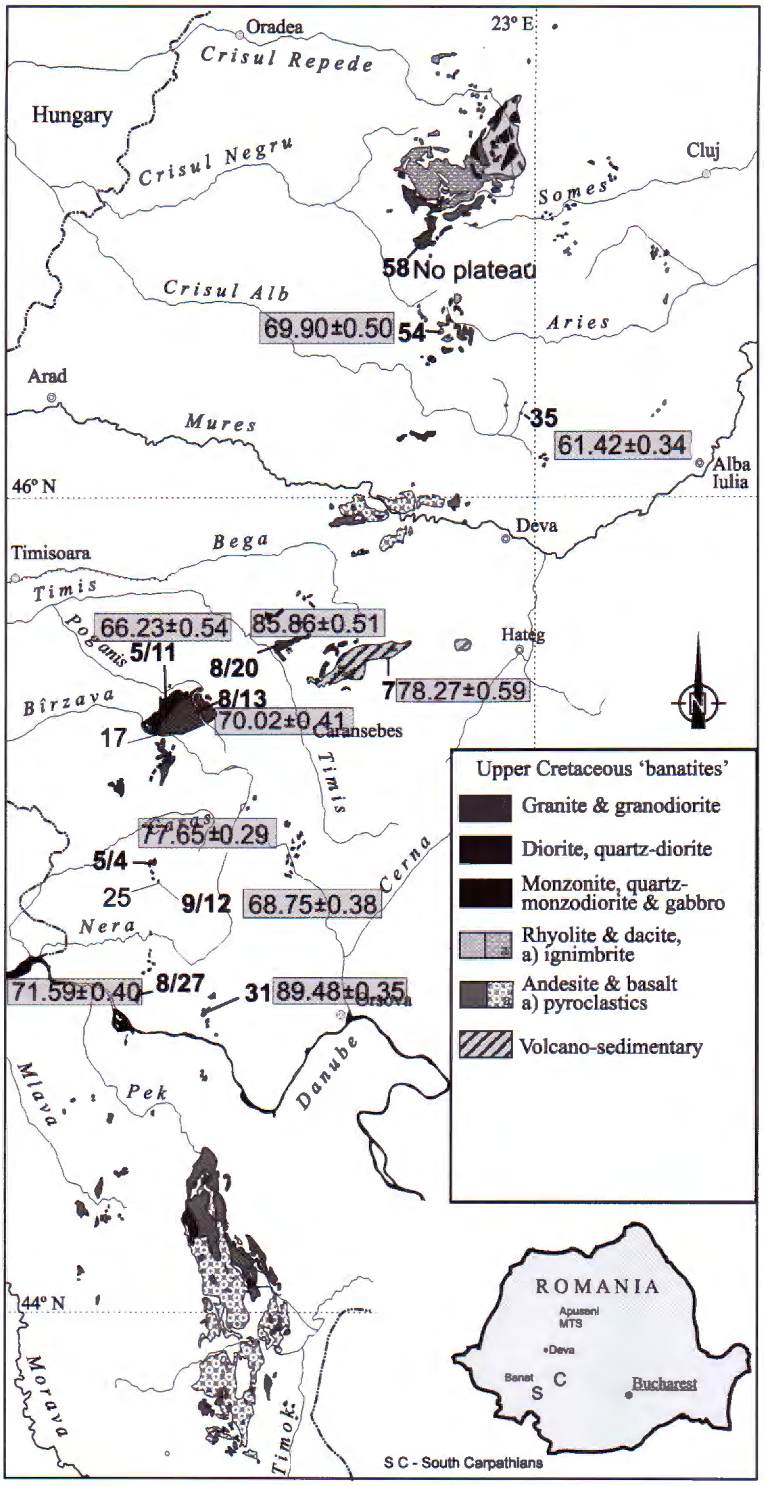

Fig. 1 Simplified map of the BMMB showing samples localities and $^{40}Ar/^{39}A$ dating results.

Exhumation of the Saualpe Eclogite Unit, Eastern Alps: Constraints from $^{40}Ar/^{39}Ar$ Ages and Structural Investigations

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Key Words: Eastern Alps, Saualpe eclogite unit, Cretaceous, $^{40}Ar/^{39}Ar$ dating.

The Cretaceous-aged Eclogite–Gneiss unit and its tectonic overburden (Micaschist, Phyllite and Lower Magdalensberg units) of the Saualpe, Eastern Alps, have been investigated in order to constrain the mode of exhumation of the type locality of eclogites. $^{40}Ar/^{39}Ar$ ages (Fig. 1) of white mica ranging from 86 to 78 Ma from the Eclogite–Gneiss unit suggest a rapid, uniform Santonian–Campanian cooling and exhumation of that unit, largely contemporaneous with subsidence in the adjacent Krappfeld–Kainach basins. Overlying units show upwards increasingly older ages with an age of 261.7±1.4 Ma in the uppermost low-grade unit (Lower Magdalensberg unit). We consider this Permian age as geologically significant and to record a Permian tectonic event. Rocks of Phyllite and Micaschist units along western margins of the Saualpe block yield amphibole and white mica ages ranging from 123 to 130 Ma. These ages are considered to closely date the age of nappe stacking. Biotite and amphibole of Micaschist and Eclogite–Gneiss units show variable contents of extraneous argon. Consequently, their ages are in part geologically meaningless whereas other samples yield meaningful ages. The ages of white mica from the Eclogite–Gneiss unit argue for cooling through ca. 400°C during the time as the westerly adjacent Upper Cretaceous Krappfeld–Kainach collapse basins formed.

The Preims unit with paragneiss and marbles is considered to represent a large synmetamorphic shear zone at the base of the overthrusting Eclogite–Gneiss unit. The unit comprises a flat-lying foliation and a SE-trending lineation. This zone is considered to represent a zone of top-NW thrusting. A major ductile low-angle normal fault with top to ESE shear has been detected between the Eclogite–Gneiss and overlying units, respectively between the Micaschist and Phyllite units. The ductile thrust at the base and the low-angle normal fault at top confine a NW-ward extruding high pressure wedge (Fig. 2). This observation argues for rapid exhumation of a subducted high-pressure wedge within a subduction channel. A generalized model following an analogue model of CHEMENDA et al. (1995) is shown in Fig. 2. Rapid erosion of the exhuming wedge facilitated exhumation. Eroded sedimentary rocks are preserved within adjacent Gosau basins, although only pebbles of low-grade rocks of the uppermost tectonic unit can be found in these basins.

References

CHEMENDA, A.I., MATTAUER, M. & BOKUN, A.N. (1995): Continental subduction and a mechanism for exhumation of high pressure metamorphic rocks: new modelling and field data from Oman.– Earth Planet. Sci. Lett., 143, 173–182.

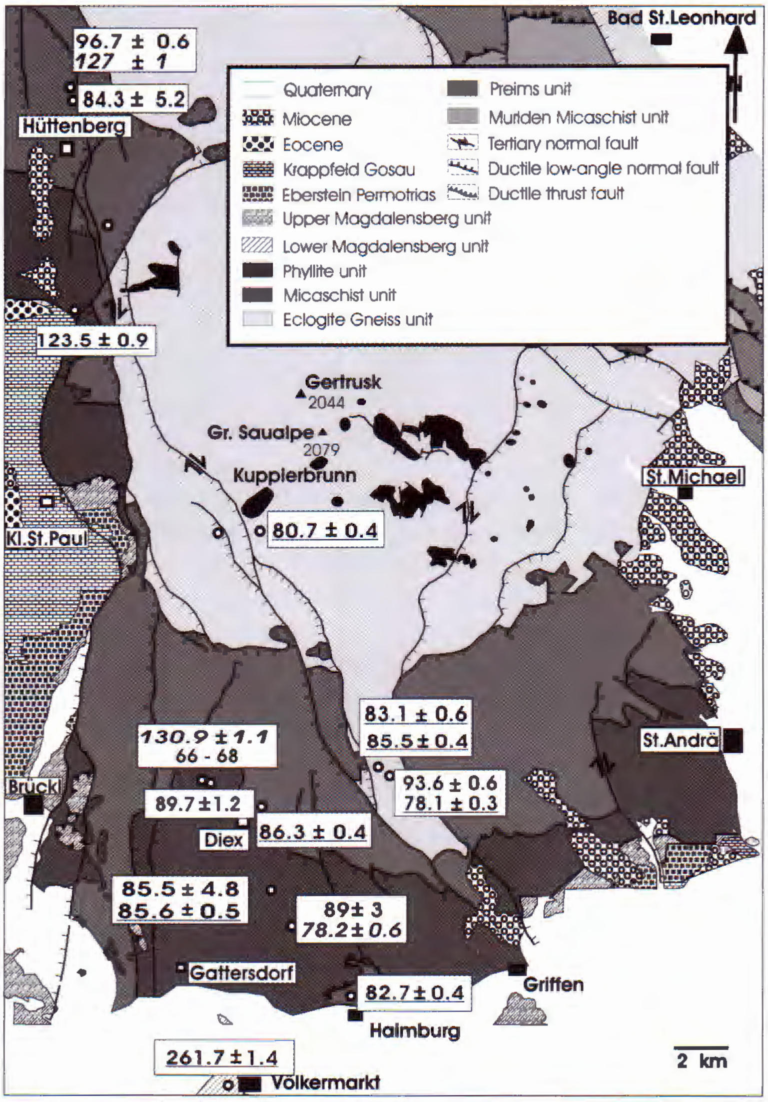

Fig. 1 Simplified geological map of the Saualpe region and new $^{40}Ar/^{39}Ar$ ages.

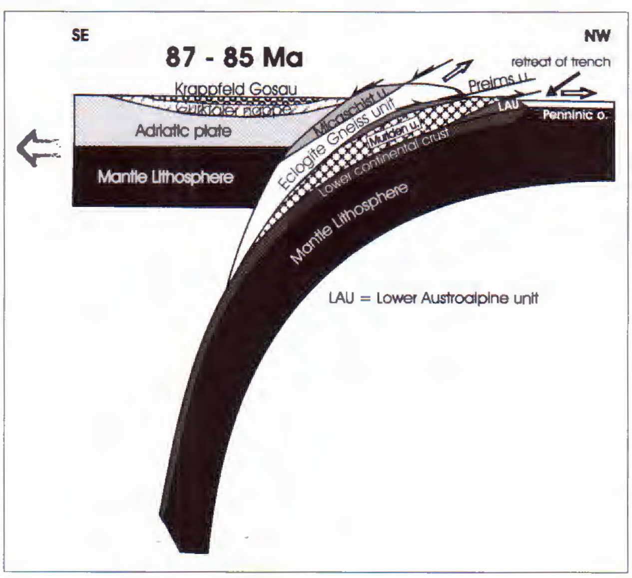

Fig. 2 Simplified tectonic model (modified after an analogue model of CHEMENDA et al., 1995) of the late Cretaceous tectonic evolution of the Austroalpine nappe complex exposed in the Saualpe cross-section.

Geodynamic Atlas of the Pannonian Basin and the Surrounding Orogens

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Key Words: Geodynamic synthesis, Neotectonic analysis, Pannonian Basin.

In the framework of a national project supported by the Hungarian Science Foundation (T034928), we have constructed a geodynamic map series of the Pannonian Basin and the surrounding mountain belt. Various geo-information of neotectonic significance have been collected and transformed into a uniform GIS system. As a consequence of the continuously expanding knowledge about the Pannonian region, systematic integration and interpretation of various data have been performed. The end product of the project is the geodynamic map series of the Pannonian region in a scale of 1:1500000, which consists of the following 11 thematic maps and corresponding explanatory text covering the same geographic area (approx. from 13°E–44°N to 28°E–51°N):

- *High-resolution digital elevation model and index map*
- *Crustal and lithospheric thickness maps*
- *Heat flow map*
- *Bouguer-anomaly map*
- *Map of seismicity*
- *Recent stress and rheology*
- *Map of morphostructural elements*
- *Map of neotectonic (active) structures*
- *Map of GPS velocity field of lateral displacement and vertical displacement trends*
- *Map of present-day geodynamics: synthesis*

Following the first successful presentation of a comprehensive map series for the area (ROYDEN & HORVÁTH, 1988), the authors offer this new map series for the use and consideration of the scientific community. It is hoped that the map series will generates contributions from different scientific teams in many countries in order to improve the quality of the available maps. Furthermore, we believe that quite a few additional maps (e.g. tectonics, magnetic anomaly etc.) can easily be constructed for the benefit of the European research community. A fair and manageable working mechanism is offered to perform this ambitions and cooperative scientific venture.

References

ROYDEN, L.H. & HORVÁTH, F. (1988): The Pannonian Basin – A study in basin evolution.– AAPG Memoir, 45, Tulsa, 394p.