

Paleomagnetic, Tectonic and Stratigraphic Correlation of Tertiary Formations in Slovenia and Hungary along the Periadriatic and Mid-Hungarian Tectonic Zone (Preliminary Communication)

Paleomagnetnska, tektonska in stratigrafska korelacija terciarja vzdolž periadriatske cone v Sloveniji in srednjemađarske tektonske cone (Predhodno obvestilo)

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Introduction

A project with the above title was conducted from 1995-1996 as a part of the Slovenian-Hungarian intergovernmental science and technology cooperation program under the No. 21/95. Although the thorough reporting of results will be published soon, we provide here a preliminary account of our activities and preliminary results.

Preliminary Communication

The understanding of the stratigraphy of the Tertiary in Eastern Slovenia was improved with the application of a tectonostratigraphic model (Jelen et al., 1992). Stratigraphic research showed that the Donat tectonic zone is a contact between two tectonostratigraphic units, and that the role of the zone is equivalent to the role of the Buda line in Hungary (Jelen et al., 1992). This new aspects of the correlation

of the Tertiary formations within the Periadriatic zone, the mid-Hungarian tectonic zone, and the adjacent areas, are important from the viewpoint of the continental escape tectonics along the Periadriatic zone, and mid-Hungarian zone (Jelen, 1994) because of the collision of the European and African tectonic plates (Kázmér, 1984; Kázmér & Kovács, 1985). In the escape process the units of the Carpatho-Pannonian area must have moved eastward. Thus, the formerly uniform Paleogene basin may be found today in two pieces, the northern part in Hungary and southern Slovakia, and the southern part in Slovenia (Csontos et al., 1992). The dextral separation of these pieces was estimated by Kázmér (1984) to be 450–500 km and by Tari (1994) to be 350–550 km.

Since the first application of the escape theory to the Alpine-Carpathian-Pannonian region in the last decade, many studies have dealt with different aspects of it. However, the problem is very complex, and several questions have remained unanswered. Our project concentrated on the following aspects of this problem:

1. Direct stratigraphic comparison (not using information from the literature only) of the Slovenian and the Hungarian Paleogene basins.

2. The study of the manner and timing of the tectonic movements in the "source" area of the displaced continental slivers in N Slovenia.

For these purposes, paleomagnetic method was applied for the first time in the Tertiary of Eastern Slovenia, along with microtectonic measurements and analysis which revealed the orientation of paleostress axes, enabled the separation of different stress regimes and their timing, and constrained the kinematics of movements along faults.

For direct stratigraphical comparison, the Slovenian team with the guidance of the Hungarian party made two field trips to Hungary and examined the following Tertiary formations (middle Eocene through Karpatian): Darvastó Formation, Szóc Formation, Padrag Formation, Dorog Formation, Szépvölgy Formation, Piszke Formation, Buda Formation, Tard Formation, lower part of Kiscell Formation, Iharkut Formation, Mány Formation, Csatka Formation, Eger Formation, Szécsény Formation, Pétervására and Budafok Formation, Gyulakeszi rhyolite tuff horizons, Garáb Formation and Egyházasserge Formation. Micropaleontologic samples were taken for the biostratigraphic correlation. Nannoplankton biostratigraphy and biochronology of the Slovenian sections was established by M. Báldi. Lithostratigraphy, foraminiferal biostratigraphy and biochronology and stratigraphic correlation were performed at the Institute for Geology, Geotechnics and Geophysics, Ljubljana.

The stratigraphic correlation gave important results. Stratigraphic equivalents of the Szépvölgy Limestone, Buda Marl and Tard Clay and sedimentary transition from Eocene beds into Oligocene beds have been found for the first time in Slovenia. Biostratigraphic analysis revealed nannoplankton biochronozone NP 21 and planktonic foraminifera biochronozone ?P17/P18 (uppermost Priabonian) for the Slovenian equivalent of the Szépvölgy Limestone, nannoplankton biochronozone NP 21 and planktonic foraminifera biochronozone P18 (uppermost Priabonian and lowermost Rupelian) for the Slovenian equivalent of the Buda Marl, and nannoplankton biochronozones from NP 21 through the lower part of NP 23 and planktonic foraminifera biochronozones from P18 through approximately P19 (lower Rupelian) for the Slovenian equivalent of the Tard Clay. These stratigraphic units which were found from Luče area (upper Savinja valley) in the west to Rogaška Slatina area in the east characterize a tectonostratigraphic unit bounded by Donat tectonic zone (in sensu Jelen et al., 1992) and Celje fault (in sensu Buser, 1979).

Structural measurements were carried out by a joint Hungarian-Slovenian team at 90 localities in Slovenia along the eastern termination of the Periadriatic zone and in the surrounding areas. The measured data were analysed and different deformation phases were separated. Paleostress calculations were carried out for sites where permitted by the data sets (the presence of slickensided fault planes). Tectonic and structural analyses and interpretations were made at the Department of Applied and Environmental Geology of Eötvös Loránd University and at the Department of Geology, University of Ljubljana.

Our analysis demonstrates repeated, progressive dextral transpression of the study area within and in-between the large shear zones of Periadriatic-Šoštanj and Sava-Celje faults. The brittle deformation is characterized by NW-SE to N-S compression and perpendicular tension. The penetrative strike-slip faulting was accompanied with folding and verticalization of beds (as in the Donat tectonic zone). Between the shear zones, in a rather rigid Savinja block, sinistral transpression occurred in the west (Smrekovec area), and dextral transtension in the east due to the accompanying mechanisms of deformation. These observations indicate a modified tectonic model of relatively rigid domino blocks rotating clockwise between the two dextral strike-slip zones.

Dextral transpression started in Early Miocene and occurred in several more intensive periods until the recent time.

Detailed study of the young transtensional activity and the relative timing of tectonic events was made in the Velenje basin area with use of the subsurface data.

The paleomagnetic studies involved drilling and orienting of paleomagnetic samples in the field by a Hungarian-Slovenian team. So far 69 localities (577 samples) were measured, demagnetized in several steps and finally evaluated from paleomagnetic point of view in the Paleomagnetic Laboratory of Eötvös Loránd Geophysical Institute of Hungary. About half of the samples were collected and processed before the start of the present project, but the conclusions we make here are based on all observations.

The main results of the paleomagnetic studies are the following:

1. A relatively large area (with Eastern Alpine basement) north of the Periadriatic lineament and the Ljutomer fault is characterised by 30-40° uniform counterclockwise rotation. The age of the rotation is post-Badenian, not yet constrained more precisely. This area must have moved as a single microplate.

2. In the area with Dinaric basement, south of the Sava-Celje fault system, data from the Tertiary show very moderate (up to 20°) clockwise rotation.

3. The zone between the above described rotated blocks is a complex shear zone, characterised mostly by large (60-140°) clockwise rotations. The distribution of the paleomagnetic declinations in time indicates that the rotations occurred in at least two tectonic phases, the first taking place in late Karpatian (about 16.5 Ma) and the second in post-Pontian (younger than 6 Ma) time.

4. In certain places, counterclockwise rotated or apparently non-rotated localities are found. This might be explained by the complex internal structure of the shear zones themselves which are right-lateral, yet allow counterclockwise rotation between a pair of secondary sinistral shear zones.

The orientation of stress axes, the presence and amount of tectonic rotation of the blocks, the chronology of deformation, and the resulting fault patterns were compared to similar data from central, north-eastern and southern Hungary. Our research confirmed the earlier suggestions that the Slovenian and the north-eastern Hungarian Paleogene basin segments must have formed a single uniform basin. Contrary to

the current opinion, our results imply that the Slovenian part of the Paleogene basin is not a homogeneous unit, but rather an assemblage of tectonic slices that originated in different Paleogene basins. The Early Miocene dextral slip along the Periadriatic fault system and the shear zone of Slovenia continued into the mid-Hungarian zone between the Lake Balaton and the Mecsek area.

The results of this project are important for the future geodynamic interpretations and reconstructions of the Alpine-Dinaric-Carpathian-Pannonian region. The stress field evolution of the study area, the young rotations indicated by paleomagnetic measurements, the chronology of intensive tectonic periods and related faulting, especially the indications for the Quaternary to Recent activity, are meaningful for the regional seismic risk evaluation. The structural correlation with the Hungarian side of the study area, where hydrocarbon resources are present, gives new insights for the hydrocarbon exploration in Slovenia.

Our studies answered several questions concerning the stratigraphic and tectonic evolution of the Alpine-Carpatho-Pannonian area. At the same time, they suggest new fields of investigation especially in constraining the timing of the young movements, exact reconstruction of the formerly Paleogene basin and diagenesis.

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Paleomagnetska, tektonska in stratigrafska korelacija terciarja vzdolž periadriatske cone v Sloveniji in srednjemađarske tektonske cone

Uvod

V letih 1995-1996 je v okviru slovensko-mađarskega medvladnega programa o znanstveno-tehnološkem sodelovanju tekel projekt št. 21/95 z zgornjim naslovom. Čeprav bodo objave kmalu tiskane, želimo predhodno poročati o projektu in njegovih rezultatih.

Predhodno obvestilo

Razumevanje stratigrafske zgradbe terciarja vzhodne Slovenije se je popolnoma spremenilo s postavitvijo tektonostratigrafskega modela (Jelen et al., 1992).

Novi vidik smo vzeli za ključnega pri potrjevanju hipoteze o bočnem iztisnjenju dela kontinentalne skorje v vzhodnih Alpah (zasilni prevod angleškega izraza lateral extrusion ali tudi continental escape) (Jelen, 1994), ki sta jo postavila Kázmér (1984) in Kázmér in Kovács (1985). V okviru hipoteze sta domnevala o 450-500

km dolgem desnem zniku ob periadriatskem lineamentu in balatonski liniji; še nekoliko daljšega, 350-550 km, pa Tari (1994). Csontos s sodelavci (1992) so zatem domnevali o razmaknitvi prvotno enotnega paleogenskega bazena na slovenski paleogenski bazen (SPB) in madžarski paleogenski bazen (MPB). Čeprav so se od postavitve hipoteze o bočnem iztisnjenju v E Alpah mnoge raziskave ukvarjale s številnimi problemi iztisnjenja, zaradi zapletenosti še vedno niso pojasnjeni vsi njegovi vidiki.

S projektom smo se lotili naslednjih dveh vidikov:

1. neposredne stratigrafske korelacije SPB in MPB,
2. načina in časovnega poteka tektonskih premikanj v severni in vzhodni Sloveniji, ki je po Csontosu s sodelavci (1992) izhodišče pobega.

Da bi dobili kriterije za presojanje, smo si v MPB ogledali razvoje terciarnih formacij od srednjega eocena do karpatija: formacijo Darvastó, formacijo Szóc, formacijo Padrag, formacijo Dorog, formacijo Szépvölgy, formaciji Piszka in Buda, formacijo Tard, spodnji del formacije Kiscell, formacije Szécsény, Pétervására in Budafok, spodnjemiocenske Gyulakesci horizonte riolitnih tufov in formaciji Gáráb ter Egyházasgerge in vzeli mikropaleontološke vzorce za biostratigrafsko korelacijo. Na novo smo morali raziskati stratigrafsko zgradbo v tektonostratigrafski enoti SPB med donačko tektonsko cono (v smislu Jelen et al., 1992) in celjskim prelomom (v smislu Buserja, 1979). V periadriatski coni in v podaljšku srednjemadžarske tektonske cone v Slovenijo ter južno in severno od njiju smo izvedli mikrotektonske meritve in strukturno analizo ter opravili paleomagnetne meritve zasukov tektonskih blokov. Sledili so korelacijski postopki. Paleomagnetne meritve in interpretacije so bile opravljene v Paleomagnetnem laboratoriju Geofizikalnega inštituta Eötvös Loránd v Budimpešti, tektonska in strukturna analiza ter interpretacije pa na Oddelku za uporabno geologijo in okolje budipeštanske univerze Eötvös Loránd in na Oddelku za geologijo Naravoslovnotehniške fakultete v Ljubljani. Nanoplanktonsko biostratigrafijo in biokronologijo je za slovenske razvoje razvrstila dr. M. Baldi. Na Inštitutu za geologijo, geotehniko in geofiziko v Ljubljani pa smo prispevali litostratigrafijo, foraminiferno biostratigrafijo z biokronologijo in stratigrafsko korelacijo.

Stratigrafska raziskava je dala pomembne kriterije za presojanje. Prvič smo v Sloveniji ugotovili sedimentacijski prehod iz eocenskih v oligocenske plasti in da so karbonatni in siliciklastični razvoji med donačko prelomno cono in celjskim prelomom stratigrafski ekvivalentni razvojem v MPB: Szépvölgy apnencem, Buda laporjem in Tard glinam. Karbonatni razvoj, ekvivaleten Szépvölgy apnencem, pripada nanoplanktonski biokronoconi NP21 oziroma planktonski foraminiferni biokronoconi P17/P18 (najvišji priabonij). Razvoj, ekvivalenten Buda laporjem, pripada biokronoconi NP 21 oziroma P18 (najvišji priabonij in najnižji rupelij). Razvoj, ekvivalenten Tard glinam, pripada biokronoconam od NP 21 do spodnjega dela NP 23 oziroma od P18 do približno P19 (spodnji rupelij). Dosedanji raziskovalci so tem ekvivalentom, ki so bili ugotovljeni od Luč v zgornji Savinjski dolini do Rogaške Slatine, določali drugačne starosti.

Mikrotektonske meritve smo opravili na 90 golicah. Rezultat terenskih meritev, določitev smeri glavnih napetosti in tektonske analize ter reinterpretacije listov osnovne geološke karte Slovenije 1:100 000 je nova strukturna karta severne in vzhodne Slovenije. Ugotovljeni so bili različni tipi in časovna obdobja deformiranja. V območju velenjskega bazena smo z analizo podpovršinskih podatkov podrobno preučili mlado tranzgenzijsko aktivnost in relativno kronologijo tektonskih dogodkov.

Desna progresivna transpresija, ki se je začela v spodnjem miocenu, traja z izrazi-
tejšimi obdobji do danes. Izraža se v dveh močnih strižnih conah: (1) med periadriat-

skim lineamentom in šoštanjским prelomom in (2) ob savsko-celjskem prelomu. Vmes je relativno togi savinjski blok, na zahodu deformiran s transpresijskimi in na vzhodu s transtenzijskimi razmerami. Penetrativne zmičke je spremljalo gubanje in vertikalizacija plasti (npr. v Donački prelomni coni). Disjunktivne tektonske deformacije so posledica tlačnih napetosti v smereh NW-SE do N-S in natezih napetosti pravokotno na smer tlačnih napetosti.

Za paleomagnetno raziskavo zasukov tektonskih blokov smo na 69 lokacijah vzeli 577 orientiranih jeder. Približno polovica vzorcev je bila odvzeta, merjena in interpretirana že pred začetkom projekta.

Glavni rezultati paleomagnetne raziskave so naslednji:

1. Severno od periadriatskega lineamenta in ljutomerskega preloma, kjer so v podlagi terciarja kamenine vzhodnoalpskega razvoja, neogenske sedimentne kamenine enotno izkazujejo rotacijo za 30-40° v nasprotni smeri urinega kazalca. Zasuk se je zgodil po badeniju in še ni natančneje datiran. Območje se je sukalo kot mikroplošča.

2. Južno od savskega in celjskega preloma, kjer leži terciar na dinaridih, so ugotovljeni zasuki do 20° v smeri urinega kazalca.

3. Med blokoma z vzhodnoalpsko in dinarsko podlago je zapleteno zgrajena prevladujoče desno zmična strižna cona z velikimi zasuki (60-140°) v smeri urinega kazalca. Porazdelitev paleomagnetnih deklinacij v času kaže na vsaj dve tektonski fazi kot povzročiteljici zasukov. Prva se je dogodila v poznem karpatorju pred ~16,5 milijonov let in druga po pontiju pred manj kot 6 milijonov let.

4. Znotraj strižne cone so ugotovljeni tudi zasuki v nasprotni smeri od urinega kazalca in ničelne rotacije. Razlagamo si jih s podrejenimi deformacijami v desnozmičnih strižnih conah, ko med dvema sekundarnima levostrižnima conama pride do zasukov v nasprotni smeri urinega kazalca.

Tektonska, paleomagnetna in stratigrafska korelacija je pokazala, da se slovenska strižna cona nadaljuje v srednjemađarsko tektonsko (strižno) cono med Balatonskim jezerom in Mecsekem in da SPB leži južno od strižne cone, MPB, ki je bil z desnim zmikom premeščen daleč na vzhod, pa severno od strižne cone. Menimo, da je projektna raziskava potrdila hipotezi Kázmérja (1984), Kázmérja in Kovácsa (1985) in Csontos s sodelavci (1992). V nasprotju s prejšnjimi raziskavami smo ugotovili, da SPB ni homogena enota, temveč je sestavljena iz tektonskih fragmentov, ki izhajajo iz različnih paleogenskih bazenov.

Rezultati projekta so pomembni za bodoče geodinamske interpretacije in rekonstrukcije Alpske-Dinarske-Karpatske-Panonske regije. Evolucija napetostnega polja, mladi zasuki tektonskih blokov in dodanašnje tektonske aktivnosti bodo zelo pomembni za oceno seizmične tveganosti. Nekatere raziskovane strukture so na Mađarskem nosilke fosilnih ogljikovodikov, zato bodo lahko rezultati strukturne korelacije v pomoč bodočemu iskanju nafte in plina v Sloveniji.

S projektom smo odgovorili na več vprašanj povezanih z bočnim iztisnitvenjem kontinentalne skorje v vzhodnih Alpah. Hkrati pa so se postavila nova vprašanja, kot npr.: datiranje mladih tektonskih premikov, rekonstrukcija prvotnega bazena in potek diagenoze bazenskih sedimentov.

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V prvem poglavju avtor za kratko in zgoščeno opisuje zgodovino balneologije in balneogeologije. Evropska kultura ušivanja mineralnih vod in njihove uporabe v balneološke namene sega že v antiko. Stari Grki so uvedli kulturo kopanja tako v vsakdanje življenje kakor tudi v religiozne obrede. Rimljani so jo izpopolnili in razširili po vsej svoji zahodni imperiji. Pomenili niso le kopalnih kuz, ampak tudi pitje, kar dokazuje najdba v Italiji. V srednji Evropi je najstarejše poznano zajetje termalne vode v St. Maurice v Franciji (Maurinnesquelle) je bil zajet že v brodati dobi, karovec kot v 12. stoletju, v 16. stoletju pa je bila balneologija praktično popolnoma pozabljena. Šele v 18. stoletju se je ponovno obnovilo zanimanje za opuščne in termalne vode. V 19. stoletju se zanimanje za mineralne in termalne vode povečuje. Najpomembnejši zbiralec in raziskovalec znanstveno po l. sistemni vojni z razvojem obnove evropske turizma. V 19. stoletju so obstoječa zdravilišča dobila ponovni razvoj, nastala jih je tudi nova zdravilišča. V Srednji Evropi so postala pomembna turistična in zdraviliška parava.

V drugem poglavju predstavlja avtor osnovne pojme, definicije in nomenklaturu. Sodobna nemška balneologija temelji na leta 1907 izdani knjigi o nemških zdraviliščih (D. Kitcher-Bauerbach). V njej sta avtorja E. Hirtz in L. Grünhut razmejlja mineralne in termalne vode z 1900 mg/liter raztopljenih trdnih snovi in temperaturno mejo 20°C. Ti dve meje sta se kasneje prevzeli skoraj vse države Srednje Evrope in sta praktično še vedno veljavni. V Neubeckerskih sklepih iz leta 1911, ki sledijo nemški knjigi o zdraviliščih, pa so postavljene definicije in mejne vrednosti za mineralno vo-

