MIDDLE CRETACEOUS (APTIAN - ALBIAN) SHORTENING AND TECTONIC BURIAL OF GERECSE MOUNTAINS, TRANSDANUBIAN RANGE, HUNGARY

Conclusions of PhD theses

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1. INTRODUCTION, AIMS

The aim of PhD work was to study the early ductile and rigid compressional structural features and burial of Gerecse Mountains, Transdanubian Range, Hungary. The main challenges are detailed as below:

- study the ductile deformation features and its related shortening;
- observations on rigid deformation and its compressional directions;
- investigation of burial in Gerecse Mountains using vitrinite reflectance data;
- compilation of burial models to evaluate the measured vitrinite reflectance data;
- elimination of young (early Middle Miocene – Recent) heat effect from vitrinite reflectance from used Late Cretaceous and Triassic calibration samples to study their areal distribution;
- interpretation of deep burial observed in Gerecse Mountains compared to the regional structural evolution of Northern Calcareous Alps area focusing on early similarities and later dissimilarities.

1.1. Ductile and rigid structural elements related to horizontal shortening

The first aim of PhD work was to investigate and interpret the previously non-published shortening direction resulting folds on work area. In the earliest phase it was felt necessary to study the rigid deformation features (striae indicating bedding parallel shear, inverse faults, thrusts, conjugated and non-conjugated compressional foliations, schistosity) and the related shortening directions. The main questions are listed below.

- Is it possible to detect *more than one* compression directon related to folding?
- If the presence of more shortening directions is assumed, can it be *significantly separated?*
- What is the *sequence* of compressional stress fields related to shortening events?
- Is it possible to detect *shear or schistosity* in relationship with ductile deformation(s)?
- What can be the *geodynamic background* of observed deformation event(s)?
- What is the age of deformation(s)?

- What is the *relation* between the observed deformation event(s) and the well studied published structural evolution of Gerecse Mountains?
- What can be the relationship between *ductile and rigid* deformation features?

1.2. Deep burial

Presence of ductile deformation, bedding parallel shear planes, conjugated and non-conjugated foliatons, schistosity – in good agreement with vitrinite reflectance data, analysis of regularly mixed-layer clay minerals, rock pyolysis results and other unpublished data – indicates the deep burial of studied area confirmed by the supposed age of shortening-related stress field activity. Vitrinite reflectance measurements were carried out to investigate the assumed deep burial of Gerecse Mountains. The main questions are the following:

- Can the results of vitrinite reflectance measurements on prooved autigenous coalified plant fragments be evaluated?
- Can the deep burial of Gerecse Mountains be prooved by vitrinite reflectence data?

1.4. Burial model

To interpret the measured vitrinitre reflectance data burial modelling was carried out. To estimate the paleo-heat flow rates of Győr and Zala Basins, calibration vitrinite reflectance data were used. The uncertainties – the contingent presence, erosion and ambiguous thickness of Late Cretaceous and Tertiary sediments covering the Gerecse Mountains – needs more combination of modelling. The significant questions related to burial models are the following:

- The burial can be resulted by the *well known and described sediment sequence* of work area?
- The burial can be related to *sedimentary effect* at all?
- Observed vitrinite reflectance data can be related to a supposed *structural burial?*
- What is the *age* of burial, taking the results from investigation on ductile and rigid shortening deformation into account?

1.5. Map of corrected vitrinite reflectance data

Heat flow data taken from burial model permits the correction of calibration vitrinite reflectance data from Late Cretaceous and Triassic calibration samples. The young (early Middle Miocene – Recent) heat effect of samples were numerically eliminated using the TTI (*time-temperature index*) data method detailed as below:

- conversion of vitrinite reflectance data to TTI;
- determination of young (early Middle Miocene – Recent) heat effect for each Late Cretaceous and Triassic samples;
- numerical elimination of adequate young heat effect from TTI value of each samples;
- conversion of corrected TTI values to corrected vitrinite reflectance data.

To correct the vitrinite reflectance data and explain the result of their map view, the following questions have to be answered:

- What is the *practical and adaptable function* between vitrinite reflectance values and TTI data which can be use at their conversion?
- They are visible *trend(s) in the changes* of Triassic and Late Cretaceous corrected vitrinite reflectance data from point to point?
- The same trend can be observed at Triassic and Upper Cretaceous samples, or they are diverse?
- What is the *geodynamic explanation* of burial pattern shown by vitrinite reflectance data?
- What is the geodynamic explanation of *extreme low* vitrinite reflectance data observed in Triassic samples from Buda and Pilis Mountains and Csővár Hill?

1.6. Discussion

To explain the results of structural and burial information taken from Gerecse Mountains, the Late Jurassic – Middle Cretaceous structural evolution of Northern Calcareous Alps have to be taken into consideration. Changes in shortening directions, clastic sediment transport directions and heavy mineral components can give detailed information on investigated tectono-sedimentary evolution. Comparison in structural deformation pattern of Gerecse and

Northern Calcareous Alps can help in explanation of some problems of assumed structural burial of work area: the whole volume of Cretaceous formations is less than 10% of the supposed nappe covering Gerecse Mountains. Two main themes have to be investigated:

- What is the moment of beginning of divergence in tectono-sedimentary evolution of Gerecse and Northern Calcareous Alps?
- What can be the present location and position of the nappe covering Gerecse Mountains?

2. METHODS

The main methods and tools using by field work and computer analysis are detailed as below:

- *field geology* to observe, note and explain ductile and plastic deformation features;
- *vitrinite reflectance measurements* to detect the deep burial using reflectance data of coalified plant fragments;
- *rock pyrolysis* to study the properties of organic components of collected rock samples;
- new computer code to separate and draw structural data collected by outcrops and data type;
- *IES PetroMod 9.0 computer code* to modelling the burial history and resulted heat effects on work area;
- *ESRI ArcMap 9.3 computer code* to map the results of field work and corrected vitrinite reflectance maps, too;
- geological database coded by MOl Plc. and Hungarian Geological Institute were used as lithological database;
- vitrinite reflectance database coded by the owner MOL Plc. were used and published with the permission of the Company.

3. RESULTS, DISCUSSION

3.1. Ductile and rigid structural elements related to horizontal shortening

Based on analysis of ductile and rigid shortening deformation features – folds, bedding parallel shear zones, reverse faults, thrusts, conjugated and non-conjugated foliations as well as schistosity – show three significant compressional events in Gerecse Mountains of which sequence can be proved using field observations.

- The first, NE-SW one can be related to Aptian compression;
- the age of the following E-W shortening event can be assigned to Early Albian age;
- the age of last, (S)SE-(N)NW one can early Middle Albian.

The first (NE-SW) and second (E-W) shortening event can be correlated to Cretaceous tectonic evolution of work area (obduction of Vardar ophiolitic unit); the last (S)SE–(N)NW one is related to syncline formation of Transdanubian Range.

3.2. Burial – burial model

Vitrinite reflectance measurements carried out on Middle Cretaceous sediments containing autigenous coalified plant fragments – in agreement with the result of rock pyrolysis method, regularly mixed-layer clay mineral analysis and structural observations – shows the deep burial of Gerewcse Mountains. This effect cannot be explained by supposed sedimentary sequence with the observed maximal formation thickness from Middle Cretaceous to Quaternary age in Transdanubian Range moreover Late Cretaceous sediments are unknown from Gerecse Mountains and the observed thickness of younger ones is more smaller than their maximal value. Burial modelling can confirm the possibility of classic nappe covering model as well as the nappe thrusting following by extensional allochton model. Structural cover of Gerecse Mountains – in accordance with tectonic processes and information on horizontal shortening – can be assumed to be Aptian – Albian age.

3.3. Map of corrected vitrinite reflectance data

After correcting the Late Cretaceous and Triassic vitrinite samples with elimination of early Middle Miocene – Recent heat effect from each samples, the burial map of Triassic as well as Late Cretaceous samples was to analysed. Corrected Late Cretaceous vitrinite reflectance data indicates monotonous burial from Zala basin and Keszthely Mountains area trending to W-NW. The picture of Triassic samples is mainly different, because

- samples of Zala Basin show 0,80% mean vitrinitre reflectance;
- samples from Rezi, Sümeg and Balatoncsicsó region indicates the absence of Mesozoic-Cenozoic burial because their 0,50% vitrinitre reflectance;
- increase in vitrinite reflectance data can be observed from Keszthely Mountains to Győr basin; the reflectance value shows monotonous increase from 0,50% to 2,00%;
- samples from Buda and Pilis Mountains as well as Csővár Hill show extreme low 0,30% reflectance indicating absence of burial.

Comparing the trends observed on Late Cretaceous and Triassic samples, notable difference can be established. The age of this effect – resulting in difference of Late Cretaceous and Triassic picture – is Early Jurassic to Middle Cretaceous and cannot be explained by sedimentary burial. The deep burial observed in NE part of Győr Basin cannot be recognised in Buda Mountains which confirms the tectonic burial effect.

3.4. Discussion

Elements of classic, well described nappe thrusting observed in Northern Calcareous Alps can be recognised in Gerecse Mountains. Results of obduction of Vardar and Juvavic-related units is clear visible in Northern Calcareous Alps, and can be proved in Gerecse Mountains confirmed by similar stress orientation, clastic sediment transport direction and heavy mineral spectra. At the Aptian-Albian bounday changes in co-evolution can be observed: the thrusting of Tirolic and Bavaric-related units are described only in Northern Calcareous Alps which difference can be confirmed by clastic sediment transport direction and heavy mineral spectra. Major changes in Albian structural evolution can be observed: the stress direction resulting the thrusting in Northern Calcareous Alps is oblique the local stress field folding the Transdanubian syncline structure.

The proposed tectonic burial of Gerecse Mountains can be one the last events of structural co-evolution at Aptian-Albian boundary. Pilis and Buda Mountains are proposed to be the extensional allochtonous nappes covering Gerecse Mountains.

4. THESES

1. Based on analysis of ductile and rigid shortening deformation features – striae indicating bedding parallel shear, inverse faults, thrusts, conjugated and non-conjugated compressional foliations, schistosity – three significant compressional events and their proven relative timing were observed in Gerecse Mountains.
2. The sequence of horizontal shortenings can be proved and their age can be well estimated. The first, NE-SW one can be related to Aptian compression; the age of the following E-W and (S)SE-(N)NW shortening events can be assigned to Early and early Middle Albian compressions, respectively. This observation indicates 90°clockwise relative rotation in horizontal stress direction.
3. Vitrinite reflection data and burial analysis indicates the deep burial of Gerecse Mountains. The heat effect resulting from deep burial cannot be explained by the burial effect of known and studied Cretaceous and Tertiary sedimentary sequences of Gerecse Mountains or of Transdanubian Range.
4. Results of burial models supposing tectonic burial (classic nappe thrusting with erosian as well as thrusting than extensional detachement) of Gerecse Mountains are in good agreement with the vitrinitre reflectance data.
5. The correction of vitrinitre reflectance of samples from Győr and Zala Basin as well as Transdanubian range allows to map the pre-Badenian burial state of Triassic and Late Cretaceous samples. The map of Triassic samples shows increasing burial from Keszthely Mounatins to (E)NE which cannot be observed on the Late Cretaceous map, therefore the age of burial can be supposed between Early Jurassic – Middle Cretaceous. The difference between the corrected Triassic vitrinite reflectance data from East Győr Basin (~2,00%) and West Buda Mountais (~0,30%) is notable and cannot be explained by differences of sedimentary burial.
6. Comparison of heavy mineral spectra, sediment transport and stress axis directions observed in synorogenic clastic sediments from Northern Calcareous Alps and Gerecse Mountains indicates an Albian divergence in their formerly identical structural evolution.

5. PUBLICATIONS

5.1. Accepted scientific publication related to PhD work

- **SASVÁRI, Á.** 2008A: A Magas-Gerecse töréses feszültségterének fejlődése a Dunántúli-Középhegységről készült publikációk tükrében: irodalmi áttekintés. — *Földtani Közlöny* **138/2**, 445-468.
- **SASVÁRI, Á.** 2008B: Rövidüléshez köthető deformációs jelenségek a Magas-Gerecse területén. — *Földtani Közlöny* **138/4**, 383-400.
- **SASVÁRI, Á.**, CSONTOS, L. & PALOTAI, M. 2009: Szerkezetgeológiai megfigyelések a gerecsei Tölgyháti-kőfejtőben. — *Földtani Közlöny* **139/1**, 55-66.

5.2. Conference abstracts related to PhD work

- **SASVÁRI, Á.** 2007: Rövidüléshez köthető rideg és képlékeny deformációk a Magas-Gerecse területéről. — *Ifjú Szakemberek Ankétja abstract-book* **38**, 15-16.
- **SASVÁRI, Á.** 2007: Ductile compressional deformation in the Gerecse Mts, Hungary. — *HUNTEK abstract book*, 3p.
- **SASVÁRI, Á.** 2008: A Magas-Gerecse betemetettsége a vitrinitreflexiós mérések tükrében. — *VII. Conference of Earth Sciences abstract book*, 4p.
- **SASVÁRI, Á.** 2008: Egy „különleges kőzetmozgási alakulat" értelmezése – nyíráshoz kapcsolható szerkezetek a gerecsei Ördöggáti-kőfejtőben. — *VII. Conference of Earth Sciences abstract book*, 5p.

5.3. Scientific publications in preparation related to PhD work

- **SASVÁRI, Á.** 2008: Egy különleges kőzetmozgási alakulat értelmezése – nyíráshoz kapcsolható szerkezetek a gerecsei Ördöggáti-kőfejtőben. — manuscript sent to *Földtani Közlöny*.
- **SASVÁRI, Á.** 2009: A Magas-Gerecse betemetettsége a vitrinitreflexiós mérések tükrében. — manuscript sent to *Földtani Közlöny*.