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Geovestník

XVIIth Congress of the Carpathian-Balkan Geological Association

Bratislava, September 1–4, 2002

Foreword

On 1–4 September 2002 the XVII Congress of the Carpathian-Balkan Geological Association took place in Bratislava.

This international event of European importance was organized by the Geological Survey of Slovak Republic in co-operation with Geological Institute of Slovak Academy of Sciences, Comenius University, Faculty of Natural Sciences, Geophysical Institute of Slovak Academy of Sciences, National Geological Committee, and Slovak Geological Society under auspices of the Ministry of the Environment of Slovak Republic.

The Carpathian-Balkan Geological Association (CBGA) belongs among the oldest international professional associations in Europe. Its constituent members were Czechoslovakia, Poland, Romania and Yugoslavia.

CBGA is non-governmental, international, scientific, non-political and non-profit association of sciences working in the field of geology in the Carpathian–Balkan region. It is a member of International Union of Geological Sciences. The congress of the Association is organized regularly every four years in one or more of the member countries.

498 participants from 24 countries from Europe, Asia and Australia took part at the XVII Congress of the CBGA. During the congress 212 lectures were presented and 132 posters were displayed. The contributions included the whole spectrum of geology; many of them concerned problems of geophysics.

The Congress included nine working groups dealing with the following themes:

1. *Paleogeography and Development of Basins: the Mesozoic and Tertiary Basins*
2. *Paleontology and Stratigraphy*
3. *Metamorphic Processes*
4. *Volcanic and Plutonic Processes*
5. *Structural Geology and Tectonics*
6. *Lithosphere Structure, Seismology and Earthquake Hazards*
7. *Mineralogy, Economic Geology and Mineral Sources*
8. *Hydrogeology and Geothermal Energy*
9. *Environmental Geology*

Several working sessions, important for development of bilateral and multilateral relationships among the individual member countries and scientific organizations, were held also:

1. *Alpine–Carpathian–Pannonian map of Terrains*
2. *Tertiary Alpine–Carpathian–Pannonian Volcanoes*
3. *IGCP Project No. 442: Rock Material of the Neolithic Stony Artifacts*
4. *IGCP Project No. 443: Magnesite and Talc*
5. *Geological Heritages and Geotourism*
6. *Changes of the Climate*

7. Radiogene and Stable Isotopes
8. Petroleum Geology – Fossilized Fuels
9. Quaternary Geology
10. Technolithology – Pathological Changes in Construction Materials

The presentations of regional geological projects were equally important:

1. DANREG 1990–1998
2. TIBREG 1995–2001
3. Regional Geological Maps
4. International Co-operations Among Poland, Slovak Republic, Czech Republic and Ukraine.

At the end of the Congress a geological excursion was organized where all fundamental units of the Western Carpathians were introduced.

During the final ceremonial the Republic of Yugoslavia took over the chairmanship of the CBGA – Yugoslavia is organizing the next congress that will be held in 2006 in Beograd.

Editors

Note: The extended abstracts, being accepted by the Scientific Committee of the XVII Congress of Carpathian-Balkan Geological Association, were published in the special issue of the journal Geologica Carpathica 53/2002. This Post-Congress issue of Mineralia Slovaca presents only the extended abstracts of authors using this publication possibility given by the Organizing Committee of the Congress during the closing ceremony.

Mineralia Slovaca, 35 (2003), 1–73

Geosciences in society – their position and goals for the 21st century

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Geosciences and society

The XVII Congress of the CBGA belongs to those ones in the field of geosciences, which are organized not long after the change of centuries and millenia. So it is a suitable moment to do evaluation of the position and role of geosciences in human communities on one, and the position of geosciences among sciences in general, on the other side. Such summary is needed for the following application of geosciences' results into society and for the better understanding of the planet Earth processes and their consequences on the quality of our daily life.

Last decades of the 20th century brought countless evidences on non-substitutional role of geosciences in human community namely keeping in mind idea of "sustainable development" proclaimed in the past.

Grandious projects of superpowers from sixties and seventies of the last century dealing with the recognition of the terrestric planets did not proved non proclaimed but hopefully expected idea on huge exploitable raw material deposits occurring there. This mankind dream has not been proved. The reality valid nowadays is, that the Earth crust was the place of the mankind origin and that the raw materials needed occur exclusivelly on, or better in the lithosphere of the planet Earth. The number of Earths' inhabitants permanently increases. Not speedy in Europe and North America, but drastically rapidly in the East Asia and Africa and Latin America. The increase of the human population on one side, but also an introduction of the new and new transport, communication and databases forming and for re-creation decized systems they all in the second half of the 20th century consumed more inorganic raw materials as was amount of them exploited in the whole previous history of mankind. This is valid namely for energetic materials: oil and gas. During the last 30 years mankind consumed more of them that before 1970. We geologists know the reality, but do take it into strategic decision also politicians of decision making people?

Following such introduction it is time to formulate the following crucial question: are geologists prepared to solve problems of mankind in the 21st century? Among principal tasks belong namely discoveries of new, from some aspects of view nontraditional raw materials, to discover sufficient amount of drinkable water, but simultaneously to fix up suitable location of communal, industrial, toxic as well as radioactive wastes, in monitoring and minimalizing natural disasters (earthquakes, overflows, landslides, volcanic hazards, radon risks and many others). How are geologists prepared in colaboration with other natural and human scientists to face danger of desertification of huge areas, danger of acidification of farmed land and the many other tasks? No less important are geological problems connected with location of huge underground noisy technologies etc.

This short review allows us to sum up ways how to solve mentioned questions. So the main tasks are as follows: how geologists shall realize all expected problems in inorganic nature having direct impact on human society in the 21st century? Only little attention have been paid to the mentioned problematic in our countries until now.

Geological sciences (or geosciences it the broader meaning) in both applications, e. g. as one of natural sciences and simultaneously as the integral part of states economies, culminated in sixties and seventies of the 20th century. Since that time geosciences in a hierarchy of the society priorities gradually loss their former positions. Such unfavourable development is based on the following:

i) Namely in the 3rd world large deposits of basic metals (but not only those) are exploited using modern technologies in excavation, dressing and what is the most important – using relativelly cheap man power.

i) In prosperous democraties the long-term activities of officials of all levels to educate human communities in respect to recyclise basic metals and the other raw material commodities reached their harvest: substantial part of the raw materials is repeatedly used.

i) It acts to a general trend to use raw material in lower amount for machines, tools, and many other products of industries construction. This aspect is concentrated in the use of highly effective electronic hardware, chips, electronic communication network etc.

As a direct consequence of lower demand of young geologists/geoscientist the numerous departments of geological sciences in various universities round the world have been closed, or their staffs have been reduced. The most

sensitive aspect of the discussed problematic is that the geological research (survey) of state territories (geological mapping included) in the majority of countries by the state quaranteed budged has been drastically reduced. While in economically prosperous countries industry supplies a part of geoscience research, in transforming Middle- and Eastern European countries industry is not prosperous enough to supply financially geosciences in their colorfull activities.

Not belonging to pesimists, it seems to the speaker, that there exist – at least partial, solutions. I will try to pointed on some of them.

Education in the earth sciences

One of the main tasks to stop above mentioned non desirable trends have geoscientists themselves. They ought to prepare the global plan- and decision makers of the unique role of geosciences (modern material sciences, i. e. geology in the whole, but namely geophysics, geochemistry, mineralogy, petrology, crystallography) in the process of discovery, identification and proposals of the practical use of new, mostly non-traditional raw materials.

For modern educated societies appropriate knowledge of inorganic nature is one of basic demands. Only educated people in the whole complexity of the current-day human knowledge will be abble to manage small or large human communities. They have to keep in mind that economic and from environmentalistic point of view non harmful exploitation of abiotic sources is a fundamental aspect for progressively developing communities in the 21st century.

Universities education in geosciences underwent changes during the very last decades. The majority of ministers of education of the European countries in 1997 signed so called "Bologna proclamation", according to which also university studies of geosciences have three consequently following levels: bachalor, magister (master) and doctor's level. The other unifying aspects of mentioned proclamation are the mobility of students and teachers within the country and on international level. This is applicable among universities which undervent international (OECD) accreditation.

Among topical aspects in education, on both, middle school as well as on the university level belong the adaptation of system of lectures and practises to the top level tasks of geology. So students of geology need more basic sciences (matematics and physics, chemistry including), they ought to be directed to learn international languages, to be abble to work on PC, internet etc.

Education in geosciences on the university level rapidly changed in the whole world dimension during the last, let say, 30 years. Meanwhile in sixties and seventies of the last century the education in geosciences on magister and namely doctor levels for students from developing countries has been performed mostly by the European and the North American universities, nowadays in the majority of the third world countries national universities have been established, where also the basic courses in geology are offered. In spite of that role of well established European and American research universities there is permanent the organization of the field courses and pre- and postdoc courses in various specialization.

In this context I would like to underline that in geology there is still valid the classical H. H. Read's well-known sentence: "the best geologist is he who has seen the most rocks". So extensive field experiences, which ought to be an integral part of the university studies, always reflect respect among geoscientists. So education in geosciences is long in comparison, for example with matematicians, who often score their brilliant successes when they are young. The geoscientists somewhat resemple the diagnosticians in medicine, where field work should be called as "clinical experience" of medicine doctors.

Namely in our country, as the relic from the past, during the secondary school study our young generation is supplied in very restricted amount by the top level scientific knowledge dealing with inorganic nature. Short course of inorganic nature and basic aspects of the Universe (restricted mostly to non atractive crystallography reduced to the crystal symmetries) is tought by teachers without appropriate education at the university level, etc. To change situation in this respect is fundamental for reaching highter level of inorganic nature understanding by the prevailing part of the society.

Author of these remarks reached conclusion that only well complexly educated members of human societies in all aspects of modern life will understand inorganic nature basic laws and will react adequatelly in respect to them. Such selected (or elected) individuals (the parliament members included) will understand basic processes in nature and will have positive standpoint to financial necessities in this respect, e. g. to geological survey of the state territory, geoscientific education at the secondary school levels, financial budget of universities departments, needed money for laboratory equipment, libraries, field courses of pre- and postdoctoral students, etc. Closing this aspect: education of all members of human society is the base request for prosperous managament of inorganic nature, its resources and namely their environmentally non-destructive exploitation.

Publication policy

In contrast to the other sciences the geosciences or better, geoscientists, represent, which is not meant absolutely, selfconsuming society in relation to spred over communities of individual states results of professional work. Only few university teachers or top level scientist from the academies and surveys have fixed among their personal priorities to publish from time to time the scientific-popular themes, or to prepare scenarios for film, TV, radio etc. Selfconsuming aspects of geoscientific communities in individual CBGA countries reflects in low amount of international scientific journals listed in the Current Contents or other accepted databases. It should be illustrated by number 2 of geoscientific journals in the space between Berlin and the Urals, which are listed in the Current Contents.

Already in the last two CBGA congresses the idea of one topical international geoscientific journal has appeared. In the past a general agreement has been reached, that for the moment such journal should be Geologica Carpathica. This journal is already included in the Current Contents and has appropriate impact factor. The only problem, which should be solved soon, is sufficient amount of manuscripts covering various fields of geosciences of international standard written by the authors from the CBGA countries. So, we call for manuscripts!

Well educated people univocally accept that the science as a whole represents one of the major parts of contemporary culture. In the context of this the geosciences play crucial role in both: the popular as well as in scientific culture. It is general opinion: majority of human beings look at the world over the last several centuries. Nowadays it is clear that a knowledge of the Earth history basicaly enriches our understanding of mankind history.

Understanding of history of our enrironment started to be a distinct field of geologists' interest only in the last decades. But human history without history of the Earth, or more precise, without history of human environment, is incomplete, it is partial. But all this ought to be remembered, or what is more effective, to be presented to the whole societies and our colleague scientists of the other specializations.

"Penetration" of geology into various fields of human activities

A wide spectrum of non-traditional applications of well trained specialists in geosciences in human societies is the other possible and desirable solution of discussed problematic. Various fields as well as laboratory methods used by geoscientists in a very broad spectrum of human activities up till now have been seldomly realized. But this aspect varies from country to country and depends on the trends of the university level education.

In the field of scientific research let us use archaeometry/petroarcheology as an exemple. Modern archeology univocally needs collaboration with material scientists (mineralogists, petrologists, geochemists, geophysicists), but also with biologists, analytical chemists, climatologists and the others. Using working research methods of mentioned sciences archeological artefacts should be defined in details: the raw materials of chipped and polished implements and settlements construction materials, types and provenances of clays for ceramic production etc. Getting basic information on raw materials used in discrete area in given time-period, migration paths of the raw materials or ready-made implements in continental dimensions should be traced. Accepted IGCP/UNESCO project No. 442 (Raw materials of Neolithic/Aeneolithic implements: their migration path in Europe) for the year 1999 and the following years should be used as an exemple of interdisciplinary approach to solve the above problematics.

Based on the fact that archeological objects differ in physical properties (electrical conductivity, density, susceptibility, radioactivity and the others) from the surrounding media, measuring of mentioned properties by sensitive instruments is highly effective. Using geophysical methods enable us to decrease the volume of technical work (excavations) and reduce financial cost and time needed. Geophysical methods have been used during last sixty years for prospecting and location of archeological sites of interest mainly in the Northem Europe. Later on these methods have been applied all over the world.

But geosciences have tremendous application also in practical technologies and human activities. Permanent problems in inorganic environment should be monitored and problems solved using geoscience methods, for example problems of soil erosion, overflows, landslides and rockfalls, prediction of earthquakes and volcanic eruptions, location of the radon risk areas, in solving problems of ancient mine wastes, underground located technologies, surveys for suitable quantity as well as quality of drinking water. Geologists in broader sense should look for jobs in rapidly developing new technologies, i. e. petrurgy (artifical melting of natural rocks and consequent production of rock-wool and bricks) surveys for places of radioactive waste deposits, places for exploitation of the "dry rock" heat and many others.

At last but not of the least meaning I would like to mention necessity of educated crossdisciplinary specialists trained both in museology as well as in geosciences. Such museum custodies are completely missing in the majority of museums in the country though several of them are concentrators of artefacts of inorgenic character. Translators into international languages educated in geosciences should get jobs in leading publishing houses, press, TV and radio, but our young colleagues ought to try to get such positions!

Concluding remarks

1. Geosciences in society will play non-replaceable role also in the 21st century. But they do have partly change their priorities. The leading slogan "geosciences in service to society" will be preferably used and will help to get money for geological activities in future.

2. For basic research there will be not enough money in individual countries with transforming economies. So the only way how not to be outsiders is to joint international teams financed by non-profitable international agences such as the UNESCO, IUGS, EU, NATO and the others. The other way is to submit international scientific or practical problems solving projects.

3. First step in reaching the high level of university education is to have high level of middle school education in basic sciences. So it should be very effective from time to time to organize short courses (lectures and practical demonstrations of geological phenomena, rocks, minerals, new geological maps and all kinds of printed matters) for the middle school teachers. In Bratislava we have already opportunities from the organization of several such courses. The middle school teachers are fully satisfied and ask for the next ones.

4. The education of the society is one of the nowadays

actual problems of geosciences. Educated individuals, when selected or elected into position in the state administration, have primary personal knowledge and there is hope that their decisions will be in accordance to the efforts of scientists. So dear colleagues: start with popularization of geosciences as soon as possible. Ways to do so are very different. In this respect, your will to do popularization of science, is in the first place.

5. Alpine Europe in its eastern sector has several unique geological phenomena. Many type localities for rocks, minerals, but also geological processes etc. are cited in the world scientific literature. But modern description (with relevant isotopic, microprobe and the other laboratory results) and evaluation of them is mostly missing.

6. In the CBGA countries several tens of geological periodicals are published. Part of them is published in international languages. It is normal that individual editors and publishers try to get papers on the possible highest level. But from the point of view of consumers to follow mentioned tens of journals is tirefull, and time consuming work. Already mentioned concentration of our best results in restricted amount of journals covering the eastern segment of the Alpine Europe should be progressive.

7. Let us offer opportunity to our university students and doctorands to finish university study in the crossdisciplinary/transsectorial specializations, e. g. geosciences – archeology, geosciences – journalism, geosciences – museology, geosciences – administration/management etc. In other words: university studies need more diversified specializations for the 21st century as they have nowadays.

This invited lecture has been presented during the opening plenary session of the XVII CBGA Congress in Bratislava (01/09/2002).

Early stages of the Carpathian basins development

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Abstract

The basement of most plates, which play an important role in the Mesozoic-Cenozoic evolution of the circum-Carpathian area, was formed during the Late Paleozoic collisional events. The Mesozoic rifting events resulted in the origin of the oceanic type basins like Meliata, Vardar-Transilvanian and Ligurian-Penninic-Pieniny Oceans. During the Late Jurassic-Early Cretaceous time the Outer Carpathian rift had developed.

Key words: plate tectonics, Tethys, Carpathians, Late Paleozoic, Mesozoic, basins

The basement of most plates, which play an important role in the Mesozoic-Cenozoic evolution of the circum-Carpathian area, was formed during the Late Paleozoic collisional events. The older, Cadomian and Caledonian basement elements experienced the Hercynian tectonothermal overprint (Rakús et al., 1998). Moesia, Rhodopes and the Alcapa superterrane which includes Eastern Alps, Inner Carpathians, Tisza and adjacent terranes, were sutured to the Laurasian arm of the Pangea, while Adria and adjacent terranes were situated near the Gondwanian (African) arm. The Paleotethys Ocean was situated between northern, Laurussian (N. America, Baltica and Siberia) and southern, Gondwanian branch (Africa, Arabia and Iranian terranes) of Pangea (Golonka, 2000). Mountains formed on the northern margin of Paleotethys, as a result of these events, were connected with the Hercynian orogen in Europe. North-dipping subduction developed along the Paleotethys margin. This subduction was a major force driving the Late Paleozoic and Early Mesozoic movement of plates in this area. It caused Triassic back-arc rifting in the proto-Black Sea area forming the Tauric basin between the Pontides and the Dobrogea-Crimea. According to Muttoni et al. (2000) Moesia was probably marginally separated, but not detached or rotated away from Europe by the North Dobrogea transtensional trough, which is also interpreted as a back-arc basin resulting from the northward subduction of the Tethys Ocean. This trough was perhaps connected with the rift situated in Poland. The Polish rift, also known as the Polish-Danish Aulacogen has SE–NW direction parallel to the Transeuropean Suture Zone.

The oceanic system was established in Southern and Central Europe during the Permian-Triassic time. The narrow branch of Neotethys separated the Apulia-Taurus platform from the African continent. The Apulia platform was connected with European marginal platforms. Its northernmost part was possibly separated from the Umbria-Marche region by a rift. The incipient Pindos Ocean separated the Pelagonian, Sakariya and Kirsehir block from the Ionian-Taurus platform (Golonka et al., 2000).

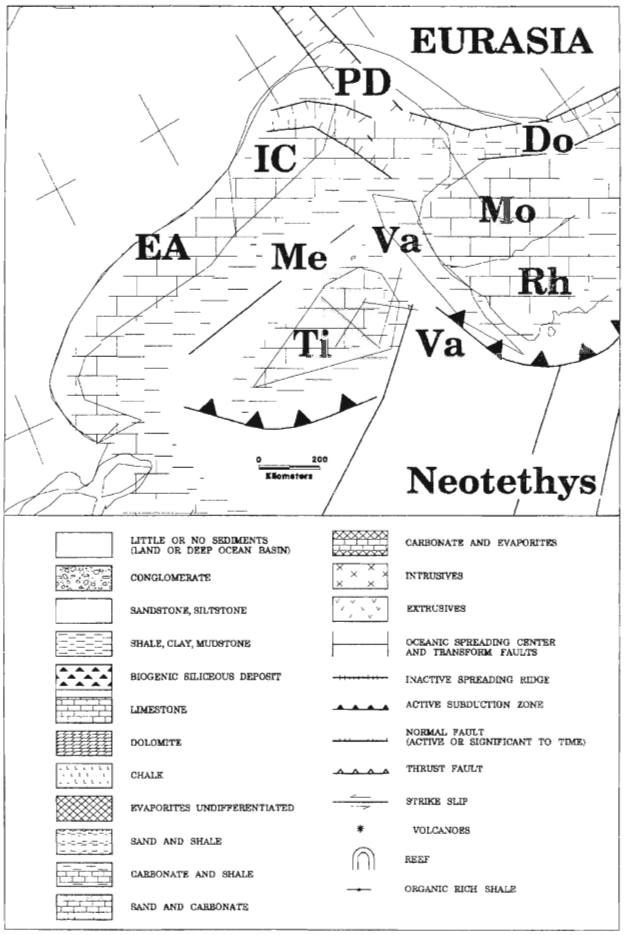

Fig. 1. Paleogeography of the circum-Carpathian area during Late Triassic; plates position at 225 Ma. Abbreviations of oceans and plates names: Ad – Adria (Apulia), Bl – Balkans, Br – Briançonnais terrane, Cr – Czorsztyn Ridge, Do – Dobrogea, EA – Eastern Alps, IC – Inner Carpathians, Li – Ligurian (Penninic) Ocean, Me – Meliata/Hallstatt Ocean, Mg – Magura Basin, Mo – Moesia plate, PB – Pieniny Klippen Belt Basin, PD – Polish-Danish aulacogene, Rh – Rhodopes, SC – Silesian Ridge (cordillera), Si – Silesian Basin, SM – Serbo-Macedonian terrane, Ti – Tisza plate, Va – Vardar

The Vardar-Transilvanian Ocean separated the Tisza (Bihor-Apuseni) block from the Moesian-Eastern European Platform (Sandulescu, 1988). There is a possibility of existence of the embayment of Vardar-Transilvanian oceanic zone between the Inner Carpathians and European Platform (Golonka et al., 2000). The pelagic Triassic limestones in the exotic pebbles in the Pieniny Klippen Belt (Birkenmajer et al., 1990) and Magura Unit (Soták, 1986) could have originated in this embayment. The embayment position and its relation to the other parts of Tethys, Vardar Ocean, Meliata-Hallstatt Ocean, Dobrogea rift and Polish-Danish Aulacogen remain quite speculative.

According to Rakús et al. (1998) two oceanic units were located south of the Inner Carpathian plate. One was open during the Triassic time, closed during the Late Triassic as a result of the Early Cimmerian collision. Another, represented by sequences at the classic profile of Meliata in Southern Slovakia, opened during Early--Middle Jurassic as a back-arc basin and closed during Late Jurassic time. The position of the Meliata Ocean, time of closing and a role of the Tisza unit in the Mesozoic collisional events is still the subject of lively discussion (see e. g. Kozur, 1991; Stampfli, 2001; Plašienka, 1999; Golonka et al., 2000; Wortman et al., 2001).

Continual sea-floor spreading occurred during the Jurassic time within the Neotethys. The Pelagonian plate, Kirsehir and Sakariya (and perhaps the Lesser-Caucasus-Sanandaj-Sirjan plate) were drifting from the Apulia-Taurus-Arabia margin. The Ligurian Ocean, as well as the central Atlantic and Penninic Ocean were opening during Early – Middle Jurassic. The oldest oceanic crust in the Ligurian-Piedmont Ocean is dated as late Middle Jurassic in Southern Apennines and in the Western Alps. Pieniny data fit with the supposed opening of the Ligurian and Penninic Ocean basins (Golonka et al., 2000). Stampfli (2001) recently postulates single Penninic Ocean separating Apulia and Eastern Alps blocks from Eurasia. We proposed similar model for the Pieniny Klippen Belt Ocean in the Carpathians. The orientation of this ocean was SW–NE (see discussion in Golonka and Krobicki, 2001). The Pieniny Ocean was divided into the northwestern and southeastern basins by the Czorsztyn Ridge. The deepest parts of both basins are documented by deep water, extremely condensed, Jurassic-Early Cretaceous pelagic limestones and radiolarites. The shallowest ridge sequences are known as the Czorsztyn Succession. In this succession the Early Jurassic Bositra *("Posidonia")* marls are followed by Middle Jurassic-earliest Cretaceous crinoidal and nodular limestones and the Late Cretaceous pelagic marl facies. The transitional slope sequences between deepest basinal units and ridge units consist of mixed cherty, limestone and marly facies. This Jurassic Ocean was connected with older, Triassic embayment of Vardar-Transilvanian Ocean.

Major plate reorganization happened at the end of Jurassic. The Central Atlantic began to propagate to the area between Iberia and the New Foundland shelf. The Melia-

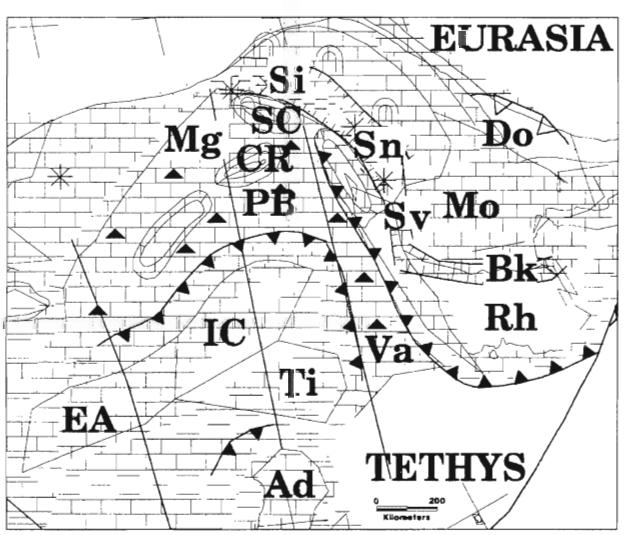

Fig. 2. Paleogeography of the circum-Carpathian area during latest Late Jurassic–earliest Lower Cretaceous; plates position at 140 Ma. For explanation – see Fig. 2.

ta-Hallstatt space was closed and subduction jumped to the northern margin of the Inner Carpathian terranes and began to consume the Pieniny Klippen Belt Ocean (Birkenmajer, 1986). The Outer Carpathian rift had developed with the beginning of calcareous flysch sedimentation. The Western Carpathian Silesian Basin probably extended in the Eastern Carpathian (Sinaia or "black flysch") as well as to the Southern Carpathian Severin zone (Sandulescu, 1988). The remnants of carbonate platforms with reefs (Štramberk) along the margin of Silesian Basin were results of the fragmentation of the European platform in this area. The Silesian Ridge separated the Silesian and Magura basins. The subsidence and spreading in the Silesian Basin was accompanied by the extrusion of basic lavas (teschenites) in the Western Carpathians during Hauterivian-Barremian and diabase-melaphyre within the "black flysch" of the Eastern Carpathians (Golonka et al., 2000; Lucińska-Anczkiewicz et al., 2000). The extension of the Silesian-Sinaia basin is mark by the beginning of the sedimentation in the Skole-Tarcau area.

The Jurassic separation of Bucovino-Getic microplate from European plate is perhaps related to the origin of the Silesian Ridge. The direct connection is obscured however by the remnants of the Transilvanian Ocean in the area of the eastern end of Pieniny Klippen Belt Basin. These remnants are known from the Iňačovce-Krichevo unit in Eastern Slovakia and Ukraine (Soták et al., 2000). In this area existed a junction of the different basinal units – PKB-Magura-Ocean, Transilvanian Ocean and Outer Carpathian Basin. The eastward-northeastward subduction along the Silesian Ridge and Bucovinian-Getic Terrane was perpendicular or oblique to the southward subduction at the northern margin of the Inner-Carpathian-Eastern Alps terrane. The Silesian – Sinaia basin developed as a back-arc basin. The eastward subduction of Getic-terranes is connected with the northward subduction under Rhodopes-Moesia plate mentioned above. The displacement within Transilvanian Ocean which began in Barremian is perhaps also related to this subduction.

The Outer Carpathian basin reached its greatest width during the Hauterivian-Aptian time. With the widening of the basin, several subbasins (troughs) began to show their distinctive features. These subbasins, like Silesian, Sub-Silesian, Skole, Dukla, Tarcau, were locally separated by uplifted areas, e. g. Inwald-Andrychów zone. The general downwarping of the Silesian Basin was probably due to the cooling effect of the underlying lithosphere. The sedimentation of calcareous sediments pass upwards gradually into black shales with turbiditic sequences in the Silesian trough.

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The Outer Carpathian basins geodynamic reconstructions: problems and pitfalls

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Abstract

The paper discusses major unsolved problems related mainly to the paleoreconstruction of the Outer Carpathian Basins during their opening stage in Triassic-Late Cretaceous. Age and location of Outer Carpathian basins, their basement, paleostructural elements separating basins and their relations to the surrounding crustal elements are major issues.

Key words: plate tectonics, paleogeography, Tethys, Carpathians, Mesozoic, basins

Introduction

Traditionally the Northern Carpathians are subdivided into an older range known as the Inner Carpathians and the younger ones, known as the Outer or Flysch Carpathians. At the boundary of these two ranges the Pieniny Klippen Belt is situated. The Outer Carpathians are built up of a stack of nappes and thrust-sheets changing along the Carpathians and built mainly of flysch representing the time span from the Jurassic up to the Lower Miocene. All the Outer Carpathians nappes are overthrusting onto the European platform covered by Miocene deposits of the Carpathian Foredeep. These nappes have mainly allochtonous character, and originated in basins situated outside their present location. The palinspastic reconstructions of the Outer Carpathian realm attempt to restore the age and past location of basins, their age, their floor or basement, relations to the surrounding crustal elements as well as character of the paleostructural elements separating them. All this goals are still not easy to achieve, many problems have to be solved and many pitfalls have to be avoided. This paper discusses some problems related mainly to the basins opening; the basin closure is another issue with an additional set of problems.

Age and location of Outer Carpathian basins

Traditionally (e. g. Ślączka and Kamiński, 1998) the following sedimentary basins have been distinguished in the Northern Outer Carpathians from south to north: The Magura Basin, the Dukla and Fore-Magura set of basins, the Silesian Basin, the Sub-Silesian Ridge and the Skole Basin). The Late Jurassic to Albian age (e. g. Pescatore and Ślączka, 1984; Ślączka and Kamiński, 1998) has been assigned for the early stage of the basin development, characterized by the basin subsidence (see also Poprawa et al., this issue). This age is certainly true for Silesian Basin. The problem starts with the Magura Basin. The main part of the Magura flysch sequences is of Late Cretaceous-Paleogene age. However, there is also widely accepted possibility of the much earlier, Early-Middle Jurassic origin of the Magura Basin (see e. g. Birkenmajer, 1986; Dercourt et al., 1993; Golonka et al., 2000). On the Stampfli (2001) reconstruction the Magura basin has been posted on the Triassic reconstruction. Indeed, there is a possibility of existence of the embayment of Vardar-Transilvanian oceanic zone between Inner Carpathian, and European Platform (Golonka et al., 2000). The exotic material of the Triassic pelagic spotty limestones which occur as pebbles within Cretaceous-Paleogene gravelstones in the Pieniny Klippen Belt (from the enigmatic so-called Exotic Andrusov Ridge – Birkenmajer 1988; Birkenmajer et al., 1990) and Magura Unit (Soták, 1986) could have originated in this embayment. The Pieniny Ocean was fully opened by the Middle-Late Jurassic time (Birkenmajer, 1986; Golonka et al., 2000). Stampfli (2001) recently postulates single Penninic Ocean separating Apulia and Eastern Alps blocks from Eurasia. The Pieniny Ocean in the Carpathians constitutes perhaps the extension of Penninic Ocean. The Czorsztyn Ridge divided the Pieniny Ocean into the northwestern and southeastern basins. The deepest parts of both basins are documented by deep water, extremely condensed, Jurassic-Early Cretaceous pelagic limestones and radiolarites. The northwestern part of this oceanic basin developed into the Magura Basin during the Late Cretaceous time. The question of the relationship between Jurassic basinal realm to the Magura Flysch remains open, there is necessity however to envision some basinal sediments preceding the deposition of Cretaceous deep water red shales of Magura Unit (Birkenmajer and Oszczypko, 1998). The original orientation of the Pieniny/Magura Ocean is also a subject of debate (see discussion in Golonka and Krobicki, 2001) with most logical SW–NE direction. During the Late Jurassic the southern part of the North European Platform, north from the Pieniny/Magura realm started to be rifted and Silesian Basin in the Western Carpathians and Sinaia basin in the Eastern Carpathians, with black, mainly redeposited marls (?Kimmeridgian-Tithonian) have been created (Pescatore and Ślączka, 1984). The other Sub-Basins were distinguished during the latest (Hauterivian–Barremian) phase of basinal development. The connection of Silesian Basin with Sinaia and Southern Carpathian Severin areas (Sandulescu, 1988) suggests the

NW–SE direc-tion of the basinal axis; so, two Outer Carpathian perpendicular directions are possible within the basins.

Basement of basins

The Outer Carpathian flysch nappes have been uprooted, therefore the relationship between the basement of basins and their sedimentary sequences is not quite clear. There is an assumption of the oceanic type of floor in the Pieniny/Magura Ocean (Birkenmajer, 1986; Golonka et al., 2000). However, the true ophiolitic sequences, which could constitute the remnants of the original oceanic floor of Outer Carpathian Basins, have not been preserved in the Western Outer Carpathian. There are perhaps known from the Eastern Carpathians (e. g. Laschkevitsch et al., 1995). The relationship between Ukrainian ophiolites and Western Carpathian Unit requires further investigations. The oceanic type of floor in the Silesian and other unit is even more problematical. The geodynamic models based on an assumption of Silesian oceanic floor (e. g. Birkenmajer, 1986; Birkenmajer et al., 1990) do exist however. The thinned continental crust appears to be present during the Late Jurassic-earliest Cretaceous phase of rifting. The teschenites intrusions appeared during the latest phase of the rifting stage (Hauterivian-Barremian; Lucińska-Anczkiewicz et al., 2000), marking perhaps the initial stage of spreading. The Silesian basin reached the maximal width at that time (Golonka et al., 2000), the Late Cretaceous inversion followed (Oszczypko et al., 2002) and oceanic crust did not have enough time to develop fully.

Relation to the surrounding crustal elements

In general, the basement of most of the plates, which play an important role in the Mesozoic-Cenozoic evolution of the circum-Carpathian area, was formed during the Late Paleozoic collisional events (Golonka et al., 2000). The Outer Carpathian basins developed during the rifting and/or drifting processes of the various parts of the European plate. The most logical assumption would be to produce a reconstruction of basins (regardless of their orientation) with European margin on one side and Inner Carpathian plate on the other. The transitional elements of the Inner Carpathian plate would constitute the Andrusov exotic ridge (Birkenmajer, 1988) with back-arc and fore-arc successions (Plašienka, 1999). The very problematic is the position of Tisza plate in this picture. Tisza is now in Hungary-Romania, south of the Inner Carpathian realm. Some reconstruction (e. g. Neugebauer et al., 2001) place Tisza originally during Mesozoic at the Eurasian margin north of Inner Carpathian plate. The role, which Tisza plate played during origin the Pieniny/Magura Ocean and Silesian basin, is very unclear and speculative. Maybe Tisza was after all originally located south of Inner Carpathians and Meliata-Halstatt Ocean. The position of the Meliata Ocean, and a role of the Tisza unit in the Mesozoic collisional events is still the subject of lively discussion (see e. g. Kozur, 1991; Stampfli, 2001; Plašienka, 1999; Golonka at al., 2000; Wortmann et al., 2001).

Character of the paleostructural elements separating basins

With the existence of several basins with different stratigraphic succession it is necessary to postulate elevated elements separating them (e. g. Książkiewicz, 1960). As many as seven such elements (cordilleras) howe been postulated (e. g. Burtan et al., 1984). With the speculative character of several of these cordilleras at least three elevations are necessary during the early stage of Outer Carpathian basins development.

The Czorsztyn Ridge (e. g. Birkenmajer, 1986) separated Pieniny Basin from Magura Basin. The existence of this ridge is widely accepted. Its structural character is somewhat less certain. There is no single piece of evidence however, supporting also well established hypothesis of the continental character of ridge basement (e. g. Birkenmajer, 1977, 1986; Krobicki and Golonka, 2001). With the assumption of single Penninic-Pieniny-Magura Ocean the existence of the mid-oceanic ridge immediately is coming to ones mind. The existence of volcanics in the eastern end of the Czorsztyn Ridge (Lashkevitsch, 1995) seems to support such an outrageous idea.

The elevation between Magura and Silesian Basin is known as Silesian Ridge (Cordillera) (e. g. Książkiewicz, 1960). This ridge is known only from exotic pebbles in flysch (e. g. Burtan et al., 1984), its existence is however widely accepted. In the western part of Polish Carpathians the Silesian ridge appears originally as a rifted fragment of the European platform (Golonka et al., 2000). Later it was perhaps reorganized and incorporated part of Magura and Silesian Basin (Oszczypko et al., 2002). The relationships between the original ridge of a passive margin character and inverted structural uplift of active margin character remain somewhat speculative. Uncertain is also eastern extension of the Silesian Ridge, its relationship with the Dukla Basin and connection with Bucovinian-Getic Terrane (see Golonka et al., 2002).

The Subsilesian High separated Silesian and Skole basins as an elevated high during the Santonian-Paleocene time (Oszczypko et al., this issue). It was formed during that time as a foreland peripheral bulge. Question remains whether Silesian High existed before Santonian, as is suggested for example in reconstruction by Birkenmajer et al. (1990). The relationship between Fore-Silesian High between Skole and Silesian Basins and Fore-Silesian Unit in westernmost Poland and Czech Republic also remains speculative.

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Girvanella limestones and the occurrence of *Girvanella minuta* Wethered in the Upper Jurassic-Early Cretaceous of the Carpathian foreland

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Abstract

Girvanella limestones and the occurrence of *Girvanella* minuta have been noted in the Oxfordian to Early Cretaceous limestones of the carbonate platform in the Carpathian foreland. *Girvanella* is associated with reefs or forming nodular horizon. The alga indicates shallow-water environment, barrier reefs or lagoon within a photic zone with depth up to 20–30 m.

Key words: Upper Jurassic, algae, paleoenvironment, Carpathian foreland, limestones

Limestones with *Girvanella minuta* have been found for a first time in the southern margin of the Holy Cross Mountains in Central Poland (Golonka, 1970b). In older literature the *Girvanella* limestones used to be described as pisolitic limestones or as onkolites. The thallus of this alga forms nodules concentrically grown around a core which most frequently is the fragment of bivalve shell, echinoderm or other organical detritus. The size of nodule varies, from a few millimeters to 2–3 centimeters. On small specimens the outer surface is smooth, on larger ones it is wavy. *Girvanella* could have formed the nodules alone or by the combination with other alga *Rothplezella jurassica* Golonka. The interior structure of this alga consists of an aggregate of tiny twisted calcareous tubes of 6–8 μm diameter with walls 2–3 μm thick. Ramifications are seldom observed from one tube start out two

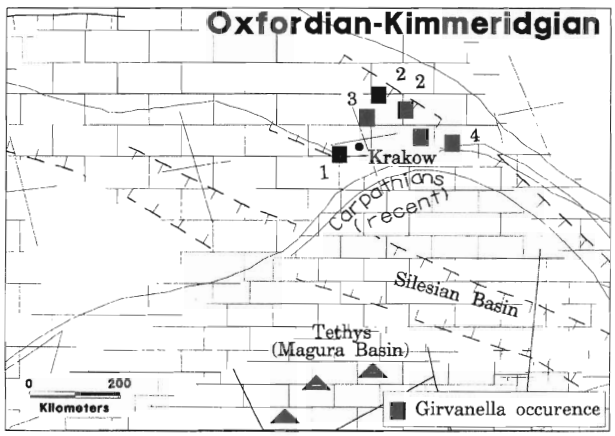

Fig. 1. Paleogeography of the Northern Carpathian and their foreland area during Oxfordian-Kimmeridgian with the *Girvanella minuta* Wethered occurrence; plates position at 155 Ma. 1 – Piekary, 2 – Holy Cross Mts. margin, 3 – Skalbmierz (Nida Trough), 4 – Ropczyce – Niwki area (Carpathian Foredeep).

new branches bifurcating at an angle of about 30 degrees. The interior structure is often blurred due to recrystallization, especially within inner zone of larger nodules.

The *Girvanella* limestones belong to the algal-oolitic series (Golonka, 1970) of the Late Oxfordian-Early Kimmeridgian age. The scattered *Girvanella* specimens have been found in the reef and reef associated limestones. The reef limestones contain red algae *Solenopora magna* Golonka, *Pycnoporiduim lobatum* Yabe et Toyama, *Marinella lugeoni* Pfender and green algae *Cayeuxia moldavica* Frollo and *Cayeuxia piae* Frollo together with corals, Bryozoa, echinoderms and other fossils. The red algae constitute the frame of the reef, while *Girvanella* and *Rothpletzella* are the binding organisms. Besides the reefs the *Girvanella* limestones occur in the upper part of the algal-oolitic series with the so-called "main oolitic" horizon. Kutek (1968, 1969) noted the occurrence of these limestones on the large area and called them "onkolitic horizon". The *Girvanella* limestones within the main oolite belong entirely to the ammonite horizon *Ataxioceras hypselocyclum* (Kimmeridgian). The algal-oolitic series with *Girvanella* have been also found in wells Skalbmierz 4, Niwki 3 and Ropczyce 3 in the Carpathian foreland. The Jurassic algae in the Carpathian foreland and SW margin of the Holy Cross Mts. lived in warm sea with normal salinity. They were growing in shallow coastal waters up to 20–30 m deep, well stirred and aerated with a rather scanty inflow of terrigenic material. Several paleoenvironments may be distinguished here (Golonka, 1970a): the reef limestones, fore reef cone talus, the lagoonal back reef and near-shore shallow water with a hard ground on numerous *Girvanella* nodules.

The *Girvanella* limestones are also known from the Dębica series of the Early Cretaceous age (see Olszewska, 2001; Maksym et al., 2001), being encountered in the wells in the vicinity of Rzeszów in front of Carpathian and below Carpathian thrust (Golonka, 1978). These limestones consist of abundant *Girvanella* nodules with Dasycladacea, brachiopods, ostracods, snails. The paleoenvironment is near-shore lagoonal, dozen deep approximately meters.

Recently the *Girvanella* specimens has been found in the vicinity of Krakow in Piekary village in the buildups of Oxfordian age. The exposure of Upper Oxfordian limestones (Bimammatum zone) in Piekary shows the lateral transition from massive limestone to bedded limestone. The massive limestone is carbonate buildup of microbiolitic-sponge mud mound type with rigid framework (Matyszkiewicz, 1989). The bedded limestone represents biostromes and fine-detritical flank-facies of the buildup.

Similar type of microfacies occurs in the massive and bedded limestone. They are mainly boundstones and wackestones-packstones. Mudstones are sporadic. The main constituent of boundstones are microbiolites. They constitute more than half of the rock volumen in the massive facies. The second rock-forming components of the both macrofacies are siliceous sponges. The *Givanella minuta* Wethered in the Piekary forms small-from a few millimeters nodules, growing around organodetritical fragments found together with *Dasycladacea* in the wackestones.

The sedimentation of the limestones from Piekary took place in a low energy but relatively shallow environment. The environment of sedimentation is documented by: (i) evolution of microbolites, (ii) assemblage of the fauna and (iii) some diagenetic features.

(i) Initial stages of cyanobacterial microbolites are represented by the leyolites (early called 'crusts', cf. Matyszkiewicz, 1989). They are subordinate upward to the peloidal stromatolites. According to Schmid (1996) this evolution points to shallowing trend and the existence of euphotic zone. According to Kaźmierczak et al. (1996) intense growth of cyanobacteria might have been connected with high alkalinity sea on the Late Jurassic shelf of the northern Tethys margin and might have eliminated nearly completely the macrofauna.

(ii) The shallowing trend of sedimentation is indicated by succesive replacement of siliceous sponges by calcareous sponges and occurrences of calcareous algae *Girvanella minuta* Wethered and *Dasycladaceae*.

(iii) In the massive limestone the dolomitization and de-

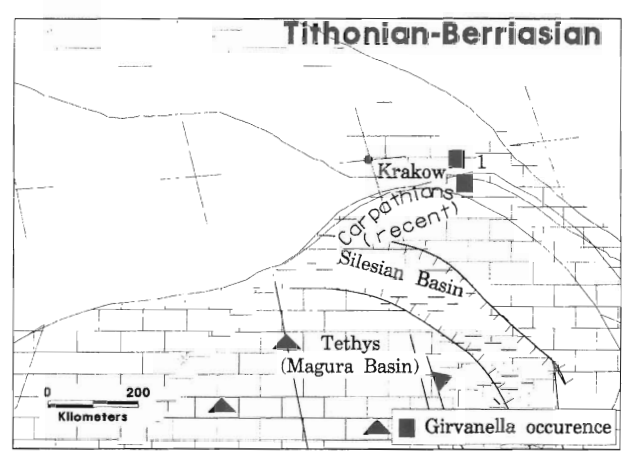

Fig. 2. Paleogeography of the Northern Carpathian and their foreland area during Tithonian-Berriasian with the *Girvanella minuta* Wethered occurrence; plates position at 140 Ma. 1 – Rzeszow area (Carpathian Foredeep).

dolomitization processes are observed, syntaxial and equant calcite cements, and internal sediments of vodose crystal silt-type (Matyszkiewicz, 1989). These features might have been interpreted as the manifestations of an early diagenetic emergence, although other explanations are also possible (cf. Selg and Wagenplast, 1990; Matyszkiewicz, 1997).

The occurrence of *Girvanelle minuta* Wethered supports the shallow-water, within the euphotic zone, bathymetric position of Oxfordian-Kimmeridgian sponge reefs from the Cracow-Wielun Upland (Matyszkiewicz, 1997) and general bathymetry of European microbolitic-sponge reefs (Schweigert, 1992; Leinfelder, 1993). The platform-reef shallow-water environment prevailed in the Krakow area during latest Oxfordian – earliest Kimmeridgian, in the eastern part of the Carpathian foreland during Kimmeridgian-Early Cretaceous.

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Geodynamic evolution stages and climate changes in the Outer Carpathians

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Abstract

The following geodynamic evolution stages could be distinguish in the Outer Carpathians: I – synrift (Late Jurassic–Albian), II – postrift-collisional (Cenomanian – Late Eocene), III – orogenic (latest Eocene–Burdigalian) and IV – postorogenic (Burdigalian – future). These stages are also closely related to the major changes in the climate setting of the region, they correspond quite well with the global sequence stratigraphy. The three supersequences encompass one stage.

Key words: Outer Carpathians, plate tectonics, paleoclimate, sequence stratigraphy

Introduction

The Magura Basin, the Dukla and Fore-Magura set of basins, the Silesian Basin, the Sub-Silesian Ridge and the Skole Basin have been distinguished in the Polish Outer Carpathians (e. g. Ślączka and Kamiński, 1998). The last three units form true Outer Carpathian realm. The basin development of this realm encompasses time from Late Jurassic to Neogene (e. g. Pescatore and Ślączka, 1984). Magura Basin has a different history (see Golonka, 2002), part of this basin was incorporated into the Pieniny Klippen Belt, part shared the geodynamic history with the other Outer Carpathians unit since Late Cretaceous.

The following geodynamic evolution stages could be distinguish in such defined Outer Carpathians (Ślączka and Kamiński, 1998; Golonka and Ślączka, 2000): I – synrift

and formation of passive margin and basin with the attenuated crust, II – postrift – collisional, development of subduction zones partial closing of oceanic basin, development of flysch basin, III – orogenic, perhaps terrane – continent collision with the accompanying convergence of two large continents, IV – postcollisional. These stages correspond quite well with the global sequence stratigraphy (Golonka and Kiessling, 2002), the three supersequences encompassing one stage, they are also closely related to the major changes in the climate setting of the region.

Stage I – synrift – Late Jurassic–Albian

During the Late Jurassic the southern part of the North European Platform, started to be rifted and small basins, proto-Silesian Basin in the Western Carpathians and Sinaia basin in the eastern Carpathians), with black, mainly redeposited marls (?Kimmeridgian-Tithonian) have been created (Pescatore and Ślączka, 1984). These basins indicate the beginning of the Outer Carpathians realm development. The black sediments mark the beginning of an euxinic cycle of the Outer Carpathian basin that lasted to the beginning of Cenomanian. The Outer Carpathian synrift period corresponds generally to three global supersequences – Lower Zuni III, Upper Zuni I and Upper Zuni II (Golonka and Kiessling, 2002). Two major global Oceanic Anoxic Events (OAE) happened during this time. The rapid supply of shallow water clastic material to the basin could be an effect of the strong tectonoeustatic sealevel fluctuations known from that time. The marls pass gradually upwards into calcareous turbidites, which created several submarine fans. Occurrence of deep-water microfauna indicates that subsidence of the basin must have been quite rapid. During the early part of the Cretaceous the calcareous turbidites gave way to black calcareous shales and thin sandstones passing upwards into black often siliceous shales. During the Hauterivian, Barremian and Aptian several coarse-grained submarine fans developed. That was connected probably with the Early Cretaceous uplift known from the Bohemian Massif. The rifting of the North European Platform lasted during the Early Cretaceous and with this period the extrusion of basic, teschenites type of magma was connected, although it can not be excluded that magmatic eruptions could started earlier, as in the case of the Eastern Carpathians. In the early Albian within the black shales, widespread turbiditic sedimentation started to develop. In the Eastern Carpathians the compressional movement started during the Aptian and Albian and the inner part of the Carpathians was folded, napped and in front of moving nappes coarse-grained sediments and olistostromes developed.

Stage II – postrift-collisional – Cenomanian – Late Eocene

This stage is characterized by formation of subduction zones along the active margin, partial closing of oceanic basin and development of main flysch basins associated with the rifting on the platform (passive margin) with the attenuated crust. Generally, the oxic conditions prevailed, and the appearance of the red and green shales is characteristic (Ślączka and Kamiński, 1998). This period corresponds generally to three global supersequences – Upper Zuni III, Upper Zuni IV and Lower Tejas I (Golonka and Kiessling, 2002). The global OAE, which occurred during the first supersequences, is reflected by mixed green and black sediments (Wójcik and Gasiński, 2000). During the Cenomanian a period of slow and uniform sedimentation embraced a greater part of the Outer Carpathians basin and green and red shales began to develop.

In the foreland of the Inner Carpathian folded area, within the Outer Carpathian realm several basins became distinctly separated, namely Magura, Porkulec-Convolute, Dukla, Silesian Charnahora-Audia Skole-Tarcau basins divided by Silesian and Kumana Ridges and Subsilesian underwater swell. The Magura Basin was at that time incorporated into the Outer Carpathian realm. The orogenic processes in the Western Carpathians produced an enormous amount of the clastic material that started to fill the Outer Carpathian basins. The material was derived from the northern and southern margins as well as from the inner ridges (cordilleras) (Książkiewicz, 1968; Dżułyński and Ślączka, 1958). Each basin had the specific type of clastic deposits, and sedimentation commenced in different time.

In the Magura and Dukla basins sedimentation commenced during the Campanian and lasted till Paleocene, and medium and thin-bedded, medium-grained turbidites prevailed there. The sedimentation of thick bedded, coarse-grained turbidites in form of several submarine fans commenced during the Eocene. In more distal parts medium – and thin–bedded sandstones and shales developed passing further towards the north into variegated shales. These lithofacies migrated northward. The lateral differences of the lithofacies across the basin (Oszczypko, 1998) allowed dividing the Magura basin on several sub-basins.

In the Silesian basin sedimentation started during the Late Turonian - Early Coniacian and lasted up to the Early Eocene and were mainly represented by thick bedded, coarse-grained turbidites and fluxoturbidites. In the Skole basin sedimentation also started during the Turonian but expired in the Paleocene and deposits were represented by calcareous turbidites and thin to thick bedded turbidites. Small turbiditic fans developed locally in the small subbasins. During the Early Eocene green and grey shales with thin and medium-bedded sandstones with intercalations of red shales prevailed. Small turbiditic fans developed only locally except the eastern part where huge clastic fan developed. This type of sedimentation gave way during the Late Eocene to green shales and yellowish *Globigerina* marls. The Subsilesian sedimentary area, which divided the Silesian and Skole basins, became uplifted and on this swell a sequence of red, green marls and grey Senonian to Eocene marls were deposited.

Stage III – latest Eocene – Burdigalian – orogenic

This stage is characterized by collision, perhaps terrane – continent, with the accompanying convergence of two large continents. The anoxic condition prevailed, the va-

riegated shales disappeared, and bituminous brown shales and grey marly siltstones and sandstones were deposited (Ślączka and Kamiński, 1998). This period corresponds generally to three global supersequences – Lower Tejas II Lower Tejas III and Upper Tejas I (Golonka and Kiessling, 2002). At the beginning of this period the global cooling took place. This event was connected with the glaciation in Antarctica (Golonka, 2000).

In the circum-Carpathian region the Adria-Alcapa (Inner Carpathians) terranes continued their northward movement during Eocene-Early Miocene time (Golonka et al., 2000). Their oblique collision with the North European plate led to the development of the accretionary wedge of Outer Carpathians. During the compressional stage flysch still continued to be deposited. Numerous olistostromes were formed during this time (Ślączka and Oszczypko, 1987). A manifestation of compression is visible in the more inner part of the Carpathians (Magura Unit) during the Eocene when migration of accretionary prism is noted (Oszczypko, 1998). In the more outer parts of the Carpathian realm the compressional movement appeared at the Eocene/Oligocene boundary (Slączka, 1969). The Oligocene sequences commenced in these basins with dark brown bituminous shales and cherts with locally developed sandstone submarine fans or system of fans of length up to several kilometers. The bituminous shales pass gradually upwards into Krosno beds sequence of micaceous, calcareous sandstones and grey marls which lasted to the Early Miocene and terminated the flysch sequence of the Outer Carpathians. The lower part of the Krosno is generally represented by a complex of thick bedded sandstones that pass upwards into series of medium to thin-bedded sandstones and grey marls. One or two olistostromes developed in the southern part of the Silesian basin. Grey marls, diachronous across the basins represent the upper part of the Krosno beds.

Trough the Miocene Africa converged with Eurasia. The direct collision of the supercontinents never happened, but their convergence did not leave much space, leading to the permanent setting of the Alpine-Carpathian system. Tectonic movements caused final folding of the basins infillings and created several imbricated nappes which generally reflect the original basin configurations. During the overthrusting movements the marginal part of the advanced nappes has been uplifted whereas in inner part sedimentation lasted in the remnant basin. Big olistolites often glided down from uplifted part of the nappes into the adjacent, more outer basins. The nappes became uprooted from the basement and the Outer Carpathians allochtonous rocks overthrust northward in the west and eastward in the East onto the North European platform for the distance of 50 to more than 100 km. The peripheral foreland basin formed along the moving orogenic front (Oszczypko and Ślączka, 1989; Oszczypko, 1998). Overthrusting movements migrated along the Carpathians from the West towards the East.

Stage IV – postorogenic – Burdigalian – Future

During and after the main orogenic phase and the suture of the continents an initial rifting system was initiated in Early Miocene time behind the Carpathian arc in the Pannonian Basin. Extension in the Alpine-Carpathian system continued during the Miocene-Pliocene, forming horst and grabens within the orogen as well as in its foreland. This period corresponds generally to two full global supersequences – Upper Tejas II, Upper Tejas III (Golonka and Kiessling, 2002), the third supersequence will last into the future. This was a cool period, climate finally entered the icehouse phase. In front of the advancing Carpathians nappes the inner part of the platform, in the eastern part also with the marginal part of the flysch basin (Borislav-Sub-Carpathian nappe), started to downwarp and tectonic depression formed during the Early Miocene. Thick molasse deposits filled up this depression. Generally it started with shallow water basal conglomerates passing upwards to brackish and marine sandstones, shales and marls, locally with olistostromes containing the material derived from the advancing Carpathians. In the Eastern Carpathians there were periodically favourable conditions for precipitation of salt. At the end of Burdigalian that basin became overthrust by the Carpathians and a new, more external one, developed. This basin and its depocenter migrated outwardly and eastward, contemporary with the advancing Carpathians nappes. As a result the Neogene deposits show clear diachrony in the foreland area. In the west sedimentation terminated already in Langhian and in the east lasted till Pliocene. Clastic and fine-grained sedimentation of the Carpathian and foreland provenance prevailed with a break during the Late Langhian to Early Serravallian, when younger evaporate basin developed. Locally olistostromes were deposited (Ślączka and Oszczypko, 1987) with material derived as well from the Carpathians as from the inner margin of the molasse deposits. During Langhian and in Serravallian part of the northern Carpathians collapsed and sea invaded the already eroded Carpathians. Further development of these processes could be predicted in the future.

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The Carpathians: geology and hydrocarbon resources

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Abstract

The authors intention is to publish a AAPG Special Publication to provide readers with a comprehensive account on the complex geology and hydrocarbon potential of the whole Carpathian system. Primary attention is paid to petroleum systems and case studies of major oil and gas fields in the region in order to provide an insight into the past and future hydrocarbon potential of the region and to guarantee the right mixture of academia and industry viewpoints.

Key words: Carpathians, Carpathian Foredeep, Pannonian Basin, Transylvanian Basin, Vienna Basin, Eastern Alps

AAPG Special Publication

The Carpathian Mountains (Fig. 1) extend over the territories of seven countries of Central and Eastern Europe with a complex political and economic history and equally complex history of scientific and technical endeavors in the field of earth sciences and petroleum industry. Enormous amounts of geological work have been conducted and thousands of papers have been published on the geology of the Carpathian Mountains during the past two hundred years (see references in: Bieda et al., 1963; Ciprys et al., 1995; Dicea, 1996; Golonka et al., 2000; Karnkowski, 1993; Krejči et al., 1994; Lafargue et al., 1994; Oszczypko, 1998; Paraschiv, 1979; Pescatore and Ślączka, 1984; Picha, 1996; Rakús, 1998; Royden and Horváth, 1988; Stranik et al., 1993; Wessely and Liebl, 1996; Ziegler and Horvath, 1996). However, because of language barriers and varying concepts and interpretations, it is not easy for students of Carpathian geology and explorationists to cut through all these often-fragmented information and get a clear picture about the geology and the hydrocarbon potential of the region. Fourteen years has past since the great success of the Pannonian Basin publication by Royden and Horváth (1988). The authors intention is to publish a AAPG Special Publication to overcome some of these problems and in a simple and understandable way to provide readers with a comprehensive account on the complex geology and hydrocarbon potential of the whole Carpathian system, including the thrust belt, its foreland, and the late orogenic intra-Carpathian basins. Primary attention is paid to petroleum systems and case studies of major oil and gas fields in the region in order to provide an insight into the past and future hydrocarbon potential of the region and to guarantee the right mixture of academia and industry viewpoints.

Carpathians as the classical territory

The Carpathians region is one of the classical territories of the world in which some concepts of geology and petroleum geology were formulated and the petroleum industry was born. It was the Carpathian region, where the first oil well was drilled in Poland in 1853, crude oil distillation discovered by Łukasiewicz in 1853 (Karnkowski, 1993), the first industrial production of hydrocarbons established in Romania in 1875 (Dicea, 1996), and organic origin of oil proposed (Zuber, 1918). In the 1950s, the Carpathian flysch became one of the principal territories in which the original con-

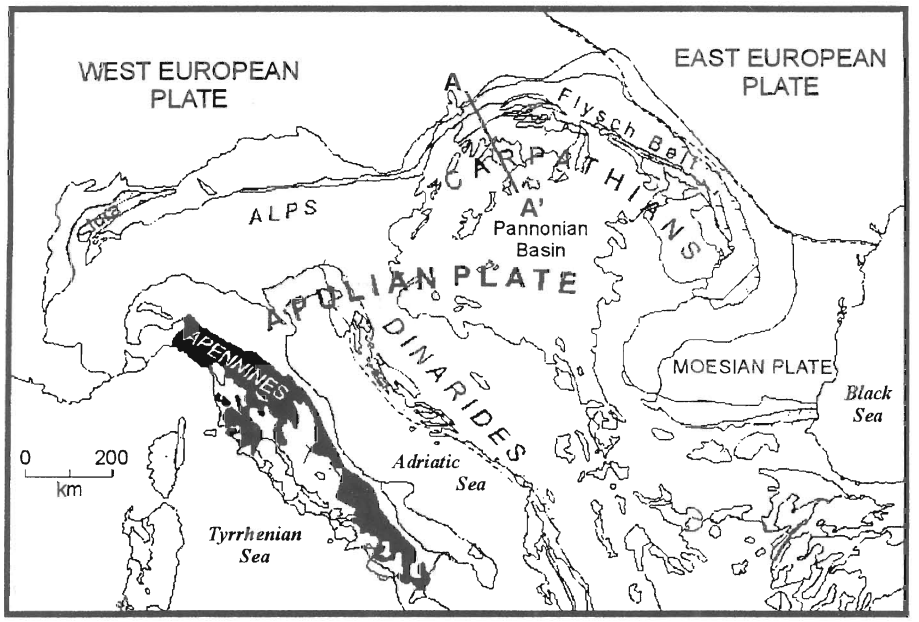

Fig. 1. Tectonic sketch map of the Alpine-Carpathian-Pannonian-Dinaride basin system (after Picha 1996, modified). A-A' – Localization of cross-section (Fig. 2).

cept of deep-water turbidites was formulated. The Carpathian flysch represents one of the best and thoroughly studied turbiditic facies exposed on land anywhere (e. g. Książkiewicz, 1954; Dżułyński and Ślączka, 1958; Dżułyński et al., 1959; Dżułyński and Walton, 1965, 1995; Picha, 1996). It has been often compared with the deep-water sequences of the Ouachita Mountains belt of Arkansas and Oklahoma. In many aspects, the Carpathian flysch, famous for its complexity and diversity, may serve as a model in exploration of hydrocarbons in deep-water deposits both along the modern continental margins and in the orogenic belts.

Exploration in subthrust plays

Significant amounts of oil and gas have been produced and a sizable production still continues in the area. By applying new technologies and new scientific concepts, there is still a good chance to find additional hydrocarbons in existing fields as well as to discover new fields, especially, at deeper structural levels. The subthrust plays below the frontal zones of the thin-skinned Carpathian thrust belt seem to be most promising (Fig. 2). There is a variety of subthrust plays in the Carpathians, some of which have been successfully tested, new fields discovered, and commercial production established from these new discoveries. The Carpathians thus represent one of the best examples of successful subthrust exploration. In 1996, Picha described the fundamentals of the hydrocarbon exploration under the thrust belts using the Carpathians as a case study. Good opportunities for subthrust exploration exist under some other thin-skinned thrust belts, e. g., the Kopet Dagh (Turkmenistan/Iran), North Caucasus, Northern Ural (Russia), Andes (South America), Apennines (Europe), Ouachita (North America) (see e. g. Pescatore and Ślączka, 1984; Picha, 1996; Golonka and Ślączka, 2000). However, as in the thrust belts proper, favorable conditions for generation, accumulation, and preservation of hydrocarbons in subthrust plays exist only in limited areas with good source rocks, reservoirs, seals, and the right timing of generation and migration of hydrocarbons. Subthrust exploration thus requires good understanding of depositional and structural history of both the foreland plate and the thrust belt. The Carpathian case studies will provide information on the complexity and diversity of subthrust plays and thus be helpful in finding significant oil and gas reserves in these plays. New exploration and producing opportunities attract foreign capital and companies, who need modern, comprehensive information about the geology and petroleum potential. The proposed publication may well serve to this purpose.

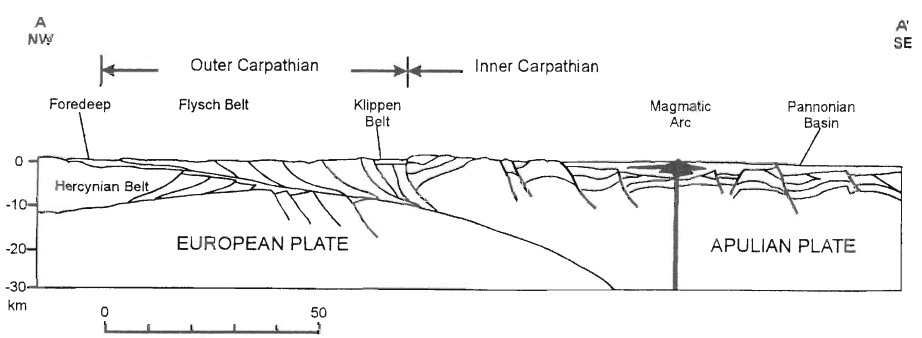

Fig. 2. Generalized cross-section across Carpathian-Pannonian region (after Picha, 1996, modified).

Traditional knowledge and new concepts and technologies

The nations within the Carpathian realm are undergoing political and economic transformation. Geological institutions, universities and extraction industries are deeply and often negatively affected by these changes. The strong postwar generation of geologists is quickly retiring and is not being fully replaced by younger colleagues. Tremendous amount of knowledge, especially, in the area of regional geology and past hydrocarbon exploration, is getting lost. It is high time to combine the traditional knowledge with new concepts and technologies and to produce a publication, which will reflect both on the past and present accomplishments in the Carpathian region. The list of authors of the proposed AAPG Special Publication, which includes both senior traditional geologists and their younger, technologically oriented colleagues, indicates that this challenge will be addressed as best as possible. All authors have already published significant papers on geology and hydrocarbon potential of the Carpathians, and presented their contributions at various conventions and conferences.

Main topics covered by the proposed publication

- Geology and hydrocarbon resources of the Carpathian Mountains and their foreland in the Czech Republic, Poland, Slovakia, Ukraine, and Romania.
- Geology and hydrocarbons of the intra-Carpathian basin: Vienna Basin, Pannonian Basin and Transylvanian Basin in Austria, Hungary, and Romania
- Geochemistry and petroleum systems
- Geodynamic evolution and paleogeography of the Circum-Carpathian area
- Major oil and gas fields case studies
- Comparing the evolution of the thrust belts: Carpathians and Ouachitas case study
- Carpathian-Alpine connections
- History of the research

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Tectono-stratigraphic evolution of the Outer Carpathian basins (Western Carpathians, Poland)

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Abstract

In the pre-orogenic and syn-orogenic evolution of the Carpathian basins the following prominent periods can be established: the Late Jurassic/Early Cretaceous subsidence, Late Cretaceous-Paleocene uplift, Paleocene-Middle Eocene subsidence, Late Eocene-Early Oligocene uplift, and Late Oligocene-Early Miocene subsidence. Syn- and post-rift thermal subsidence and accretionary prism migration controlled the depositional processes.

Key words: Outer Carpathians, rifting, inversion, subsidence, tectono-sedimentary evolution

The Outer Carpathians are composed of Upper Jurassic to Lower Miocene flysch deposits, which are completely uprooted from their basement and separated from the Inner Carpathians by the Pieniny Klippen Belt suture zone. The Western Outer Carpathians form an accretionary wedge. Its formation was completed by the Late Oligocene/Middle Miocene. The flysch deposits built up several nappes, subhorizontally overthrust onto the Miocene deposits of the Carpathian Foredeep or directly onto Precambrian, Paleozoic or Mesozoic rocks of the Carpathian foreland. The presented paleotectonic reconstructions are based on the paleotectonic mapping and subsidence modelling of the Polish Outer Carpathians (Fig. 1). The paleotectonic maps have been prepared for several time spans, whereas the burial history has been reconstructed on the basis of 50 selected sections from the Magura, Dukla, Silesian, Subsilesian and Skole units.

Middle Jurassic-Early Cretaceous opening of basins

The Outer Carpathian Basin can be regarded as the remnant ocean basin, which developed between the colliding European continent and the intra-oceanic arcs (Oszczypko, 1999). The Early/Middle Jurassic opening of the Magura Basin probably was coeval with opening of the Ligurian – Penninic Ocean and its supposed prolongation to the Pieniny Ocean (Golonka et al., 2000). The Pieniny Ocean was divided by the submerged Czorsztyn Ridge into the NE and SE arms. The Czorsztyn Ridge and the Inner Carpathian domain were separated by the SE arm of the Pieniny Ocean known also as the Vahicum Oceanic Rift, whereas NE arm was occupied by the Magura deep–sea basin situated south of the European shelf (Fig. 2). During the thrust movements, the main part of the Magura nappe was uprooted roughly at the base of the Upper Cretaceous sequence. The more or less complete sections of the Jurassic-Lower Cretaceous deposits of the Magura nappe are known only from that part of the basin which was incorporated into the Pieniny Klippen Belt, i. e. from the Grajcarek unit (Birkenmajer, 1986). This part of the basin reveals the prominent Late Jurassic, post-rift subsidence which was followed by the Barremian-Aptian uplift and Albian-Cenomanian subsidence (Fig. 3). The Late Jurassic-Early Cretaceous deposits are represented by deep water, condensed, pelagic limestones and radiolarites with very low rate of deposition (Fig. 4). At the end of Jurassic in the southern part of the European shelf, the paleorifts were floored by a thinned continental crust (Birkenmajer, 1988; Sandulescu, 1988). This rifted European margin was incorporated into the Outer Carpathian basin (the Skole, Subsilesian and Silesian basins). The rifting process was accompanied by a volcanic activity (teschenite sills, dykes and local pillow lavas), which persisted up to the end of Hauterivian (Lucińska-Anczkiewicz et al., 2000). This part of the rifted continental margin probably extended in the Eastern Carpathians (basic effusives, Tithonian–Neocomian "Black Flysch" of the Kamyany Potic scale and Rachiv (Sinaia) beds) as well as to the Southern Carpathians (Severin zone, see Sandulescu, 1988). During the initial stage of development, the Silesian Basin was filled with calcareous flysch followed by siliciclastic flysch and pelagic shales. The Late Jurassic–Hauterivian deposition of the Silesian Basin was controlled by normal fault and syn-rift subsidence, and latter (Barremian-Cenomanian) by post-rift thermal subsidence, which culminated with the Albian-Cenomanian expansion of deep-water facies (Figs. 3 and 4).

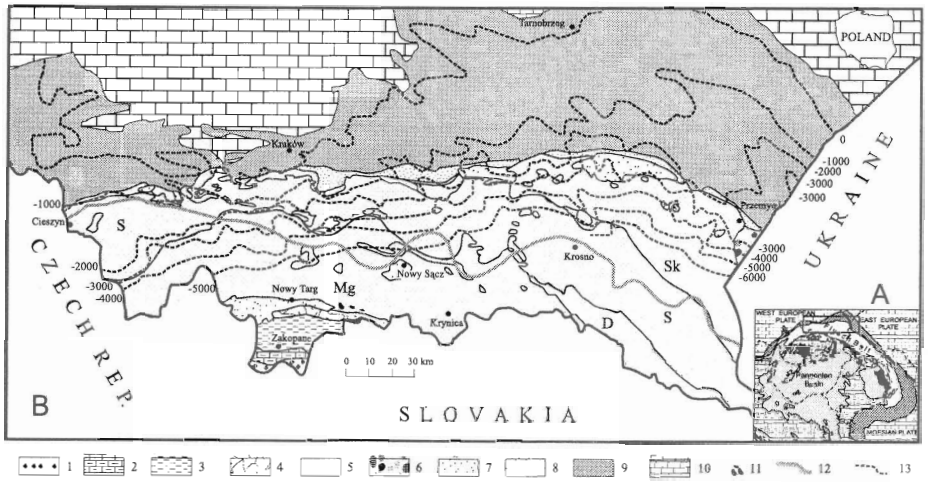

Fig. 1. A – Position of the Polish Carpathians. B – Map of the Polish Carpathians and their foredeep (after Oszczypko, 1998, supplemented). 1 – crystalline core of Tatra Mts., 2 – High-Tatric and Sub-Tatric units, 3 – Podhale Flysch, 4 – Pieniny Klippen Belt, 5 – Outer Carpathians, 6 – Stebnik Unit, 7 – Miocene deposits resting on the Carpathians, 8 – Zgłobice Unit, 9 – Miocene deposits of the Carpathian foredeep, 10 – Mesozoic and Paleozoic foreland deposits, 11 – andesites, 12 – northern range of the Lower Miocene, 13 – isobath of the Miocene basement.

Late Cretaceous-Paleocene inversion and Early/Middle Eocene subsidence

At the end of Turonian, in the central part of the Outer Carpathian domain, the Silesian Ridge (Cordillera) was restructurized and uplifted. The inversion affected most of Silesian, Subsilesian and Skole basins as well as part of the northern periphery of the Magura Basin. The amplitude of the uplift reached several hundreds meters (Fig. 3). The uplift of the Silesian Ridge was accompanied by increase of the deposition rates in the Silesian (up to 400–500 m/Ma; Godula and Istebna formations) Basin (Fig. 4). The uplift of the Silesian Ridge was coeval with regional uplifting in the southern margin of continental Europe from the Carpathian and Alpine foreland to the Spain. This inversion could be correlated with the development of the rift of Biscay Bay (Golonka and Bocharova, 2000). The uplift of the Silesian Ridge could be connected with the shortening of the Silesian Basin (Oszczypko, 1999) and development of the Subsilesian High (Fig. 3). The latter separated Silesian and Skole basins as an elevated high (like peripheral bulge) during the Santonian-Paleocene time. The sedimentation of the pelagic marls with low rate of deposition: dominated in the Subsilesian High area (Fig. 4). The shortening of the Silesian Basin was probably a continuation of the pre-Late Albian subduction of the Outer Dacides (Sandulescu, 1988). At the end of the Paleocene the Carpathian basin was affected by general subsidence and rise of sea level (Fig. 3). During the Eocene, a wide connection of the Outer Carpathian basins and the World Ocean was established. This resulted in unification of facies, including the position of the CCD level and sedimentation rates. This general trend dominated during the Early to Middle Eocene time in the northern basins (Skole, Sub-Silesian, Silesian and Dukla ones) as well as in the northern part of the Magura Basin.

In the Magura Basin the Paleocene–Middle Eocene subsidence was related to the uplift of the Pieniny Klippen Belt (PKB). The migrating load of the Magura and PKB accretionary prism, caused a subsidence and a shift of depocenters to the north (Figs. 2, 3 and 4). As a result, narrow and long submarine fans developed. They were supplied from the southeast, probably from the Median/Inner Dacide terranes. The northern deepest part of the basin, often located below the CCD was dominated by basi-

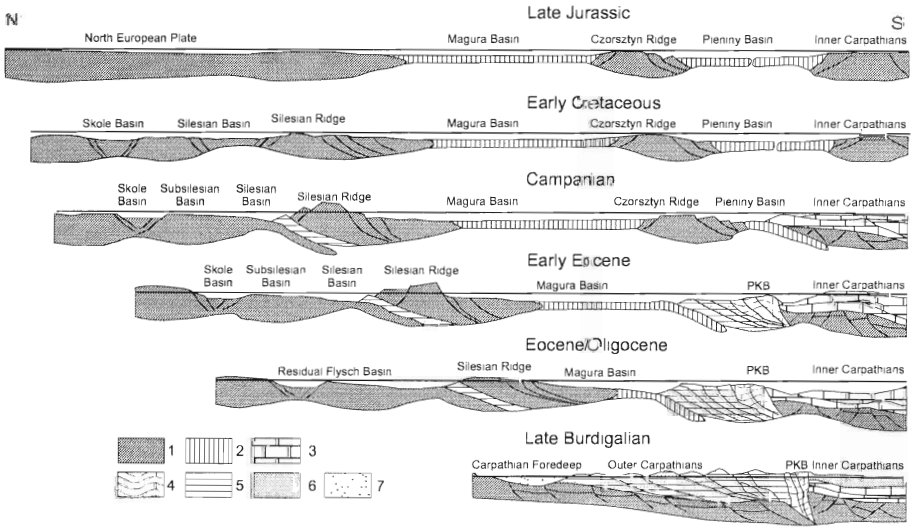

Fig. 2. The Late Jurassic–Late Burdigalian palinspastic evolution model of the Western Outer Carpathians after Oszczypko (1999, supplemented). 1 – continental crust, 2 – oceanic crust, 3 – Inner Carpathian units, 4 – Pieniny Klippen Belt (PKB), 5 – Outer Carpathian accretionary wedge, 6 – Podhale Flysch, 7 – molasse deposits.

nal turbidites and hemipelagites. The rate of sedimentation varied from 6–18 m/Ma on the abyssal plain to 103–160 m/Ma in the outer fan and between 180 and 350m/Ma in the area affected by the middle fan-lobe systems (Oszczypko, 1999). During the Eocene, the axes of subsidence of the Magura Basin migrated towards the north and finally during the Late Eocene and Oligocene reached the Rača and Siary facies zones.

The Late Eocene–Oligocene uplift and Oligocene–Early Miocene subsidence

During the Priabonian and Rupelian, a prominent uplift in the Outer Carpathian basin was recorded (Fig. 3). This was contemporaneous with the final stage of the formation of accretionary wedge in the southern part the Magura Basin (Krynica Zone) and with the main collision phases in the Alpine belt (Fig. 2). This was accompanied by transformation of the Outer Carpathian remnant oceanic basins into foreland basins (Oszczypko, 1999). As the consequence, the Early Oligocene Outer Carpathian basin was partly isolated from the World Ocean, forming the Prototethys, which was dominated by deposition of the black (Menilite) shales. The Oligocene subsidence was accompanied by a progressive migration of axes of depocenters towards the north (Fig. 4), and increase of deposition rates from 350 m/Ma in the Rupelian (northern part of Magura Basin) to 950 m/Ma at the end of Oligocene (SE part of Silesian Basin). After the Late Oligocene folding, the Magura nappe was thrust northwards onto the terminal Krosno flysch basin. This was followed by the last, minor subsidence event (Oligocene-Early Miocene) which can be partially related to the load of accretionary wedge. The centers of subsidence were located in the Krosno basin and Magura piggy-back basin. The restored width of the Early Burdigalian basin probably reached at least 150 km. During the Early Burdigalian high stand of sea level, the connection between Magura piggy-back basin and the Vienna Basin via Orava was established (Oszczypko et al., 1999; Oszczypko-Clowes, 2001). During Ottnangian, the Krosno flysch basin shifted towards NE (Zdanice Unit, Boryslav-Pokuttya and Marginal Fold units) and underwent desiccation (evaporates of the Vorotysche Formation in the Ukraine and Salt Formation in Romania).

The Outer Carpathian residual Krosno flysch basin was finally closed by intra-Burdigalian folding and uplifting of the Outer Carpathians, connected with the collision between the European Plate and overriding Alcapa and Tisza-Dacia microplates. This was accompanied by the north and north-east overthrust and the formation of the flexural depression of the Carpathian Foredeep - related to the moving orogenic front (Oszczypko, 1998).

Conclusions

1. In the pre-orogenic and syn-orogenic evolution of the Outer Carpathian domain the following main tectonic events took place: the Late Jurassic–Early Cretaceous subsidence, Late Cretaceous–Paleocene uplift, Paleocene--Middle Eocene subsidence, Late Eocene-Early Oligocene uplift, and Late Oligocene-Early Miocene subsidence. The

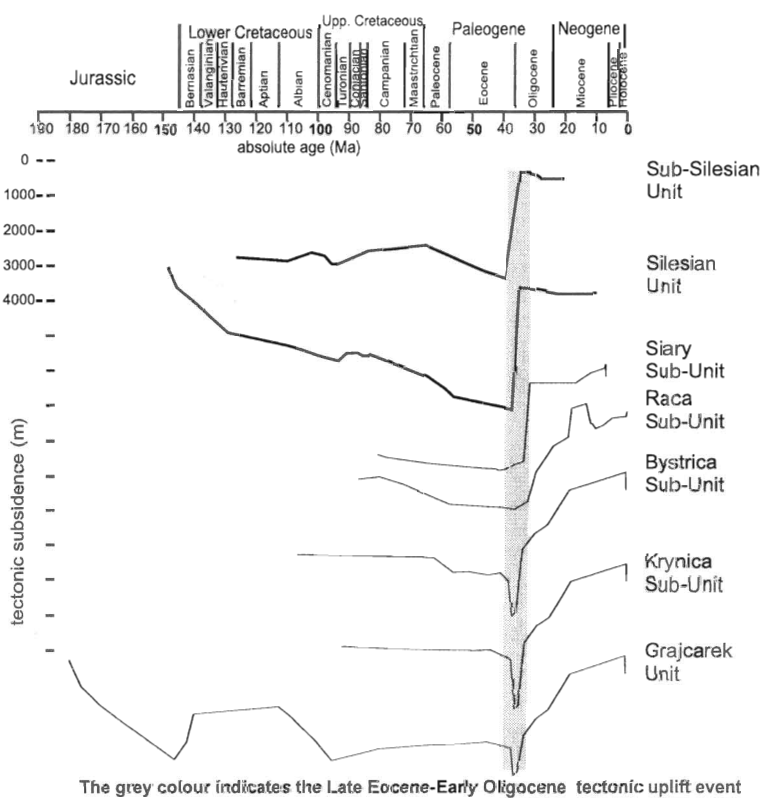

Fig. 3. Tectonic subsidence curves for selected synthetic profiles from the Polish Outer Carpathians.

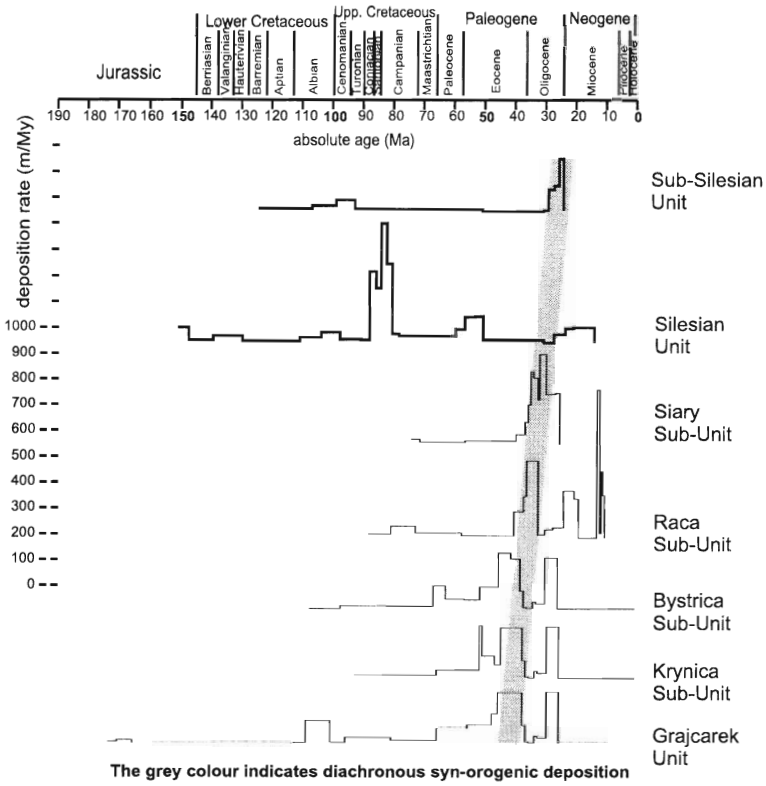

Fig. 4. Diagrams of deposition rates versus time for synthetic profiles from the Polish Outer Carpathians.

total subsidence in the Silesian Basin was two times higher than in the Magura Basin and more than three times higher than in Subsilesian and Skole basins.

2. The important driving forces of the tectonic subsidence were syn-and post-rift thermal processes as well as the emplacement of the nappe loads related to the subduction processes.

3. Similarly to the other orogenic belts, the Outer Carpathians were progressively folded towards the continental margin. This process was initiated at the end of the Paleocene at the PKB/Magura Basin boundary and completed during the Early Burdigalian in the northern part the Krosno flysch basin.

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Pre-Alpine tectonics and metamorphism of basement rocks in the central part of Kohút Zone (Southern Veporicum, Inner Western Carpathians)

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Abstract

Original relations of the Lower Paleozoic volcano-sedimentary environs document the gradual transitions between the individual lithologic units and/or the preserved sedimentary lithologic variations inside certain metamorphic layers in mesoscale. Intensive Alpine tectonometamorphic reworking preceeded three pre-Alpine metamorphic episodes, which are briefly outlined. The E–W directed Alpine transpressional deformation largely copies the dominant Hercynian ductile structures ("D_2"). Occasionally there occur the steep foliation planes established also in amphibolite facies, being associated with N–S directed folding ("D_1") and represent the relatively oldest deformation record.

Key words: Veporicum, Hercynian, basement, tectonics, deformation, polystage metamorphism, granitization

Introduction and geological setting

The investigated area is spread between the so-called Muráň line and the Gemeric units in the south (a polygon confined by local towns Muráň – Revúca – Tisovec). Metamorphic rocks of volcano-sedimentary origin, with largely accepted Lower Paleozoic age, underwent the polyphase metamorphic reworking. Generally, the Southern Veporicum basement, namely its southermost part – the Kohút Zone (Fig. 1) suffered the most intensive Alpine imprint within the Western Carpathian realm (Zoubek, 1936; Vrána, 1966 a. o.).

In broader regional scale the polystadial basement tectonics was interpreted in terms of vertically arranged basement nappe rock-complexes – either Alpine – (Klinec, 1966) or Hercynian (Bezák, 1994) in age. For practical geological purposes, concerning mainly separation of the pre-Alpine metamorphic rock-units, it appears as appropriate to divide of the Kohút Zone into four zones (according to Zoubek, 1932 and Šuf, 1938): the so-called northern migmatite zone, the garnet-micaschist zone (incl. paragneisses), the southern migmatite zone and the phyllite zone. Age of the considered granitoid rocks was basically to geologic relations mostly seen as Carboniferous (Zoubek, 1932; Nemčok, 1953; Kamenický, 1977), which was later proved by geochronological dating (Bibikova et al., 1988 a. o.).

Pre-metamorphic relations

Geological cross-section (Fig. 2) illustrates not only the Hercynian tectonics, related to metamorphism and granitization, but the Pre-Hercynian lithological arrangement can be due to variegated lithology discerned, too (Kováčik, 1998). The so-called Muráň orthogneisses presumably occupied the lowermost parts of the investigated rock pile. Geological mapping revealed preservation of some pre-metamorphic lithologic features showing gradual transition zone between the "Muráň" orthogneiss body and the gneiss-micaschistose material in the hanging-wall. The almost whole uppermost contact zone of the "Muráň orthogneisses" is rimmed by these rock-assemblages. The transitional contact zone is enriched in amphibolitic rocks and the light fine-grained varietes of the "Muráň orthogneiss" occur more frequently in this zone, too. Conformable fragments of garnetiferous metapelites are also located along basal parts of "Muráň orthogneiss" body, so, the acid magmatic body is enclosed within the above metapelites. This metapelitic rock-assemblage, which is spatially related to "Muráň orthogneisses", we preliminary labelled as the "lower gneiss–micaschistose horizon". The "upper gneiss–micaschistose horizon", spread in the wider area of the elevation point (e. p.) Krížna Poľana (1018 m). As to the rock inventory, the second, southernmost, horizon comprise amphibolite rocks only very scarcely. In the whole, the both horizons might originally have formed a continuous rock-complex, which was only discontinued by intrusion of coarse granite with its high-graded metamorphic mantle in the area of "Tri chotáre" (e. p. 963 m; see Fig. 2, column 7). It may be assumed, that in the Carboniferous time this granite, as well as the southernmost granitoids (Fig. 2, columns 8, 9), significaly disturbed the primary volcano-sedimentary and pre-granitization metamorphic records.

Metamorphic geology

These basic rock-types were distinguished as the Hercynian metamorphic products: "Muráň" orthogneisses, biotitic gneisses (widely absorbed by granitoids), migmatites (Fig. 3), biotite gneisses with coarse garnets, graphitic metaquartzites, garnet-biotite gneisses (dominating lithology), (staurolite)-garnet micaschists, (garnet) amphiboli-

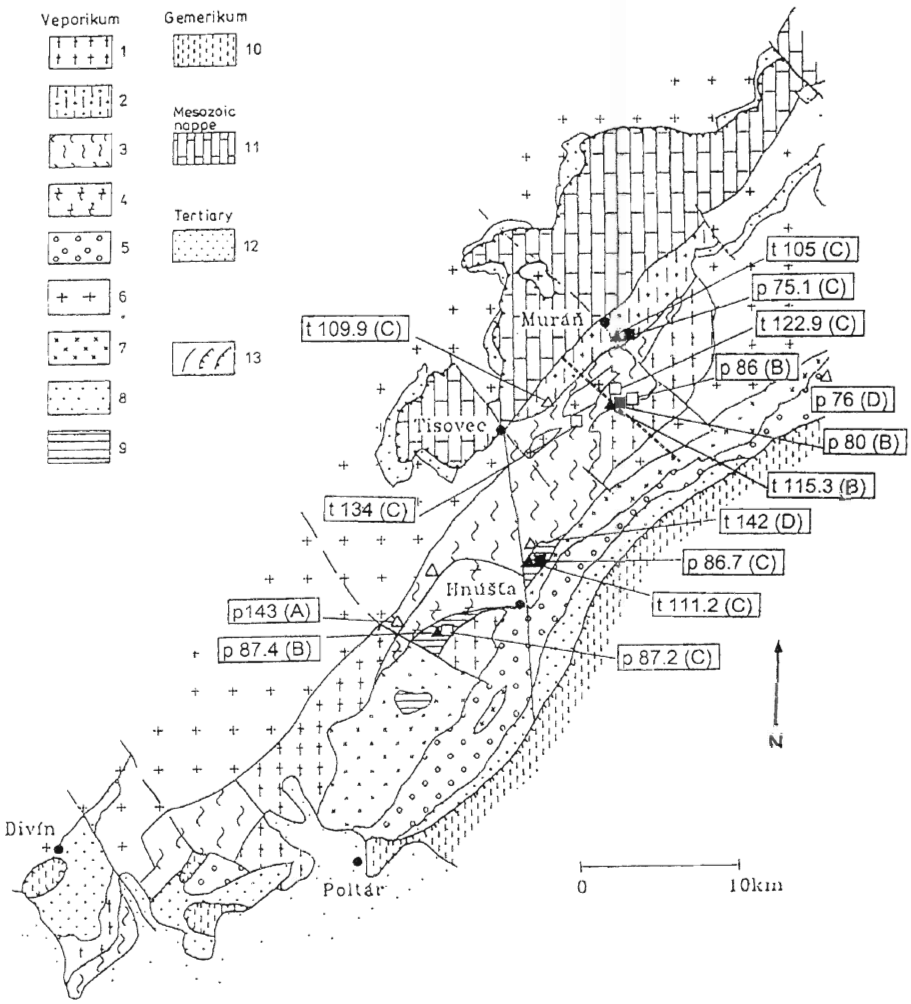

Fig. 1. Geological sketch map of the Kohút zone with reuslts of $^{40}Ar/^{39}Ar$ dating given in Ma: p – plateau or nearly plateau age record, t – total gas age (Fig. 1B. in Kováčik et al., 1997). Dashed line, positioned in-between the "Muráň" fault and the southernmost basement rocks, indicates course of the profile in Fig. 2. 1–7 – Pre-Permian rocks: 1 – complex of gneisses and migmatites, partly granitized, 2 – "Muráň" orthogneisses with amphiboles, 3 – micaschist complex with lenses of amphibolites, 4 – garnetiferous-biotitic gneiss, 5 – complex of biotitic metasandstones, muscovitic phyllites, 6 – granitoids of Vepor pluton (porphyric, non-porphyric, hybrid), 7 – "Rimavica" type granites, 8 – Permian and Triassic cover sediments, 9 – rocks of uncertain origin (strongly altered granitoids or metasediments), 10 – "Gemeric" Carboniferous (mainly the Ochtiná Formation), 11 – Silica nappe, 12 – Tertiary deposits, Miocene volcanics and partly Quaternary, 13 – faults and geological boundaries; Gemericum thrusted over Veporicum; boundary of Silica nappe.

tes a. o. Appart from the intense Alpine overprint, ensued by newly-formed mineral assemblages reaching up the boundary between greenschist and amphibolite facies, there can be discerned three basic metamorphic phases having developed during the Hercynian time:

1. "pre-granitization" metamorphic fabrics attributed to regional metamorphism
2. (regional) periplutonic metamorphism associated with granitoid intrusions
3. local thermal effects of leucocrate granitic veins.

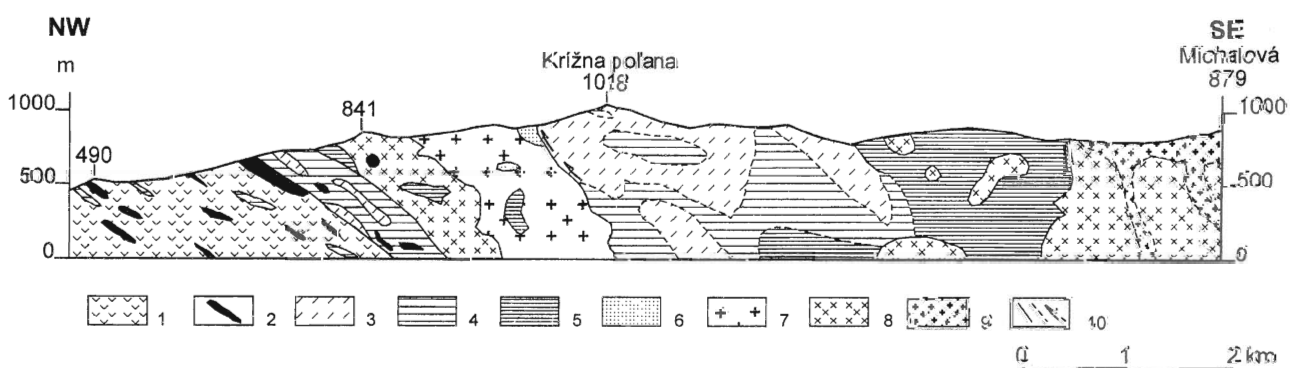

Fig. 2. Geological profile indicates pre-Hercynian lithologic relations and contiguity between granitoid intrusions and metamorphic degree in metamorphites. 1 – "Muráň" orthogneiss rock complex, 2 – amphibolites, 3 – garnet micaschists, 4 – garnet-biotite gneisses, 5 – biotite gneisses, migmatites, 6 – graphitic metaquartzites, 7 – porphyric granites, 8 – "hybrid" granitoids, 9 – fine-grained leucogranites, 10 – geological boundaries: observed, approximated; sense of reverse fault movement.

Fig. 3. Syndeformation leucosome material penetrates into stromatitic migmatite during regional anatexis processes. Flebicitic migmatite. 2 km north from Revúca.

The periplutonic metamorphism (2nd phase) mostly veiled the metamorphic constrains of the initial regional metamorphism (1st phase). We assume that the prevailing conditions of the pre-granitization regional metamorphism did not overcome the higher parts of the greenschist facies. The local younger aplitic-pegmatitic veins developed variegated contact selvages (the 3rd phase), according to field observations, frequently filled with biotite.

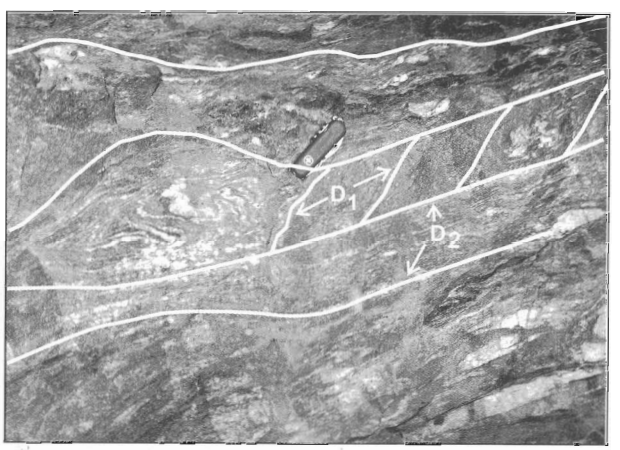

Fig. 4. Dominant Hercynian fabrics (D_2) controlled by E–W directed folding was frequently reactivated during the Alpine collision. Rarely observed N–S structures (D_1) express the relatively oldest deformation record: gneiss-migmatite zone north from Revúca

In the whole, the intensity of the most decisive metamorphic reworking (2nd phase) rise towards the south, where volume of granitization increase, until almost pure granitoids occur (so-called granites of Rimavica or Kohút type). The peak metamorphic reworking, constrained between the middle and upper part of the amphibolite facies, is clearly demonstrated by migmatitization zones (Fig. 3). Inspite the intrusive nature of granitoids, the forming conditions of migmatites are suggested conformable with partial anatexis of the metasemipelites. Gneisses with large (2–3 cm in across) garnet porphyroblasts or biotite gneisses with hornfelsic texture enclosed as xenoliths in porphyric granite appear locally. Generally shown, the higher temperature the lesser amount of muscovite, or increase in K-feldspar and/or biotite content are noticed. The metamorphic relics enclosed in the hybridic granitoids usually do not preserve any pre-Alpine metamorphic muscovite. Close relation between the overall metamorphic degree and periplutonic reworking indicate a certain relationship between the regional tectonometamorphism (1st phase) and abyssal thermal effects of granitic intrusions (2nd phase). As the 1st metamorphic phase was probably related to crustal thickening, so the 2nd phase manifested also by dynamometamorphic crystallization could still have responsed on overall collisional regime. We suggest, that the "southern migmatite zone" (Šuf, 1938) is not confined only on contacts between the Kohút zone granitoids (s. l.) and the southernmost phyllite zone, but should be also expanded on contact/periplutonic effects upon the northerly positioned metapelites (Fig. 2).

Structural observations

The dominant Hercynian deformation structures show approximatelly the W–E strike, which presumably reflects the more-less perpendicular sense of collisional shortening. This is expressed by the chiefly W–E directed fold axes – frequently of cylindrical shape – with predominantly south dipping foliation planes. (In adjacent northernmost area the fold limbs of high graded basement usually dip to north.) Inside this deformation pattern – the relic structures, controlled by folding with N–S direction of b-axis, were occasionally found (Fig. 4). Both the observed Pre-Alpine deformational fabrics passed in the amphibolite facies metamorphic conditions with formation of mesosome and leucosome banding, corresponding to the above established 2nd metamorphic phase. The W–E directed predominant deformation ("D_2") could anticipate (or be early-synkinematic) with the peak thermal reworking related to granitoid intrusions. The steeper, relatively older N–S strike ("D_1") may reflect either a metamorphosed sedimentary relic fabric or an earlier metamorphic structure. If the case of older tectono-metamorphic record would be assumed, it might have resulted in an earlier Hercynian (pre-Hercynian?) event with a different polarity. However, we take as more probable, that both the deformation records can formed during one-stadial orogenetic evolution. "D_1" may represent deeply seated initial migmatitization with presence of granitic melt, whereas "D_2" can express

more flat shearing processes connected with final emplacement of granitoid bodies.

The Alpine semi-ductile deformation of transpressional style is largely accommodated along the pre-Alpine W–E (SW–NE) direction and/or other structural and lithological inhomogeneities. The prevalent regional overprint is represented by the process of "regional phyllonitization" and the usually reactivated foliation planes were often covered with new muscovite and other phyllosilicates. Clear lithological, metamorphic or structural evidence about a large-scaled basement nappe tectonics were in the studied area not justified. Potential Alpine overfault plane between the "upper gneiss-micaschistose horizon" and the porphyric granite (Fig. 2) is suggested.

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Hercynian and Alpine strike-slip tectonics – a dominant element of tectonic development of the Inner Western Carpathians

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Abstract

Tectonic units, from which the Inner Western Carpathians are composed, originated within the compressional tectonics of the Hercynian and Alpine orogen. However, the present structure of the Western Carpathians was influenced mainly by strike-slip tectonics. We present the most significant Hercynian and Alpine strike-slips in the middle part of the Western Carpathians. In most cases Hercynian and Alpine shear zones are identical.

Key words: Western Carpathians, Hercynian, Alpine, strike-slips

Introduction

The tectonic units, of which the Inner Western Carpathians (south of the Klippen Belt zone) are composed at present, originated during long-dated development of the Hercynian and Alpine orogen. From the point of view of all-European context of correlations they originated in various areas. Despite, the development of these orogens had common features. It was mainly a transition from collisional compressional tectonics to transpressional tectonics and to the end to extensional disintegration. Distinct manifestation of strike-slips at shear zones in certain periods (mainly the Late Paleozoic, Late Cretaceous, Neogene) is a feature of great importance in the development of both orogens. Tectonics of strike slips was of greatest influence on present-day distribution of tectonic elements in the Western Carpathians.

Strike-slips zones in the central part of the Western Carpathians

Structure of the Inner Western Carpathians consists of several thrusted crustal units (Tatricum, Veporicum, Gemericum and supracrustal nappes) originated in Paleo-Alpine stage of the tectonic development (mostly Cretaceous). First three units are composed of crystalline basement and Upper Paleozoic and Mesozoic cover. Similarly, in the structure of basement the traces of overt-

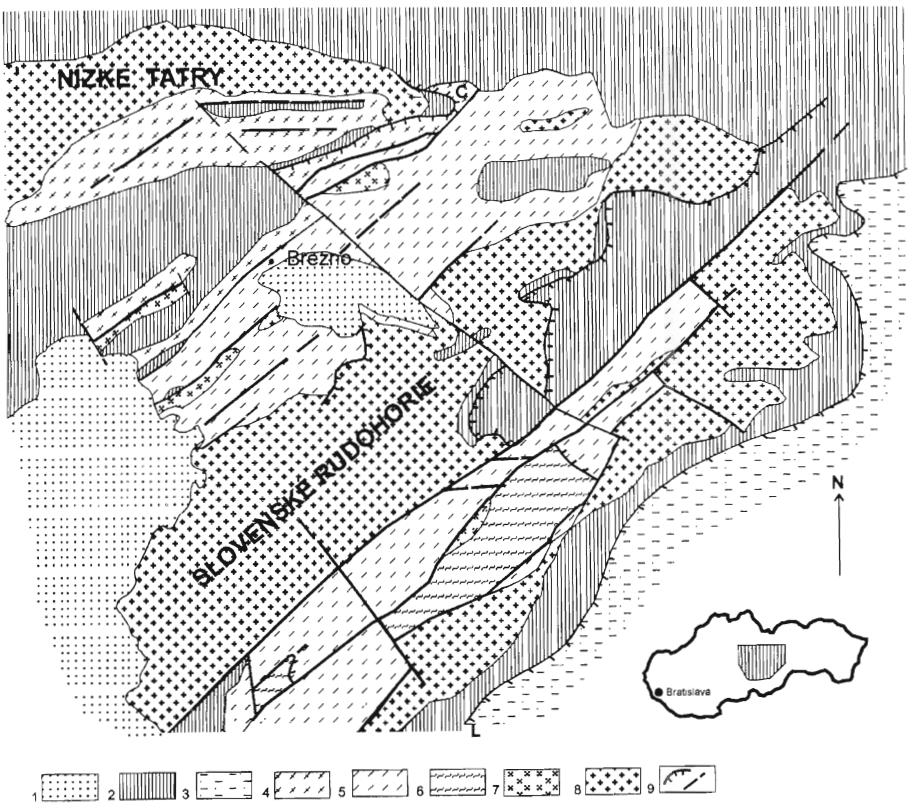

Fig. 1. Tectonic scheme of the central part of the Western Carpathians. 1 – Tertiary sediments and volcanics, 2 – Upper Paleozoic and Mesozoic units, 3 – Gemericum; Hercynian lithotectonic units: 4 – Upper unit, 5 – Middle unit, 6 – Lower unit, 7 – Permian magmatites, 8 – Hercynian granitoids undiferentiated, 9 – a) thrusts, b) faults and shear zones with combined sense of movements (mostly strike slips), C – boundary between Tatricum and Veporicum (Čertovica line), L – boundary between Veporicum and Gemericum (Ľubeník line).

hrust and superposition of large Hercynian crustal lithotectonic units 4–6 km thick have been preserved (Bezák et al., 1997). This results from field observation as well as analysis of deep seismic profiles. This is valid for the basement of the Tatricum and Veporicum as well as Gemericum. However, the Gemeric segment in the Early Paleozoic was emplaced in other area and had a different composition and development of units (Vozárová, 1998).

Most conspicuous, however, in the basement of the Inner Carpathians are distinct shear zones tens–hundreds meters thick with extensive manifestations of diaphthoresis and mylonitization mostly in greenchist facies. Structural marks (subvertical foliations, subhorizontal lineations, asymmetric structures) prove for these zones mostly strike-slip type of movements. Also thrust boundaries of the large nappe units are often superimposed by strike--slips (Fig. 2).

In the Inner Western Carpathians there is a series of such subvertical shear zones. From the point of view of latest knowledge we shall characterize as an example the most significant of them (Fig. 2), occurring in the central part of the Western Carpathians in the area between the Nízke Tatry Mts. and the Ľubeník line (Fig. 1).

Nízke Tatry Mts. (Tatric part)

Špíglová shear zone is mostly Alpine shear zone oriented NE–SW. The zones of low temperature blastomylonites are ore-mineralized (Adamija et al., 1992). Older W-Au-mineralization is of stockwork-impregnation character, biotite at the margins of ore veins is dated back to 300 Ma by K/Ar method. Hercynian shear zones of E–W direction in the environment of banded and eyed orthogneisses are connected with mylonitization and ore mineralization (Bystrá zone). The age of newly formed muscovites in this shear zones is 332 Ma (Ar/Ar method, Dallmeyer et al., 1993). Trangoška zone is young (possibly Neogene) strike-slip (Nemčok and Nemčok, 1998) based on inherited structures from Paleoalpine stage.

Northern Veporicum

Kolba shear zone is NE–SW oriented zone of blastomylonites with Cu-mineralization and intrusions of Permian granite-porphyries. The ore-mineralization does not pass into the Mesozoic envelope. It is obvious, that this is a Upper Paleozoic shear zone, however, movements along it were also repeated in the Cretaceous. In the parallel Osrblie zone in strike-slips superimposed in Alpine slices also Mesozoic rocks are present. Pohorelá and Vydrovo zones are parallel NE–SW striking zones of blastomylonites being used by the intrusions of Permian to Triassic A-type granites (Petrík et al., 1995; Putiš et al., 2000). Muscovites from these shear zones are dated back to 256 Ma (Dallmeyer et al., 1996). Movements and mylonitization on these zones repeated also in the Cretaceous (testified by wedged Triassic rocks, Hók and Hraško, 1990).

Southern Veporicum

Shear zones in the Southern Veporicum are mostly oriented to NE. They are superimposed to older E–W zones

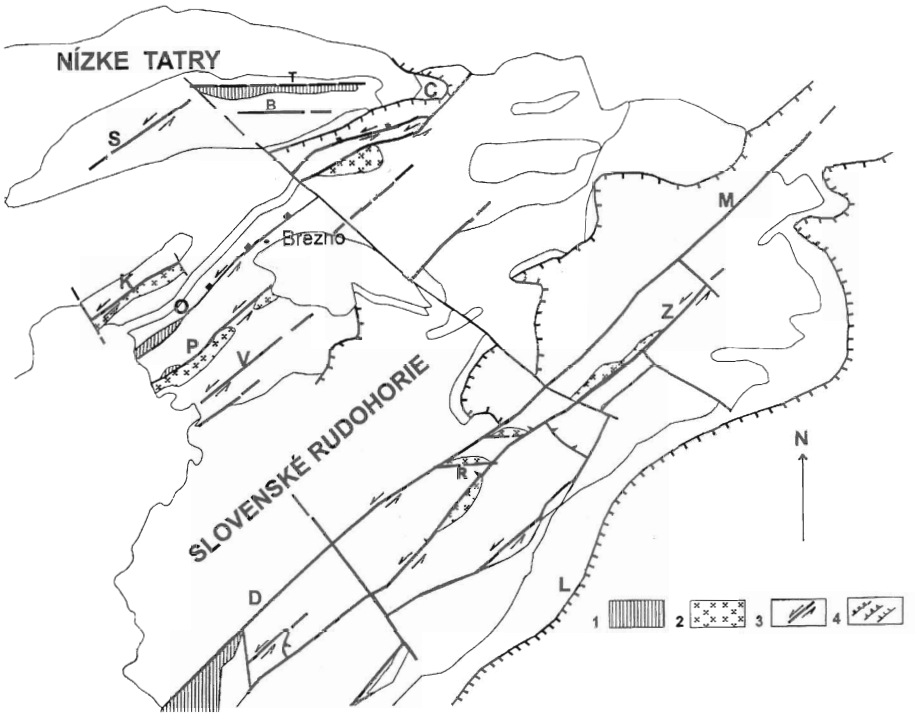

Fig. 2. Hercynian and Alpine strike-slips in the central part of the Western Carpathians. 1 – Mesozoic rocks, 2 – Permian granites, 3 – faults mostly of strike-slip character· S – Špiglová, B – Bystrá, T – Trangoška, K – Kolba, O – Osrblie, P – Pohorelá, V – Vydrovo, D – Divín, M – Muráň, R – Ráztočno, Z – Zdychava, 4 – thrusts: a) Paleohercynian, b) Mesohercynian, c) Paleoalpine (C – Čertovica line, L – Lubeník line).

(Ráztočno zone) connected with intrusions of porphyric granites (Lexa and Bezák, 1996), younger than collisional granites of 350 Ma and older then I-type Sihla granites of 300 Ma. Wide zones of blastomylonites of NE–SW direction on the Divín fault are characterized by postkinematic formation of orthoclase (Ondrášik et al., 1987) and on the Zdychava fault by intrusions of Hercynian granites, diorites and special type of Permian granites (Hraško et al., 1997). Movements along these shear zones were also repeated in the Alpine orogen, because in the area of Divín also Mesozoic complexes of the envelope of crystalline rocks are caught by the strike-slip in the Divín fault (Bezák, 1988). The last manifestations of the Muráň fault are the normal faulting superimposed on the Paleoalpine strike--slip (Marko, 1993).

Conclusions

The middle part of Western Carpathians is characterized by several subvertical shear zones with prevailingly strike-slip character of movement. The movements along them took place either within Hercynian orogen (proved by radiometric datings, Hercynian granitoid intrusions in shear zones, Hercynian ore-mineralization linked to shear zones), as well as within Alpine orogen (radiometric datings, occurrences of Mesozoic rocks within shear zones). In most of cases the Hercynian and Alpine shear zones are identical. There is evidence of long-living faults, some are even active up to present time. The strike-slips always followed after the compressional phase of both orogens. The extent of movements along them cannot be established because of lacking of geological markers.

The older Hercynian shear zones of E–W direction were identified and dated by newly formed muscovites about 330 Ma by Ar/Ar method and by intrusions of Upper Paleozoic porphyric granites. They are often linked with the ore-mineralization. Younger shear zones are mostly of NE–SW directions, being dated by Ar/Ar method around 250–260 Ma. In these zones the ore-mineralization is developed, but they are also an environment of emplacement of Permian magmatites.

In the Alpine orogen the movements along inherited shear zones repeated – mainly shear zones of NE–SW orientation were used, but, naturaly, also new ones were formed. The movements took place under conditions of lower grade greenschists facies, they were also connected with extensive circulation of fluids, ore mineralization and mylonitization.

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Timing of the Tertiary magmatic activity in the Central and Western Rhodopes and "Serbo-macedonian massif" (SW Bulgaria and N Greece) – radiometric data evidence

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Abstract

The available and new radiometric ages of the Tertiary (Paleogene and Neogene) orogenic volcanics and plutons in SW Bulgaria and N Greece are summarized and briefly discussed. The largest Paleogene plutons are intruded obviously in Bartonian–Priabonian time. The volcanic activity was the most widespread and most powerful in Rupelian time (34–29 Ma). Rare Sarmatian (12–11 Ma) volcanic manifestations are distinguished as well.

Key words: Tertiary, Bulgaria, Greece, radiometric ages, volcanics, plutons

Introduction

Tertiary (both Paleogene and Neogene) orogenic igneous rocks crop out over large territories of the central and southern parts of the Balkan Peninsula between the main Tethyan suture (Vardar – Izmir – Ankara) to the South and the Late Cretaceous Banat – Srednogorie island-arc system (Srednogorie unit) – to the North (Fig. 1).

The aim of the authors of this overview is to outline the time-span of the Tertiary magmatic activity in both the central and western parts of Bulgarian and Greece Rhodopes and "Serbo-Macedonian massif" using the available and the new radiometric ages.

Geological data about the Tertiary igneous rocks

Paleogene volcanic bodies of different facies and plutons are strongly dominating among Tertiary magmatics in the described territory, while the Neogene magmatics crop out as rare bodies in its south-western part only (Fig. 2).

1. The Paleogene volcanism took place in conditions of a NE–SW to N–S directed extension and in a subaeral environment. It was roughly contemporaneous with the accumulation of continental and marine molasses upon a basement of high grade metamorphics and granitoids. The volcanics are mainly acid (dacites, rhyodacites, rarely – rhyolites) and belong to the high-K calc-alkaline to shoshonitic series. Large and thick, high aspect ratio lava-like ignimbrites are typical for the Central Rhodopes: Persenk (Pk), Perelik = Zakardenia – (P-Z), Dipotama = Kotily-Chaitou -Vitinya (D-KV) and Bracigovo-Dospat (BD; Figs. 2, 3 and 4). Smaller ignimbrite-like bodies (North Rhodopes ignimbrites – NRI) crop out in a E–W strip along to their north slopes. The acid volcanics built also complex volcanic structures (Mesta calderas – M, Levocevo

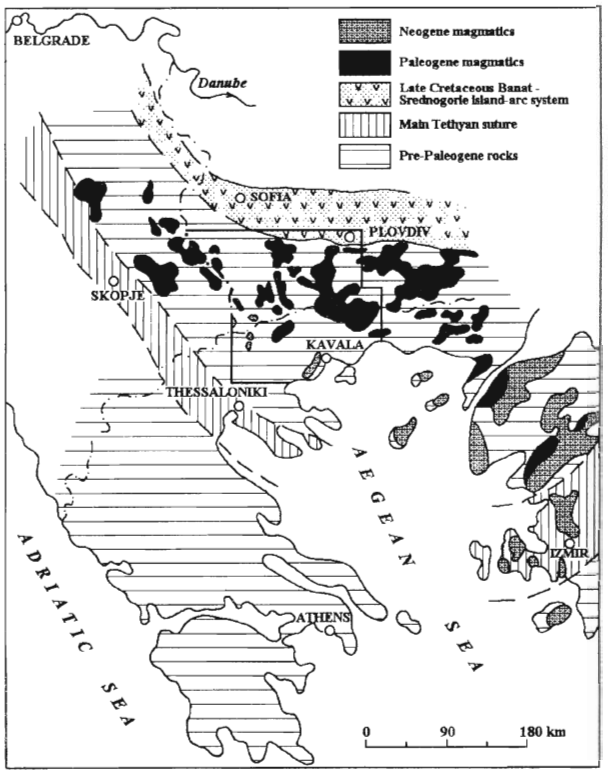

Fig. 1. Regional position of the Tertiary igneous rocks in the central and southern parts of the Balkan Peninsula and in the North Aegean region. The studied area is framed.

caldera – L, etc.) and outline pronounced linear NW–SE (135–140°) trending polystadial and polyfacial magmato-tectonic zones (Rouen – R, Gorna Ribnitsa – GR, etc.) which continue on the territories of Macedonia and Serbia. Dykes of acid or acid (rhyolitic) and intermediate (latitic) composition built some of the Central Rhodopes linear dyke swarms. In some of the swarms rare basaltic dykes are also presented (Zagrazden dyke swarm – Zg, etc.).

The Paleogene plutons are hypabyssal, the Central Pirin pluton being suggested to be a member of a volcano-plutonic association. With one exception (Xanti pluton – X) they are hosted into the crystalline basement only. These are: Central Pirin (CP), Rila-Western Rhodopes (RWR – second and third phases), Teshevo (T), Vrondu (V), Ossogovo (Os), Elatia = Baroutin-Bouynovo (E–BB), etc. (Figs. 2, 3 and 4). Rocks of acid composition (biotite-hornblende granites and granodiorites) strongly predominate. Subordinate intermediate (monzonitic, monzodioritic) and basic rocks (gabbro, monzogabbro – including two-pyroxene-olivine gabbro) are described in some of the plutons (Xanti, Vrondu, etc.).

2. The Neogene volcanic bodies crop out in small dykes, as irregular subvolcanic bodies (Neo Petritsi – NP), or as a cryptodome (Kozhouh – Kz – Figs. 3 and 4). All of them are hosted by the high grade metamorphics on the both sides of the Bulgarian-Greek state border along the Strouma (Strymon) river valley (Fig. 2). They are of acid (dacitic, rhyodacitic) to intermediate (trachytic) composition and belong to the high-K calc-alkaline to shoshonitic series. The plutonic bodies, referred recently to the Neogene, are also of acid composition. The unusual gneiss-like structure of the largest (Kavala – Kv) granodioritic pluton is interpreted as a record of special tectonic conditions of emplacement.

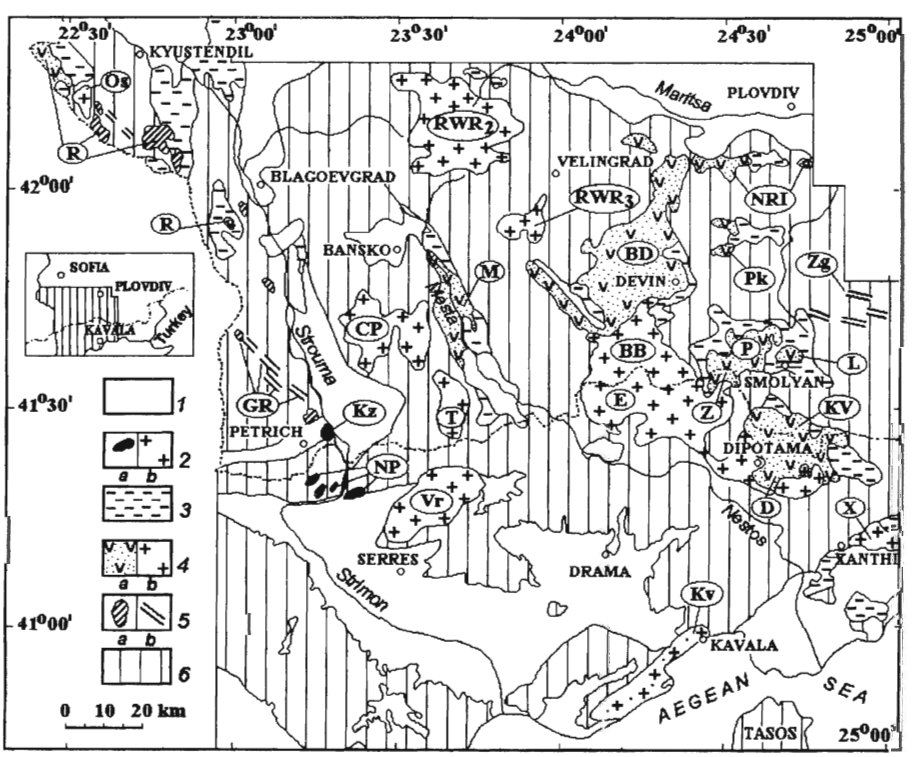

Fig. 2. Tertiary igneous rocks in the Bulgarian and Greek parts of the Central and Western Rhodopes and "Serbo-Macedonian massif". 1 – Quaternary and Neogene deposits, 2 – Neogene igneous rocks: a) subvolcanic bodies and dykes, b) plutons, 3 – Paleogene sedimentary and volcano-sedimentary deposits, 4–5 – Paleogene igneous rocks: 4a – extrusive volcanics, 4b – plutons, 5a – subvolcanic (to hypabyssal) bodies, 5b – dykes, 6 – high-grade metamorphics. The full names of the igneous bodies and magmato-tectonic structures are given in the text and/or in Figs. 3 and 4.

Radiometric data – comments and discussion

The available and new radiometric ages, determined in different laboratories during the last two decades are summarized and compared in Figs. 3 and 4.

The volcanics are dated as a rule by K-Ar method on whole rock and/or mineral (biotite, sanidine, plagioclase) fractions. The Rb-Sr, U-Pb, single fission-track and the single $^{40}Ar/^{39}Ar$ ages of the plutons are commented only. Their K-Ar ages are not taken into consideration, having in mind the strong rejuvenation of the hosting high grade metamorphics all over the territory of Rhodopes and "Serbo-Macedonian massif" as a result of the Tertiary tectono-magmatic events. The following comments on the ages presented could be made:

1. The Paleogene magmatic activity in the region started probably in Bartonian(?) by emplacement of hypabyssal plutons. It continued in Priabonian time mainly as a volcanic activity and became most widespread and most powerful during Rupelian time span (34–29 Ma);

2. The Rupelian ages of the dyke swarms (s. s.) and of the polyfacial linear magmato-tectonic zones, located outside of the Paleogene basins and hosted in the crystalline rocks only (GR), fall also within the Early-Middle Rupelian time-span above mentioned, underlying the regional character of the Rupelian magmato-tectonic processes;

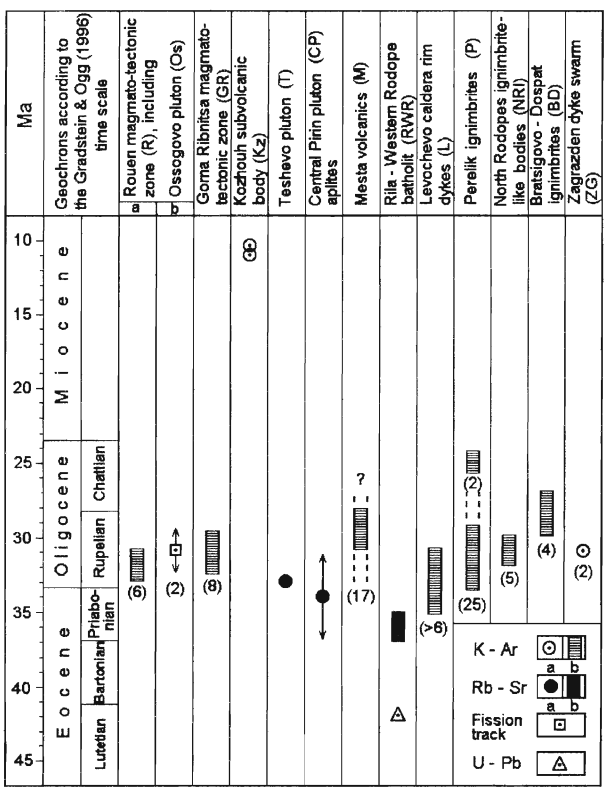

Fig. 3. Time-chart of the Tertiary igneous activity in the Bulgarian parts of the Central-Western Rhodopes and "Serbo-Macedonian massif". 1 – K-Ar ages: a – single dating, b – interval of data (the limits of the instrumental error are ±0.7 – ±1.4 Ma), 2 – Rb-Sr ages (both iso-, and errochron): a – single dating, b – interval of data, 3 – fission track ages, 4 – U-Pb ages. The number of measurements - in brackets. References: R – Harkovska and Pecskay (1997), Os – Kounov et al. (2001), GR – Pecskay et al. (2001), T – Machev et al. (2000), CP – Zagorcev et al. (1987), M – Pecskay et al. (2000), RWR – Kamenov et al. (1999) and the references therein, L – Harkovska et al. (1998), P – Harkovska et al. (1998) and the references therein, NRI – this paper, BD – Lilov and Bacheva (1989) and new data, Zg – Harkovska et al. (1998), Kz – this paper.

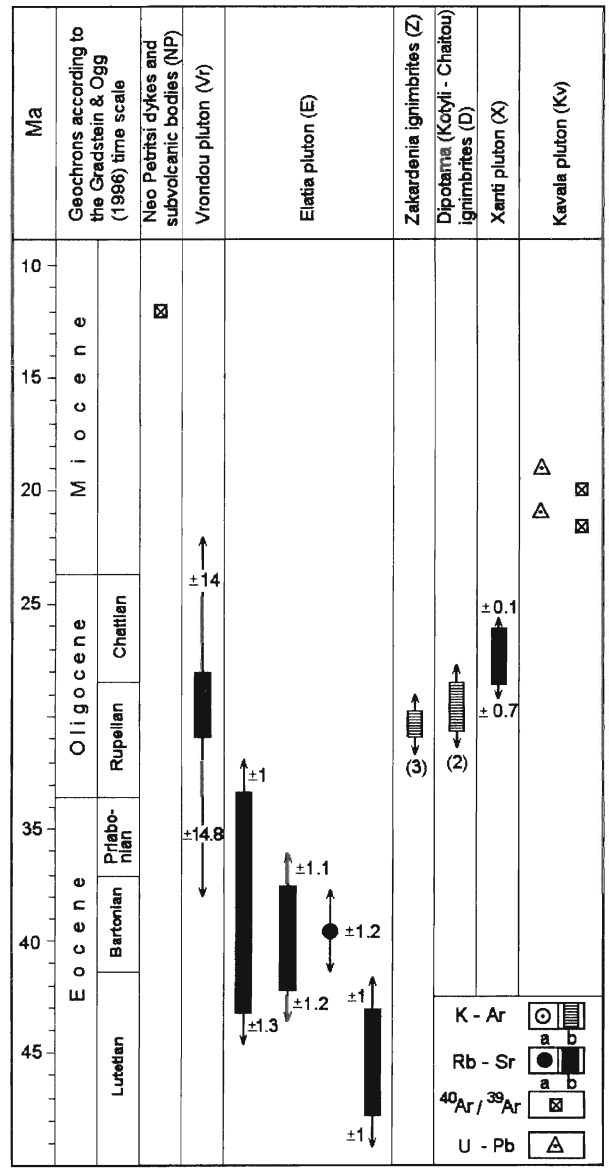

Fig. 4. Time-chart of the Tertiary igneous activity in the Greek parts of the Central-Western Rhodopes and "Serbo-Macedonian massif". 1 – K-Ar ages – interval of data, 2 – Rb-Sr ages (both iso-, and errochron): a – single dating, b – interval of data, 3 – U-Pb ages, 4 – $^{40}Ar/^{39}Ar$ ages. The number of measurements - in brackets. References: NP – Eleftheriadis and Staikopoulos (1997), Vr – Kolokotroni (1992), E – Soldatos et al. (2001), Z – Eleftheriadis and Lippolt (1984), D – Innocent et al. (1984), Eleftheriadis and Lippolt (1984), X – Kyriakopoulos (1987), Kv – Dinter et al. (1995).

3. Most of the ages of the Paleogene volcanics and the Xanti pluton age are in agreement with the geological interrelationships of the respective magmatic bodies with their hosting and/or underlying paleontologically dated sedimentary rocks. Therefore their age is confirmed by two different independent methods.

4. A special attention has to be paid to the Paleogene ages obtained for the plutons, because before the respective datings (Figs. 3 and 4) most of them were suggested to be older (Late Cretaceous, Paleozoic, or even – Pre-Cambrian): a) The Rupelian fission-track ages on zircon and apatite of the Ossogovo pluton agree with its first preliminary U-Pb ages on zircon (Fig. 3), but taking into account some geological interrelations, these ages have obviously to be confirmed by more precise methods; b) The same considerations have to be addressed to the Priabonian (37–35 Ma) age of the Central Pirin pluton and to the ages of the second and third phase of the complex Rila-Western Rhodopes pluton; c) The Eocene ages of the complex Elatia=Baroutin-Bouynovo pluton, determined using new Pb-Sr isochrones on different mineral fractions, outline a very wide time-span (47–34 Ma). It has to be mentioned that the older of these ages are not in contradiction with the field interrelations between the granitoids and the Late Rupellian–Early Chattian (30–27 Ma) BD-ignimbrites (Fig. 2), suggesting possible intensive processes of Late Eocene uplifting and exhumation. On the other hand such inconsistencies in the ages could be due to the evolution of the respective magmas through AFG – or MFC – processes. The same explanation could be proposed for the errochrone ages of the Vrondu pluton (Fig. 4).

5. The preliminary Sarmatian K-Ar ages (about 11 Ma) of the Kozhouh-body (Fig. 3) are in full agreement with the $^{40}Ar/^{39}Ar$ ages (12 Ma) of the Neo-Petritsi dykes and subvolcanic bodies (Fig. 4), indicating a northward migration of the Neogene magmatic activity along the Strouma fault zone. Such a migration would be even more impressive, if the new Neogene ages of the Kavala pluton (Figs. 2 and 4) are taken into consideration.

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Contact metamorphism and hydrothermal alterations around andesite intrusion of the Jarmuta hill, Pieniny (Poland)

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Abstract

Contact metamorphic zones, developed around andesite intrusions of the Jarmuta hill (Pieniny Mts.), were studied. Sedimentary rocks were subjected to contact metamorphism under pyroxene-hornfelse facies conditions. It is possible that sanidinite facies conditions were developed temporarily within sedimentary rocks in the immediate vicinity of the intrusion. Contact zone (andesite and metamorphosed sedimentary rocks) were subsequently altered by hydrothermal solutions. Hydrothermal activity took place within broad range of temperature conditions. Chemical composition of solutions was changing during the decline of temperature.

Key words: contact metamorphism, hydrothermal activity, andesites, Pieniny Mts.

Introduction

Tertiary andesites in the Pieniny Mts. in Poland occur in the form of small intrusions, sills and dykes. Contact metamorphism and hydrothermal activity, related the alterations of andesites and country rocks, were investigated by numerous authors (e. g. Wojciechowski, 1950, 1955; Birkenmajer, 1956, 1986, 1996; Małoszewski, 1956; Gajda, 1958; Małkowski, 1958; Banaś et al., 1993; Sokołowska and Wojciechowski, 1996; Pyrgies and Michalik, 1998). Andesites and hydrothermal veins connected with them were the object of ore prospection since 15th century (vide Wojciechowski, 1955; Małkowski, 1958).

Contact metamorphism, hydrothermal alterations and ore deposits formation related to Tertiary volcanics were broadly investigated in Slovakia (e. g. Štohl et al., 1994; Kraus et al., 1999; Lexa et al., 1999).

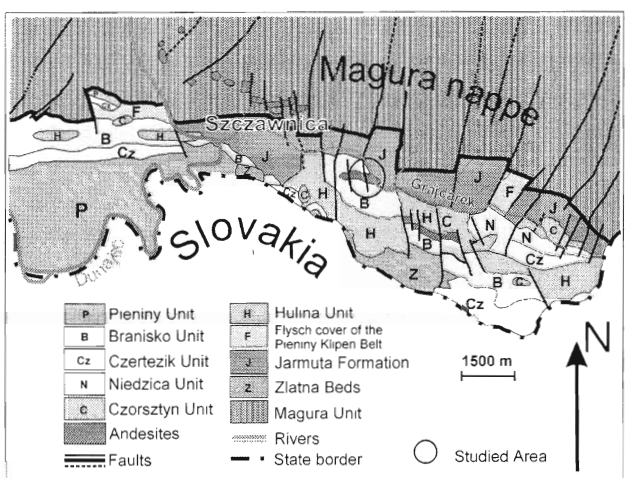

Fig. 1. Sketch map of studied area (after Kulka et al., 1991; simplified).

Geologic settings

Several vein-like intrusions of andesite are present in the Jarmuta area (the Grajcarek stream valley near Szczawnica). Localization of intrusions based on geophysical methods was determined by Małoszewski (1956). Two lithological varieties of andesite can be distinguished here:

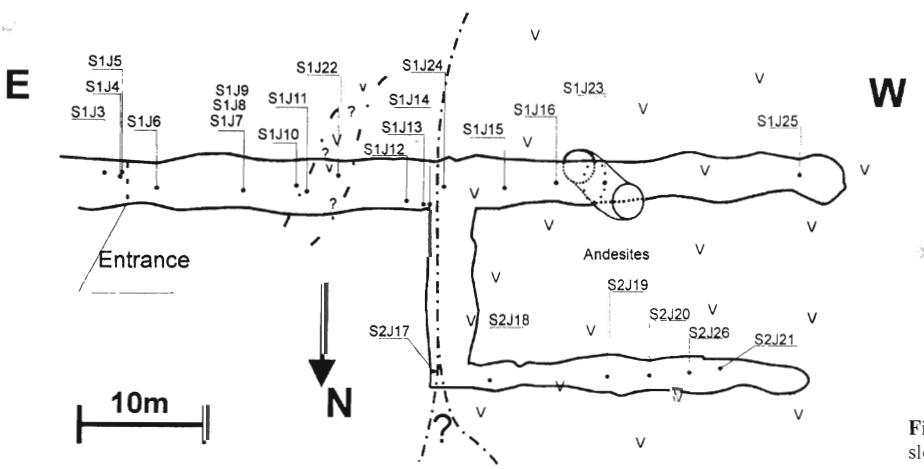

Fig. 2. Plan of the old adit on the eastern slope of the Jarmuta hill and sampling sites.

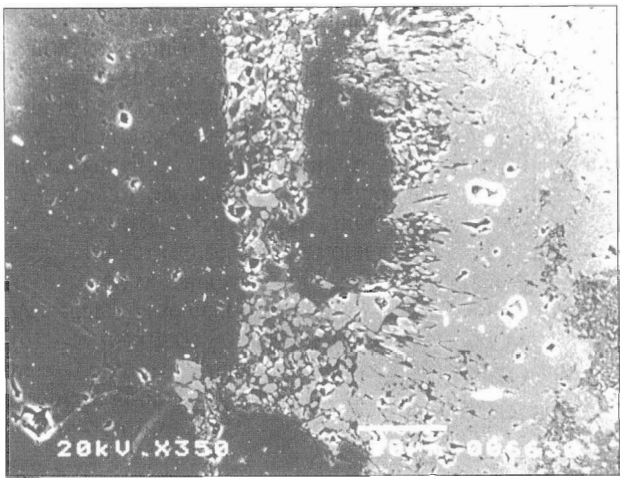

Fig. 3. Contact zone between andesite and mudstone SEM

Fig. 6. Biotite replaced by Fe oxides and sulphides SEM

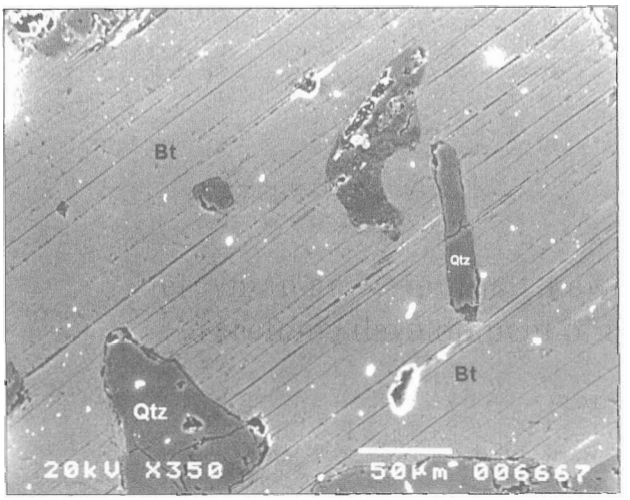

Fig. 4. Poikilite biotite (Bt) with quartz (Qtz) SEM

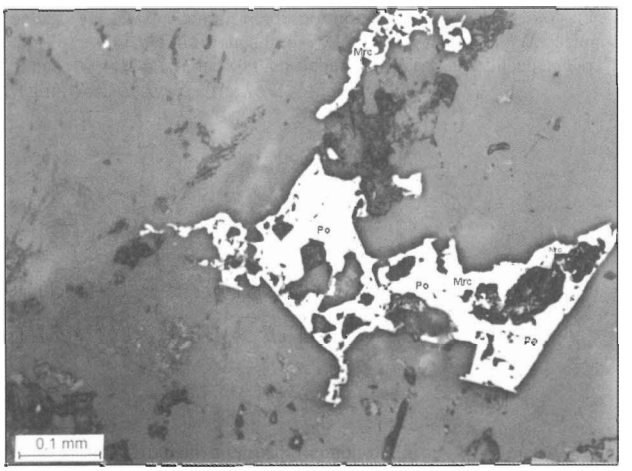

Fig. 7. Marcasite (Mrc) replaces pyrrhotite (Po) Optical microscope, reflected light

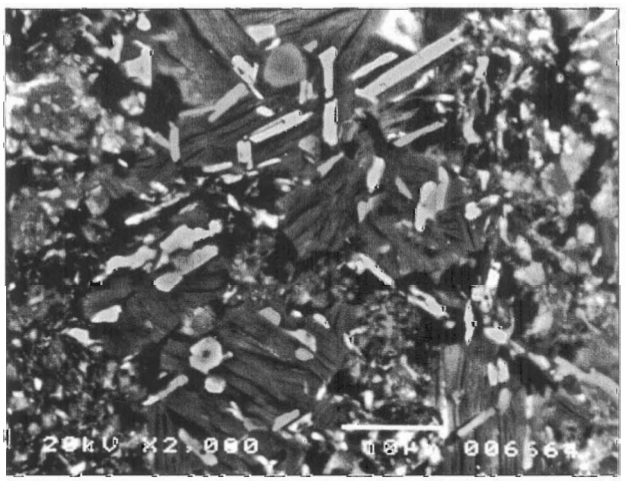

Fig. 5. Pyroxene and biotite partly replaced by sulphates SEM

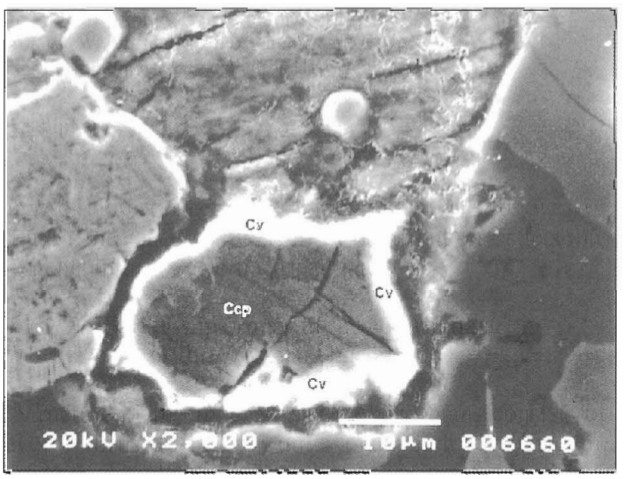

Fig. 8. Chalcopyrite (Ccp) changed by covellite (Cv). SEM.

so–called amphibole andesite (the older variety) and pyroxene-amphibole andesite (the younger one; Małkowski, 1958).

Andesites of the Jarmuta area intruded various sedimentary rocks of the Grajcarek group (shales, marls, sandstones, tuffaceous intercalations; Fig. 1). The intrusion age

determined using K-Ar method corresponds to Sarmatian (Birkenmajer and Pécskay, 2000).

Sampling

Samples were collected in two localities – in the Malinowa quarry (fresh and altered andesite) and in the old adit on the eastern slope of the Jarmuta hill. Samples from the adit (Fig. 2) represent altered andesites and sedimentary rocks (various mudstones and sandstones) cut by hydrothermal veins.

Methods

Optical microscopy both in transmitting and reflected light was applied. X-ray diffractometry (Philips X'Pert APD apparatus) was used for identification of rock components. Powdered preparations were investigated in Cu radiation monochromatized using graphite monochromator. Pelitic material was separated from several samples after carbonate dissolution in acetic buffer and Fe-oxides removal after reduction using Na-dithionite in Na-bicarbonate and Na-citrate solution. Infrared spectrometry (Bio-Rad FTS-135 type spectrometer) was used also. Samples were prepared as pressed disc with KBr. Scanning electron microscopy (JEOL JSM 5410 microscope) with energy dispersive spectrometry (NORAN, Voyager 3100) was applied. Samples were coated with carbon film.

Results

Altered sedimentary rocks

Two mineral zones were observed in sedimentary rocks in the vicinity of intrusion. Sanidine, diopside, wollastonite, pigeonite and cristobalite zone (Fig. 3) is present close to the contact. Determination of sanidine and cristobalite is XRD based. XRD patterns indicate that sanidine is usually accompanied by other, more ordered, potassium feldspar phase. Wollastonite, diopside and garnet zone is more distant from the contact. Sulphides are dispersed locally in altered rocks (pyrrhotite, chalcopyrite, pyrite) of both zones. In rocks situated more distant from the contact than previous ones, only recrystalization (increase of average grain-size in the rock) and Fe, Ti or Fe-Ti-oxides can be seen. Fine-dispersed graphite is present in several samples. Secondary carbonates (calcite and siderite) and clay minerals (chlorite and kaolinite) can be observed in samples collected in a bigger distance from the contact.

Most newly formed minerals mentioned above can be present both in altered mudstones and sandstones. Graphite is a secondary mineral present only in mudstones. Primary texture of sedimentary rocks are visible, however, these textures are modified by alterations to various degree.

Contact alterations are observed macroscopically by the change of the colour of rocks and in modification of their mechanical properties (rocks are harder and splits into sharp-edged fragments) as it was pointed out by Birkenmajer (1956).

Alterations in andesite

Assemblage of newly formed minerals in altered andesite is relatively rich. Sanidine is present as anhedral grains. Potassium feldspar of adularia-like optical characteristics can also be observed. Diopside forms relatively big crystals enclosing older decomposed minerals, probably pyroxene phenocrysts. Wollastonite can be observed both as discrete grains and as complex intergrowths with feldspar and quartz (secondary quartz?).

Poikilitic biotite (Fig. 4) contains inclusions of quartz, apatite and rarely feldspar. Poikilitic biotite is characterized by relatively high content of chlorine. Apatite occurs commonly in rocks representing highest degree of alteration. Numerous apatite crystals are chlorine-rich. Fine-crystalline epidote is scarce in altered andesite. Secondary carbonate minerals (calcite and subordinately siderite) are present in andesite groundmass. Low amount of chlorite was determined in some samples using XRD.

Sulphide minerals were observed also (Figs. 5 and 6). Pyrrhotite is the most common among sulphides. It is often accompanied by chalcopyrite. Sphalerite and rarely electrum occurrence is related spatially to chalcopyrite. Marcasite replaces pyrrhotite (Fig. 7) and covellite replaces chalcopyrite (Fig. 8). Pyrite and galena are present but in a very small amount. In strongly altered rocks Fe-hydrooxides (for example goethite) are present.

Veins

Veins cut both andesites and sedimentary rocks. High degree alteration of wall rocks around veins cause determination of the thickness of vein difficult. Type of alteration in wall rock near veins is similar to those described in the andesites.

Siderite is present in vein and dispersed within altered rocks. Sulphide minerals, secondary pyroxene and biotite similar to those described in altered andesite are present in vein and highly altered wall rocks around it. Growth of secondary clay minerals is wide-spread. Kaolinite often replaces biotite (Fig. 9). Coarse crystalline vermiculite (up to 7 mm in size) (Fig. 10) occurs in clusters in fine-crys-

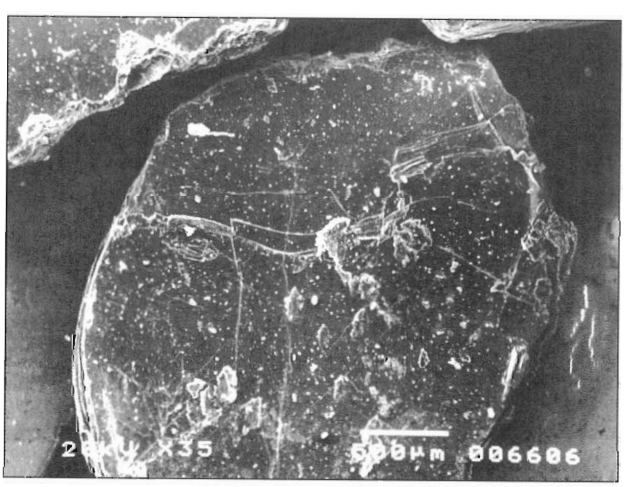

Fig. 9. Fine grain of crystalline vermiculite. SEM.

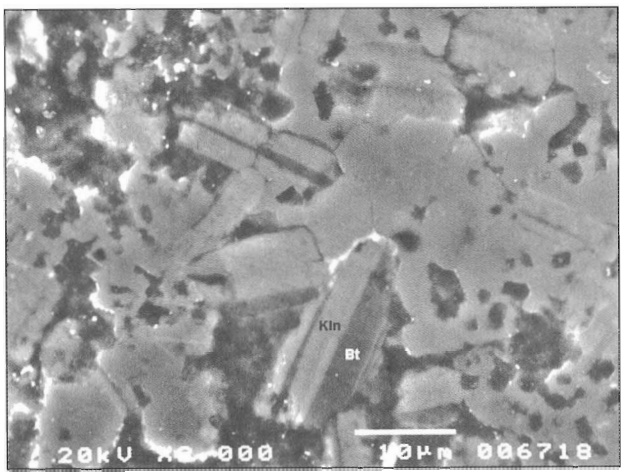

Fig. 10. Biotite (Bt) replaced by kaolinite (Kln). SEM.

talline clayey matrix composed of kaolinite, chlorite, swelling mixed-layer minerals, and siderite.

Discussion

Neomorphic minerals and their assemblages

Two main secondary mineral assemblages were distinguished in altered rocks based on their inter-relationships and textures. The first one is related to contact metamorphism and conditions of relatively low activity of fluids. The second assemblage contains minerals formed under hydrothermal conditions.

Assemblage containing sanidine, wollastonite, diopside, pigeonite, garnets, cristobalite and Fe-Ti-oxides crystallized in contact metamorphism and relatively low fluid activity conditions. Graphite is present in mudstones and was probably formed at the expense of primary organic matter. The assemblage represents minerals crystallized in various temperatures.

The second assemblage is related to hydrothermal alteration and comprises biotite and apatite with high content of chlorine, quartz, K-feldspars (adularia-type), carbonates, epidote, kaolinite, vermiculite, chlorite and swelling mixed-layer sheet silicates. Sulphides and hydrooxides (pyrrhotite, pyrite, sphalerite, chalcopyrite, covellite, electrum, galena, marcasite and goethite) can also be included into hydrothermal conditions related assemblage.

Conditions of metamorphism and hydrothermal alterations

Determination of contact metamorphism and hydrothermal alteration conditions is difficult because mineral assemblages have not attained equilibrium, what is evidenced by their texture.

Presence of sanidine and wollastonite (±diopside) can suggest that sanidinite facies conditions were developed temporarily within sedimentary rocks in the immediate vicinity of the intrusion. Moreover sanidine can be found also in marginal zones of the andesite intrusion. The presence of sanidine can indicate rapid cooling from high temperature, but not necessarily from sanidinite facies conditions temperature. Bigger volume of rock was subjected to pyroxene–hornfelse facies metamorphic conditions.

Hydrothermal alterations also took place in several stages. Biotitization was probably connected with high temperature alteration in narrow zone near intrusion. Development of secondary biotite was earlier discussed by Gajda (1958). Secondary (poikilitic) biotite is usually rich in chlorine. It is possible that chlorine-rich apatite was formed in this stage. Formation of sulphides (pyrrhotite, chalcopyrite, electrum), quartz and scarce epidote and chlorite took place at lower temperature range. This stage can correspond to propylitization, although mineral assemblage typical of propylitization is not fully developed here (scarcity of epidote and chlorite). Formation of carbonates (calcite and siderite) is related to the period of decreasing temperature. Wide-spread carbonatization was described earlier by Birkenmajer (1958).

In the hydrothermal vein and strongly altered wall rocks the vermiculite, chlorite, swelling mixed-layer silicates, and kaolinite were formed probably under wide-span of temperature conditions. Kaolinite (which replaces biotite) was formed at relatively low temperatures and at lowered pH.

Lowering of temperature and pH value influenced sulphides assemblage also. Pyrrhotite is partly replaced by marcasite and chalcopyrite by covellite. Formation of Fe hydroxides replacing sulphides and mafic silicates was related to low temperature oxidation conditions.

Conclusions

Sedimentary rocks around andesite intrusions of the Jarmuta hill area were subject to contact metamorphism under pyroxene-hornfelse facies conditions. It is possible that sanidinite facies conditions were developed temporarily within sedimentary rocks in the immediate vicinity of the intrusion. Contact zone (both in andesite and metamorphosed sedimentary rocks) was altered during hydrothermal solutions activity. Hydrothermal activity took place within broad range of temperature conditions. Chemical composition of solutions was changing during the decline of temperature.

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Experimental volcanic glass from Streda nad Bodrogom (SE Slovakia)

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Abstract

The volcanic glass from Streda nad Bodrogom was used for experimental transformation into zeolites. Samples of obsidian were treated with the NaOH solutions of various concentrations and kept in autoclave in 75–175 °C for 72 hours. Four zeolite phases were obtained: analcime-O (ANA), NaP1 (GIS), sodalite-OH (SOD) and hydroxycancrinite-type phase (CAN). Analcime has shown the highest crystallinity and has been found in the highest amount among products of syntheses.

Key words: obsidian, zeolitization, hydrothermal synthesis, Streda nad Bodrogom

Introduction

Zeolites are materials of unique framework structure. As they include channels from angstroms to nanometers of size inside, they have useful properties: high cation exchange capacity and molecular sieving. Zeolites are widely used, e. g. in the building and chemical industries. The huge deposits of zeolites form as a result of zeolitization of the volcanic glass. This process is studied by geochemical modelling and hydrothermal experiments (Alberti and Brigatti, 1985; Petrova and Kirov, 1995). Laboratory simulations are needed to better understanding of zeolitization processes of natural glass and formation of great zeolite deposits. These studies have been already carried

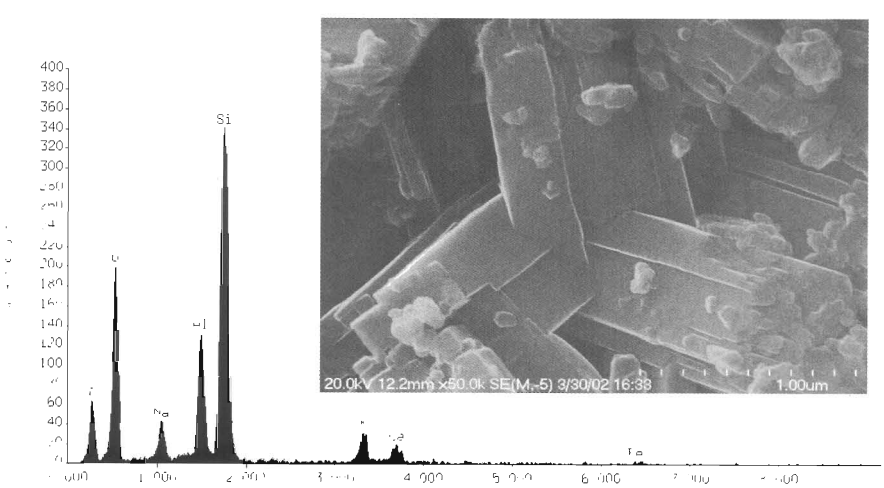


Fig. 1. SEM image and EDS spectrum of NaP1 (GIS) phase synthesised in 125 °C and at 0.1M NaOH solution

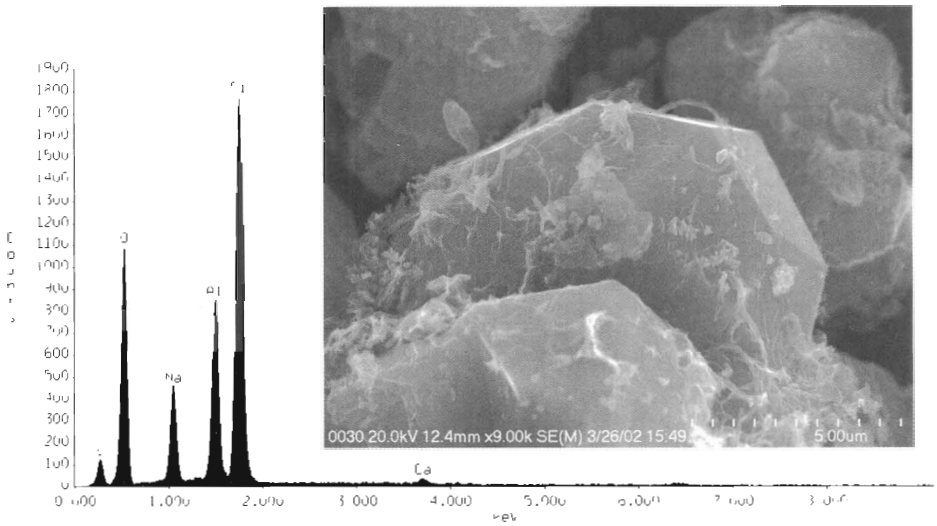


Fig. 2. Crystal of analcime (SEM image) and its chemical composition (EDS spectrum). Sample after reaction in 125 °C, with 1M NaOH solution

out in order to explain the possibilities of transformations in natural geological environment (Wirsching, 1981; Gottardi, 1989; Hall, 1998).

This paper concentrates on experiments on hydrothermal zeolitization of the Sarmatian volcanic glass from Streda nad Bodrogom (SE Slovakia).

Materials and methods

The sample of volcanic glass was collected in the quarry near Streda nad Bodrogom. Chemical composition of the obsidian was determined as an average composition from many point analyses with energy dispersive spectrometry (EDS), during scanning electron microscope (SEM) observations.

Chemical composition (wt. %): SiO_2 – 74.30; Al_2O_3 – 16.29; Fe_2O_3 – 1.12; MgO – 0.08; CaO – 1.35; Na_2O – 3.27; K_2O – 3.59;

This composition corresponds with the data from chemical analysis of bulk sample (Broška and Bačo; personal information).

Hydrothermal treatment. Samples of obsidian (500 mg) were grounded in the agate mortar and treated with 15 ml of NaOH solution of the following concentrations: 0.1M, 0.2M, 0.5M, 1M, 2M and 5 M. Reactions were carried out in Teflon (PTFE) autoclave for 72 hours, in temperatures: 75 °C, 100 °C, 125 °C, 150 °C and 175 °C. The samples after reactions were separated from supernatant liquid, then they were washed in distilled water and dried.

The products were identified by X-ray diffractometry (XRD) and the patterns were compared with PDF-2 JCPDS database (names and classification of zeolite phases after Baerloche et al., 2001 as well as Treacy and Higgins, 2001). Some of the samples were studied using SEM, with EDS system.

Results and discussion

Four zeolite phases were identified as the products of the reactions: analcime-O (ANA), NaP1 (GIS), hydroxycancrinite-like structure (CAN), sodalite-OH (SOD). Trace amounts of unidentified PHI phases were detected in some samples. The changes of the amount (from XRD intensities of characteristic peaks) of zeolite phases during

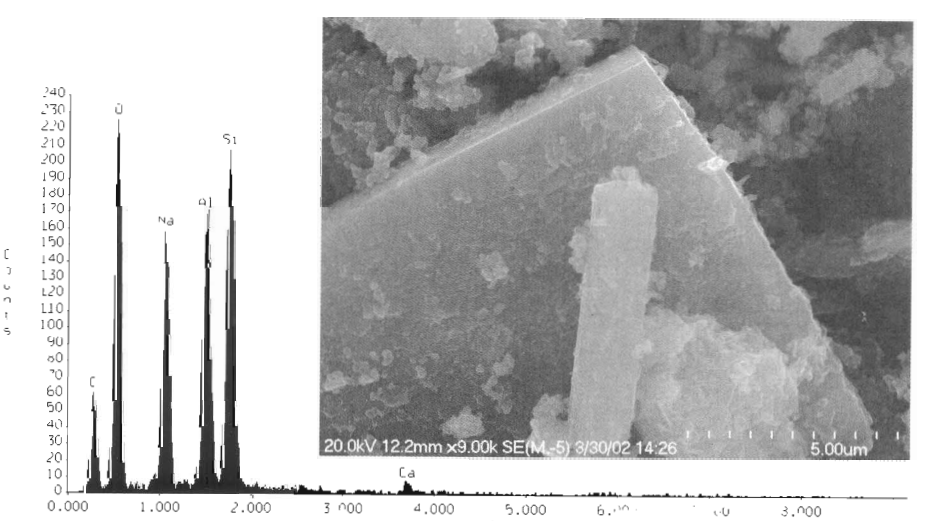
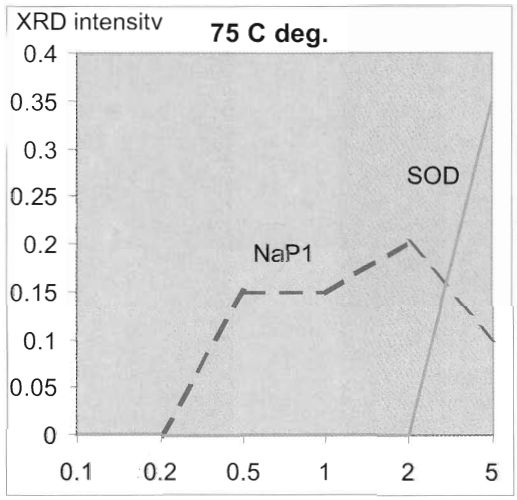
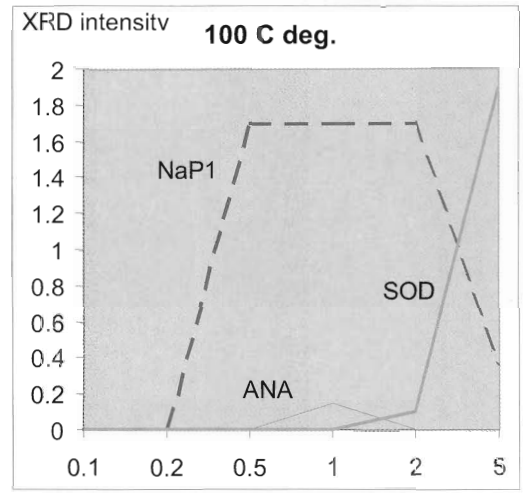
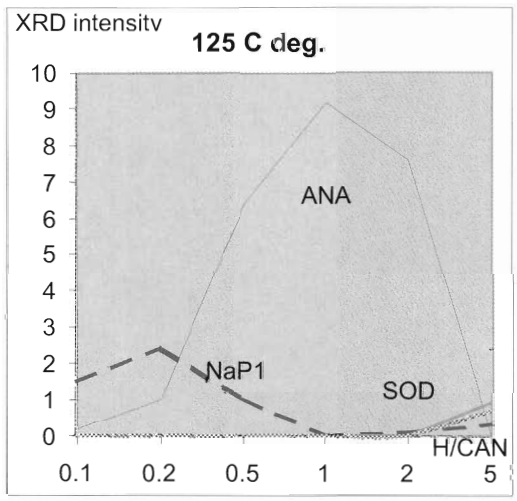
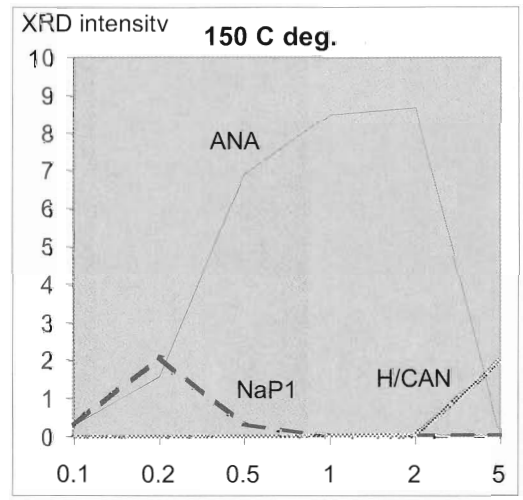


Fig. 3. Crystals of hydroxycancrinite-type phase (CAN) obtained during reaction with 5M NaOH solution in 175 °C (SEM image and EDS spectrum)









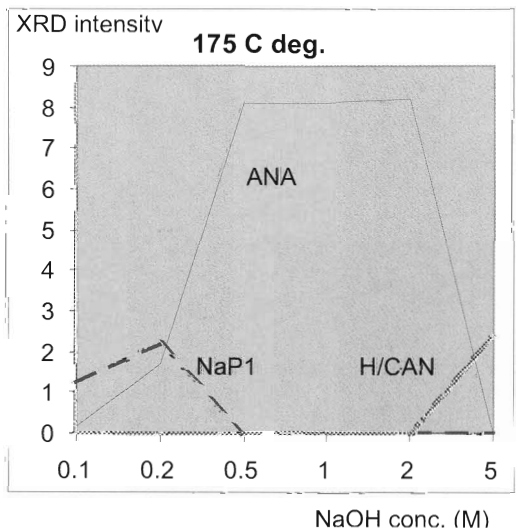


Fig. 4. Changes of XRD peaks intensity of zeolite phases in relation to the concentration of NaOH solution used in reaction, for various temperatures. ANA – analcime-C (ANA-group), NaP1 – NaP1 phase (GIS-group), SOD – sodalite-OH (SOD-group), H/CAN – hydroxycancrinite-type phase (CAN-group).

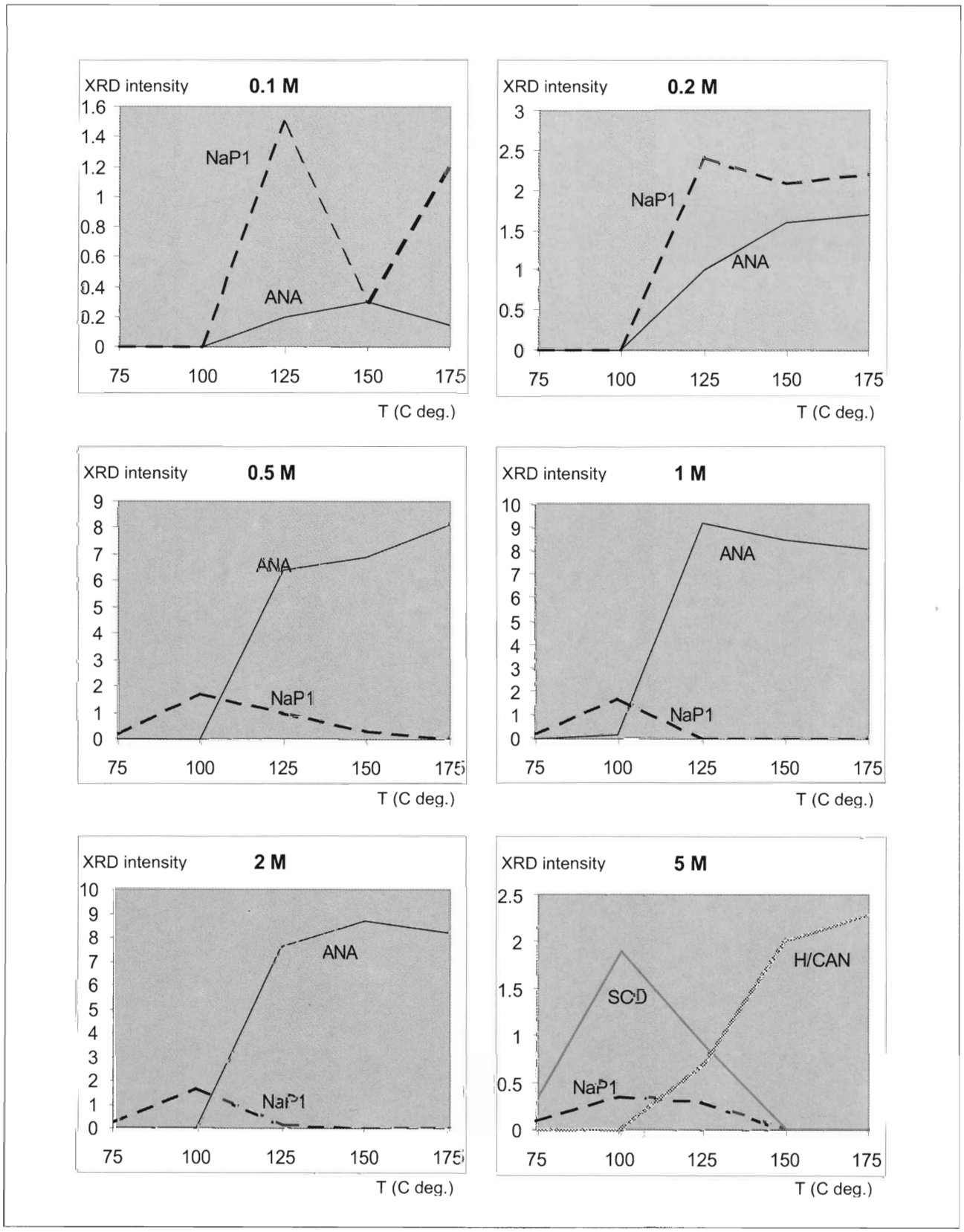


Fig. 5. Changes of XRD peaks intensity of zeolite phases in relation to the temperature of reaction, for various concentrations of NaOH solution. ANA – analcime-C (ANA-group), NaP1 – NaP1 phase (GIS-group), SOD – sodalite-OH (SOD-group), H/CAN – hydroxycancrinite-type phase (CAN-group).

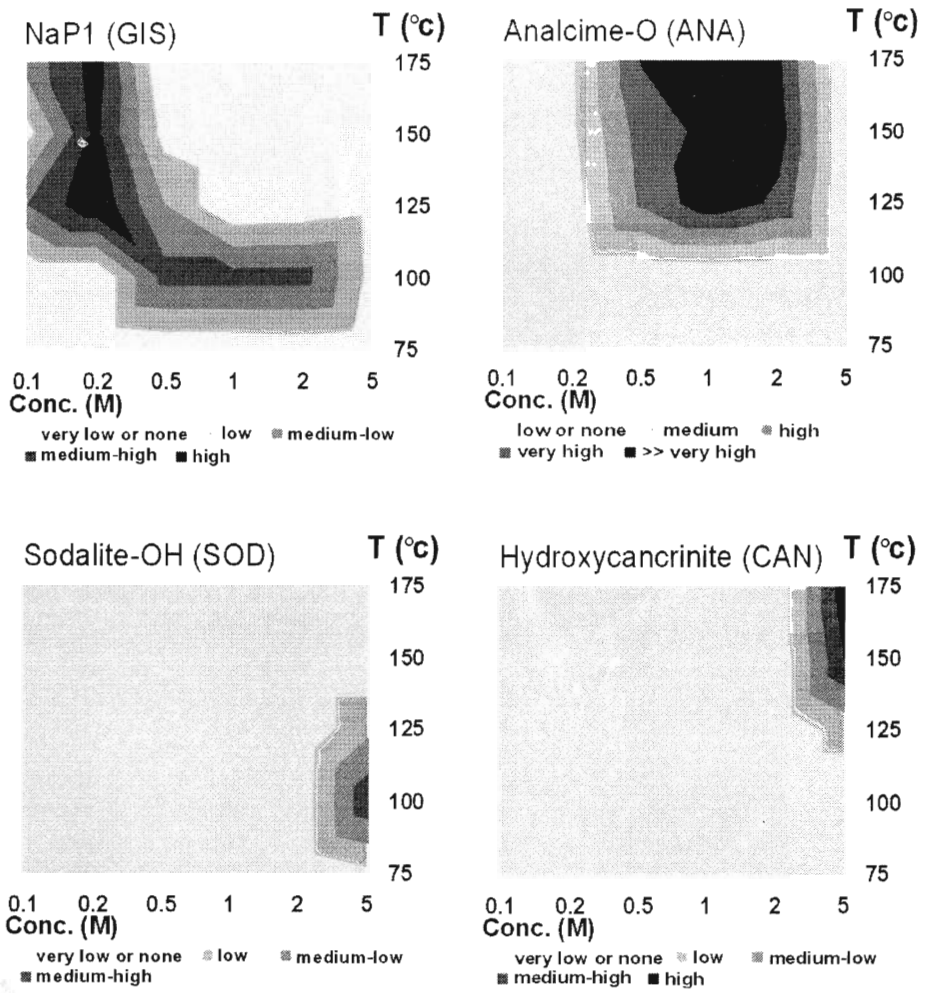


Fig. 6. Interpolated fields of crystallization conditions of zeolite phases obtained during reactions.

reactions in relation to temperature or NaOH concentration have been studied in details (Figs. 1, 2, 3, 4 and 5).

In lower temperatures (75–100 °C) the NaP1 phase occurs as the main product and is replaced by sodalite in reactions at highly concentrated NaOH solutions. NaP1 is present in the products of high temperature syntheses only at low concentrations of NaOH solutions (0.1–0.5 M), while analcime is the predominant phase. Hydroxycancrinite was found among products of syntheses in the highest temperature and at the highest concentration of NaOH.

The amount of each zeolite phase was determined semiquantitatively in relation to the reactions parameters (temperature and concentration of NaOH solution), in order to define fields of their crystallization conditions (Fig. 6). The highest crystallinity (among zeolites obtained during syntheses) has been reached for XRD monomineral samples of analcime. Other zeolite phases show minor crystallinity.

Conclusions

Analcime can be formed within the broad range of synthesis conditions and reaches the higher crystallinity. This suggests that the transformation of volcanic glass (of composition similar to one from Streda nad Bodrogom) to analcime is very probable, however, the natural hydrothermal conditions are usually more complex than applied in experiments.

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Paleoecological remarks about the Late Cretaceous foraminiferids from the Frydek–type marls (Subsilesian Unit, Polish Outer Carpathians)

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Abstract

Foraminiferal assemblages from the Campanian to Maastrichtian deposits of the Frydek–type marls have been studied within the Lanckorona–Żegocina Zone in the Wiśniowa and Rajbrot tectonic windows (the Subsilesian Unit, Polish Outer Carpathian). The microfauna from the both places partly consists of the same species, but there are a few taxa which occur only in materials from the Wiśniowa tectonic window In majority samples planktonic and benthic calcareus foraminiferids are predominant.

Key words: Lanckorona – Żegocina Zone, Frydek–type marls, foraminiferids, paleoecology

Geological setting

The Lanckorona–Żegocina Zone belonging to the Subsilesian Unit (Polish Outer Carpathians) extends from the Skawa river in the West to the Rajbrot village in the East (Skoczylas and Ciszewska, 1960). That structure consists of small tectonic windows that occur at the front of the Magura nappe overthrust. One of them is the Wiśniowa tectonic window occurring in the middle part of this zone, and the most eastern part of this structure is formed by the Rajbrot tectonic window.

The Frydek–type marls which appear within above mentioned tectonic windows have been studied. Deposits of these marls from both localities are mainly pelitic beds built up of grey, marly claystones, rather hard with intercalations of thin- and medium bedded sandstones and exotic blocks. However, marls from Rajbrot are softer than ones from Wiśniowa and they contact with the adjacent Żegocina marls and variegated sediments (Gasiński et al., 1999). Studied foraminiferids come from the Frydek–type marls, that have been collected from the Podlesie and Kluzówka creeks (the Wiśniowa tectonic window) and from the Uszwica and Boczny creeks (the Rajbrot tectonic window).

Micropaleontological comments

Examinated foraminiferal associations consist of planktonic (even up to 65 %) and benthic calcareous as well as agglutinated species. Besides foraminiferids there have

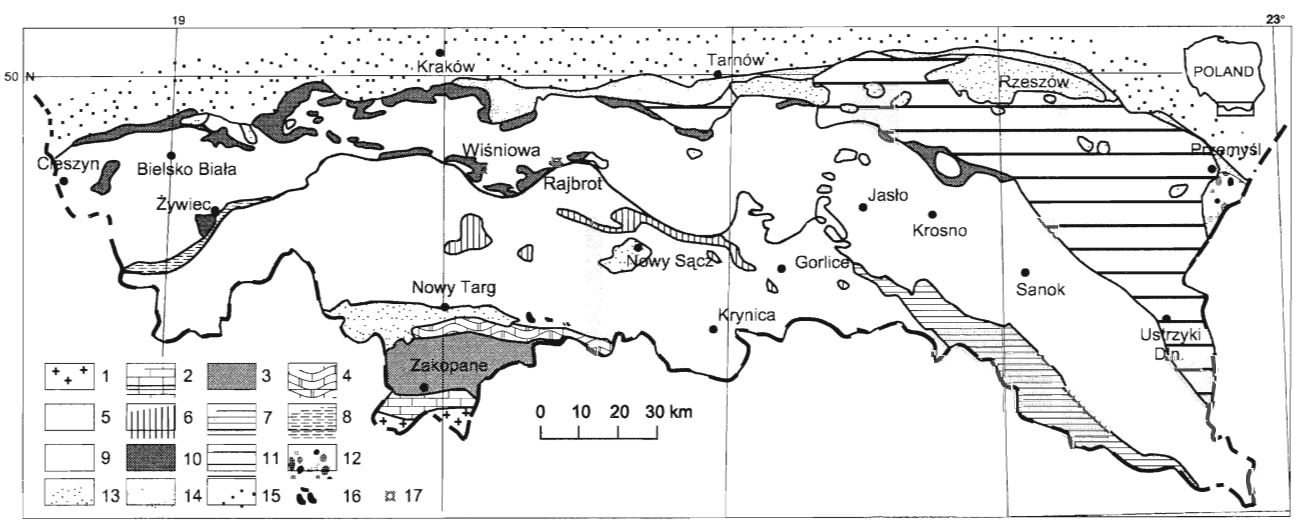

Fig. 1. Geological sketch-map of the Polish Outer Carpathians (after Malata et al., 1996). 1 – crystalline core of the Tatra Mts., 2 – High Tatra and sub-Tatra units, 3 – Podhale flysch, 4 – Pieniny Klippen Belt, 5 – Magura nappe, 6 – Grybów unit, 7 – Dukla unit. 8 – Fore-Magura unit, 9 – Silesian unit, 10 – Sub-Silesian unit, 11 – Skole unit, 12 – Sambor-Sożniatov unit, 13 – Miocene deposits upon the Carpathian, 14 – Zgłobice unit, 15 – Miocene deposit of the Carpathian Foredeep, 16 – andesite, 17 – investigated area.

been found ostracods, fragments of echinoids, sponge spicules. The age of the Frydek–type marls has been established mostly on the base of the planktonic foraminiferids. Marls appear in the Wiśniowa tectonic window are considered as the Late Campanian and the Early Maastrichtian (Robaszyńki and Caron, 1995; Brandys, 2000b). Whereas, marls from the Rajbrot tectonic window have been defined as the Campanian–Late Maastrichtian (Gasiński et al., 1999; Brandys, 2000a).

There have been recognized a lot of the same taxa in sediments from both places. The planktonic species belong to *Heterohelix, Globotruncana, Rugoglobigerina, Hedbergella, Globigerinelloides, Globotruncanella* genera. However, only within the microfauna from Rajbrot there has been found characteristic planktonic taxa *Abathomphalus mayaroensis* (Bolli) that indicate the latest Maastrichtian age of the examinated marls (Brandys, 2000a). There is a similarity in the compositions of the benthic foraminiferids, but within studied materials from the Rajbrot tectonic window there have been recognized a number of tubular forms (mainly *Rhabdammina*) and quite a lot of representatives of *Nothia*. The deposits from the Wiśniowa tectonic window include only a few specimens. Moreover, when taxa belonging to the agglutinated benthic foraminiferids genera like: *Ammodiscus, Dorothia, Gerochammina, Glomospira, Rzehakina* being rather scarce in marls from Wiśniowa, occur in a relatively large number within marls from Rajbrot. Nodosariids and calcareous benthic foraminiferids (for example: *Lenticulina, Gyroidina, Gyroidnoides, Osangularia*) have been found in the Frydek–type marls from both places and their number is comparable and relatively abundant. Moreover, among studied microfauna only characteristical taxa from the Wiśniowa tectonic window have been recognized: *Reussella szajnochae* (Grzybowski) and *Daviesina minuscula* (Hofker).

Paleoecological remarks

The quantitative analysis of the studied microfauna from the Frydek–type marls from the Wiśniowa and Rajbrot tectonic windows has been done. It shows that planktonic foraminiferids taxa are predominant in many samples from both localities.

The relation between keeled and non–keeled planktonic foraminiferids has been also studied. The presence of non–keeled epipelagic taxa is predominant among studied materials from both places. That indicates that examinated Frydek–type marls were deposited in the shallow water environment – the lower part of the shelf or/and the upper continental slope (Sliter, 1972). The existence of *Reussella szajnochae* (Grzybowski) and *Daviesina minuscula* (Hofker), which is characteristic taxa for rather cold water environments, within deposits from Wiśniowa area has not been taken into consideration due to their scarcity.

Conclusions

The microfauna from the Frydek–type marls occurring in the Wiśniowa tectonic window corresponds to the studied foraminiferal assemblages from deposits recognized in the Rajbrot tectonic window. Foraminiferids indicating on the Late Campanian and the Early Maastrichtian age of marls from Wiśniowa area consist of many equal species of foraminiferids as those found within marls from Rajbrot area.

Thus, Frydek-type marls from both localities disclose not only lithological but also microfaunal resemblance. It implies that these sediments were deposited in the similar shallow marine environments during the same time period.

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Glaucony in flysch deposits at the front of the Magura nappe near Folusz (Polish Outer Carpathians)

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Abstract

The most significant textural, mineralogical and chemical data are presented for green grains from deposits of lower part of the Magura Beds and the Menilite Beds near Folusz. The analyses indicate that the most frequent glauconitic facies is granular and the grains are K-rich glauconitic mica with high Fe_2O_3 content – they represent evolved and highly evolved stages of glauconitization. These data can be the basis for discussion on depositional environment and the origin of parent material of the studied beds.

Key words: glaucony, mineralogy, Magura Beds, Menilite Beds

Introduction

In the Carpathian flysch there is quite large number of formations containing green grains which resemble glauconite. This mineral is useful, on account of its special properties, in different fields of geological science. It can, for example, be a possible tool for sedimentologic interpretation of marine deposits, stratigrafic correlation or radiometric dating (Amorosi, 1996).

Unfortunately, the investigations of green grains occurring in the Polish Carpathians are very poorly developed. In general, geologists regarded them as glauconites in most cases without examination their mineralogical and chemical character. The preliminary result of the mineralogical and chemical investigations of glaucony from the sandstone and mudsone of the Magura Beds were presented by Koszowska and Leszczyński (2001).

This paper presents the results of mineralogical and chemical analyses of several samples of green grains from flysch deposits of the marginal zone of the Magura nappe and its foreland (the Jasło nappe). They can be the basis for discussion on geological conditions of origin of the deposits containing them.

Geological setting

The study area is situated in the Polish Outer Carpathians near Folusz. Four representative samples were collected from two cross-sections exposed along Kłopotnica stream. One of them is situated in the marginal, northern part of the Magura nappe (Siary subunit) and the other in the area at its front regarded as the Jasło nappe (Koszarski and Koszarski, 1985; Koszarski, 1999). Although, because of its very complicated tectonic setting there are many different in opinions on geology of this area (see: Szymakowska, 1966; Jankowski, 1997).

Two samples were collected from sandstones of the Magura Beds and the other two from the Menilite Beds (sandstone and limestone). Both formations are Lower Oligocene in age.

Methods of investigation

The collected samples were separated using the following methods: glaucony-bearing rocks were disaggregated, submitted to magnetic separation, heavy-liquid fractionation, purification by ultrasonic cleaning, and finally handpicking.

The main properties (morphology, mineralogy and che-

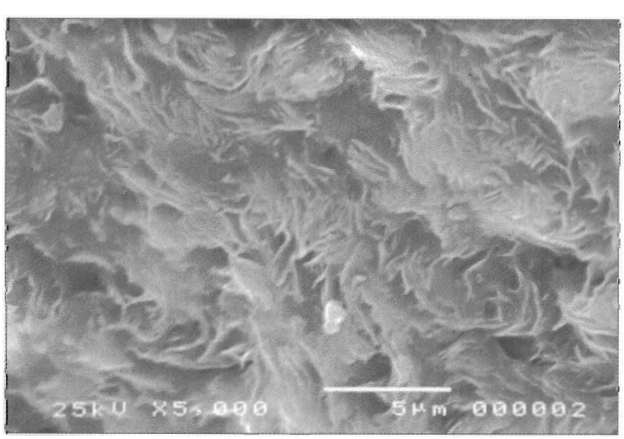

Fig. 1. Initial stage of formation of honeycomb-like structure

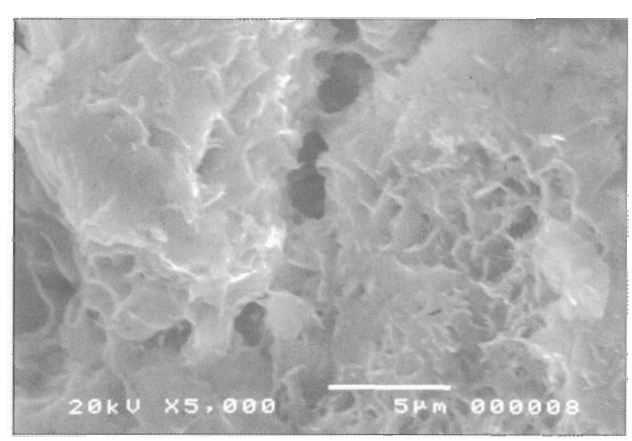

Fig. 2. Honeycomb-like structure of the surface of glauconitic grain

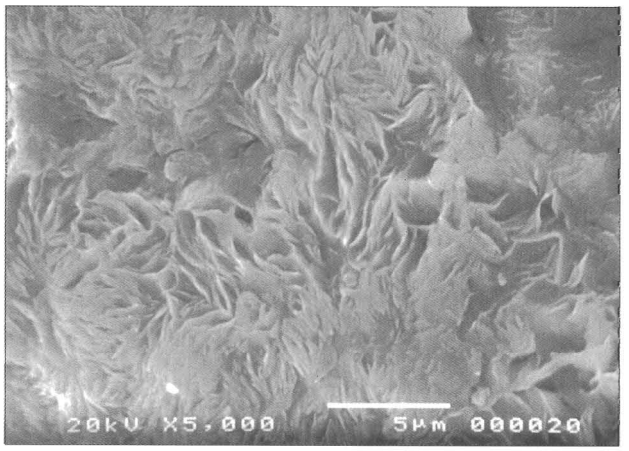

Fig. 3. Surface of glauconitic grain (Fig 4) with random aggregates of flakes.

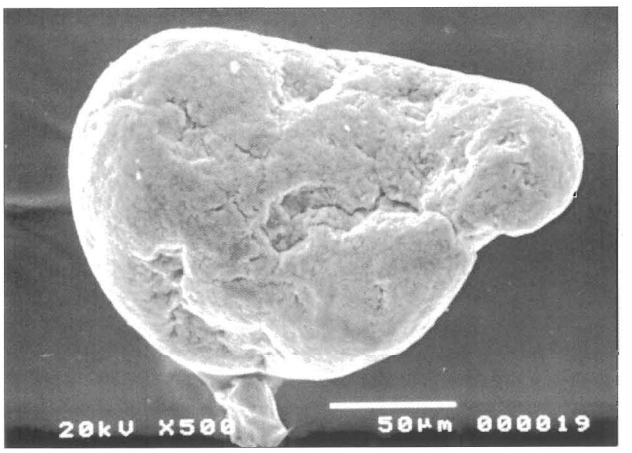

Fig. 4. Grain with porous coarse surface

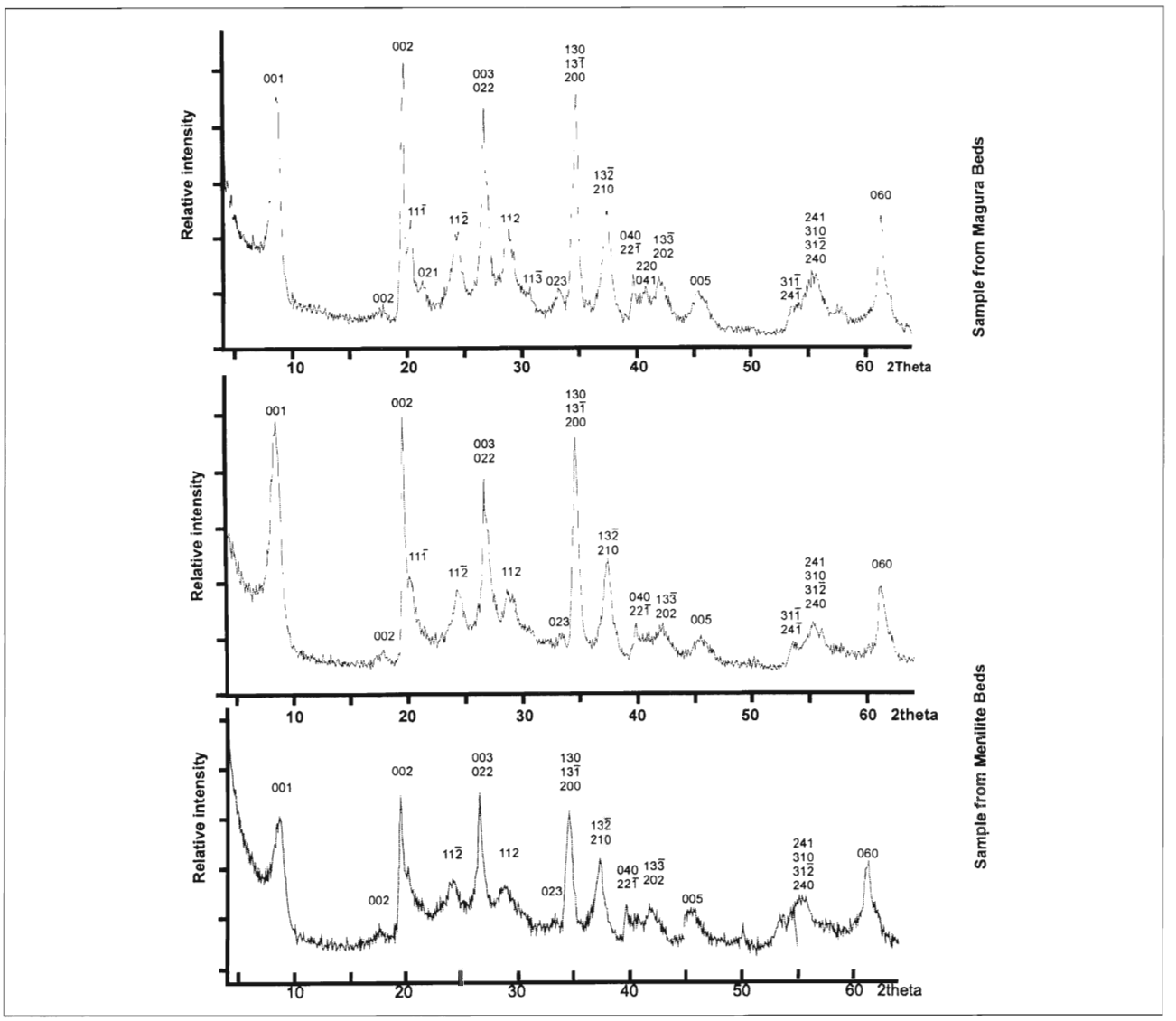

Fig. 5. X-ray diffraction paterns of two oriented samples (untreated – blue and glycolated – red).

mistry) of green grains were studies by applying: optical microscopy, scanning electron microscopy (SEM-EDS) and XRD of oriented powder samples.

Results of investigation

Physical properties

The colour, density, morphology and internal structure of green grains were examined in detail. The green grains occur mainly in size range of 0.1–0.5 mm. They are mainly dark-green in colour (light coloured grains represent only small percentage of each sample). They exhibit considerable variety in morphology. Most frequent glauconitic facies type is granular, but the diffuse type was also identified. Among the morphological types the most representative are (according to Triplehorn, 1966): the spheroidal –ovoidal (30–40 % in each sample) with smooth surface, mammillated, tabular-discoidal and irregular shape were also observed. Rarely composite pellets and pellets resembling internal cast of foraminifers are present, too.

The electron microscopy observations allow to distinguish two types of microstructure (according to Wiewióra and Łącka, 1979):

– "honey-comb" microstructure (Figs. 1 and 2), observed in grains with smooth surface,

– random aggregates of flakes (Fig. 3), which are characteristic for grains showing porous, coarse surface (Fig. 4) interpreted as an effect of abrasion and transport.

Mineralogy

The mineralogical characteristic was mainly based on powder mounts. X-ray diffraction investigations on untreated and glycolated oriented samples were made for defining the mineralogical type of green grains and the amount of expandable layers.

Investigations reveal that the grains of each sample represent glauconitic mica (Fig. 5). The content of expandable layers, which is the main criterion for defining glauconitic species, is relatively small (less than 10 %). The procedure for defining illite/smectite interstratifications proposed by Środoń (1984) was used in the case of studied glauconites (Fig. 6).

Short distance d between the (001) and (020) peaks on diffractograms (see: Odin and Matter, 1981; Odin an Fullagar, 1988) indicates high potassium content in the structure of studied glauconitic material. It also indicates that the grains consist of well-ordered glauconites.

Chemistry

Chemical analyses of the grains confirm their glauconitic nature. The calculated chemical formula does not differ significantly from the others presented in previous references (Fig. 7). The $Fe_2O_{3Tot.}$ content of the studied glaucony is high (up to 29 %). The K_2O content, which is directly related to the content of expandable layers and provides information about the maturity of glaucony (as

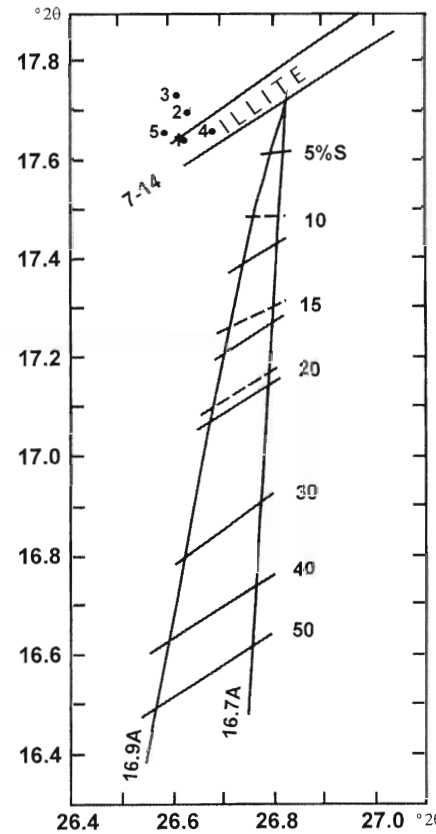

Fig. 6. Plot for determining illite/smectite ratio from 002 and 003 reflections (see: Środoń, 1984) used in the case of studied gluconites.

documented by Burst, 1958; Hower, 1961; Odin and Matter, 1981 and others), is also very high – more than 7 %.

The composition (high K_2O content) and structure (*d* spacing, shape and intensity of peaks on XRD diagrams) indicate that the studied material represents the last stages of glaucony evolution. Glauconite from sandstones of the Magura Beds and sandstones and limestones of the Menilite Beds are evolved and highly-evolved. The same stage of evolution is characteristic for materials from embedding mudstones of the Magura Beds (Koszowska and Leszczyński, 2001).

Author	Number of analyses	Formula
Presented work	14	$(K_{0.74}Ca_{0.05})_{0.77}$ $(Al_{0.31}Fe3+_{1.01}{}_{17}T_{10.01}Mg_{0.41})$ $(Si_{3.51}Al_{0.50})O_{10}(OH_2)$
Smulikowski (1954)	60	$(K_{0.67}Ca_{0.08}Na_{0.08})_{0.83}$ $Al_{0.40}Fe3+_{1.05}Fe2+_{0.17}Mg_{0.41})$ $(Si_{3.66}Al_{0.34})O_{10}(OH_2)$
Turnau-Morawska et al. (1975)	1	$(K_{0.70}Ca_{0.09}Na_{0.01})_{0.80}$ $(Al_{0.76}Fe3+_{0.79}Fe2+_{0.15}Mg_{0.31})$ $(Si_{3.64}Al_{0.36})O_{10}(OH_2)$
Odom (1984)	6	$(K_{0.76}Ca_{0.03})_{0.79}$ $(Al_{0.39}Fe3+_{1.10}Fe2+_{0.18}Mg_{0.35})$ $(Si_{3.62}Al_{0.38})O_{10}(OH_2)$

Fig. 7. Chemical formula of studied glaucony compared with data from previous references.

Conclusions

The deposits hosting glaucony were formed by gravity-flow processes in an environment that was poorly suited to glauconitization. This suggests that the glauconitic grains were redeposited.

According to the model proposed by Amorosi (1996) the glaucony of each sample is considered to be allochthonous. Nevertheless, more investigations are required to state if the glaucony is detrical (extrasequential) or parautochthonous (intrasequential).

The features of glaucony in individual sample indicate that the composition of grains is similar. They represent similar maturity and morphological types. Therefore, the genetic relationship between green grains is really possible (the maturity of glaucony may be used as an index for correlation with putative sources – Amorosi, 1996).

The presented results provide a new information on the origin of glauconite-bearing deposits in the studied area. Further detailed mineralogical and sedimentological investigations are needed to better understanding of the origin of glauconite-bearing sediments in the units of the Polish Outer Carpathians and to provide more adequate interpretation of origin of these units.

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Dating of the Tertiary "Pteropoda events" in Hungary by magnetostratigraphy

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Abstract

The Hungarian Tertiary marine sediments contain relatively rich pteropoda fauna. Nearly 30 species, assigned to 8 genera have been recognized from 33 Eocene, 21 Oligocene and 43 Miocene localities. In Hungary, the first planktonic gastropods appeared in Middle Eocene, 43 Ma ago in the C20n magnetic chron and disappeared in the Miocene (Badenian), in the chron C5ADn with an age of 14.2 Ma, according to time scale of Berggren et al. (1995).

Key words: Holoplanktonic Mollusca, Euthecosomata, biostratigraphy, magnetostratigraphy, Tertiary, Hungary

The aim of this report is to present the latest results of the research of Tertiary pteropods in Hungary, particularly the correlation with biostratigraphic and magnetostratigraphic data.

Tertiary marine sediments containing a rich fauna of holoplanktonic gastropods cover large areas of Hungary.

Recent studies of marine fossil holoplanktonic gastropods suggest that this group of molluscs is an effective biostratigraphic tool for correlation of Tertiary marine sediments all over the world.

The heteropods and pteropods are two groups of planktonic gastropods that have been preserved in fossil re-

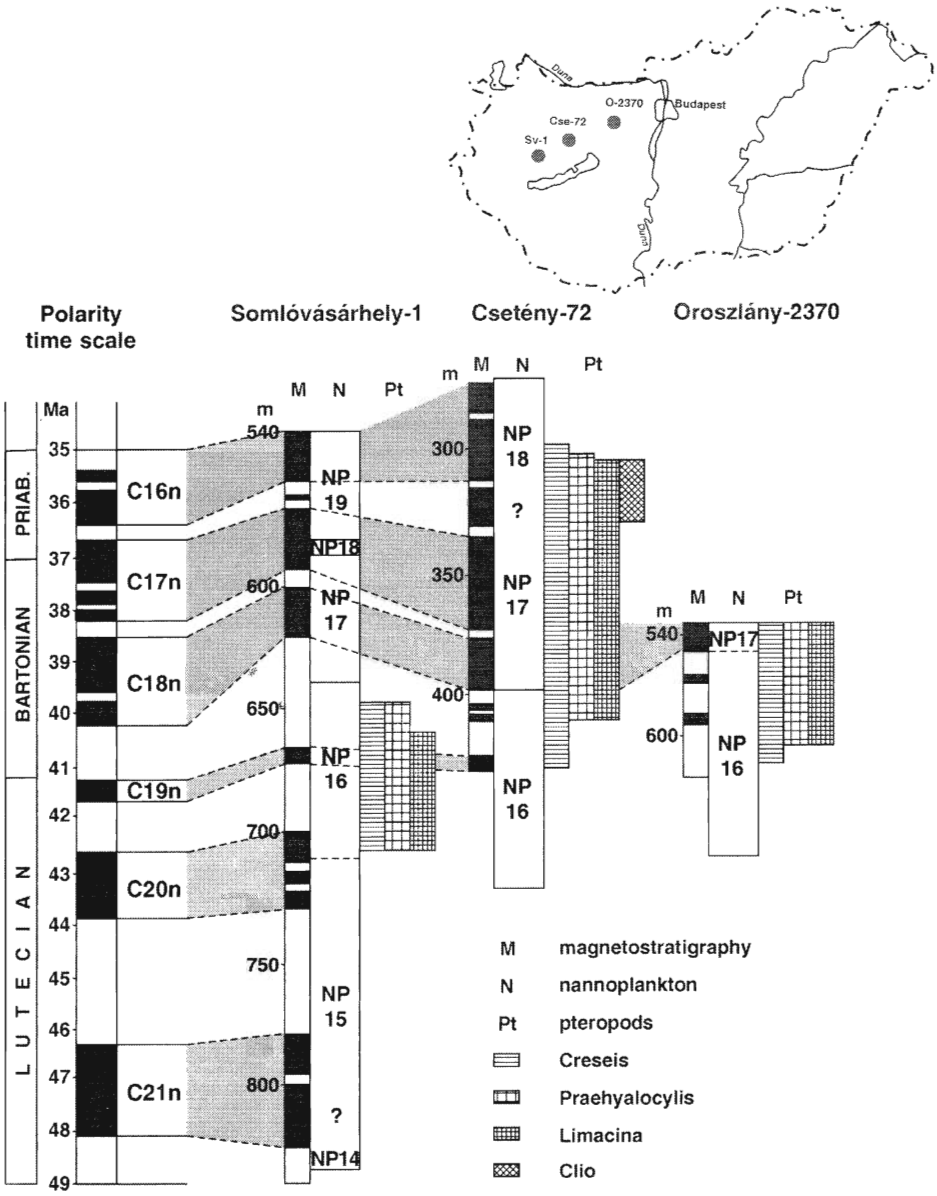

Fig. 1. Eocene. Correlation of polarity zones, nannoplankton and pteropods of the studied drillings.

cords. Pteropods are represented by eight genera of Euthecosomata *(Limacina, Creseis, Praehyalocylis, Clio, Styliola, Vaginella, Diacrolinia, Ireneia)* distributed from the Middle Eocene to Middle Miocene.

In Hungary it is particularly important that nannoplankton, plankton foraminiferal and magnetostratigraphic zonation are available from most parts of the boreholes yielding pteropods. It offers an excellent opportunity for multidisciplinary approach in correlation.

Eocene pteropods occur in 33 localities in Hungary, being mostly in continuously cored drillings. Nannoplankton and planktonic foraminiferal zones are available in large part of these boreholes, supported by several magnetostratigraphic correlations.

Eocene deposits contain a rich fauna of pteropods, 10 species have been identified, assigned to 4 genera. Most characteristic are *Limacina bartonense, Limacina sp. A., Creseis hastata,* and *Praehyalocylis annulata.*

The first planktonic gastropods in Hungary – *Limacina, Creseis, Praehyalocylis* – appeared some 43 Ma ago, in the NN16 nannozone, the Morozovella lehneri plankton foraminiferal zone and the magnetic chron C20n (Lantos et al., 2000).

The first appearance of *Clio* genus at the top of the nannozone NP16, around 40 Ma is the oldest occurrences worldwide (Bohn-Havas and Lantos, 2000).

Pteropods disappeared at 36 Ma in Hungary, in the nannozone NP 18, *Globigerinoides semiinvoluta* planktonic

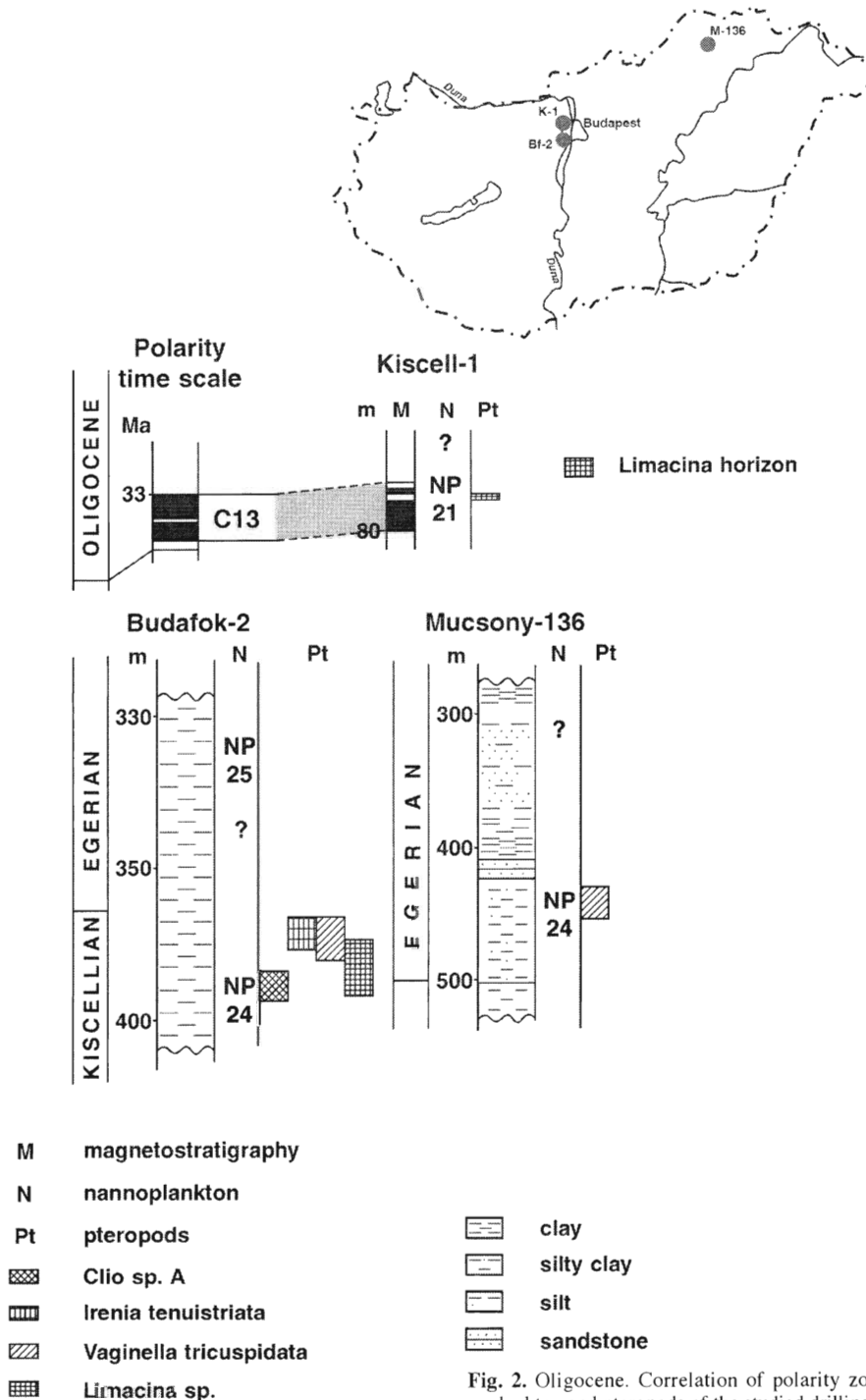

Fig. 2. Oligocene. Correlation of polarity zones, nannoplankton and pteropods of the studied drillings.

foraminiferal zone and magnetic chron C16n (Lantos et al., 2000).

Oligocene marine sediments (NP21-25) in 21 localities (5 outcrops, 16 drillings) also contain a rich pteropod fauna, (7 species 5 genera). Most part of localities were studied and dated by nannoplankton (Báldi-Beke, 1983; Nagymarosy, 1984).

The mass occurrence of *Limacina* (lower part of NP 21/22); the presence of *Ireneia tenuistriata* (NP 24) which is an index fossil for pteropod zone 16 in NW Europe (Janssen and King, 1988) and *Vaginella tricuspidata* (NP 24/25) which is an important species of a correlation of Late Oligocene deposits in Europe, are noteworthy (Janssen and Zorn, 1993).

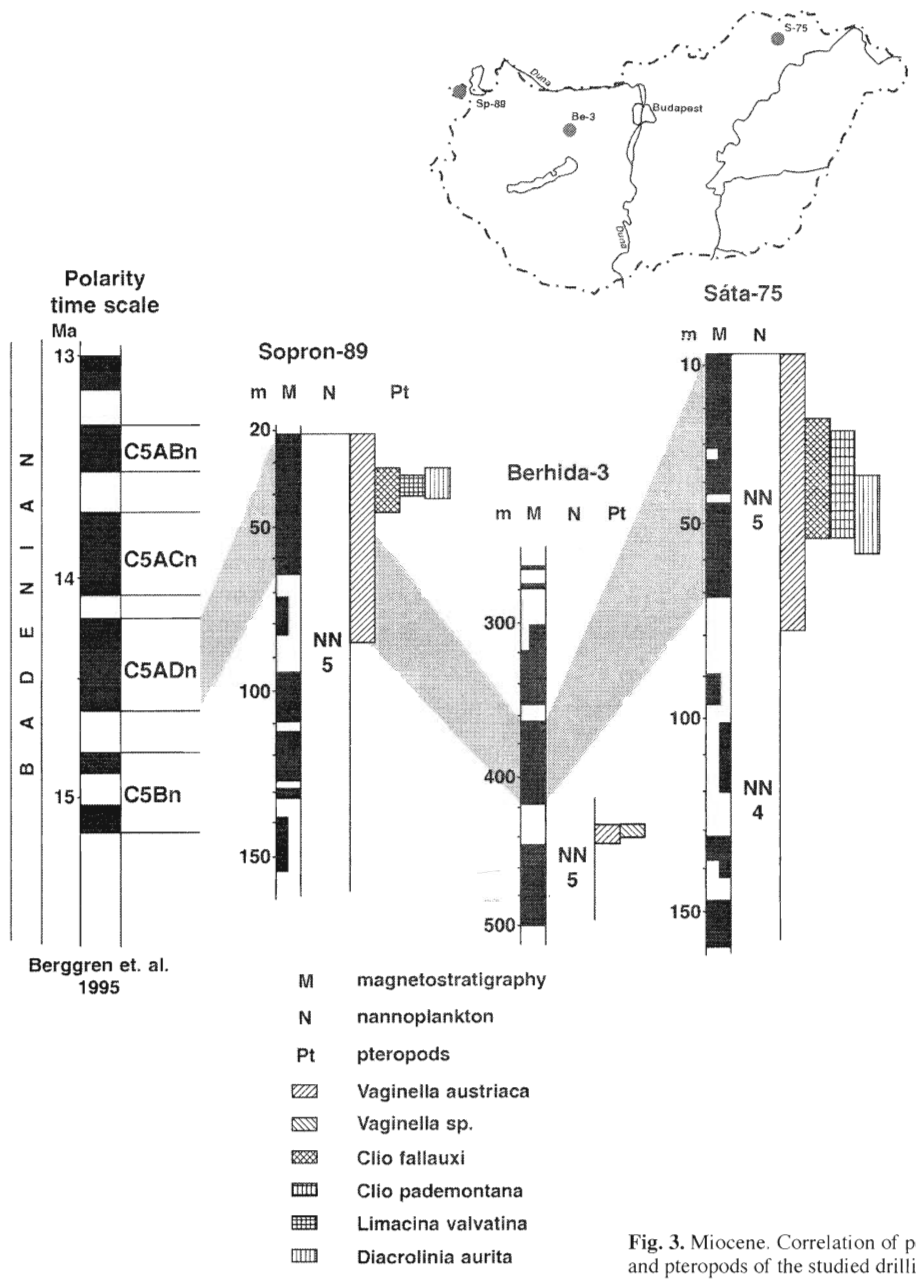

Fig. 3. Miocene. Correlation of polarity zones, nannoplankton and pteropods of the studied drillings.

Of 6 genera *(Vaginella, Limacina, Clio, Diacrolinia, Creseis, Styliola)* assigned 11 species are known from 43 localities of the Hungarian Miocene marine deposits. Most of pteropods occur in continuous cores which can be well-dated by nannoplankton and magnetostratigraphy (Nagymarosy, 1985; Bohn-Havas and Lantos, 1997).

Vaginella austriaca, Clio fallauxi, Clio pedemontana, Diacrolinia aurita are important for further classification of the Middle Miocene.

Among the above mentioned important species *Vaginella austriaca* is the most widespread in space and time. It is remarkable that this species appeared first (Karpatian, NN4 nannozone) and only small number can be found in the Early Badenian chron C5ADr, about 14.9 Ma.

14.5 MA ago (chron C5ADn) *Clio fallauxi, Clio pedemontana, Diacrolinia aurita* and *Limacina valvatina* appeared. A rapid increasing in the diversity number of specimens and geographic distribution of pteropods are characteristic at the same time.

After this "acme" planktonic molluscs show an abrupt rapid decrease and disappear at the end of chron C5ADn about 14.2 Ma.

The mass occurrences of *Limacina* (= *Spiratella* horizon) that is very characteristic in the Late Badenian deposits in the Paratethys but this horizon has not been identified in Hungary yet.

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The age of the Badenian salt deposits of the Wieliczka, Bochnia and Kalush areas

(Polish and Ukrainian Carpathian Foredeep)

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Abstract

Within Carpathian Foredeep basin the open marine condition evolved into restricted evaporitic basin during the Late Badenian (Serravalian). In the West it embraced outer part of the foredeep only, whereas in the East also its inner part. Along the Carpathians front the chloride sub-basins developed. Biostratigraphic researches proved that chloride, and in Ukrainian part also potassium salts were deposited, generally during the same period corresponding to zone NN6.

Key words: nannoplankton, foraminifera, salt deposits, Badenian

Geological setting

The Carpathian Foredeep Basin (CFB) (Fig. 1) belonged to the Central Paratethys biostratigraphic province of the Central and Eastern Europe (Kovac et al., 1998). The Carpathian Foredeep Basin (CFB) developed in front of the advancing Carpathian orogene on the southern edge of the Northern-European Platform (Oszczypko and Slączka, 1985; Oszczypko, 1998). CFB can be subdivided into two sub-basins: inner and outer ones. The inner sub-basin is generally composed of the Early and Middle Miocene continental, brackish and marine deposits. The outer one is filled with Middle Miocene (Badenian and Sarmatian) mainly marine deposits. During Badenian the evaporitic deposits developed in the foredeep basin. In the western part these deposits developed only in the outer sub-basin when in the eastern part they embraced also the inner sub-basin (Chlebowski, 1947; Djinoridze, 1980). The broad,

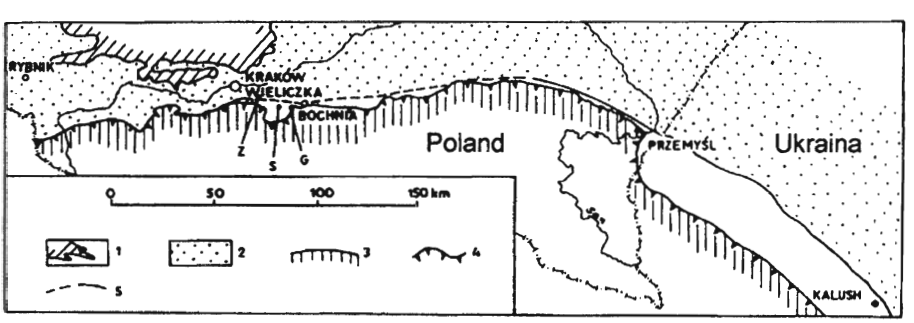
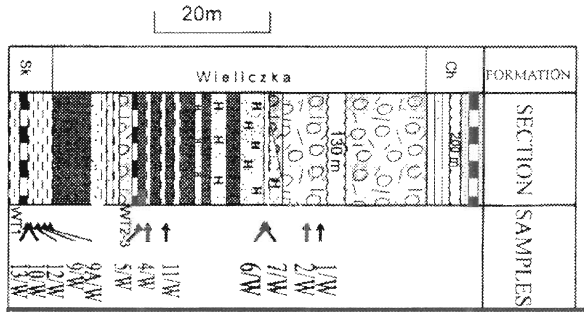


Fig. 1. Sketch-map of the Carpathian Foredeep and localization of investigated places (based on Garlicki, 1979). 1 – boundary of Carpathian Foredeep deposits, 2 – autochthonous Miocene deposits in Poland, 3 – Carpathian orogen, 4 – Carpathian overthrust, 5 – outer boundary of the folded Miocene (Wieliczka-Zgłobice Unit in the West and Sambor-Rozniativ Unit in the East). Z – Zabawa, S – Sułków, G – Gierczyce.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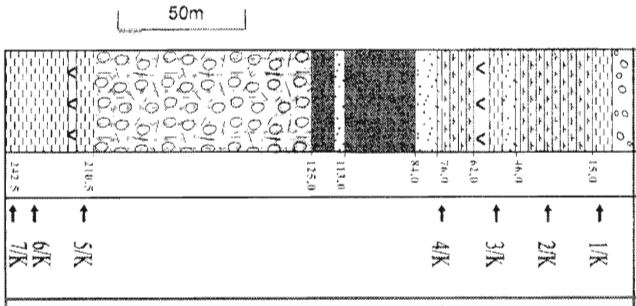

CALCAREOUS NANNOPLANKTON	7/K	6/K	5/K	4/K	3/K	2/K	1/K
Coccolithus pelagicus	X	X	X		X	X	X
C. miopelagicus	X	X	X		X	X	X
Cyclicargolithus floridanus	X	X	X		X	X	X
Calcidiscus leptoporus			X		X	X	X
Umbilicosphaera rotula			X		X	X	X
Coronocyclus nitescens			X			X	X
C. nitescens f. elliptica			X			X	X
Discoaster exilis			X				
D. bouweri			X				
D. sp.		X	X			X	X
Helicosphaera carteri			X			X	X
H. intermedia			X				
H. wallichii			X				
H. walbersdorfensis			X				
Pontosphaera multipora	X		X				
Reticulofenestra pseudoumbilicus	X	X	X		X	X	X
R. minuta	X	X	X		X	X	X
Rhabdosphaera sicca			X				X
Sphenolithus abies			X		X	X	X
S. moriformis			X		X	X	X
Scyphosphaera apsteinii			X				
Holodiscolithus macroporus			X				
Reworked K_2, P	X	X	X		X	X	X

Fig. 3. Distribution of the calcareous nannoplankton in the Kalush 340 mine.

shallow-water area, both on the platform and northern margin of thrust belt were dominated by sulphate facies, whereas the narrow and deeper part, located along the active Carpathian front were occupied by chloride-sulphate facies and locally (Ukrainian part) also by sulphate facies (Fig. 1). Generally the salts were deposited as an effect of precipitation. However in some areas redeposition processes took also place, and salt conglomerates and sedimentary breccia have been deposited (Ślączka and Kolasa, 1997).

As an effect of the Miocene tectonic movements a narrow zone of the folded Middle Miocene deposits that contain evaporitic deposits (Zgłobice unit in the West and Sambir-Rożniativ unit in the East) was developed along the Carpathian thrust. These units were overthrusted on the autochthonous Miocene deposits of the more external part of the foredeep.

The age of salt deposits was controversial for a long time. In Wieliczka-Bochnia area the salt deposits were considered to be of the Middle Badenian age (Garlicki, 1979) while in Sambor–Rozniatov unit they were considered to be of the Burdigalian in age. However, new data implied the Badenian age also for the salt from the Borislav-Rozniatov unit (Andreyeva-Grigorovich and Kulczytsky, 1984; Andreyeva-Grigorovich et al., 1997; Andreyeva-Grigorovich et al., 1999) and from its prolongation towards the south (Crichon, 1999; Marunteanu, 1999).

Location of samples

Several sections in the Polish and Ukrainian part of the foredeep have been investigated to obtain lithostratigraphy of the salt deposits and a new biostratigraphic data which could confirm their development and age. In the Polish Foredeep five sections were detaily sampled: Wieliczka (Fig. 2) and Bochnia salt mines, Sujków, Gierczyce brickyards, Zabawa exposure, whereas in the Ukrainian Foredeep two sections from the Sambor–Rożniatov Unit (Dombrovian salt quarry, and borehole Kalush 340, Fig. 3) were investigated.

Biostratigraphic results

Nannoplankton data: In the Kalush mine from rosy marls (Stebnik Beds), in the sub-evaporite deposits the calcareous nannoplankton representing NN 5 zone has been found with species Coccolithus pelagicus (Wall.), Cyclicargolithus floridanus (Roth and Hay) Bukry, Discoaster variabilis Mart. & Braml., D. exilis Mart. & Braml., Calcidiscus leptoporus (Murray et Black.), Helicosphaera carteri (Wall.), Pontosphaera multipora (Kampt.), Rhabdosphaera sicca (Str.), Sphenolithus heteromorphus Defl. In the sub-evaporite deposits and the lower part of the salt deposits in Wieliczka, in the sub-evaporite deposits in Bochnia Salt (Skawina Fm.) as well as in the grey marly

clays below the evaporites in the borehole Kalush 340 the nannoplankton assemblage belonging to boundary between NN 5 and NN 6 zones – and lower part of NN 6 zone has been established. Nannoplankton association contains the most abundant species: Coccolithus pelagicus (Wall.), C. miopelagicus Bukry, Calcidiscus leptoporus (Murray & Black.), Cyclicargolithus floridanus (Roth. & Hay) Bukry, Reticulofenestra pseudoumbilicus (Gartner). Less common, but particulary notable are: Calcidiscus premacintyrei Theodoridis, Coronocyclus nitescens forma elliptica (Kampt.), Discoaster exilis Mart. & Braml., D. brouweri Tan, Helicosphaera carteri (Wall.), H. walbersdorfensis Muller, Sphenolithus abies Defl., Umbilicosphaera rotula (Kampt.) Varol. Sphenolithus heteromorphus Defl. and Discoaster cf. kugleri Mart. & Braml. which are very rare. In the Wieliczka and in the Bochnia Salt Mines nannoplankton assemblage belonging to undivided zones NN 6–NN 7 with most common species: Calcidiscus leptoporus (Murray & Black.), Coccolithus pelagicus (Wall.), C. miopelagicus Bukry, Reticulofenestra pseudoumbilicus (Gartner), less common: Calcidiscus macintyrei (Bukry & Braml.), Discoaster exilis Mart. & Braml., D. variabilis Martini & Braml., D. kugleri Mart. & Braml., Helicosphaera carteri (Wall.), Sphenolithus abies Defl., Thoracosphaera heimii (Lohm.) Kampt., Umbilicosphaera rotula (Kampt.) Varol has been found in a mudstone intercalation within green salts complex, above or near tuffite horizon WT 3 (Layered Member). The similar nannoplankton (NN 6–NN 7 zones) has been identified in the lower part of the Chaotic Member. The nannoplankton assemblage from clays (Chodenice Beds) above the evaporite horizon in the Sulkow quarry east from Wieliczka contains Calcidiscus leptoporus (Murray & Black.), Calcidiscus macintyrei (Bukry & Bramb.), Helicosphaera carteri (Wall.), Reticulofenestra pseudoumbilicus (Gartner), Sphenolithus abies Defl.; less common or rare are Discoaster kugleri Mart. & Braml., Pontosphaera multipora (Kampt.), Holodiscolithus macroporus (Defl.), Scyphosphaera amphora Defl., Braarudosphaera bigelowi (Gran & Braar.), that suggests zones NN 6–NN 7. The nannoplankton complex, analogous by the contents and corresponding the NN 6–NN 7 zones, has been found within Bogucica sandstones near Zabawa. Very poor nannoplankton assemblages with Coccolithus pelagicus (Wall.), C. miopelagicus Bukry, Calcidiscus leptoporus (Murray & Black.), Reticulofenestra pseudoumbilicus (Gartner), R. spp. small, Helicosphaera carteri (Wall.), Umbilicosphaera rotula (Kampt.) Varol have been found in the Gierczyce brickyard (Chodenice Beds), also within grey clays above the evaporitic sequence in the borehole Kalush 340 and in Dombrowsky quarry. The species-markers are absent. These data suppose the correlation of above mentioned sediments with zone NN 6–NN 7.

Foraminiferal data: Generally similar results have been obtained from the foraminiferal researches carried out in the Wieliczka Salt Mine. In the sub-evaporite deposits (Skawina Beds) the Badenian assemblage with Globigerina foliata Bolli, G. cf. falconensis Blow, Turborotalita quinqueloba Natland, Globigerinella obesa (Bolli), Valvulineria arcuata (Reuss.), V. complanata (Orb.), Cassidulina carinata Cushm. et Park., C. oblonga Reuss., Cibicides pseudoungerianus Cushm., Ammonia beccarii (Linne), Bulimina elegans Orb., Bolivina dilatata brevis Cicha et Zapl., Elphidium crispum (Linne) have been found. Within the lower part of the boulder salt deposits there exists the assemblage with Globigerina praebulloides Blow., G. bulloides bulloides Orb., G. apertura Cushm., Globorotalia pseudopachyderma Cita, Prem.-Silv. et Rossi, Valvulineria complanata (Orb.), Bolivina dilatata dilatata Reuss, Uvigerina macrocarinata Papp et Turnovcky typical to the Late Badenian. Only in several samples an assemblage with Siphonodosaria sp., Anomalinoides badenensis (Orb.), Bulimina elongata Orb., and Halicoryne morelleti (Pokorny), that show an affinity to the lower part of the Early Sarmatian, has been present. The assemblages from the Skawina Beds and from evaporitic sequence from the Bochnia Salt Mine correspond to the Late Badenian only: Globigerina praebulloides Blow., G. bulloides bulloides Orb., G. diplostoma Reuss, G. foliata Bolli, Turborotalita quinqueloba Natl., Globorotalia mayeri (Cushm. et Ellis.), G. scitula Brady, Globigerinoides trilobus Reuss., Cassidulina oblonga Reuss., Cibicides ungerianus (Orb.).

The foraminiferal assemblages from the Sulków area are typical for the Late Badenian and contain Martinotiella communis (Orb.), Turborotalita quinqueloba Natl., Globorotalia mayeri (Cushm. et Ellis.), Bulimina elongata Orb., B. striata striata Orb., Bolivina dilatata dilatata Reuss., B. aff. simplex (Phleg. et Park.).

In the Gierczyce brickyard the Badenian foraminifera Globigerina bulloides Orb., G. praebulloides Blow, G. juvenilis Bolli, Globorotalia aff. bykovae (Aisen.), Bulimina striata mexicana Cushm., Bitubulogenerina reticulata Cushm., Elphidium macellum (Ficht. et Moll) have been established. Because of the poor foraminiferal content in washed samples it was not possible to determine more precise the age of sediments.

The foraminiferal assemblages from the clays situated above the evaporite horizon in Dombrowsky quarry are similar to the Late Badenian ones. They contain Atriculina problema (Orb.), Quinqueloculina consobrina Orb., Globigerina juvenilis Bolli, Turborotalia quinqueloba Natl., Globigerinella regularis (Orb.), Bulimina gutsulica (Liv.), Angulogerina angulosa (Will.), Bolivina dilatata dilatata Reuss., Hanzawaia boueana Orb., Ammonia becarii (Linne), Elphidium crispum (Linne).

Conclusions

1. The results of the biostratigraphic researches show that the age of salt deposits is generally of the Late Badenian age. Calcareous nannoplankton assemblages correspond to NN6 zones and undivided zones NN6–NN 7 and microfauna assemblage to the Late Badenian in the Wieliczka, Bochnia and Kalush salt deposits.The sub-evaporitic beds in Wieliczka, in Bochnia (Skawina Beds), in borehole Kalush 340 sections belong to boundary between NN 5 and NN 6 zones as well as to lower part of NN 6

zone. Generally there is consistence between foraminifers and nannoplankton assemblages, apart of the occurrence of the Sarmatian-like foraminifers in the chaotic (boulder) part of the Wieliczka Salt Mine. It can be explained by local development of brackish environments caused by the influx of river water from the nearly Carpathian Range.

2. The hitherto obtained biostratigraphic data show clearly that the Zglobice and Sambir–Rozniatov units were folded during the similar, post-Badenian time, and they can represent one continuous tectonic unit (SALIDY) that stretch out in front of the Carpathians.

3. Our biostratigraphic data prove that the Wielician stage of the Central Parathetys does not belong to the Middle Badenian, as it has been traditionally accepted, but to the Late Badenian.

4. During the Middle Miocene (Badenian and Sarmatian) evolution, the Carpathian Foreland Basin in Poland and Ukraine underwent through four principal, environmental stages: terrestrial, open marine, hypersaline, open marine, and brackish.

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Badenian evaporitic – clastic succession in the East Slovakian basin (Zbudza FM, the well P-7)

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Abstract

The study presents new results of sedimentological and geochemical investigations of Badenian salt series (Zbudza Fm.) from the well P-7 situated within the Zbudza salt deposit.

Key words: Miocene, evaporitic petrology, geochemistry, East Slovakian basin

Introduction

The Zbudza Formation is developed in local depressions of the central part of the East Slovakian Basin. This Middle Badenian (Karoli, 1998; Vass et al., 2000) evaporitic horizon was discovered in several localities during oil and gas prospection led in the 1950s. It turned out that only in the area of Zbudza (8 km N from Michalovce), where the deposit was well documented, it is economically significant. First note about the deposit was published by Janáček (1958), who determined stratigraphical position of Badenian sedimentary formation and presented litho-

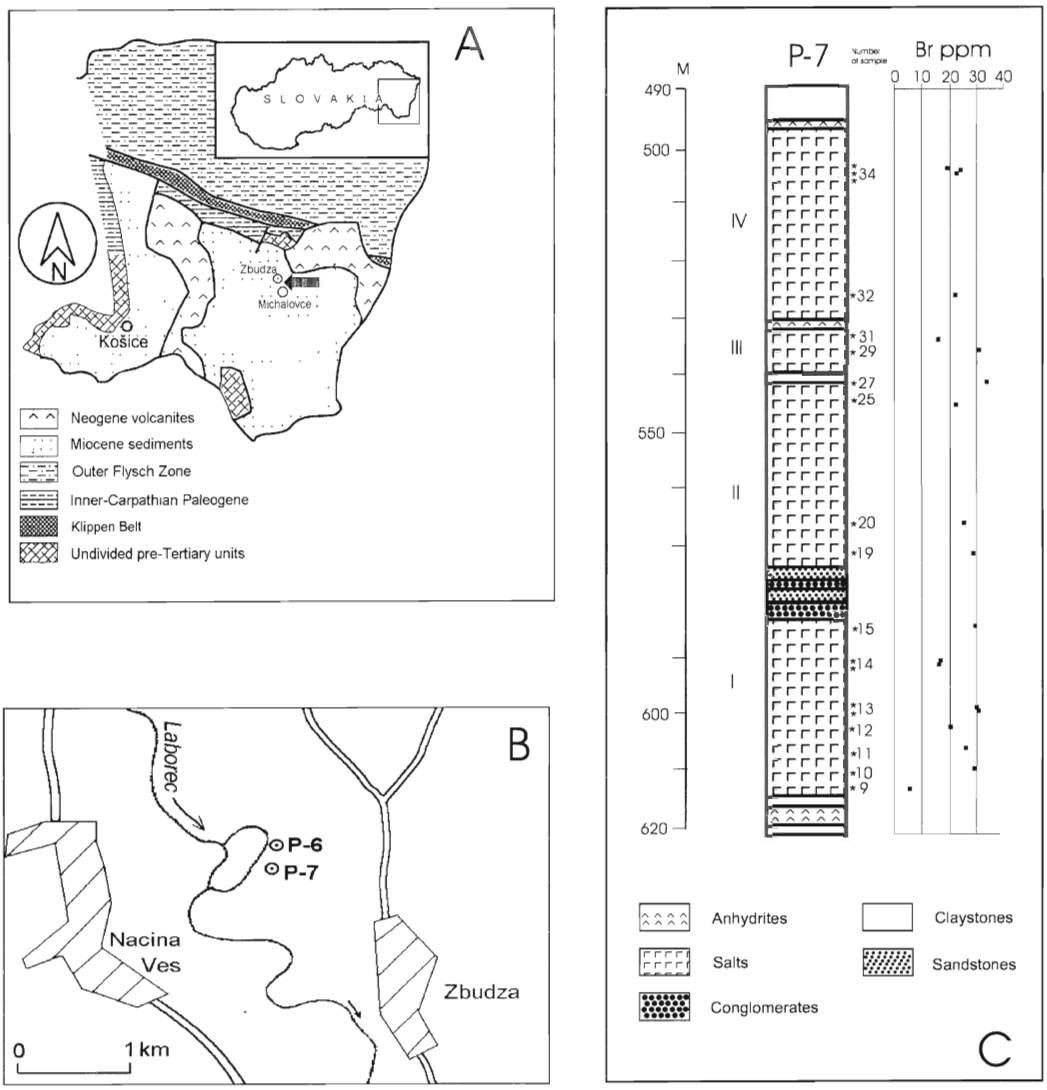


Fig. 1A, B. Location of borehole P-7 in the East Slovakian Basin. **C** – Sedimentary succession and the bromine content in 19 samples of halite.

facial characteristics of the discussed Zbudza Formation. In the following years 20 wells were drilled, described by Džubera and Grech (1963). Results of these works were synthetically presented by Slávik (1971). Since the 1980s new boreholes have been drilled in this area (Karoli, 1993). Maximum thickness of evaporitic formation near Zbudza is 120–150 m (Karoli et al., 2001). Preliminary lithofacial investigations were rather surprising, evidencing that most of halite is redeposited which could significantly influence on the extent and quality of the deposit.

The study presents new preliminary results of sedimentological and geochemical analyses of samples from the borehole P-7 located in the vicinity of Zbudza (Fig. 1A, B).

Characteristics and depositional history of chlorides from the borehole P-7

The Middle Badenian evaporitic succession from the P-7 well consists of pure and clayey halites, with interbeds of siliciclastics (conglomerates, fine sandstones and laminated silt/claystones) and nodular clayey anhydrites. Halites are developed as:

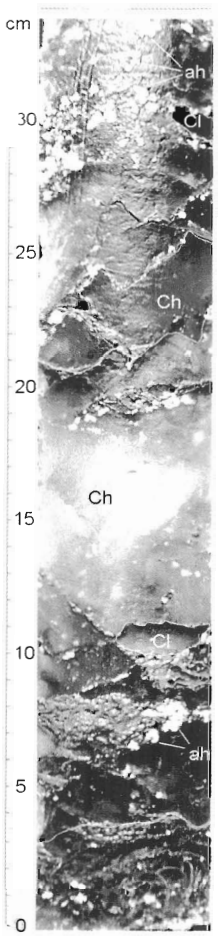
(a) coarse halite-rudites to salt breccias (deposited by mass flows),

(b) finer halite-arenites (current/wave mobilization of halite crystals) and

(c) salt/clay rhythmites (chemical precipitates from fluctuating brines).

They all contain frequent clasts of cloudy and zonal (hopper, chevron) halite, dispersed sulphate nodules, clay matter (crystal included, intercrystal infill, matrix and laminae) and carbonized plant remains, particularly common in the lower part of section. *In situ* chevron crystals prevail in the chemically deposited units.

Four salt units (Fig. 1C) with comparable thickness (29–32 m) were distinguished within studied section, separated by siliciclastics and sulphates. All they begin and finish with coarse halites (halite-rudites to salt breccias) alt-



Br ppm	Sr ppm	K %	Mg %	NaCl %	$CaSO_4$ %	clay %
19.4	584	0,3	0,69	64.82	13,62	21.4

Br ppm	Sr ppm	K %	Mg %	NaCl %	$CaSO_4$ %	clay %
24.3	86	0,03	0,04	94,72	3,29	1,9

Br ppm	Sr ppm	K %	Mg %	NaCl %	$CaSO_4$ %	clay %
21.7	122	0,12	0,13	86,98	3,60	9,4

Ch - chevron crystals
Cl - clasts of halite
ah - nodular anhydrite

Fig. 2. Fabric of the rock salt, sample no 34, major and trace component contents in various parts of the sample are presented in tables.

hough the total thickness of two main components – rudites and arenites with salt rhythmites – is similar except of the thin unit III (8.5 m) wholly constituted of rudites.

The lowermost unit, with numerous thicker (cm) claystone intercalations and fine plant remains, manifests effect of slumps and adherent mass flows, produced by tectonic activity of basin frames and reworked material from marginal mud-salt flats. Periodic stabilization has registered as salt rhythmites and arenites, accumulated in brines with fluctuating concentration and affected by currents/waves. Top halite-rudites of this unit precede the 11 m thick unit of conglomerates and successive fine sandstones, representing submarine fan deposits, invaded the evaporitic pan due to intensive clastics supply from uplifted margins and correspond to a phase of maximum tectonic activity.

Next salt unit (II) continued depositional style of the former one (slumps and chemical precipitation) and it is toped by 2 m thick bed of claystones with displacive halite crystals, reflected maximum brine refreshment/dilution and pelites accumulation in basinal conditions. Overlain (8.5 m thick) halite-rudites with decimetre marl interbeds and sporadic plant remains became a product of successive mass flows. Following brine refreshment has resulted in 2.5 m nodular anhydrite bed, with fine chevron halite intercalations at the bottom.

The uppermost, thickest (32 m) salt units evidence return of successive episodes of slope slumps with adherent mass flows and periods of chemical precipitation in relatively calm brines. Whole succession is overlain by siltstones of open marine environment, corresponding to the Late Badenian transgression (the Lastomir Fm. – Vass et al., 2000).

Geochemical investigations

A total number of 19 samples were selected from the borehole Zbudza P-7.

For these samples exhaustive geochemical analyses of major and trace elements were carried out with the ICP methods. In geochemical analyses of chlorides the particular attention was paid to Br content. Its determination in rock salts is most frequently carried out in order to define the degree of maturity of the evaporitic cycle (Br content is proportional to the original concentration of evaporating brine). Depending on the lithologic type of salts the bromine content was generally between 17 and 35 ppm. Only in one sample from the bottom salt series this value was significantly lower (6 ppm). Particularly low values of the bromine content may be explained by dissolving of primary salts in waters undersaturated with NaCl, and subsequent precipitation of secondary halite (Holser 1979). In such case the bromine concentration in brine comes mostly from dissolved salts, and not from the evaporating seawater, as for primary salts. This salt complex also contains considerable amounts of carbonized flora and lydites registering inflows of fresh water dissolving earlier deposited salts.

Values of bromine content in analysed salts are presented in the Fig. 1C.

Among other studied/analysed elements some variations in percentage content were observed for K, Mg and Sr.

Concentrations of potassium and magnesium in salts from Zbudza mostly depend on admixtures of terrigenous material, i. e. clay content in the analysed salts. Potassium content varies from 0.01 % to 0.49 %, and Mg content is between 0.01 % and 0.69 %. Sr content, varied from 5 to 5338 ppm, is closely related to the amount of dispersed anhydrite. These relationships are illustrated with results of analysis of the sample No. 34 (Fig. 2).

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Relation between Jurassic klippen successions in the Polish and Ukrainian parts of the Pieniny Klippen Belt

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Abstract

The Jurassic successions of the Pieniny Klippen Belt in Poland and Ukraine differ in several features, although some their intervals are similar each other The Svalyava Succession from the western part of the Pieniny Klippen Belt in Ukraine may be possibly correlated with Polish successions of the Klippen Basin. The Kamenets Succession represents possibly the transitional succession deposited on the southeastern slope of the Czorsztyn Ridge.

Key words: Pieniny Klippen Belt, Jurassic, paleogeography, Poland, Ukraine

Deciphering of the relations between the particular paleogeographic-facies successions representing the different zones of the original basins of the Pieniny Klippen Belt, in southern Poland and Transcarpathian Ukraine, needs detailed analysis of the lithological sequences supported by microfacies study, and a good paleontological documentation of the deposits. The preliminary results of currently carried studies (Project No. 6 P04D 022 21 granted by Polish Committee for Scientific Research) indicate similarity of some fragments of the particular successions from the two parts of the Pieniny Klippen Belt.

The oldest Jurassic rocks known only from the Ukrainian part of the Pieniny Klippen Belt consist of different type of clastic sediments (Gresten-like facies with *Cardinia* bivalves) with minor intercalations of black limestones in its upper part containing spiriferinid brachiopods and grypheoid bivalves (?Hettangian-?Sinemurian). Still younger are spotty limestones and marls of Fleckenkalk/Fleckenmergel-type facies, which deposited till Pliensbachian. These Lower Jurassic deposits from western part of the Ukrainian Pieniny Klippen Belt (Novoselica near Perechin, and Priborzhavskoye sections) are correlated with Svalyava Succession (see also Kalinichenko and Kruglov, 1969; Slavin, 1971). The discussed Fleckenkalk/Fleckenmergel deposits have their time and facies equivalents in spotty limestones from the Polish part of the Pieniny Klippen Belt (Birkenmajer and Myczyński, 1994). On the other hand, Toarcian-Lower Bajocian oxygen-depleted *Bositra ("Posidonia")* black shales with spherosiderites (Skrzypny Shale Fm.), as well as dark marls and spotty limestones (Krempachy Marl Fm., Harcygrund Shale Fm. and Podzamcze Limestone Fm. – see Birkenmajer, 1977) typical of Polish part of the Pieniny Klippen Belt are almost completely absent in Ukraine. The age equivalent of these facies in Ukrainian sections (Priborzhavskoye section) of the Pieniny Klippen Belt are fairly thin calcareous deposits rich in ammonites (Kalinichenko and Kruglov, 1971) and showing features indicating the reduced sedimentation rate, such as stromatolites, ferro-manganeous crusts and microconcretion as well as abundance of glauconite.

The discussed facies differentiation in Toarcian-Lower Bajocian could reflect an episode of initial extensional regime, and desintegration and/or transformation of the original basins. The most important role in such geodynamic reorganization have had the Czorsztyn Ridge showing NE–SW orientation (see discussion in Golonka and Krobicki, 2001; Aubrecht and Túnyi, 2001), according to paleogeographic and paleoclimatologic evidences. The existence of the Czorsztyn Ridge dividing the southeastern –

Klippen Basin, from the northwestern – Magura Basin, is postulated already during late Early Jurassic times by Birkenmajer (1986, and earlier papers cited therein). On the other hand, according to Aubrecht et al. (1997), the initial movements during Toarcian-Aalenian had to precede the appearance of the Czorsztyn Ridge which did not exist as the main paleogeographic unit before Bajocian.

Beginning from late Early Bajocian both the character of deposits in Polish and Ukrainian parts of the Pieniny Klippen Belt appear similar. Thick massive crinoidal limestones (Smolegowa Limestone Fm.) developed in more elevated parts of the Pieniny Klippen Basin (Czorsztyn, Niedzica and Czertezik successions), but continuing towards deeper-water Branisko Succession as the crinoidal cherty limestones of the Flaki Limestone Fm. in Poland, have their exact facies and possibly age equivalents in the crinoidal limestones of the western part of the Ukrainian part of the Pieniny Klippen Belt in the Svalyava Succession (Kalinichenko et al., 1965). More eastwards in Ukraine, in the Kamenets Succession (especially in its type section at Veliky Kamenets), the crinoidal limestones, although similar in age (currently found specimens of *Nannolytoceras polyhelictum* (Boeckh.) typical of the Bajocian), differ both in smaller thickness and more autochtonous character of sediments from other parts of the Pieniny Klippen Belt. The bulk of the crinoidal limestones of the Pieniny Klippen Belt sedimented some distance from the place of growth of crinoid communities (Głuchowski, 1987).

The onset of deposition of the ammonitico-rosso nodular limestones, lying directly on the crinoidal limestones, everywhere seems isochronous. In Poland in the Czorsztyn and the Niedzica successions, ammonites collected at the base of these deposits indicate their latest Bajocian age (Wierzbowski et al., 1999); in Ukraine ammonites described from a lower part of the nodular limestones (Rakús, 1990) both in Priborzhavskoye section (western part of Ukrainian Pieniny Klippen Belt), and in Veliky Kamenets section (eastern part of the Pieniny Klippen Belt) have indicated the Bathonian to Callovian age of the deposits, but new findings, such as *Dimorphinites* sp. in Priborzhavskoye, and *Parkinsonia* sp. in Novoselica near Perechin at the base of nodular limestones, suggest onset of their sedimentation already during latest Bajocian. The analysis of thin-sections from lower (Bajocian to Callovian) part of the ammonitico-rosso deposits in Poland (lower part of the Czorsztyn Limestone Fm. in the Czorsztyn Succession, and Niedzica Limestone Fm. in the Niedzica Succession), and in Ukraine – in the Svalyava Succession, and in the Kamenets Succession, indicates, moreover, that these deposits are everywhere developed as the filament–dominated microfacies (according to mass occurrence of strongly crushed Bositra shells). The stromatactis-bearing mud mounds occur within this part of nodular limestones (Kamenets section), but these structures firstly appear in underlying crinoidal limestones both in western (Priborzhavskoye) and eastern (Veliky Kamenets) parts of Ukrainian Pieniny Klippen Belt (Aubrecht et al., in preparation).

Beginning from latest Callovian/Early Oxfordian the ammonitico-rosso type deposits in Poland show the presence of the planktonic foraminifer *Globuligerina ("Protoglobigerina")* dominated microfacies in the Czorsztyn Succession, or they are laterally replaced by radiolarites (e. g. in the Niedzica Succession), whereas the overlying ammonitico-rosso deposits of the Czorsztyn Limestone Formation both in the Czorsztyn and Niedzica successions are of the *Saccocoma* microfacies mostly of Kimmeridgian to Early Tithonian age (Wierzbowski, 1994; Wierzbowski et al., 1999); these are followed by micritic limestones of the Dursztyn Limestone Formation developed in their younger part in the calpionellid microfacies. Similar microfacies succession is recognized in the Veliky Kamenets section in Ukraine (Kamenets Succession), where the *Globuligerina* microfacies deposits of the ammonitico-rosso type showing presence of early Middle Oxfordian ammonites, such as *Perisphinctes* cf. *plicatilis* (Sow.), occur directly above the hard-ground surface developed on Middle Jurassic deposits of the filament-dominated microfacies. Still higher in the Veliky Kamenets section there occur red-coloured radiolarian cherts alternating with micritic limestones and marly shales, which are followed by another nodular limestones of the ammonitico-rosso type of the *Saccocoma* microfacies; the latter yielded fairly numerous ammonites found about 0.5–0.75 m above the top of the last radiolarian bed, such as *Progeronia progeron* (v. Ammon), *Nebrodites agrigentinus* (Gemmelaro), *Aspidoceras* spp., and *Taramelliceras pugile* (Neumayr), indicating early Late Kimmeridgian age (Acanthicum Zone).

The youngest Jurassic to earliest Cretaceous deposits in the Veliky Kamenets section are pink-coloured micritic limestones showing presence of abundant calpionellids. On the other hand, the Upper Jurassic deposits in western part of the Ukrainian section – in the Svalyava Succession, although less well known than these of the Veliky Kamenets (Kamenets Succession), show possibly different facies development. The dominant here are the white limestones sometimes with cherts attributed to the Svalyavska Svita. These deposits show presence of the *Globuligerina* microfacies (recognized so far in the Novoselica near Perechin), and the widely distributed *Saccocoma* microfacies, as well as the calpionellid microfacies, what suggest that these deposits may span stratigraphical interval from (?)Oxfordian through Kimmeridgian and Tithonian to Lower Cretaceous.

The formation of limestones of the ammonitico-rosso type was mostly related with the existence of elevated part of sea bottom (Czorsztyn Ridge and its slopes), whereas deposition of radiolarites, and white cherty limestones of the maiolica type took place in deeper parts of the bordering basins. According to that cherty limestones of the Svalyavska Svita of western part of the Ukrainian Pieniny Klippen Belt possibly originated in the Klippen Basin, southeast of the Czorsztyn Ridge. The existence of thin, red radiolarite beds within nodular limestones in the Velky Kamenets section makes difficult detailed comparison of the Kamenets Succession with the Polish successions. In standard lithostratigraphical scheme (Birkenmajer, 1977) ammonitico rosso deposits of the Czorsztyn Succession are completely devoid of siliceous intercalations. On the other hand, the deeper Niedzica Succession

shows well developed radiolarites of the Czajakowa Radiolarite Fm. Hence, the studied Middle to Late Jurassic deposits of the Kamenets Succession show similarity to the Czorsztyn Succession (especially crinoidal limestones) and to the Niedzica Succession (radiolarites within ammonitico-rosso limestones).

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New knowledge of Cretaceous lithostratigraphy and biostratigraphy in the Silesian Unit in the Moravskoslezské Beskydy Mountains and the Podbeskydská pahorkatina Upland (Outer Western Carpathians, Czech Republic)

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Abstract

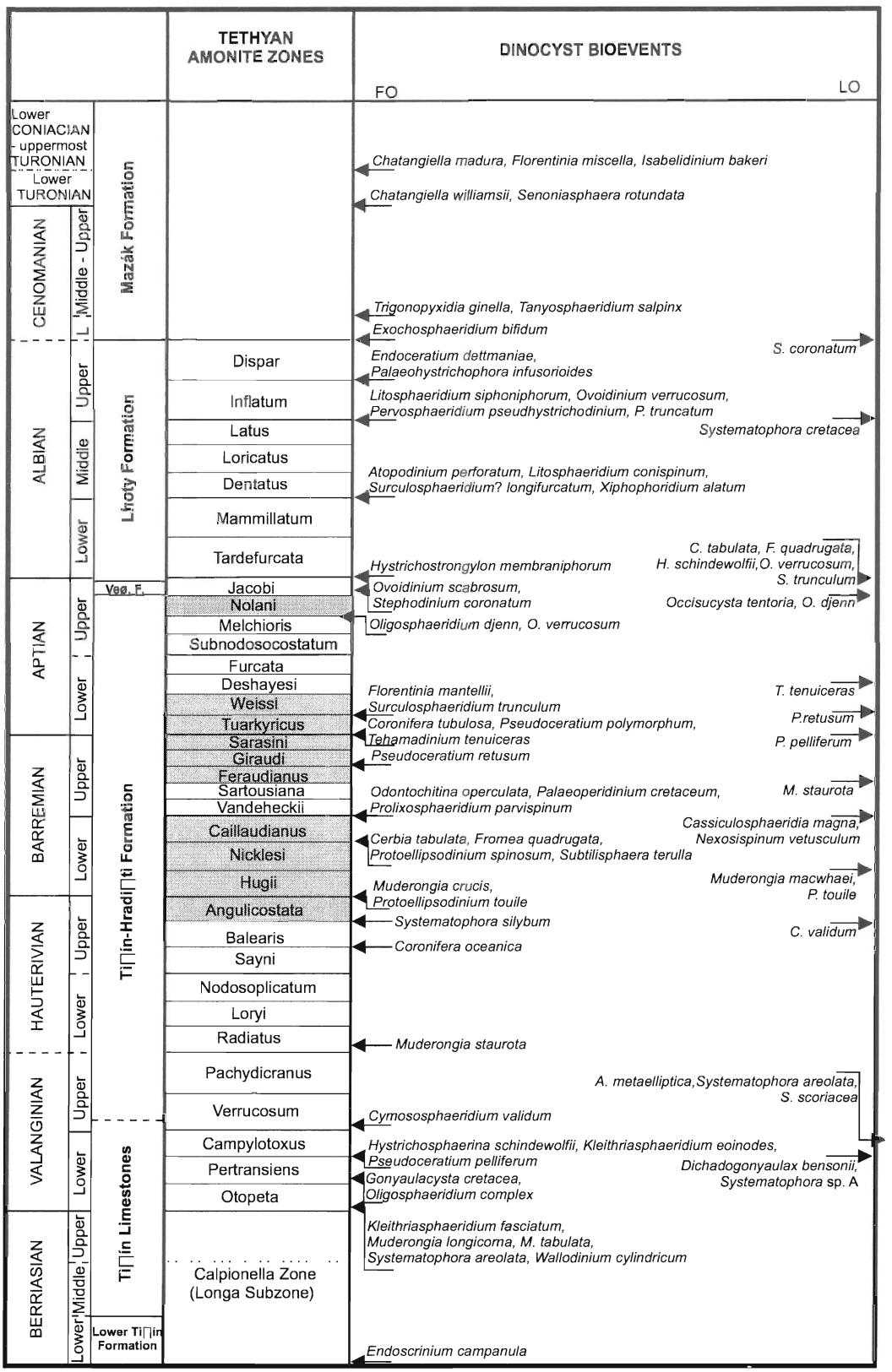
In the framework of solving the grant project of the Grant Agency of the Czech Republic, we paid attention to several issues not sufficiently clarified yet concerning the field of the lithostratigraphy and biostratigraphy of Lower Cretaceous deposits in the Silesian Unit. In addition to the precise field documentation of suitable sections, we had taken samples for thin sections and non-calcareous dinoflagellates, and tried to collect macrofaunas. It is the confirmation of Těšín Limestone occurrence in the Godula nappe and especially the detailed biostratigraphic characteristics and paleoecological evaluation of Lower Cretaceous and also the lower part of Upper Cretaceous deposits of the Silesian Unit based on dinoflagellates that belong to the new knowledge.

Key words: Cretaceous, biostratigraphy, Silesian Unit, Western Carpathians

The uppermost Jurassic and the Cretaceous of the Silesian Unit in north-eastern Moravia and in Silesia are characterized by complicated facial relations. Whereas for the Těšín area, a classical lithostratigraphic scheme formulated by Hohenegger (1860) is valid, in the western part of the Silesian Unit in the Godula partial nappe, i. e. west of the Ostravice River valley, the development of the uppermost Jurassic and the Cretaceous of the Silesian Unit differs in many features (e. g. absence of the lower Těšín Formation, limited occurrence of the Těšín Limestone,

Tab. 1

Proved ammonite zones in the Silesian Unit and the bioevents of stratigraphically significant dinocysts. Grey fields represent those parts of the formation studied, that are deducible well from positions in the sequence of strata, or that are evidenced with ammonites; white fields represent parts without ammonites



specifics in the development of the Těšín-Hradiště Formation, pelitic development of the Veřovice Formation, and others), especially however in relation to the lithologically different Baška development of the Silesian Unit.

The biostratigraphy of the studied sequence of strata is complicated. In the lower part of the sequence, in the course of stratigraphic analysis of the lower Těšín Formation and the Těšín Limestone, tintinnids are helpful (Nowak, 1968). However, of Upper Jurassic and primarily Lower Cretaceous deposits, often monotonous grey to dark grey claystones are typical that are often non-calcareous, poor in macrofauna and microfauna as well. In places, they can contain ammonites and foraminifers. Lately, those dark grey rocks have shown to be promising as for the occurrence of non-calcareous dinoflagellates that rank among persistent microfossils usable both stratigraphically and ecologically.

By our study, the Těšín Limestone on the base of the Godula nappe by Měrkovice (west of Frýdlant n. O.) has been confirmed on the strength of the occurrence of calpionellids (e. g. *Calpionella elliptica, Tintinnopsella longa* – determined by D. Boorová, Bratislava), which represents the westernmost occurrence of it, known so far. On the evidence of the calpionellids, the limestones of that place pertain to the middle Berriasian. By increasing the number of dark grey claystone layers, the limestones pass little by little into the Těšín-Hradiště Formation. According to the non-calcareous dinoflagellates in claystones in the immediate overlying beds of the limestones *(Kleithriasphaeridium fasciatum, Gonyaulacysta cretacea, Oligoshpaeridium complex),* basal deposits of the Těšín-Hradiště Formation in this place belong to the Late Berriasian to the Early Valanginian (Leereveld, 1995). In the locality of Skalice, the limestone layers in the upper part of the Těšín Limestone are less thick (60 cm maximally). The limestones pass gradually into the overlying Těšín-Hradiště Formation. In accordance with the content of dinocysts, e. g. *Gonyaulacysta cretacea, Kleithriasphaeridium eoinodes,* this gradual transition falls stratigraphically into the Early Valanginian (ammonite Pertransiens and Campylotoxus Zones). In the uppermost part, dinocysts were determined (e. g. *Cymososphaeridium validum*) indicating the beginning of the Late Valanginian (ammonite Verrucosum Zone). The lower part of the Těšín-Hradiště Formation at Skalice belongs prevailingly to the Late Valanginian.

According to Matějka and Chmelík (1956), sedimentation of the Těšín-Hradiště Formation began oftenest by the Berriasian/Valanginian boundary. In the Hauterivian, primarily at the north limitation of the original Silesian Basin, deep-sea fans of Hradiště sandstones occurred, whereas in the Barremian and the Early Aptian, sandy layers (flysch development) were rare. Claystones of Barremian to Early Aptian age contain also ammonites together with dinoflagellates, which enables the correlation between them (Skupien and Vašíček, in print). The lithofacial character of the deposits in this part of the Baška development and that in the Godula development are quite similar to one another.

The overlying Veřovice Formation, according to Matějka and Roth (1949), lacks fossils. It consists of dark grey to black non-calcareous claystones formed during the maximum of the Lower Cretaceous anoxic event (OAE 1). On the basis of superposition, we consider it to be pertinent to the Late Aptian. In the Baška development, partly the Chlebovice Member (conglomerates and flysch with claystones of the Veřovice type) is an equivalent of the Veřovice Formation. Towards the south, i. e. towards the Magura overthrust, the Veřovice Formation wedges out into the common development of the Těšín-Hradiště Formation.

In the whole area under study, the Lhoty Formation is characterized by a claystone development, merely with a low portion of apparent turbidites. It is composed of grey to green-grey chondrite-spotted claystones representing the Albian. In the Bystrý potok stream by Frenštát p. R., about a 10 m thick zone of light grey claystones with rare thin intercalations of dark grey claystones and silicified siltstones to cherts, which are an equivalent of the Mikuszowice cherts in Poland, is locally inserted between the Lhoty and the Mazák Formation. In its higher part, several centimetres thick intercalations of grey fine-grained siliceous sandstones with glauconite appear. In compliance with dinoflagellates, these deposits belong to the Early Cenomanian.

The Mazák Formation is characterized by the prevalence of variegated (red, red-brown and green) claystones interbedded with thin slabs of greenish grey quartzose sandstones. They contain up to several meters thick deep-sea fans of the Ostravice Sandstone. Higher in the overlying beds in the Bystrý potok stream, dark grey pelites are there that pertain, in virtue of the association of dinoflagellates *(Chatangiella williamsii, Senoniasphaera rotundata),* to the Early Turonian (Robaszynski et al., 1980). On them, a complex of pelitic deposits with thin layers of brown-grey and brown-red claystones interbedded with more than 13 m thick sandy turbidites continues. In virtue of non-calcareous dinoflagellates in pelites *(Chatangiella madura, Isabelidium bakeri),* it belongs to the uppermost Turonian to the Coniacian. The mentioned complex represents most likely an anomalous development of the lower part of the Godula Formation. Only in its overlying beds, the thick sandy flysch of the Godula Formation *sensu stricto* follows.

The palynological study has also brought interesting results following from the quantitative composition of palynomorphs. In the uppermost part of the lower Těšín Formation and in pelitic intercalations of the Těšín Limestones, cysts of dinoflagellates are dominant; merely in the Early Valanginian part of the Těšín Limestone, sporomorphs occur more. As far as the composition of palynomorph assemblages is concerned, sporomorphs play a more important role in the Těšín-Hradiště Formation in the Late Valanginian–Early Aptian period. This is proved by an increased supply of terrestrial material. The composition of Early Barremian palynomorphs of the Silesian Unit is characterized by a presence of prasinophytes (those indicate decreased surface water salinity).

In the other parts, sporomorphs represent only a negligible part of palynomorph assemblages.

In the lower part of the sequence of strata in the Silesian Unit from the Těšín Limestone (Berriasian to Early Hauterivian), dinocysts corresponding to the shallow-sea environment of variable salinity prevail (e. g. *Circulodinium, Muderongia, Pseudoceratium*). Towards the overlying beds, neritic species increase in number *(Achomosphaera, Oligosphaeridium, Spiniferites)* and especially deep-sea (oceanic) dinocysts *(Pterodinium)*. The quantitative composition of dinocysts of the Těšín-Hradiště Formation of the uppermost Barremian and the Early Aptian is characteristic of the deeper shelf environment. In the Albian, it is already the case of sedimentation in a basinal sedimentary environment (oceanic dinocysts are present here as an autochthonous element) with the redeposition of material supplied from littoral to deeper shelf areas.

The quantitative composition of dinocyst assemblages reflects a gradual deepening of the sedimentary space from the Berriasian till the Cenomanian that is, however, also a reflection of the rising sea level in the upper part of the Lower Cretaceous (according to the 2nd order eustatic curve – see Haq et al., 1988). In the uppermost Albian, a sudden increase in the portion of peridinioid dinocysts occurred reflecting the eutrofization of surface waters, and probably their cooling as well.

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Integrated biostratigraphy of Lower Cretaceous of the Manín Unit (Strážovské vrchy, Western Carpathians)

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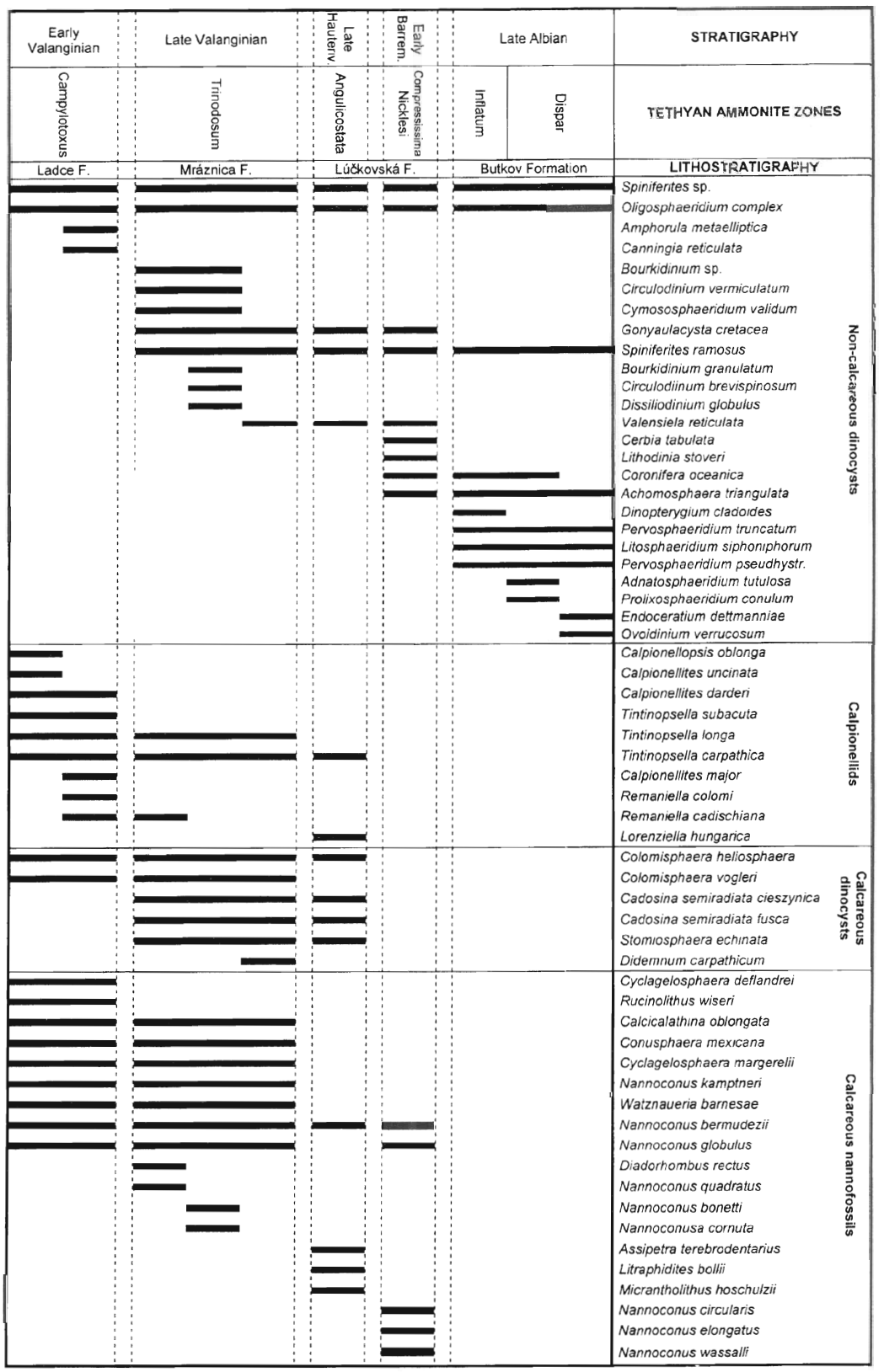
Abstract

New studies of Lower Cretaceous deposits of the Manín Unit made it possible to correlate ammonites, calpionellids, calcareous nannofossils, non-calcareous and calcareous dinocysts of the following ammonite zones: the Early Valanginian (Campylotoxus Zone), the Late Valanginian (higher part of the Trinodosum Zone), the Late Hauterivian (the base of the Angulicostata Zone) and the Early Barremian (along the boundary between the Nicklesi Zone and the Compresissima Zone).

Key words: biostratigraphy, Lower Cretaceous, Central Western Carpathians

Lower Cretaceous deposits uncovered in the Butkov quarry, which pertain to the Manín Unit of the Central Western Carpathians, represent one of the most complete sections of the Lower Cretaceous deposits in the Western Carpathian System that are significant especially for the richness of ammonites. In the 1980s, the section was processed in detail in Vašíček and Michalík (1986), or in Borza et al. (1987), where a new lithostratigraphic division of the Lower Cretaceous deposits of that place was proposed. Here, results in a summary form following

Tab. 1
The occurrence of chosen calpionellids, calcareous and non-calcareous dinoflagellates in the Butkov quarry. The ammonite zones are defined according to ammonites found in outcrops; merely in the Late Albian the ammonite zones presented were deduced in virtue of non-calcareous dinoflagellates



from new macrofaunistic and micropaleontological studies of parts enabling the definition of ammonite zones are presented. Those are arranged according to the stratigraphic sequence of strata from bottom to top, i.e. the Ladce Formation, the Mráznica Formation, part of the Lúčkov Formation and the Butkov Formation.

The finding of the zone ammonite species *Busnardoites campylotoxus* (Uhlig) in the lower part of the Ladce Formation shows that the beginning of sedimentation of the Ladce Formation falls to the upper part of the Early Valanginian, by the boundary of the ammonite Pertransiens and Campylotoxus Zones.

The calpionellid association evidencing the Calpionellites Zone (Darderi and Major Subzones) confirms this result. Marly micrite limestones of the Ladce Formation contain calpionellids, *Calpionellites darderi, C. major, Tintinopsella carpathica,* and others, and calcareous dinoflagellates, *Colomisphaera heliosphaera, C. vogleri,* and others. In addition, globochaets, ostracods and sponge spicules supplement this association of microfossils.

Of palynomorphs, spores and bisacate pollen grains occur sporadically in the samples. They evidence a low supply of terrestrial material. Dinoflagellate cysts are present sporadically. To stratigraphically significant ones, *Oligosphaeridium complex* and *Spiniferites* sp. belong, according to which the part under study is not older than the middle part of the Early Valanginian (i. e. ammonite Pertransiens Zone).

As far as calcareous nannoplankton is concerned, it is *Calcicalathina oblongata,* whose first occurrence in the Early Valanginian is dated at 136.66 Ma (Hardenbol et al., 1998), *Nannoconus bermudezi* and *N. kamptneri* with the first occurrence on the base of the Valanginian, and *Rucinolithus wisei* – with the last occurrence in the Late Valanginian that are of stratigraphic importance.

The studied part of the overlying Mráznica Formation is much more richer in the occurrence of ammonites, of which the following were determined: *Neolissoceras grasianum* (d'Orbigny), *Teschenites subflucticulus* Reboulet, *T. subpachydicranus* Reboulet, *Olcostephanus nicklesi* Wiedmann & Dieni, *O. balestrai* (Rodighiero), *Criosarasinella mandovi* Thieuloy, *Himantoceras trinodosum* Thieuloy, and others. From the stratigraphical point of view, *H. trinodosum* and *C. mandovi* are the most significant; the former being a zone species of the middle part of the Late Valanginian (Trinodosum Zone) and the latter being an equivalent of the subzone species *C. furcillata* that is the index for the upper part of the zone mentioned. The occurrence of *O. nicklesi* is also of importance. That is a subzone species of the lower part of the Trinodosum Zone. With regard to the fact that *O. nicklesi* occurs together with *C. furcillata,* it is necessary to suppose that merely the higher part of the Trinodosum Zone is represented here.

In the uppermost part of the Mráznica Formation, assemblages being rich in ammonites, e. g. *N. grasianum* (d'Orbigny), *T. subpachydicranus* Reboulet, *O. nicklesi* Wiedmann & Dieni, *Oosterella cultrataeformis* (Uhlig), *Criosarasinella subheterocostata* Reboulet, *Himantoceras trinodosum* Thieuloy were found. According to the occurrence of *C. subheterocostata,* the representation of the ammonite Subheterocostata horizon, which is defined in the uppermost part of the Trinodosum Zone by Atrops and Reboulet (1995), can be confirmed.

It is again the case of prevailingly marly limestones, in which *Cadosina semiradiata cieszynica, C. s. fusca, Remaniella cadischiana, Stomiosphaera echinata, Tintinopsella carpathica* appear most frequently. Benthic foraminifers, globochaets, ostracods and crinoids are present as well.

As for palynomorphs, dinoflagellate cysts are prevailing. The composition of assemblages of dinoflagellates reflects their original sea environment of the depth of several hundred meters (littoral to brackish types predominate, e. g. *Circulodinium, Muderongia*). For instance, *Cymososphaeridium validum, Gonyaulacysta cretacea* belong to the most stratigraphically significant dinoflagellates; representatives of the genus *Bourkidinium* appear very often. The assemblage corresponds to the Cymososphaeridium validum dinocyst zone defined by Leereveld (1995) for the Late Valanginian – the lowermost Hauterivian.

The association of nannofossils is similar to that of the Ladce Formation. Newly, species appear the first occurrences of which are confined to the Early Valanginian (e. g. *Nannoconus bonetii, N. cornuta*) and the last occurrence is related to the Late Valanginian *(N. quadratus)*. In the uppermost part, an increased number of *Calcicalathina oblongata, Nannoconus globulus, Watznaueria barnesae* could be observed. Specimens of this interval can be assigned to the zone of calcareous nannoplankton of Calcicalathina oblongata (NK3), Bralower (1989) with the stratigraphic range from the Early to the Late Valanginian.

In the deposits of the Lúčkovská Formation, we found ammonites preserved imperfectly and remains of belemnites. Of them the most complete finding belongs to *Duvalia dilatata majoriana* Stoyanova-Vergilova. As for the ammonites, it is the case of *Lytoceras subfimbriatum* (d'Orbigny), *Partschiceras infundibulum* (d'Orbigny), and *?Pseudothurmannia "binelli"* Thomel (non Astier). According to Hoedemaeker (1995), the latter mentioned species occur in the lower part of the ammonite Angulicostata Zone (uppermost Hauterivian).

It is a case of biodetritic and marly limestones, in which *Cadosina semiradiata cieszynica, C. s. fusca, Colomisphaera heliosphaera, Tintinopsella carpathica, Stomiosphaera echinata* are present. Foraminifers, sponge spicules, globochaets, radiolarians, fragments of bivalves, crinoids and bryozoa are abundant.

As for nannoplankton, the species *Litraphidites bolii* (appeared at the level of 131.14 Ma in the Loryi Zone, Hardenbol et al., 1998 for the first time) not perfectly preserved was found very rarely. The abundance of micrantholiths (e. g. *Micrantholithus hoschulzii*) and nannoconids (e. g. *Nannoconus bermudezii*) is characteristic; *Assipetra terebrodentarius* appears here. The specimen can be assigned to the zone of Litraphidites bollii, Thierstein (1971, 73), subzone NC5b (Bralower 1987) in the Late Hauterivian and the lowermost Barremian.

In the higher part of the Lúčkovská Formation, an am-

monite-bearing layer was found containing abundant barremites and some interesting, or stratigraphically very significant species, such as *Nicklesia pulchella* (d'Orbigny), *Moutoniceras nodosum* (d'Orbigny), *Dissimilites dissimilis* (d'Orbigny), *Spitidiscus gastaldianus* (d'Orbigny), *Holcodiscus tzankovi* Avram, *H. alpha* Tzankov, *H.* cf. *ziczac* Karakasch, *H.* ex gr. *nicklesi* Karakasch, *Paraspiticeras* sp., and others. In the framework of the discussed zone division of the Barremian (Rawson and Hoedemaeker, 1999), *N. pulchella* forms a horizon in the upper part of the ammonite Nicklesi Zone. *D. dissimilis* in Spain begins on the base of the following ammonite Compressissima Zone. According to them and also according to holcodiscids found one can judge that the ammonite-bearing horizon belongs to the Early Barremian, to deposits on the boundary between the ammonite Nicklesi and Compressissima Zones, in the underlying beds of the ammonite Caillaudianus Zone.

In the higher part of the Lúčkovská Formation – in the ammonite-bearing horizon, the assemblage of dinoflagellates consists especially of littoral *(Cerbia)* and neritic *(Oligosphaeridium, Spiniferites)* representatives. It is the presence of the species *Cerbia tabulata* that is interesting. The species is generally known only from the higher part of the Early Barremian ammonite Caillaudianus Zone.

In the sample taken from the ammonite-bearing layer, an increased number and higher diversity of nannoconids (e. g. *Nannoconus bermudezii, N. globules*) were observed. Representatives of nannoconids, the first occurrences of which are connected with the base of the Barremian (e. g. *N. elongatus, N. circularis*), appeared here. The absence of *Calcicalathina oblongata* (whose last occurrence is indicated in the ammonite Nicklesi Zone) makes it possible to determine the Early Barremian subzone NC5c (Bralower 1987).

In the assemblages of palynomorphs of samples taken from the Butkov Formation, dinoflagellate cysts dominate; acritarchs (e. g. *Wallodinium, Veryhachium*), bisacate pollen grains and microforaminifers occur sporadically. The dinoflagellates are represented primarily by deep-sea species typical of both the open neritic sea (genera *Achomosphaera, Litosphaeridium*) and the ocean (genus *Pterodinium*). From the above mentioned, a basinal sedimentary environment can be deduced.

The samples contain stratigraphically significant species of dinoflagellates, such as *Endoceratium dettmanniae, Litosphaeridium siphoniphorum, Ovoidinium verrucosum, Prolixosphaeridium conulu* that make it possible to define two Late-Albian ammonite zones. The first occurrence of *L. siphoniphorum* determines the ammonite Inflatum Zone and the first occurrence of *P. conulum* delimits the ammonite Dispar Zone, which is supported by the presence of species *E. dettmaniae* and *O. verrucosum*.

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Microfacies, stratigraphy and sedimentary environment of Jurassic ammonitico rosso facies of the Czorsztyn and Niedzica Successions in the Pieniny Klippen Belt in Poland, Carpathians

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Abstract

The microfacies and their stratigraphical position in the Jurassic ammonitico rosso type deposits in the Czorsztyn and Niedzica Successions of the Pieniny Klippen Belt have been recognized. Three zones differing in their sedimentary development are distinguished.

Key words: Pieniny Klippen Belt, Jurassic, ammonitico rosso, microfacies, ammonites

Introduction

The study is based on selected sections from various parts of the Pieniny Klippen Belt in Poland that are representative for the northern part of the Pieniny Klippen Basin of the northern Tethys. The deposits of the ammonitico rosso type are well developed in the Czorsztyn and Niedzica Successions, representing the submarine Czorsztyn Ridge together with its southern slope, and a located south deeper area between the ridge and the Central Furrow (Birkenmajer, 1986). In both successions the ammonitico rosso type deposits are underlain by crinoidal limestones. This turnover from shallow-water carbonate platform type deposition to deeper-water pelagic sedimentation was one of the most distinct changes during the whole Jurassic in the area of study (Wierzbowski et al., 1999).

The ammonitico rosso type deposits described in the present paper are developed mostly as red or pink nodular and non-nodular limestones and occur in western, central, and eastern parts of the Pieniny Klippen Belt in Poland (Fig. 1): these are representative of the Czorsztyn Limestone Formation of the Czorsztyn Succession studied in five sections (Stankowa Klippe, "Wapiennik" quarry in Szaflary, Obłazowa Klippe, Czorsztyn Castle Klippe and Krupianka Creek) as well as of the Niedzica Limestone Formation of the Niedzica Succession studied in two sections (Niedzica–Podmajerz Klippe, and Czajakowa Skała). The directly underlying crinoidal limestones of the Krupianka Limestones Formation and the Smolegowa Limestone Formation were also studied in the same sections. All the discussed lithostratigraphic units are used according to the formal lithostratigraphic scheme proposed by Birkenmajer (1977).

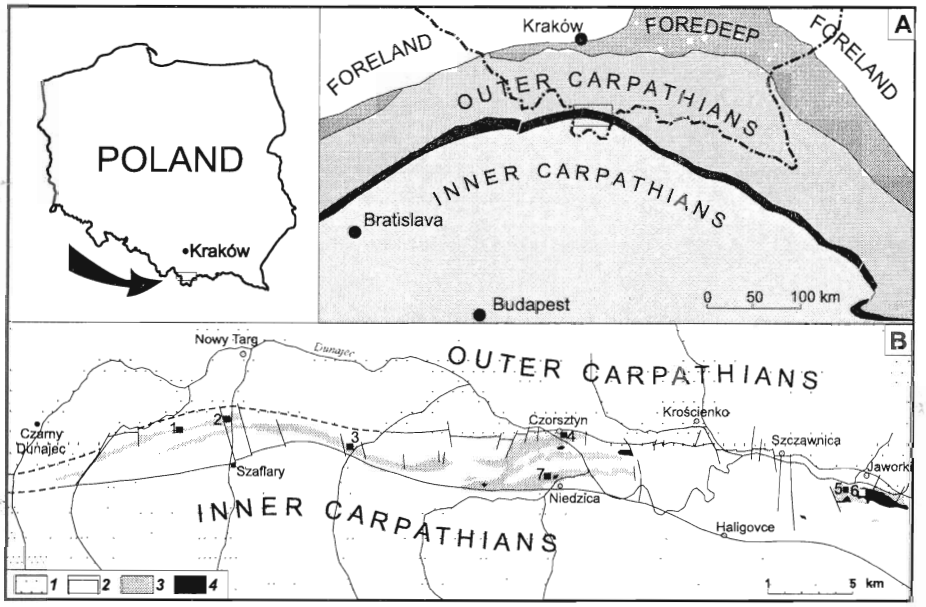

Fig. 1. A. Location of the Pieniny Klippen Belt (in black) within the Carpathians. **B.** Location of the studied sections of the Pieniny Klippen Belt in Poland (base map simplified from Birkenmajer, 1963, 1977). 1 – Magura Paleogene flysch (Magura nappe), 2 – Podhale Paleogene flysch (autochthonous), 3 – Czorsztyn Succession: 1 – Stankowa Klippe, 2 – "Wapiennik" quarry in Szaflary, 3 – Obłazowa Klippe, 4 – Czorsztyn Castle Klippe, 5 – Krupianka Creek, 4 – Niedzica Succession: 6 – Niedzica Podmajerz Klippe, 7 – Czajakowa Skała.

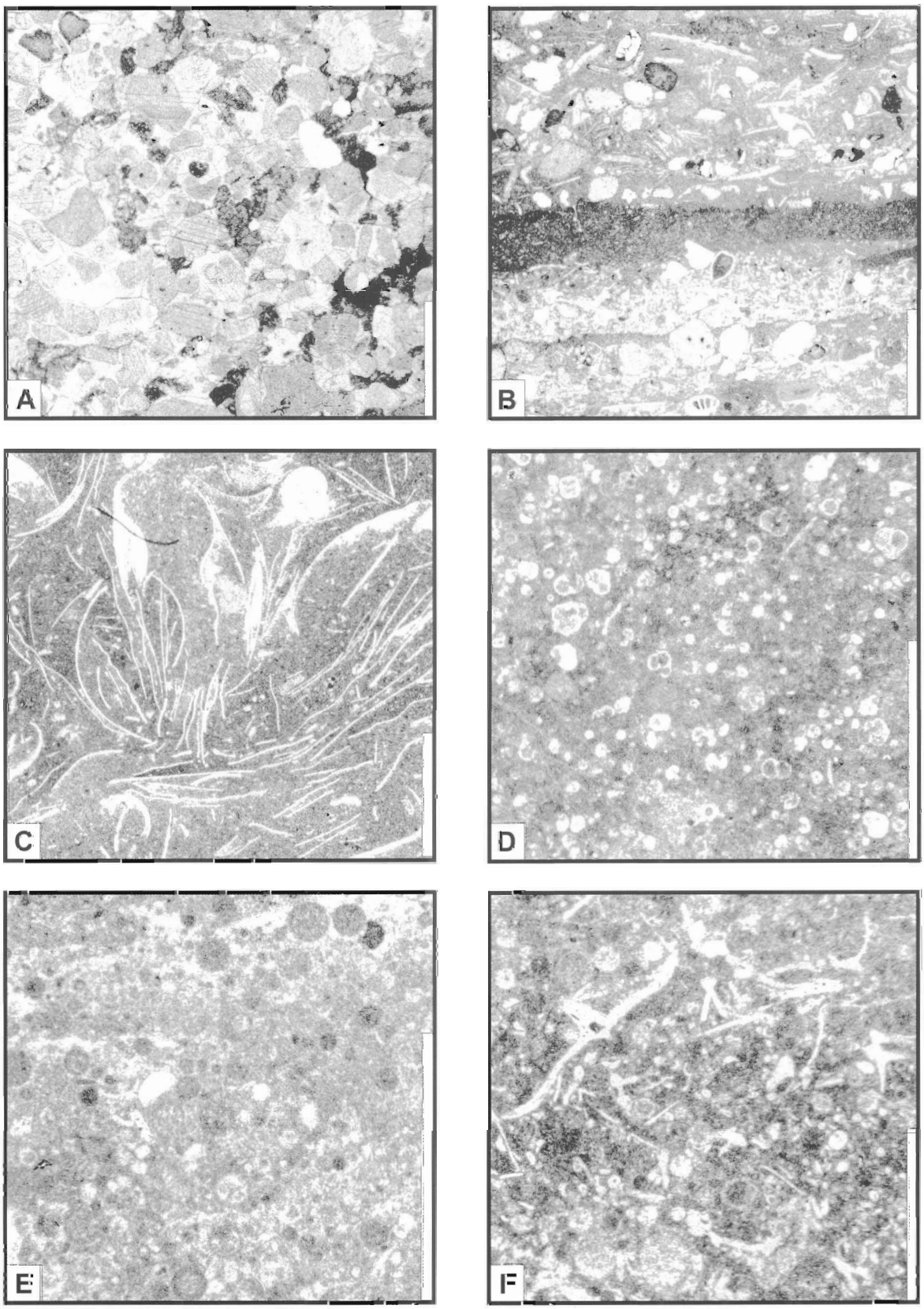

Fig. 2. Microfacies of distinguished groups. Bar scale is 1 mm. A – crinoidal microfacies. B – "mixed" microfacies. C – filament microfacies. D – *Globuligerina* microfacies. E – radiolarian microfacies. F – *Saccocoma* microfacies

Microfacies

Six microfacies groups have been distinguished: (1) the crinoidal microfacies, (2) the "mixed" microfacies, (3) the filament microfacies, (4) the *Globuligerina* microfacies, (5) the radiolarian microfacies, and (6) the *Saccocoma* microfacies. The microfacies groups have been subdivided into 30 microfacies types.

Crinoidal microfacies (Fig. 2A): these are mostly packstones and grainstones, containing abundant crinoid ossicles (10–60 %), ranging from 0.2 mm to 1 mm in diameter, and fairly common detrital quartz grains (1–12 %); thin-shelled bivalves of the genus *Bositra* (filaments) are rarely found.

"Mixed" microfacies (Fig. 2B); these occur mainly in sets of laminated deposits and in fillings of neptunian dykes; they are developed as grainstones, packstones, wackstones and less frequently mudstones; main components are: peloids, filaments, echinoderm fragments – mostly crinoids, and detrital quartz grains.

Filament microfacies (Fig. 2C): these are mostly packstones or wackstones, less commonly grainstones containing filaments and accompanying components in various abundance; they show variable filament content (5–60 %), but in smaller quantities occur also juvenile gastropod shells, echinoderm fragments, sponge spicules, *Globochaete* spores, foraminifers, aptychi, juvenile ammonite shells and quartz grains.

***Globuligerina* microfacies** (Fig. 2D): these are represented by wackstones or packstones with abundant (10–70 %) tests of planktonic foraminifer *Globuligerina ("Protoglobigerina")* and less commonly occurring brachiopods and ammonite shells, filaments, rare crinoid ossicles and *Saccocoma* fragments.

Radiolarian microfacies (Fig. 2E): these are represented by wackstones, packstones and less commonly grainstones with abundant calcified radiolarian tests (10–50 %) and with rare planktonic foraminifers *Globuligerina,* peloids and fragments of *Saccocoma.*

***Saccocoma* microfacies** (Fig. 2F): these are mostly packstones, less commonly grainstones and wackstones, consisting of fragments of pelagic crinoids *Saccocoma* (10–70 %); are also found other echinoderm fragments, planktonic foraminifers *Globuligerina,* radiolarian tests and diversified skeletal remains - juvenile ammonite shells, aptychi, brachiopods, bivalves. Limestone clasts containing abundant *Saccocoma* are stated in the grainstones.

Stratigraphy and sedimentary environment

The stratigraphic position of the deposits is based mainly on ammonite fauna (Wierzbowski et al., 1999; Jaworska, 2000 and earlier cited therein).

The deposits of the crinoidal microfacies group are of Bajocian age. In the Bajocian the Czorsztyn Ridge was inhabited by a population of benthic crinoids and supplied material for the deposition of crinoidal limestones of Smolegowa Limestone Formation and Krupianka Limestone Formation represented by crinoidal microfacies group.

At the turn of the Bajocian and the Bathonian, in effect of *Meso-Cimmerian* movements, a part of the Czorsztyn Ridge subsided, what resulted in sedimentation of the ammonitico rosso type deposits – limestones packed with filaments representing the filament microfacies group. An elevated area existed only in the north-western part of the Pieniny Klippen Basin, and supplied material for the sedimentation of specific "mixed" microfacies group deposits. The fracturing of the Czorsztyn Ridge is recorded by the occurrence of neptunian dykes filled with similar type deposits as in the north-western part of basin, as well as and the scarp breccias developed on the contact of the uplifted – north-western part ("A" in Fig. 3) of the ridge with its lowered central ("B" in Fig. 3) and southern ("D" in Fig. 3) parts. The discussed two zones the Czorsztyn Succession ("A"+"B") differ in presence either of the "pure" filament microfacies or the mixed crinoidal-filament microfacies in the lower part of the ammonitico rosso type deposits (Fig. 3). The third zone ("C" in Fig. 3) of sedimentation is that of the Niedzica Succession which is represented by the filament microfacies group. The filament microfacies and "mixed" microfacies groups span a stratigraphical interval from uppermost Bajocian to Callovian.

In the Oxfordian the sedimentation changed due to the deepening of the basin what resulted in unification of the sedimentary environment. Deposits rich in planktonic microorganisms: foraminifers *Globuligerina* sp. and ra-

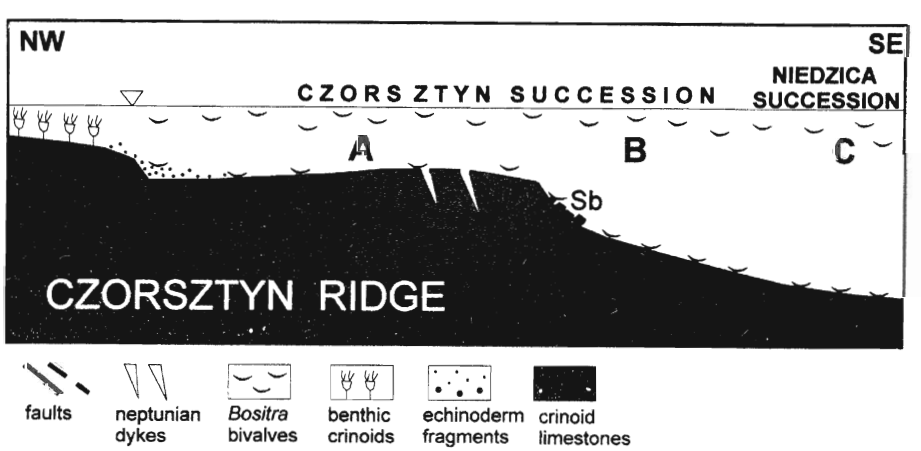

Fig. 3. Beginning of sedimentation of ammonitico rosso type deposits in northern part of the Pieniny Klippen Basin (Late Bajocian – Callovian). A, B and C – zones of sedimentation (explanation in text), SLF – Smolegowa Limestone Formation, KLF – Krupianka Limestone Formation, Sb – scarp breccias.

diolarians, spread over the whole studied area of the Czorsztyn Ridge being replaced south by the radiolarites in the Niedzica Succession.

In the Kimmeridgian and the Tithonian very abundant deposits were rich in rests of pelagic crinoids *Saccocoma*. At the turn of Kimmeridgian and Tithonian in many parts of the Pieniny Klippen Basin, particularly in north-western and central parts, there occur thin grainstone layers rich in redeposited crinoid fragments and limestone clasts containing *Saccocoma*. These are found within limestone of the *Saccocoma* microfacies group. The occurrence of redeposited limestone clasts as well as abundant rests of benthic crinoids may indicate the onset of the *Neo-Cimmerian* movements.

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Heavy mineral assemblages from recent stream alluvia in the Tatra Mts.

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Abstract

Heavy minerals from the recent alluvia in the upper parts of valleys in the Tatra Mts. were studied. Heavy mineral assemblages generally reflect the mineral composition of source rocks. Heavy fractions seem to be relatively enriched in some minerals comparing to the source rocks. Morphology of numerous grains reflects the glacial transport and their subsequent extraction from moraines. Activity of humic acids in alluvia causes leaching porosity of less stable minerals. Relatively high content of oxidized sulphide grains in heavy mineral assemblages in the Western Tatra indicates influence of old mining activities.

Key words: Tatra Mts., alluvia, heavy minerals

Introduction

Heavy minerals assemblages in recent alluvia in the Tatra Mts. were studied by several authors (e. g. Krysowska, 1961; Kiebała, 2001; Kiebała et al., 2001; Ladenberger, 2001). Application of new methods of studies allows to identify higher number of mineral species. Characteristics of heavy minerals in the Tatra Mts. are very important in interpretation of the provenance of detrital material of the Quaternary deposits in the Podhale and Orava. Selective extraction of accessory minerals can be considered basing on the study of heavy minerals in sediments deposited close to their source rocks. The influence of climatic conditions, typical for high mountains, transport in moraines and weathering in environment rich in organic acids related to podzolization processes, can be also discussed.

Geological setting

About 10 kg samples were collected from alluvia of several stream valleys on the northern slopes of the Western and High Tatra Mts.: the Chochołowski Potok stream, the Jarząbczy Potok stream, the Starorobociański Potok stream, the Goryczkowy Potok stream, the Roztoka stream, the Rybi Potok stream (Kiebała, 2001; Ladenberger, 2001). The samples were taken in the upper parts of valleys where igneous and metamorphic rocks outcrops dominate. The source area in the Western Tatras is built predominantly of several types of granitoids and metamorphic rocks (e. g. gneisses, migmatites, amphibolites) whereas in the High Tatras the most abundant are granitoids of various types (granodiorites, tonalites, granites).

Methods of study

Samples were sieved and <0.32 mm fractions was subjected to magnetic and magnetohydrostatic separation. Three fractions were extracted from each sample according to magnetic susceptibility ("magnetic", "paramagnetic", "nonmagnetic"). Polished thin sections of heavy mineral fractions were prepared and studied in optical microscope in transmitting and reflected light and examined in scanning electron microscope fitted with energy dispersive spectrometer (SEM-EDS).

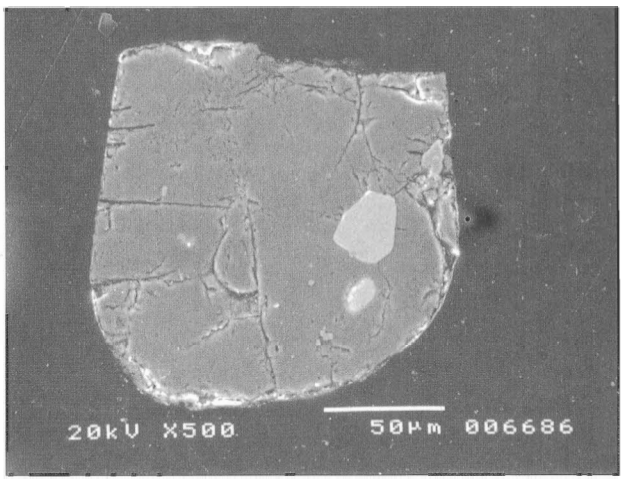

Fig. 1. Crashed grain of apatite with inclusions of monazite and zircon (SEM image)

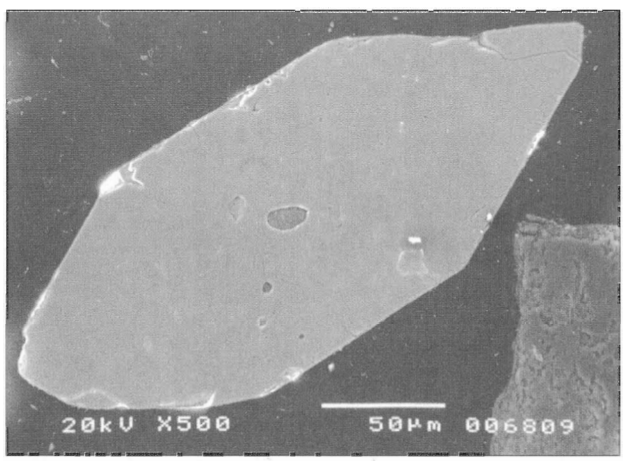

Fig. 2. Idiomorphic grain of zircon with inclusion of biotite in the central part (SEM image)

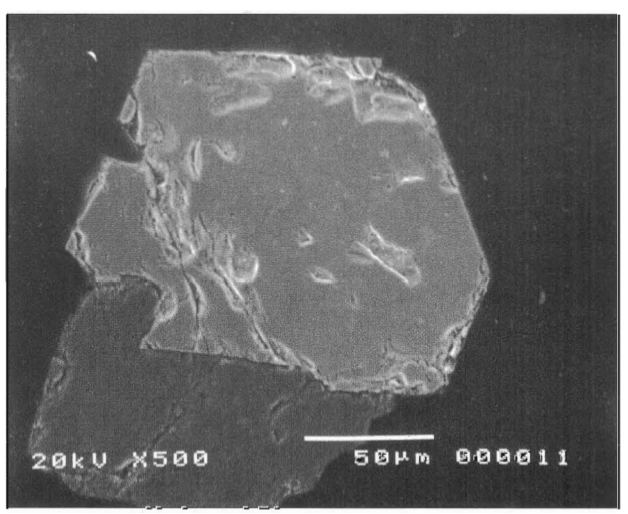

Fig. 3. Intergrowth of magnetite and Na-Ca-feldspar (SEM image).

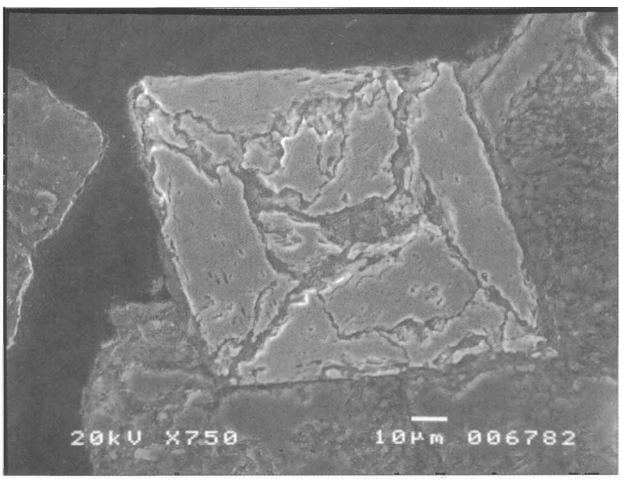

Fig. 4. Partly oxidized grain of magnetite. Replacement magnetite by martite along fractures (SEM image)

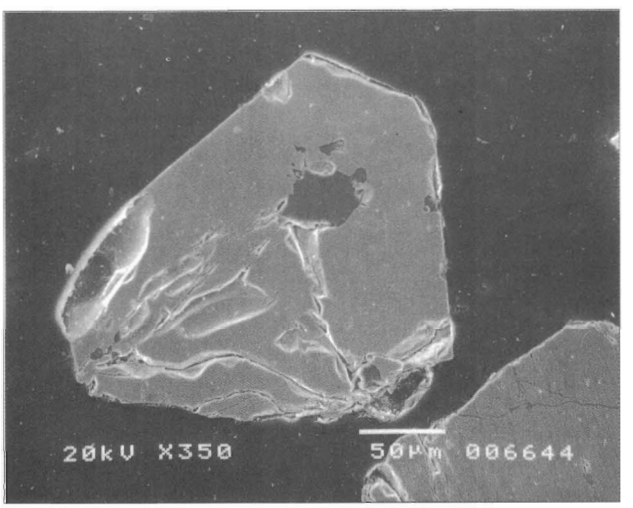

Fig. 5. Magnetite with inclusion of K feldspar (SEM image)

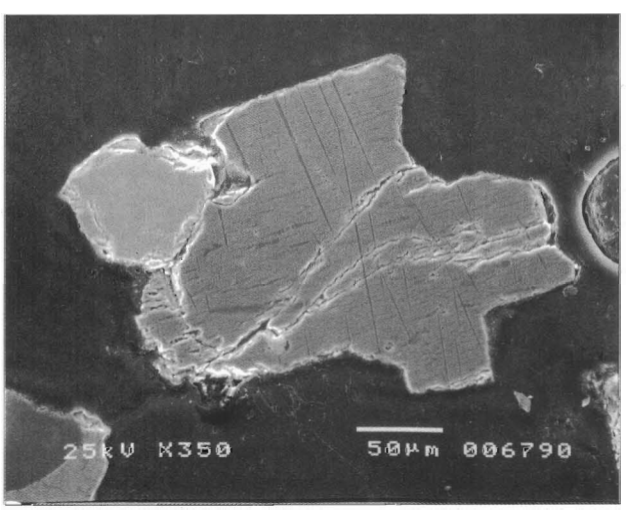

Fig. 6. Ilmenite and monazite – very common mineral association in heavy mineral assemblages. Ilmenite exhibits intergrowths of thin lamellae and lenses of Ti-ilmenite and rutile. The darker lenses are more enriched in Ti (SEM image).

Heavy mineral assemblages

Heavy mineral assemblages obtained from recent alluvia in the Western Tatras are composed of garnet, magnetite, hematite, pyrite, ilmenite, amphiboles, zircon, tourmaline, rutile, xenotime, monazite, Fe-Cu-sulphides. Staurolite, apatite and sillimanite are present as minor components. Cu-Zn-alloy grain are scarce. Garnet grains are characterized by high content of almandine end-member (Alm 45–75 %); spessartite is also present in significant amount (Sps 5–55 %). Amphiboles are represented mostly by magnesio-hornblende. Gedrite and tschermakite end-member rich amphiboles are present in minor amounts. All sulphide grains (pyrite, Fe-Cu sulphides) are strongly oxidized. Grains are surrounded by Fe-oxide rims. The Fe-oxide rim thickness is often greater than diameter of sulphide core.

In the High Tatras apatite (Fig. 1) and epidote are the most abundant. Monazite is less abundant. Zircon (Fig. 2), ilmenite, chlorite, titanite, rutile, magnetite (Figs. 3 and 5), hematite, sillimanite were found in minor amounts. Amphibole, prehnite, xenotime, allanite, barite and pyrite are scarce. Apatite grains exhibit variations in chemical composition (Mn and Cl content). Fe-Ti-oxide grains are present in form of complex intergrowths (rutile and titanite in hemoilmenite-ilmenohematite) typical of the High Tatra granitoids (Fig. 6). In a few monazite grains exsolutions of Th-U-oxides are present. Intergrowths of monazite and xenotime were also noticed.

Micas and intergrowths of heavy minerals with rock-forming minerals are present in heavy fractions extracted from all samples.

Heavy minerals assemblages from different streams alluvia from the Western Tatras are very similar. Also in the High Tatras such differences are negligible.

Heavy mineral forms are variable. All heavy fractions are rich in crushed, irregular, and angular grains. Grain margins are often porous (e. g. titanite, ilmenite, epidote, monazite).

Discussion and conclusions

Heavy mineral assemblages generally reflect the composition of accessory minerals (both primary and formed during hydrothermal alterations) present in source rocks. Although more precise study is needed, it seems that the heavy mineral fraction is relatively enriched in some minerals (e. g. monazite), comparing to source rocks. It is well visible taking into account the zircon/monazite ratio in granitoids and in heavy mineral fraction (e. g. the High Tatra granites). It indicates that in close vicinity to the source rock numerous accessory minerals (e. g. zircon) are present in gravel or coarse-grained sand fraction rock fragments or as inclusions in mica flakes.

High abundance of crushed and irregular grains can be related to glacial transport and subsequent extraction of grains from moraines. The presence of grains with porous margins indicates intense leaching related probably to the activity of humic acids in alluvia. Scarcity of sulphide veins in the Western Tatras suggests that relatively high content of oxidized sulphide grains in heavy mineral assemblages is related to their removal from old mines tailings present in upper parts of valleys. Cu-Zn-alloy grains also indicate an anthropogenic impact on the environment in the past.

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Review of the Pliensbachian brachiopods of the Northern Calcareous Alps

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Abstract

Pliensbachian brachiopod fauna of the Northern Calcareous Alps contains a series of distinctive taxa, documenting clearly its Mediterranean character, and enabling well-based paleogeographic comparisons.

Key words: Brachiopoda, Liassic, Pliensbachian, Alps

In comparison to the relatively abundant Sinemurian brachiopod fauna of the Northern Calcareous Alps the Pliensbachian brachiopods in average less numerous are. One of the reasons of this disproportion is the fact that the Sinemurian facies of the biosparitic red or white crinoidal limestones ("Hierlatzkalk") yielding at most locali-

ties rich brachiopod fauna is not so spread in the Pliensbachian. The most common Pliensbachian facies yielding brachiopods is represented by red biomicrites. Numerous and varied Pliensbachian brachiopod fauna in the Mediterranean domain is well known from the Italian territory and was described in detail e. g. by Zittel (1869), Canavari (1880, 1881, 1883), Parona (1880, 1892), Böse and Schlosser (1900), etc. Interesting and rich brachiopod fauna of the same age was studied and described in the last years from Hungary by Vörös (1983, 1986, etc.). Diversified Pliensbachian brachiopod fauna from the Northern Calcareous Alps (87 species!) was monographed by Böse in 1897 who had at disposal the material from most of the important localities known at that time. According to him, the very rich Austrian localities were those of Hilariberg near Kramsach in Tirol and Hinterschafberg near Bad Ischl in Salzkammergut, the other localities yielded not so abundant brachiopods (Vorderthiersee near Kufstein, Fonsjoch in Karwendel, Gschöllkopf in Rofan Mts., Kammerköhr on Steinplatte near Waidring, etc.). Among further localities, from where the Pliensbachian brachiopods were described by other authors, esp. Kratzalpe near Golling and Adnet should be mentioned here. Several localities in the Bavarian part of the Northern Calcareous Alps are known from the vicinity of Berchtesgaden.

Some of the mentioned localities were visited in the last years and new data were gained by sampling and later study at some other places, too. Pliensbachian brachiopod assemblage was distinguished in the "Hierlatzkalk" at the Erlakogel near Ebensee. Such species as *"Terebratula" schlosseri, "Terebratula" gracilicostata* and *Zeilleria thurwieseri* are there common and characterize well the stratigraphical level. All these species were established by Böse (1897) and originate from Kramsach, where the Pliensbachian age was well documented by the accompanying ammonites.

New samplings in red micritic infillings of the neptunian dykes at the classical locality of Hierlatz (Feuerkogel) near Hallstatt contain *Phymatothyris cerasulum* (Zitt.), a characteristic Pliensbachian species, and may thus document the Pliensbachian age of respective dykes. The species was ascertained by Vörös also in the Upper Sinemurian of the Bakony Mts. in Hungary, however.

New collections from 2001 in the red Pliensbachian micrites at the Kratzalpe and on the NE slopes of Tannhausberg near Golling in the Hagengebirge contain *Apringia paolii* (Can.), *Orthotoma apenninica* (Can.), *Liospiriferina* aff. *alpina* (Opp.), *Bakonyithyris* cf. *pedemontana* (Par.) and large specimens of the leading form – terebratulid *Securithyris adnethensis* (Suess). A long list of the Sinemurian and Pliensbachian brachiopods from there was published already by Krafft (1898). A small collection from there is in the *Geologische Bundesanstalt* in Vienna, and an old, large collection made by Waagen is deposited in the Institute of Paleontology *(Geozentrum)* of the University in Vienna.

Very abundant brachiopod fauna comes from Schafberg and its vicinity. Böse (1897) reported 48 species from "Hinterschafberg", and gave fossil lists from several nearby localities. Red micritic limestones yielded in 2000 near the Mittersee and Suisensee *Apringia paolii* (Can.), *Apringia atlaeformis* (Böse), *Liospiriferina sicula* (Gemm.), *Liospiriferina semicircularis* (Böse), *Liospiriferina* cf. *obtusa* (Opp.), *Securithyris adnethensis* (Suess), *Viallithyris gozzanensis* (Par.) and *Bakonyithyris apenninica* (Zitt.).

Pliensbachian terebratulid *Securithyris adnethensis* (Suess) seems to be a good leading fossil. It occurs according to Böse (1897, p. 146) in red limestones only. It is reported from Kramsach, Kammerköhr on Steinplatte, Kratzalpe, NE slopes of Tannhausberg near Golling, Adnet, and Schafberg and its vicinity – Mittersee, Suissensee, Feuchteneck, Burgaugraben, Schwarzensee, and ENE of Meislalm. Its occurrence in Adnet has not been proved by our recent samplings in Adnet quarries but the specimens from Adnet are deposited e. g. in the collections of the *Bayerische Staatssammlung für Paläontologie und historische Geologie* in Munich, and of the "Haus der Natur" in Salzburg. The species was also ascertained in Glasenbach near Salzburg and in the Lorüns quarry in Vorarlberg (material deposited in the *"Haus der Natur"* in Salzburg and in the *Vorarlberger Naturschau* in Dornbirn, resp.). Among genera, characteristic of the Pliensbachian of the Northern Calcareous Alps, the following should be mentioned: *Apringia, Pisirhynchia, Securithyris, Orthotoma* and *Koninckodonta*. Among species *Apringia paolii* (Can.), *Apringia* (?) *atlaeformis* (Böse), *Cirpa subcostellata* (Gemm.), *Prionorhynchia* (?) *flabellum* (Menegh.), *Liospiriferina semicircularis* (Böse), *Securithyris adnethensis* (Suess), *Linguithyris aspasia* (Zitt.), *Phymatothyris cerasulum* (Zitt.), *Rhapidothyris* (?) *ovimontana* (Böse), *"Terebratula" schlosseri* Böse, *Zeilleria oenana* (Böse) and *Orthotoma apenninica* (Can.) are to be named. On the other hand, the peculiar Mediterranean genera *Lokutella* and *Kericserella* established by Vörös, have not been ascertained in the Northern Calcareous Alps. Very dubious has seemed an information about occurrence of *Terebratula rotzoana* and *Terebratula renierii* on Plassen, given by Spengler (1919). *Lychnothyris rotzoana* (Schaur.) and *Hesperithyris renieri* (Catullo) are strictly South European elements, representing according to Vörös (1986, p. 264) a low-diversity fauna of the basinal areas. The occurrence on Plassen was neither confirmed by the later authors nor by our careful samplings in the last years. However, a part of Spengler's specimens was traced in 2002 in the collections of the *Geologische Bundesanstalt* and of the *Naturhistorisches Museum* in Vienna.

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Regional geological cartography of Slovak Republic

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Abstract

An indubitable basis for whatever geomaps of various larger scales is a geological map of good quality. On the territory of the Slovak Republic regional the geological mapping of a new edition has been taking place for already 30 years and at present it approaches its final phase.

Key words: Western Carpathians, Slovakia, Regional geological maps

Regional geological cartography of Slovakia

The product of geological cartography in Slovakia are geological maps of regions at the scale 1 : 50 000. So far 42 regional geological maps have come out in print, which cover around 80 % of the territory of the Slovak Republic (Fig. 1).

These map works were the basis for compiling the geological maps at large scales, the geological map of the Slovak Republic 1 : 500 000 and 1 : 1 000 000.

At the same time they form the basic material, used for

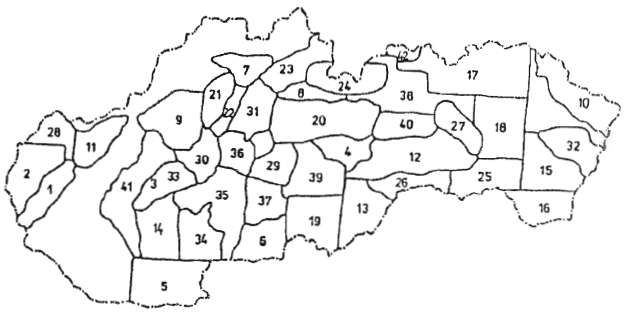

Fig. 1. Regional-geological maps of Slovakia issued in the scale 1 : 50 000. 1 – Malé Karpaty Mts., 1972, 2 – Záhorská lowland, 1973, 3 – Tribeč Mts., 1975, 4 – Slovenské rudohorie and Nízke Tatry Mts., 1976, 5 – Podunajská lowlad – SE part, 1976. 6 – Ipeľská depres. and S part of Krupina pl., 1978, 7 – Kysucké vrchy and Krivánska M. Fatra Mts., 1980, 8 – Liptovská depression, 1980, 9 – Strážovské vrchy Mts., 1982, 10 – Nízke Beskydy Mts. – E part, 1983, 11 – Myjavská upland, Brezovské and Čachtické Karpaty Mts., 1984, 12 – Slovenské rudohorie Mts. – E. part, 1984, 13 – Rimavská depression, 1985, 14 – Podunajská lowland – NE part, 1988, 15 – Východoslovenská lowland – N part, 1988. 16 – Východoslovenská lowland – S part, 1988, 17 – Pieniny, Čergov Mts., 1990, 18 – Slanské vrchy Mts. and Košická depres., 1991, 19 – Lučenecká depression, 1992, 20 – Nízke Tatry Mts., 1992, 21 – Lúčanská Malá Fatra Mts., 1993, 22 – Turčianska depression, 1993, 23 – Southern and eastern Orava, 1994, 24 – Vysoké Tatry Mts., 1994, 25 – Slanské vrchy Mts. and Košická depres., 1996, 26 – Slovak karst, 1996, 27 – Branisko and Čierna hora Mts., 1996, 28 – Chvojnická upland, 1996, 29 – Mt. Poľana, 1997, 30 – Vtáčnik Mts. and Hornonitrianska depres., 1997, 31 – Veľká Fatra Mts., 1997, 32 – Vihorlatské and Humenské vrchy Mts., 1997, 33 – Tribeč Mts., 1998, 34 – Podunajská lowland and Štiavnické vrchy Mts., E part, 1998, 35 – Štiavnické vrchy Mts., 1998, 36 – Kremnické vrchy Mts., 1998, 37 – Mt. Javorie, 1998, 38 – Levočské vrchy Mts., 1999, 39 – Slovenské rudohorie Mts. – W part, 1999, 40 – Slovak paradise, 2000, 41 – Danube lowland – Nitrianska pahorkatina uplant, 2000, 42 – Spišská Magura Mts., 2000.

compiling of a new edition of geological maps of the Slovak Republic at a scale 1 : 200 000.

These basic regional-geological maps are the background for overstructure sets of maps of various specializations as mainly of maps of environment geofactors. The set consists usually of the following types of maps for each region:

- geological map
- map of geochemical rock types
- hydrogeological map
- map of natural water quality
- pedological an paleogeochemical map
- geochemical map of fluvial sediments
- engineering geological maps
- map of natural radioactivity
- geological educational maps of Slovakia

In the last decade author's originals of regional geological maps are treated by computer technology. In preparing of digital geological map the following proceeding is used:

1. Compiling of the author's original 1 : 50 000, its vindication and approbation
2. Redrawing of the geological map on transparent foil
3. Scanning of the background on large-scale scanner CANON A1
4. Vectorization (half-automatic) in programme Map CAD
5. Editation – complex graphical treatment: topology, point, line and areal atributes in Auto CAD, TNT MIPS, Micro Station programmes
6. DTP treatment of vector sets in DTP programmes Adobe, Corel Draw
7. Lightening + Print.

GeOvestník

Informačný spravodajca pre geológiu, baníctvo, úpravníctvo a životné prostredie

Príloha časopisu Mineralia Slovaca, roč. 35, č.1

Obsah

Nové trendy a výsledky geologického výskumu Západných Karpát 1

Slovenská geologická spoločnosť – súhmná správa o činnosti za rok 2002 13

Nové trendy a výsledky geologického výskumu Západných Karpát

Slovenská geologická spoločnosť pri SAV usporiadala 13. decembra 2002 v Bratislave celodňový vedecký seminár *Nové trendy a výsledky geologického výskumu Západných Karpát.* Cieľom akcie bolo priblížiť širokej odbornej verejnosti súčasné smerovanie geologického výskumu na Slovensku a niektoré jeho významnejšie výsledky z posledného obdobia. Na seminári odznelo 19 prednášok (z 13 publikujeme abstrakty).

Seminár mal prierezový charakter. Boli na ňom príspevky syntetizujúce súčasné poznatky o vývoji a stavbe Západných Karpát, ako aj príspevky o najnovších poznatkoch z rozličných geologických špecializácií. Okolo päťdesiat poslucháčov získalo spoľahlivé informácie aj o moderných náhľadoch na paleotektonický vývoj Západných Karpát rekonštruovaný na základe štruktúrneho a metamorfného horninového záznamu (vývoj západokarpatského orogénneho klina – Plašienka; tektonochronológia iňačovsko-kričevskej jednotky – Biroň et al.; štádiá kontinentálnej subdukcie a reaktivácie fundamentu – Putiš; meliatsky akrečný klin – Faryad; postupnosť paleozoických a mezozoických tektonometamorfných udalostí – Schulmann; kriedová deformácia gemerika – O. Lexa; umiestnenie krížňanského príkrovu – Prokešová a Plašienka), na báze datovania pseudotachylitov (výzdvih Tatier – Kohút) a paleomagnetických meraní (terciérne jednotky – Túnyi). Hovorilo sa aj o geologickej a tektonickej stavbe niektorých oblastí (Turčianska kotlina – Rakús a Hók; Lúčanská Fatra – Hók et al.), o magnetickej stavbe granitoidných masívov (Malé Karpaty a Veľká Fatra – Gregorová et al.) a predstavili sa aj doterajšie výsledky refrakčných seizmických meraní získané v rámci projektu CELEBRATION 2000 (Vozár a Bielik et al.).

Za najcharakteristickejší znak prezentovaných paleotektonických a geodynamických rekonštrukcií možno pokladať úsilie o koreláciu tektonických udalostí na veľkých územiach a o ich čo najpresnejšie zaradenie do časovej škály.

Druhý okruh prednášok sa týkal genetickej interpretácie sedimentárneho horninového záznamu (spodnokriedový sled manínskeho príkrovu – Michalík et al.; vrchnokriedové a paleogénne klimatické eventy – Soták a Stárek; evolúcia centrálnokarpatskej paleogénnej panvy – Janočko; viedenská panva – Baráth et al.; magurská panva – Teťák). V prednáškach s touto problematikou sa akcentovalo veľmi presné biostratigrafické datovanie pozorovaných fenoménov a rekonštruovaných procesov a ich korelácia s globálnymi klimatickými a eustatickými udalosťami.

Podľa môjho náhľadu príspevky seminára dobre vystihli súčasný celosvetový trend základného geologického výskumu – orientáciu na genetickú interpretáciu pozorovaných javov a nameraných údajov, ako aj na časovú a priestorovú rekonštrukciu procesov produkujúcich horninový látkový a štruktúrny záznam.

S potešením možno konštatovať, že sa slovenskej geológii aj napriek ťažkostiam rozličného druhu darí držať krok so svetovým geologickým výskumom aspoň v odvetviach, ktoré nevyžadujú vysoké finančné náklady.

Veľký záujem o aktívne vystúpenie na seminári, bohatá účasť a diskusia, ako aj miestami výborná úroveň prednášok nás oprávňujú navrhnúť, aby sa podobné „predvianočné" semináre širokého tematického zamerania konali každý rok. Výbor SGS sa podujíma pripraviť takúto výročnú akciu aj začiatkom decembra 2003, a to i s cieľom pripomenúť významné obdobie v geologickom výskume nášho územia seminárom pod názvom *Sto rokov príkrovovej teórie v Západných Karpatoch.* Vyzývame záujemcov o vystúpenie na túto alebo príbuzné témy, aby si svoje prednášky už začali pripravovať.

Dušan Plašienka
predseda SGS

Štádiá kontinentálnej subdukcie a reaktivácie fundamentu z pohľadu petrotektoniky (Alpy – Karpaty)

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Pre konvergentné zóny orogénov sa zrekonštruoval resp. aj pripravil nasledujúci model etapovitého vývoja kontinentálnej (litosférickej) subdukcie, t. j. subdukcie typu A, zaznamenaný aj v austroalpínskom fundamente výskytom kriedových eklogitov (prehľad in Putiš et al., 2002):

– kontinentálna konvergencia (x cm/rok) po subdukcii oceánskej kôry (meliatika) v zázemí má tendenciu vytvoriť spodnokôrový resp. aj gravitačne nestabilný podkôrový koreň,

– reakciou je „decoupling" spodnoplatňovej litosféry: 1. teplotno-mechanické oddelenie vrchnokôrovej od spodnokôrovo-vrchnoplášťovej litosféry na základe rozdielneho frikčného indexu a produkcie tepla v týchto fragmentoch oddelených duktilnou zónou v strednej kôre; 2. možnosť nasledujúceho oddelenia spodnokôrovej od vrchnoplášťovej litosféry duktilnou zónou blízko MOHO,

– v zónach, kde „oddeleniu" nenastane, viskóznejší (chladnejší a rigidnejší) podkôrový litosférický koreň sa pod vplyvom kompresie, gravitácie a konvekcie astenosféry odtrhne („delamination") a zaklesne do plášťa; kým ľahká vrchná kôra bráni subdukcii spodnej kôry, ktorá zvyčajne predstavuje koreň kolízne zhrubnutého kontinentálneho klina,

– v zónach s „oddelením" nastáva subdukcia spodnokôrovo-vrchnoplášťovej litosféry (_ tenké fragmenty vrchnej kôry) pod vrchnokôrový/strednokôrový orogénny klin do prostredia vrchnoplášťovej litosféry,

– eklogitizácia prebieha metamorfnými reakciami s trendom zvyšovať hustotu hornín vrchnej kôry – 2,76 (granodioritická), resp. spodnej kôry – 2,94 (gabroidná) na 3,1 (do 20 kbar), alebo až 3,56 (nad 30 kbar); ak má subdukovaný fragment vyššiu hustotu (ako 3,3 ~ vrchný plášť), môže nastať jeho delaminácia a recyklácia,

– hĺbku kontinentálnej subdukcie riadi vztlaková sila závislá od hustotného kontrastu medzi eklogitizovaným fragmentom a vrchnoplášťovou litosférou; nízky kontrast spomaľuje subdukciu aj exhumáciu.

– stupeň eklogitizácie – závisí aj od konvekcie astenosféry do vrchného plášťa: vzostupná konvekcia bráni subdukcii a umožňuje len čiastočnú eklogitizáciu (v hĺbke 40–70 km); zostupná konvekcia podporuje úplnú eklogitizáciu (v hĺbke zväčša nad 100 km),

– trvanie subdukcie A a exhumácie – čím hlbšia, tým rýchlejšia (z porovnania Lu-Hf vs. Ar-Ar vekov: 5–15 Ma),

– časové obmedzenie kontinentálnej subdukcie predstavuje nová geodynamická udalosť, a to začiatok subdukcie B oceánskej kôry predpolia (penninika), a tým aj zmena režimu na extenzný už v aktívnom kontinentálnom okraji,

– mechanizmus exhumácie: extenzný zlom nad HP komplexom – štruktúrnou denudáciou približne od 70 do 20 km; rohovým tokom – spätnou extrúziou aktívnym subdukčným kanálom asi od 40 do 20 km; finálna exhumácia – kolaps strednokôrového/vrchnokôrového klina s morfologickou eróziou.

Načrtnuté podmienky a etapy sa splnili resp. platia pre HP komplexy stredného austroalpinika Východných Alp. Subdukcia A časti pasívneho okraja (~ 130–100 mil. r.) nadväzuje na subdukciu B v zázemí (~ 170–150 mil. r. v meliatiku), hoci s posunom o niekoľko miliónov resp. až niekoľko desiatok miliónov rokov. Obidve subdukcie (~ 170–100 mil. r.) sú časovo korelovateľné s extenziou v predpolí (otváranie penninského bazéna). Až subdukcia oceánskej kôry penninika zmenila geodynamiku pasívneho okraja na aktívny a jeho režim z kompresného na extenzný. Tým sa subdukcia A zastavila a vystriedala za extenznú exhumáciu eklogitizovaných komplexov (100–60 mil. r.; Dallmeyer et al., 1996).

Úloha duktilného zlomu pri exhumácii je štruktúrno-petrologicky dokumentovaná na eklogitickom Sieggrabenskom komplexe, kde vývoj duktilných stavieb od vysokoteplotných až po nízkoteplotné (navyše s rovnakou kinematikou Px, Amp, Pl, Qtz a Cal) súvisí s takmer izotermálnou dekompresiou dokumentovanou P-T údajmi reakčnej rekryštalizácie. Mladšia nízkoteplotná etapa exhumácie (s odlišnou kinematikou) odráža kolaps strednokôrového/vrchnokôrového kolízneho klina.

V profile fundamentu veporika centrálnych Západných Karpát, najmä v blízkosti kriedových sinistrálnych transpresných zlomov, akým bol aj pohorelský, sa nachádza exhumovaná variská spodná kôra reprezentovaná leptynitovo-amfibolitovým komplexom (LAC) pripojená k strednej a vrchnej kôre s granitoidmi a subvulkanitmi resp. aj s obalovou jednotkou. Tak bol LAC, s vysokým podielom mafických členov a preddisponovanou hlbokou štruktúrnou pozíciou, jedným z najväčších „favoritov" možnej ranoalpínskej (kriedovej) eklogitizácie juhoveporického fundamentu. Napriek tomu vykazuje len metamorfné podmienky spodnej amfibolitovej fácie (T do 530 °C s P_{max} 8–9 kbar), ktoré možno interpretovať ako podmienky podsunutia v hrubnúcom kontinentálnom kolíznom kline. Podobne ani komplexy južného veporika na S od lubeníckej línie nepresiahli podmienky strednej časti amfibolitovej fácie pri tlaku 8–10 kbar. Namieste je otázka príčin kriedovej „nesubdukcie" v paleotektonicky laterálne nadväzujúcom fragmente južného veporika na stredné austroalpinikum:

– znížená rýchlosť skracovania/podsúvania, napr. pri šikmej konvergencii, keď podsúvanie neprejde do kontinentálnej subdukcie,

– „neoddelenie" na strednej kôre mohla spôsobiť relatívne malá hrúbka kolízneho klina,

– metamorfóza v kolíznom kline veporika dosahuje maximálne vrchol stredného tlaku (8–9 kbar, fácie zelených bridlíc až amfibolitovej).

– „oddelenie" v oblasti MOHO? späté s delamináciou? chladnejšej a rigidnejšej vrchnoplášťovej litosféry a jej nahradenie horúcou, hustotne lahšou astenosférou, ktorá vyvoláva rýchle extenzné ohriatie kôry až jej natavenie (rochovský granit?), čo umožňuje exhumáciu jej hlbokých úrovní symetrickou alebo asymetrickou štruktúrnou denudáciou.

Geodynamické a paleogeografické závery stratigrafického a sedimentologického štúdia pelagických spodnokriedových súvrství manínskej jednotky, Butkov

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Manínska jednotka je v karpatskej geológii jablkom sváru viac ako polstoročie. Tím z Geologického ústavu SAV (grant VEGA 7215), UK v Bratislave a TU v Ostrave (postdoktorandská úloha GAČR 205/00/D030) študoval rozsiahle odkryvy jej vrchnojursko-spodnokriedového sledu vo veľkolome Butkov cementárne v Ladcoch (Borza et al., 1987; Michalík a Vašíček, 1987; Michalík et al., 1990; Vašíček a Michalík, 1986, etc.). Ide o najbohatšiu lokalitu spodnokriedových amonitov v celých Západných Karpatoch s množstvom výhradne mediteránnych druhov od ranovalanžínskych (amonitová zóna Campylotoxus) až po neskorobarémske (z. Vandenheckii). Asociácia sa podobá faune z Vokontskej priekopy vo Francúzsku. Nebyť sústavnej ťažby cementárskych surovín, ktorá súvislé profily obnažila, ale dokumentovaný sled rok čo rok likviduje, Butkov by mohol byť oporným profilom porovnateľným s klasickými francúzskymi a španielskymi lokalitami mediteránnej oblasti. Na integrovanú stratigrafickú koreláciu sme okrem sekvenčnostratigrafického litologického štúdia a zberu makrofauny súčasne odoberali aj vzorky na štúdium nevápnitých dinocýst, kalpionel, mikroproblematík a vápnitého nanoplanktónu.

Ladecké súvrstvie

Na báze spodnokriedovej sekvencie vystupuje sedimentárna brekcia. Zvyšky hladkoschránkových amonitov zodpovedajú širokomorskému prostrediu a ojedinelé skulptúrované schránky *Olcostephanus* svedčia o valanžínskom veku. Chýbanie valanžínskej amonitovej zóny Pertransiens, výskyt *Neolissoceras* a *Vergoliceras salinarium* (Uhlig), ktoré by sa mali objaviť až koncom zóny Pertransiens a prežívať do zóny Verrucosum, ako aj výskyt *Busnardoites campylotoxus* – indexu zóny Campylotoxus, svedčia o tom, že ladecké súvrstvie začalo sedimentovať až v ranom valanžíne. *Neocomites platycostatus* (Borza et al., 1987; Michalík a Vašíček, 1987) z 12. etáže indikuje vyššiu časť strednovalanžínskej zóny Campylotoxus. Slienitý biomikrit obsahuje kalpionelidy *Calpionellites darderi, C. major, Tintinopsella carpathica*, vápnité dinoflageláta *Colomisphaera heliosphaera, C. vogleri*, globochéta, ostrakóda a spikuly hubiek. Kalpionelová asociácia zodpovedá zóne Calpionellites (subzóny Darderi a Major). Spóry a bisakátne peľové zrná dokazujú slabý terestrický prínos. Sporadické dinoflageláta *Oligosphaeridium complex* a *Spiniferites* sp. indikujú mladší vek ako stredný až raný valanžín (amonitová zóna Pertransiens). Zástupcovia vápnitého nanoplanktónu *Calcicalathina oblongata* a *Eiffelithus windii* sa prvý raz vyskytli v zóne Otopeta (136,66 miliónov rokov – podľa Hardenbola et al., 1998), *Rucinolithus wisei* v zóne Verrucosum (Bergen, 1994) a nanokóny *Nannoconus bermudezi* a *N. kamptneri* na začiatku valanžínu. Asociácia patrí subzóne NK3A Rucinolithus wissei zóny Calcicalathina oblongata NK3 (Bralower et al., 1989).

Mráznické súvrstvie

V bohatej asociácii amonitov (vyše 150 jedincov od šachty na 11. etáži) dominujú skulptúrované typy, ako je *Himantoceras trinodosum, Criosarasinella furcillata, Criosarasinella heterocostata, Teschenites subpachydicranus* a i. Zaujímavé sú výskyty najstarších kryoceratitov *(C. primitivus)*. Aptychy, belemnity a ramenonožce sú ojedinelé. Asociácia patrí amonitovej zóne Furcillata (koniec raného valanžínu). Slienitý biomikrit obsahuje *Cadosina semiradiata cieszynica, C. s. fusca, Remaniella cadischiana, Stomiosphaera echinata, Tintinopsella*, bentické foraminiferá, globochéta, ostrakóda a krinoidy. Asociácia dinoflagelát odráža šelfové podmienky (litorálne až brakické *Circulodinium, Muderongia* prevládajú). Podľa Leerevelda (1995) výskyt *Cymososphaeridium validum, Gonyaulacysta cretacea* a zástupcov *Bourkidinium* zodpovedá neskorovalanžínskej – ranohoterivskej zóne Cymososphaeridium validum. V asociácii nanofosílií oproti ladeckému súvrstviu chýba *Rucinolithus wisei*, občas sa objavuje *Tubodiscus verenae* a vzácne prvé valanžínske nanokóny (*Nannoconus boneti, N. cornuta*, ktoré vymreli do konca valanžínu), postupne pribúda *N. quadratus, Calcicalathina oblongata* a *Cruciellipsis cuvillieri*, vyššie *Calcicalathina oblongata, Nannoconus globulus* a *Watznaueria barnesae* indikujúce subzónu NK3B Tubodiscus verenae zóny Calcicalathina oblongata NK3 (Bralower et al., 1989). Valanžínske asociácie sa skladajú z kozmopolitných foriem (*Watznaueria barnesae, Cyclagelosphaera margerelii, Rhagodiscus asper, Zeugrhabdothus embergeri, Cretarhabdus* spp. a *Micrantholithus* spp.) a tetydných taxónov (*Conusphaera mexicana, Cyclagelosphaera deflandrei, Cruciellipsis cuvillieri* a *Nannoconus* spp.). Zriedkavé boreálne formy (*Micrantholithus speetonensis, Crucibiscutum salebrosum, Nannoconus pseudoseptentrionalis), Rhagodiscus asper, Nannoconus* spp., *Micrantholithus* spp., *Conusphaera* spp. bývajú interpretované ako teplovodné. Hojnosť *Watznaueria barnesae* naznačuje jej oportunistickú („r-selekčnú") stratégiu.

Kališťianske súvrstvie

Začína sa kalciturbiditmi Lowstandové sústavy súvrstvia (hrúbka 1–3 m) sú hrubolavicovité, obsahujú brachiopóda a kalíšky krinoidov. Bohaté spoločenstvá amonitov a nanofosílií charakterizujú transgresné systémové sústavy. Sústavy vysokého stavu sa skladajú z tenkodoštičkovitého vápenca s hrubými slieňovcovými vložkami. *Teschenites subflucticulus* a *T. flucticulus* indikujú ranohoterivskú amonitovú zónu Radiatus. V amonitovej asociácii ďalšej zóny Loryi sú teschenity nahrádzané kryoceratitmi (najmä *C. nolani*). Ojedinelé aptychy a amonity (*Subsaynella sayni, Plesiospitidiscus ligatus*, vyššie *Balearites balearis*) dokladajú neskorohoterivský vek rozhrania kališťianskeho a lúčkovského súvrstvia. Indexy najmladšej hoterivskej (Ohmi) a najstarších barémskych zón (Hugii a Nicklesi) tu však chýbajú. Slienitý biomikrit obsahuje *Cadosina semiradiata cieszynica, C. s. fusca, Colomisphaera heliosphaera, Stomiosphaera echinata* a poslednú *Tintinopsella carpathica*. Foraminifery, spikuly hubiek, globochéta, rádioláriá, úlomky bivalvií, krinoidy a machovky sú hojné. Vzácny výskyt nanoplanktónneho *Litraphidites bollii* (objavujúceho sa v zóne Loryi v úrovni 131,14 mil. rokov; podľa Hardenbola et al., 1998) v asociácii s hojnými mikrantolitmi *(Micrantholithus hoschulzii)* a s *Nannoconus bermudezi*; objavenie sa *Assipetra terebrodentarius* a zmiznutie *Cruciellipsis cuvillieri* zodpovedá subzóne NC5b nanoplanktónovej zóny Litraphidites bollii (Thierstein, 1973). *Nannoconus* býva bežnejší vo vrchnohoterivských a spodnobarémskych ako vo valanžínskych asociáciách.

Spodnokriedové bohaté a málo diverzifikované asociácie *Nannoconus* riadené selekciou typu „r" žili v plytkých pásmach tropických morí, odkiaľ občas migrovali do iných stanovíšť. *Nannoconus abundans, N. borealis,* možno aj *N. inornatus* a *N. pseudoseptentrionalis,* boli endemitmi adaptovanými na chladnejšie vody severonemeckej panvy.

Lúčkovské súvrstvie

Nález cca 150 jedincov amonitov v skĺznutom bloku pod bázou podhorského súvrstvia v Západných Karpatoch predstavuje doteraz neznámu asociáciu. Medzi nimi dominujú holkodiscidy *(Holcodiscus, Metahoplites, Parasaynoceras, Avramidiscus)* a stratigraficky nevýznamné baremity. Výskyty *Nicklesia pulchella, Moutoniceras nodosum, Dissimilites dissimilis, Patruliusiceras lateumbilicatum, Paraspiticeras* sp. a *Karsteniceras* sp. zodpovedajú rozhraniu ranobarémskych zón Pulchella a Compressissima. Nález heteromorfného amonita *Ancyloceras vandenheckei* indikuje, že sedimentácia súvrstvia trvala ešte začiatkom mladšieho barému (zóna Vandenheckei). Hojné sú ramenonožce, hubky (Calcispongia), lastúrniky, nautilidy a belemnity. Asociácia dinoflagelát sa skladá z litorálnych *(Cerbia)* a neritických *(Oligosphaeridium, Spiniferites)* foriem. *Cerbia tabulata* je známa z vyššej časti ranobarémskej amonitovej zóny Caillaudianus. Hojná *Watznaueria barnesae* sa vyskytuje spolu s pestrou asociáciou nanokónov *(Nannoconus steinmanni, N. bermudezi, N. globulus)* a častým *Micrantholithus hoschulzii.* Nanokóny zastupujú formy objavujúce sa začiatkom barému *(N. elongatus, N. wassalli, N. circularis).* Chýbanie *Calcicalathina oblongata* nad amonitovou zónou Nicklesi umožňuje stanoviť subzónu NC5d (Bown et al., 1998).

Butkovské súvrstvie

Dinoflagelátne cysty, zastupujúce typy otvoreného neritika *(Achomosphaera, Litosphaeridium)* a pelagiálu *(Pterodinium),* dominujú nad akritarchami *(Wallodinium, Veryhachium),* bisakátnymi peľovými zrnami a mikroforaminiferami. Prvý výskyt *L. siphoniphorum* sa zhoduje s vrchnoalbskou amonitovou zónou Inflatum a prvý výskyt *P. conulum* spolu s prítomnosťou *E. dettmaniae* a *O. verrucosum* určuje amonitovú zónu Dispar.

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Výskum vnútornej magnetickej stavby granitoidného masívu Veľkej Fatry – predbežné výsledky

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Štúdium anizotropie magnetickej susceptibility hornín ako efektívneho nástroja na hľadanie odpovedí na otázky tektonického vývoja a stavby geologických jednotiek sa rozvíja ruka v ruke s modernizáciou meracích prístrojov. Magnetickú stavbu centrálnych Západných Karpát (CZK) najúplnejšie spracoval Hrouda (Hrouda, 1983, 1986; Hrouda a Hanák, 1990; Hrouda a Kahan, 1991; Hrouda et al., 1983, 1988, 2002a). Sumárne výsledky štúdia z takmer všetkých granitoidných telies CZK sú v práci Hroudu et al. (2002b). V rámci jadrových pohorí Západných Karpát je magnetická stavba granitoidných masívov väčšinou podobná magnetickej stavbe metamorfného plášťa a často aj sedimentárnych hornín obalovej jednotky, čo odráža jej spoločný tektonický (deformačný) pôvod v alpínskej orogenéze.

Predmetom nášho príspevku je anizotropia magnetickej susceptibility (AMS) ľubochnianskeho veľkofatranského granitoidného plutónu, jedného z troch masívov jadrových pohorí, v ktorom sa doteraz takýto výskum plošne nevykonal.

Ľubochniansky granitoidný masív buduje viac typov granitoidných hornín, ktoré tvoria typický kompozitný a normálne zonálny plutón (Kohút, 1992; Kohút et al., 2001). Dominantou východnej časti masívu sú smrekovické tonality (ST) so zvyškami starších deformovaných magmatických hornín – ortorúl, ako aj ich xenolitov. Vo vertikálnom reze sa na stavbe plutónu zúčastňujú aj kornietovské granodiority (KGD), lipovské granity (LG) a najmladšie ľubochnianske leukogranity (LLG), ktoré po tektonických líniách intrudovali do už solidifikovaného plutónu zloženého z ST + KGD + LG. Terénny, detailný petrografický a geochemický výskum potvrdili relatívnu samostatnosť granitických hornín, ktorých genéza a skladba odrážali zmeny vývoja hercýnskeho orogénu. Spodnokarbónsky vek magmatizmu sa detekoval pri KGD s konkordantným vekom monazitov (340 ± 2 Ma) a podobný vek vykazujú aj LG (356 ± 25 Ma) pri datovaní zirkónov metódou *single grains* (Kohút et al., 1997). Naproti tomu datovanie ST preukázalo ich

vnútrokarbónsky vek (304 ± 2 Ma; Poller et al., 2000), ale leukokratné žilné intrúzie LLG permský vek od 283 ± 15 Ma do 254 ± 13 Ma (Poller et al., 2001). Odlišné magnetické vlastnosti jednotlivých granitoidných typov v ľubochnianskom masíve indikoval už primárny výskum magnetickej susceptibility (Kohút, 1992) z neorientovaných kusových vzoriek s hodnotou ST – κ = 1700–3150 x 10^{-6} [SI], KGD – κ = 200–1000 x 10^{-6}, LG – κ = 50–400 x 10^{-6}, LGG ako nemagnetické horniny mali takmer nulovú magnetickú susceptibilitu.

Prvá fáza súčasného výskumu vnútornej magmatickej stavby masívu Veľkej Fatry sa opiera o výsledky merania AMS 251 vzoriek získaných terénnou vŕtačkou s výplachom a jadrovnicou z 23 lokalít. Aby boli výsledky štatisticky relevantné, každú lokalitu reprezentuje aspoň deväť typizovaných orientovaných vzoriek. Merania AMS sa vykonali na modernom kapamostíku KLY-3S (Jelínek a Pokorný, 1997) vo firme Agico, s. r. o., Brno, ktorá tento prístroj aj vyvinula, takže boli zabezpečené optimálne podmienky na presné a citlivé meranie.

Výsledky objemovej magnetickej susceptibility z 84 vzoriek z ôsmich lokalít ST varírujú od 326 x 10^{-6} po 5270 x 10^{-6} [SI] s priemerom 2200 x 10^{-6} [SI] a indikujú , že ide o granitoidy typu I, kým magnetická susceptibilita KGD zo 67 vzoriek šiestich lokalít je od 46 do 3960 x 10^{-6} [SI] s priemerom 620 x 10^{-6} [SI], čo je v rámci rozsahu granitov typu S. Podobne nízku susceptibilitu majú aj LG z 90 vzoriek ôsmich lokalít, a to od 23 do 1570 x 10^{-6} [SI] a priemer 160 x 10^{-6} [SI]. Veľmi nízku hodnotu mali ortoruly – 10 vzoriek z jednej lokality 4 až 90 x 10^{-5} [SI] s priemerom 41 x 10^{-6} [SI].

Aj keď objemová susceptibilita v každom type hornín v závislosti od obsahu antiferomagnetických a feromagnetických minerálov, najmä magnetitu, výrazne kolíše, jej priemerná hodnota stúpa od granitu cez granodiorit po tonalit, kde je o jeden rád vyššia (priemer 2,2 x 10^{-6} [SI]). Aj tento rozdiel potvrdzuje výsledky predchádzajúceho petrologického štúdia, ktoré smrekovický tonalit zaradili medzi granitoidné horniny typu I. Presnejšie údaje o obsahu a povahe magnetických minerálov v jednotlivých horninových typoch prinesie plánované meranie tepelnej závislosti susceptibility a analýza výsledných termokriviek.

Merania anizotropie magnetickej susceptibility odhalili odlišnosti vo vnútornej magnetickej stavbe granitoidných jednotiek. Stupeň foliácie a lineácie výraznej väčšiny vzoriek všetkých troch skúmaných granitoidných typov kolíše od 1,02 až do 1,05, iba foliácia smrekovického tonalitu je mierne výraznejšia – stupeň foliácie väčšiny vzoriek je 1,5 až 1,10. Vo všetkých typoch, ale najmä v kornietovskom granodiorite, prevažuje planárna magnetická stavba nad lineárnou.

V smrekovickom tonalite tvorí magnetická lineácia výrazné, mierne anizotropické maximum – priemerný smer je ZJZ–VSV a sklon okolo 10° na VSV. Veľmi dobre definovateľné maximum vytvárajú aj póly magnetickej foliácie. Magnetická foliácia je pomerne plochá a v priemere má smer SZ–JV so sklonom 10 až 20° na SV. V kornietovskom granodiorite tvorí magnetická lineácia pomerne dobre definovaný nepravidelný pás orientovaný na SV–JZ so sklonom pod stredným uhlom na JV. Póly magnetickej foliácie vytvárajú dve výrazné a jedno menej výrazné maximum a maximá dovedna jeden nedokonalý pás orientovaný na SZ–JV. V lipovskom granite tvorí magnetická lineácia dosť dobre definovaný nepravidelný pás v smere SV–JZ, ktorý sa pod malým uhlom skláňa na SZ. Póly magnetickej foliácie vytvárajú výrazné anizotropické maximum s tendenciou prechádzať do začínajúceho sa pomerne strmého pásu orientovaného smerom SZ–JV.

V tejto fáze výskumu nie sú výsledky AMS z hľadiska pôvodu magnetickej vnútornej stavby jednoznačne interpretovateľné, ale ponúkajú nasledujúce čiastkové závery:

Vzhľadom na okolitý kornietovský granodiorit, mladší vek smrekovického tonalitu a zároveň tvar jeho telesa v geologickej mape výsledky naznačujú, že by mohlo ísť o intruzívny peň typu I do starších typov S. Podľa analógie s výsledkami AMS iných pňov by bolo možno očakávať pomerne strmú magnetickú foliáciu. V prípade smrekovického tonalitu, pre ktorý je charakteristická veľmi strmá foliácia, je takáto predstava nepravdepodobná.

Orientácia magnetickej stavby lipovského granitu a kornietovského granodioritu je prekvapujúco rozdielna, hoci obidva typy magmatitu majú podobný vek. Z toho vyplýva, že magnetická stavba týchto hornín nie je jednoznačne alpínska, deformačná. Úplné alpínske pretlačenie pôvodnej stavby by sa prejavilo zhodnou orientáciou magnetickej stavby v obidvoch typoch. Superpozíciu takejto deformácie na pôvodnú stavbu v obidvoch typoch hornín však zatiaľ úplne vylúčiť nemožno.

Na zodpovednú analýzu a jednoznačnejšiu interpretáciu prvých meraní bude nevyhnutné odobrať ďalšie vzorky v iných častiach granitoidného masívu a z jeho obalu, aby bolo možno komplexnejšie porovnať ich vnútornú magnetickú stavbu a rekonštruovať tektonické procesy, ktorých pôsobenie túto stavbu v jednotlivých jednotkách vytvorilo.

Vznik, rast a zánik západokarpatského orogénneho klina

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Cieľom príspevku je celokarpatská korelácia a geodynamická interpretácia hlavných deformačných udalostí, čo umožnilo začlenenie štruktúrneho horninového záznamu do časovej škály. Štruktúrotvorné procesy sa hierarchicky členia na deformačné štádiá, regionálne tektonické fázy, tektonické epochy a orogenetické cykly a analyzujú sa v systéme izotektonických zón – rozsiahlych priestorových domén charakteristických porovnateľným štruktúrnym vývojom. Vyčlenilo sa 18 primárnych izotektonických zón: magurská, oravická, váhická, infratatrická, tatrická, fatrická, severoveporická, dve juhoveporické (obalové komplexy a fundament), gemerická, meliatická, turnaická, szarvaskőická, bükkická, hronická, silicická, severotransdanubická a juhotransdanubická. Zóny sa v priebehu tektonickej amalgamácie postupne spájali do regionálnych pásiem, ako je transdunajské pásmo, pásmo Slovenského krasu, pásmo Rudabánye a Bukových vrchov (Bükku), veporsko-gemerské pásmo, tatransko-fatranské pásmo, považsko-pieninské pásmo a pieninské bradlové pásmo. Časová korelácia deformačných udalostí v súčinnosti s interpretáciou geodynamického pozadia formovania látkového (sedimentárneho, magmatického a metamorfného) horninového záznamu je základom na definovanie nasledujúcej sústavy paleotektonických udalostí a procesov v alpidnej evolúcii západokarpatského orogénu.

Alpidný orogenetický cyklus nadviazal na starší hercynidný cyklus. Ten sa skončil *neskorovariskou (hnileckou) tektonickou epochou* (270–240 Ma, spodný perm až spodný anis), vyznačujúcou sa gravitačným kolapsom variského horstva za sprievodného riftingu

a magmatizmu (betliarska riftogénna fáza). Vlastný alpidný orogénny cyklus sa začal pred zhruba 240 Ma v anise roztrhnutím *(breakup)* meliatického oceána ako zaoblúkovej panvy – okrajového mora oceána Paleotethys subdukovaného počas predchádzajúceho variského cyklu pod eurázijský kontinent. Otvorením meliatického oceána v žarnovskej riftovej fáze sa začala prvá alpidná – *paleokimerská (slanská) tektonická epocha* (240–205 Ma, stredný – vrchný trias), pre ktorú bolo charakteristické rozpínanie meliatického oceána a celkový distenzný tektonický režim na jeho širokých pasívnych okrajoch. Vo vzťahu k nasledujúcemu vzniku orogénneho klina možno hnileckú a slanskú epochu označiť ako predispozičné štádium západokarpatskej orogenézy.

V liase sa geodynamická situácia zmenila. Široký severný šelf meliatika podľahol v *mezokimerskej (bodvianskej) epoche* (205–170 Ma, spodný lias až stredný doger) rozsiahlemu areálovému riftingu (zliechovská a neskôr podružná devínska extenzná fáza), ale pravdepodobne sa súčasne už začala subdukcia meliatickej oceánskej litosféry. Podľa všetkého to súviselo so zmenou kinematiky pohybu veľkých platní – jv. driftom Afriky a Jadranu voči Európe pri otváraní stredného Atlantiku. Akréciou materiálu zoškrabnutého zo subdukovanej meliatickej litosféry na čelný okraj vrchnej platne sa začal nukleovať západokarpatský orogénny klin, a tak táto epocha reprezentuje embryonálne štádium rastu subdukčno-akrečného klina. Orogén začal fungovať ako autonómny konvergentný systém hnaný a kontrolovaný subdukujúcou meliatickou doskou, ktorej ťah a ústup vyvolal roztrhnutie kontinentálnej litosféry ako v predpolí (krasinská riftová fáza a otvorenie váhického oceána), tak aj v tyle akrečného komplexu (bányahegyská fáza zaoblúkového riftingu vedúca k vytvoreniu oceánskej panvy Szarvaskő).

Neokimerská (ipeľská) epocha (170–130 Ma, vrchný doger až vrchný neokóm) sa začala kolíziou po uzavretí meliatického oceána a nasunutím akrečného komplexu na pasívny okraj spodnej, slovenskokarpatskej platne (šugovská tektonická fáza). Vzápätí vznikol skrátením a obdukciou kôry zaoblúkovej panvy szarvaskőický retroklin a nasunul sa až na distálne – bükkické zázemie kolíznej zóny (bátorská fáza). Kolízne skracovanie sa potom opäť presunulo do proklina, tam bolo v tuhárskej fáze nasunuté gemerikum na veporikum. V predpolí – v spodnej platni konvergentného systému – však stále panoval extenzný tektonický režim a kulminoval walentówskou riftovou fázou a otvorením magurského oceána. Obidva procesy – kolízne skracovanie i rifting predpolia – boli generované ťahom meliatickej dosky napojenej na spodnú, slovenskokarpatskú platňu, a tak táto epocha reprezentuje iniciálne štádium rastu západokarpatského kolízneho klina.

V *paleoalpínskej hronskej epoche* (130–90 Ma, vrchný neokóm až turón) bivergentný západokarpatský orogénny klin svoju konfiguráciu príliš nezmenil (je to konzervatívne štádium kolízneho klina). Aktivizoval sa hlavne retroklin v transdanubických zónach (litérska fáza). Proklin aj vyzdvihnutá „zátka" *(plug)* v strede klina *(Andrusovovo pohorie)* boli stále vo výraznom kontrakčnom režime, ktorý sa spočiatku propagoval do predpolia (solírovská fáza), potom po vytvorení zóny podsúvania medzi fatrickou a severoveporickou zónou proklin anektoval fatrickú zónu (benkovská fáza). Epocha sa končí donovalskou fázou presunu pripovrchových príkrovových systémov fatrika a hronika.

V *mezoalpínskej vážskej epoche* (90–15, spodný senón až spodný miocén) progradoval západokarpatský orogénny klin odlišným, indentačno-subdukčným spôsobom. Súviselo to so zmenou kinematiky pohybu veľkých platní v západnej Tethys, predovšetkým so začiatkom konvergencie medzi Afrikou a Jadranom na jednej strane a Európou. Jadranský indenter sa v kontakte so západokarpatským orogénom reprezentovaný pelsónskym blokom najskôr v senóne značne skrátil a modifikoval centrálne, termálne zmäknuté časti pôvodného kolízneho klina a v transpresnom režime exhumoval veporický metamorfný dóm (kohútska fáza). Vo vyšších štruktúrnych úrovniach prebiehala exhumácia „odstrešením" *(unroofing)* pri extenzii paralelnej so smerom orogénu. Kompresívne napätie sa zároveň z indentera prenieslo do čela rigidnej tatrickej platne a tam vznikla zóna podsúvania váhickej oceánskej zóny (selecká fáza). Kompresný režim však zachvátil celé predpolie alpsko-karpatského orogénu, zasiahol hlboko do vnútra severoeurópskej platformy a prejavil sa tam ako tzv. saxónske vrásnenie.

Laterálne extenzné rozpínanie tyla klina viedlo k zníženiu jeho gravitačného potenciálu, a preto v ňom kolízna udalosť čela klina s oravickým kontinentálnym ribónom na hranici senónu a paleocénu vyvolala silnú kontrakčnú udalosť (jarmutsko-zdychavsko-miglinecko-gantská fáza). Eocénny gravitačný kolaps klina (súľovská fáza) pri vrchnooligocénno až spodnomiocénnej beskydskej kolízii akrečného klina so severoeurópskou platformou podobne vystriedala kompresia spätne gradujúca do klina (kamenicko-šumiacko-darnóska fáza). Postupujúci orogénny klin sa teda pohyboval ako húsenica striedaním extenzných a kompresných eventov.

V *neoalpínskej dunajskej epoche* (15–0 Ma, od stredného miocénu po recent) rýchlosť ústupu *(roll-back)* subdukčnej zóny oceánskych domén externých Západných Karpát (najskôr magurskej, potom aj moldavskej) prekonala rýchlosť postupu indentačného klina, čím sa konvergentný systém zmenil z postupujúceho *(advancing)* na ustupujúci *(retreating)*. Výsledkom toho bolo, že sa západokarpatský orogénny systém dostal do všeobecného extenzného režimu (alföldská riftová fáza), stratil svoju identitu a postupne aj integritu. V kompresnom režime fungovala už len jeho na V migrujúca špička, ktorej rast bol podmienený čelnou akréciou sedimentárnych jednotiek zoškrabnutých zo subdukovanej moldavskej litosféry a pasívneho okraja severoeurópskej platformy.

Meliatsky akrečný klin – jeho litológia a metamorfný vývoj

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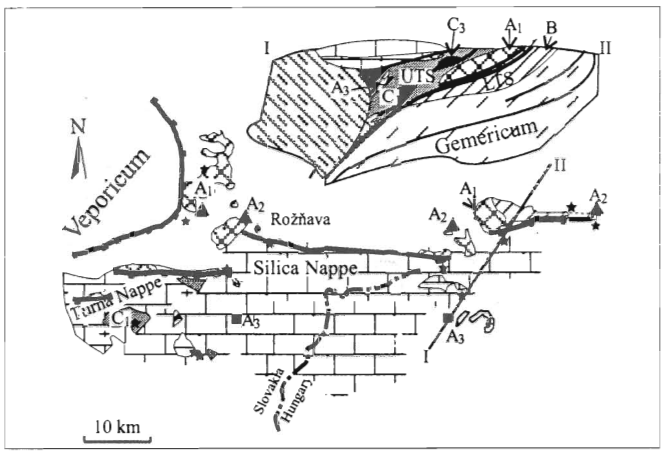
Subdukčné komplexy často obsahujú pestrú asociáciu hornín, ktoré sa navzájom odlišujú nielen litológiou a metamorfným stupňom, ale aj geotektonickou pozíciou protolitu metamorfitov. Pri uzatvorení oceánskeho bazéna sa do subdukčnej zóny dostávajú nielen horniny oceánskeho prostredia, ale aj časti kontinentálnej kôry. Ľahký kôrový materiál vyvoláva vztlak a to vedie k výzdvihu a exhumácii relatívne ťažkej oceánskej dosky. Exhumáciu zvyčajne sprevádza retrográdna premena a deformácia a tie metamorfne zbližujú horniny vyzdvihnuté z rozličných úrovní subdukčnej zóny. Ak je litológia hornín aspoň trochu podobná, možno ich rozlíšiť iba na základe detailnej mineralogickej a geochronologickej analýzy. Meliatska jednotka je typickým príkladom akrečnej prizmy obsahujúcej širokú varietu hornín. Podľa súčasnej pozície, stupňa a veku metamorfózy sa dajú rozlíšiť tri skupiny hornín (obr. 1).



Obr. 1. Schematická geologická mapa a rez znázorňujúce pozíciu hornín meliatskeho akrečného klina. Trojuholníčky označujú horniny fundamentu (A_2), štvorčeky gabrá a bazalty v karbonátovo-evaporitovej melanži (A_3) a hviezdičky výskyty serpentinitu (C_3). Bazalty tvoria malé polohy v slabo metamorfovaných sedimentoch a nie sú na mape vyznačené.

A. Metamorfity fácie modrých bridlíc

A_1. Najbežnejšou horninou je mramor rozličného druhu s polohami metabazaltov, ktoré sa pokladajú za triasovú sekvenciu. Tieto horniny sú súčasťou vrchnej tektonickej šupiny *(Upper Thrust Sheet – UTS)*. Podľa zloženia tvoria bázické horniny prechod medzi bazaltmi MORB a ARC. Súčasťou tejto podskupiny sú glaukofanické fylity, ktoré sa vyskytujú v spodnej časti alebo na hranici tektonických šupín mramoru s bazaltmi. Podľa Ar-Ar metódy je metamorfóza fácie modrých bridlíc strednojurského veku (151–155 Ma). Maximálne P-T podmienky metamorfózy zodpovedajú 13 kbar/460 °C, čo naznačuje hĺbku ponorenia okolo 40 km.

A_2. Horniny starej kontinentálnej kôry, hlavne amfibolity, granaticko-biotiticko-amfibolické ruly a svory. Podľa Ar-Ar veku z reliktného muskovitu (374 Ma) predstavujú variský resp. starší fundament a z hľadiska pozície sa zaraďujú do vrchnej tektonickej šupiny *(UTS)*, aj keď miestami tvoria samostatné tektonické šupiny nasunuté na paleozoikum gemerika.

A_3. Gabrá a metabazalty obsahujúce relikty richteritu a Ti paragazitu a zložením pripomínajú počiatok riftingu. Horniny tohto typu sa vyskytujú uprostred karbonatovo-evaporitovej melanže a zistili sa vo vrtoch pod silickým príkrovom na území Slovenska i Maďarska.

B. Metamorfity prechodu fácie modrých a zelených bridlíc predstavujúce chloritoidové fylity a konglomeráty, ktoré sa považujú za permské. Označujeme ich ako spodnú tektonickú šupinu *(Lower Thrust Sheet – LUS)* a spolu s nadložnou tektonickou šupinou *(UPS)* sú nasunuté na paleozoikum gemerika. Vek metamorfózy sa určil na 172 Ma a P-T podmienky týchto hornín sa odhadujú na 350–400 °C/8–9 kbar (hĺbka ponorenia okolo 26 km).

C. Metamorfity veľmi nízkeho stupňa

C_1. Sedimenty, prevažne pieskovec, pelity, karbonáty, lokálne s rádiolaritmi a silicitmi. Pelitické a psamitické variety tvoria hlavnú časť melanžového matrixu obsahujúceho telesá modrej bridlice a ultramafických hornín. P-T podmienky troch odlišných lokalít sa odhadujú na 3–6 kbar (ekvivalent 9–18 km) a teplota 250–350 °C. Najvyšší tlak sa stanovil pri mylonitizovaných fylitoch fácie modrých bridlíc.

C_2. Bazalty, ktoré z hľadiska chemizmu predstavujú typ MORB, tvoria polohy v pelitoch a psamitoch, ako aj tektonické šupiny v severnej časti gemerika, hlavne na lokalite Jaklovce.

C_3. Serpentinity tvoria telesá rozličnej veľkosti s nie vždy jasnou geologickou pozíciou. Ich zaradenie do skupiny veľmi nízko metamorfovaných hornín je iba predbežné. Ich P-T podmienky sa nestanovili.

Evoluční model meliatského akrečního prizmatu v Západních Karpatech na Slovensku

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Meliatský akreční klín je situován podél jižního okraje Západních Karpat na Slovensku a v severním Maďarsku. Celý klín je kompozitní těleso násunových šupin, jež bylo nasunuto přes nízce metamorfované břidlice basementu gemerika. V tradičním pojetí vznikly LT/HP horniny meliatského klínu během jižní subdukce a následné severovergentní obdukce triasové meliatsko-hallstattské oceánské pánve a jejího severního pasivního kontinentálního okraje. Nová strukturní a petrologická data kombinovaná s Ar-Ar a K-Ar věky chladnutí ukazují, že současná pozice meliatského akrečního klínu je výsledkem dvou oddělených procesů: západovergentní středně jurské obdukce a severovergentní křídové kolizní tektoniky.

Meliatský akreční klín je komplexem násunových korových a oceánských šupin a tvoří ho odzdola nahoru: 1) Spodní násunová deska (SND) složená z křemitých fylitů a konglomerátů permského stáří se zachovanými zbytky metamorfózy stupně nižších modrých břidlic (8–10 kbar, 350–400 °C). 2) Svrchní násunová deska (SvND) tvořena mramory, metabasity a fylity derivovanými z triasového oceánského materiálu a zbytky fundamentu variského stáří metamorfovaného v amfibolitové facii. Všechny tyto horniny byly postiženy výraznou metamorfózou ve facii modrých břidlic (10–13 kbar, 400–450 °C). 3) Velmi slabě metamorfované (4–6 kbar, 300–350 °C) horniny meliatské melanže (MM) tvořené permskými evapority, jurskými břidlicemi, vápenci a pískovci obsahují bloky (olistolity) triasových radiolaritů, vápenců, serpentinitů, gaber a modrých břidlic. 4) Velmi nízce metamorfované až nemetamorfované superficiální příkrovy (turňanský a silický) odvozené z apulského šelfu a tvořené svrchně permskými až jurskými vápenci, břidlicemi, pískovci a místy i vulkanity. Strukturní a metamorfní vývoj meliatského akrečního klínu je charakterizován stavbami a minerálními asociacemi, jež indikují HP subdukční stadium, retrogresi během exhumace a vmístění násunových šupin včetně pozdního zkrácení celého klínu během zablokování střižných násunů. HP deformační stadium D_{1-2} v SND a SvND je charakterizováno penetrativní metamorfní stavbou zapadající k JV, jež nese intenzivní lineaci protažení, jež rovněž zapadá k JV. Metamorfní stavba S_{1-2} v meliatské melanži, jež je spjata s akreční metamorfozou (svrchní jura/spodní křída), je zachována pouze v kompetentních triasových vápencových olistostromách. D_3 deformační stadium – zablokování násunů – je vyvinuto ve všech jednotkách meliatského klínu, jakož i v podložním gemerském paleozoickém fundamentu. Toto stadium je charakterizováno ohybovými vrásami probíhajícími směru S–J a strmou, na VJV zapadající klivází. Křídový kolizní proces byl polyfázový a spjatý s aktivním pohybem rigidního jižního indenteru směrem na S. Křídové stavby lokálně přepracovávají struktury jurského klínu, nicméně jak charakter struktur tak i jejich geometrie se liší natolik, že obě události jsou jasně identifikovatelné.

Krížňanský príkrov na strednom Slovensku – štruktúrny záznam a mechanizmy umiestnenia

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Od objavenia príkrovových a násunových jednotiek ako typických stavebných prvkov kompresných orogénov sa o príčinách ich vzniku a mechanizmov ich presunu diskutuje aj polemizuje veľmi často. Bázou diskusií sa stalo viac fyzikálnych modelov (Hubbert a Rubbey, 1959; Kehle, 1970; Elliott, 1976; Ramberg, 1977), ale tie nevyhnutne problém zjednodušujú, lebo pracujú s homogénnym a izotropným materiálom krehkého, viskózneho alebo dokonale plastického charakteru. Horninové sekvencie – najmä vo vrchnej časti zemskej kôry – však predstavujú anizotropné a mechanicky veľmi heterogénne médium (napr. Price a McClay, 1981), a preto je detailná deformačná analýza pri získavaní informácií o procesoch vedúcich k vzniku a vývoju príkrovových a násunových jednotiek rozličnej mierky stále mimoriadne dôležitá.

Krížňanský príkrov je klasickou príkrovovou superficiálnou jednotkou tvorenou prevažne nemetamorfovanými mezozoickými sedimentárnymi horninami. Jej takmer úplne zachované alochtónne časti navyše plynulo prechádzajú do koreňových subautochtónnych zón, ktoré signalizujú nadväznosť na fundament severného veporika, čo je pri sledovaní deformačného postihu v profile celej jednotky výnimočne výhodné.

Deformačná analýza, ktorú v príspevku prezentujeme, bola zameraná na štúdium štruktúrneho záznamu v nemetamorfovaných alochtónnych sekvenciách. Tie sú typickým príkladom mnohovrstvového súboru charakteristického vysokou anizotropiou vyvolanou častými zmenami litológie, kompetencie, hrúbky vrstiev, ako aj premenlivými vlastnosťami medzivrstvových plôch. Všetky tieto faktory – výrazne ovplyvňujúce vznik, vývoj a povahu štruktúrnej asociácie v deformovaných horninách – sme sa usilovali zahrnúť do našej analýzy.

Terénnymi a laboratórnymi výskumnými metódami sme sa pokúsili dešifrovať sukcesie štruktúrnych asociácií a pracovne sme ich začlenili do piatich deformačných štádií, z ktorých prvé tri, D_1–D_3, veľmi pravdepodobne priamo odrážajú genézu krížňanského príkrovu. Počiatočná kompresia, spätá so skracovaním horninových sekvencií v smere paralelnom s vrstvovitosťou, sa zachovala v podobe štruktúrnej asociácie patriacej do deformačného štádia D_1, ďalšie deformačné štádiá, D_2 a D_3, sú charakteristické rastom strižnej deformácie vyvolanej reorientáciou pôvodných plôch anizotropie, vznikom nových plôch anizotropie (sekundárna anizotropia), ako aj reorientáciou hlavných osí tektonického napätia.

Pri pokuse charakterizovať mechanizmy vzniku a presunu krížňanského príkrovu sme sa opierali o náš výskum, o ďalšie publikované práce (Jaroszewski, 1982; Milovský, 2000; Plašienka, 1981, 1983, 1995a, b, 1999), ako aj o známe teoretické modely (Hubbert a Rubey, 1959; Kehle, 1970; Elliott, 1976; Ramberg, 1977; Chapple, 1978; Davis et al., 1983; Dahlen et al., 1984).

Z našich aj z citovaných prác iných autorov je zrejmé, že mechanizmus vzniku a umiestnenia krížňanského príkrovu nemožno vysvetliť pomocou jednoduchého modelu, lebo deformácia podobných príkrovových jednotiek má zväčša polyštádiový tektonický charakter, odrážajúci zložitý tektonický vývoj. V prípade krížňanského príkrovu deformačné štádiá odrážajú:

1. počiatočné stlačenie sedimentárnej výplne zliechovského bazéna – kompresiu, subparalelnú so smerom pôvodnej vrstvovitosti,
2. kompresnostrižnú (násunovú) etapu deformácie spätú s elimináciou podložia sedimentárnych súvrství a s prvou fázou násunu na jednotky južného tatrika,
3. extenznostrižnú, neskôr extenznú etapu deformácie, odrážajúcu gravitačné (pravdepodobne mechanizmom gravitačného rozpínania) dosunutie (konečné umiestnenie) krížňanského príkrovu (zrejme už spolu s chočským príkrovom) do čela tatrika,
4. popresunovú etapu, riadenú tektonickým vývojom väčších geologicko-tektonických celkov (gravitačný kolaps centrálnokarpatského bloku, pohyby pozdĺž čela centrálno-karpatského orogénneho bloku, aktivita priečnych transformných zlomov a pod.).

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Kedy a ako sa začal výzdvih Tatier?

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V literatúre o Západných Karpatoch sa už vyše troch desaťročí hľadá odpoveď na otázku, kedy boli Tatry vyzdvihnuté do podoby hrastu uprostred sedimentárnych sekvencií centrálnokarpatského paleogénu. Problém zdanlivo vyriešila interpretácia výsledkov FT *(fission track)* analýz apatitu v práci Burcharta (1972), Kráľa (1977), ale najmä v sumárnom diele Kováča et al. (1994). Podľa dominancie FT vekov apatitu (20–10 Ma) sa hlavná fáza výzdvihu Tatier tradične zaraďuje do miocénu. Podľa autorov (l. c.) dáta z apatitu predstavujú vychladnutie horninového bloku pod 100 °C v hĺbke 5 km. V tejto súvislosti treba pripomenúť, že odbornej verejnosti je výskyt bazálnych sedimentov borovského súvrstvia priamo na granitoidných horninách kryštalického masívu Tatier v oblasti Košarísk známy už vyše sto rokov.

Aj keď borovské súvrstvie takmer vždy leží na karbonátových súvrstviach subtatranských príkrovov (Gross et al., 1984, 1993) a litologický výskum autorov (l. c.) tektonický transport na tejto lokalite vylúčil, nemusí to znamenať, že kryštalinikum Tatier bolo výrazne erodované už vo vrchnom lutéte, ako predpokladal Gorek a Scheibner (1966), ale je to náznak, že by sa s ďalším výrazným sedimentačným zaťažením masívu Tatier vo vrchnom paleogéne nemalo počítať.

Výzdvih Tatier sa všeobecne spája s funkciou podtatranského zlomu. Podľa vypukllého tvaru sa mnoho desaťročí pokladal za severovergentný prešmyk s násunom na paleogénne sedimenty Liptovskej kotliny a Spiša (napr. Koutek a Matějka, 1931; Gorek, 1954; Biely a Fusán, 1967). Vrty a geofyzikálne práce potvrdili jeho normálny, poklesový charakter so strmým sklonom na J (Gross, 1973). Je prekvapujúce, že sa ešte nedávno na základe mikroštruktúrnej analýzy (Sperner, 1996) opätovne predpokladal jeho prešmykový charakter s násunom na J na sedimenty paleogénu, ako aj nereálny výzdvih Tatier – viac ako 10 km – v miocéne. Na základe nesúladu s regionálnymi geologickými štruktúrami, problémov pri balansovaní kôrových štruktúr pri výzdvihu Tatier, ako aj v súvislosti s chýbaním súvekého extenzného miocénneho bazéna Spencerov náhľad (l. c.) spochybnil Plašienka (in Janák et al., 2001). Plašienka (l. c.) výzdvih fundamentu Tatier spája s kompresnými štruktúrami v zmysle modelu Narra a Suppeho (1994) najmä v združení zlomových a vrásových štruktúr pozdĺž hlboko založeného listrického zlomu, pričom podtatranský zlom predstavuje čelný subvertikálny poklesový zlom. Na tvorbu zlomových štruktúr často poukazuje aj výskyt pseudotachylitov (tmavých jemnozrnných hornín zložených z taveniny a úlomkov hornín a minerálov z okolia) na zlomoch. Pseudotachylity boli opísané aj z južných svahov Tatier v oblasti Gerlachu – Batizovského plesa a Velickej doliny (Petrík a Reichwalder, 1996). Pseudotachylity však v sutine možno nájsť aj na iných miestach, napr. v Bystrej doline, v Žabích a Hincových plesách. Tieto žilné horniny, späté s tvorbou zlomov, sa datovali Ar/Ar metódou s fokusovanou CW Nd-Yag laserovou sondou spojenou s hmotnostným spektrometrom MAP 215-50 (Open University Milton Keynes) vedno s okolitými biotitickými tonalitmi (Kohút a Sherlock, 2002). Naše nové datovanie potvrdilo, že biotity tonalitov vychladli pred 325 ± 3 Ma, čo je v zhode so staršími výsledkami (Maluski et al., 1993). Štyri vzorky pseudotachylitov sa analyzovali bodovou laserovou sondou (vyše 50 analýz), pričom je relevantný vek získaný zo živcov 36 až 28 Ma. Ojedinelý vyšší vek (nad 65 Ma) ovplyvnila heterogénna distribúcia ^{37}Ar, veľmi variabilný atmosférický Ar komponent, ako aj veľmi nízky obsah K (^{39}Ar). Na tomto základe predpokladáme, že študované tatranské pseudotachylity vznikli ako odraz seizmických otrasov vo vrchnom paleogéne pred 36 až 28 Ma.

Vek tatranských pseudotachylitov sa zhoduje s vekom bazálnych sedimentov – borovského súvrstvia – vyskytujúcich sa na V od Tatier v rámci centrálnokarpatského paleogénu (Buček, 2001). Keďže borovské súvrstvie sa ako hrubozrnný konglomerát skladá hlavne z karbonátov chočského príkrovu, nemožno vylúčiť, že časť materiálu bola deponovaná z nadložia Tatier pri formovaní podtatranského zlomu ako reakcia na transpresno-transtenzné pohyby v strednom až vrchnom paleogéne. Na otázku, kedy sa výzdvih Tatier začal, odpovedáme, že to bolo najpravdepodobnejšie vo vrchnom eocéne až v spodnom oligocéne pri seizmickej aktivite vedúcej k tvorbe podtatranského zlomu, ako aj k začiatku sedimentácie centrálnokarpatského paleogénu. Výzdvih pokračoval v miocéne a kulminoval v pliocénno-kvartérnom období, lebo takéto procesy nebývajú jednoaktové, ale prebiehajú vo viacerých štádiách.

Štruktúrno-magnetické vzťahy medzi granitoidnými masívmi Malých Karpát a ich obalovými jednotkami

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Pred dvadsiatimi rokmi v rámci úlohy *Geofyzikálny prieskum flyšového pásma a vnútrokarpatských jednotiek v západnej časti Slovenska* (1986) boli zverejnené prvé výsledky z merania anizotropie magnetickej susceptibility (AMS) hornín Malých Karpát. F. Hrouda a J. Hanák odobrali a zhodnotili vzorky z 33 lokalít, pričom sa usilovali získať horniny z obidvoch granitoidných masívov, obalových jednotiek a príkrovov. Výsledky prieskumu viedli k záveru, že magnetická stavba granitoidov má výrazne rozdielnu orientáciu: pri magnetickej lineácii aj magnetickej foliácii granitov bratislavského masívu prevláda smer SV–JZ, čo je podobná orientácia, ako majú metamorfované horniny tzv. ostatného kryštalinika. Pre magnetickú stavbu granodioritov a tonalitov modranského masívu a hornín pezinsko-perneckého kryštalinika však bola charakteristická kolmá orientácia – smer SZ–JV – a to viedlo autorov ku konštatácii, že modranský masív spolu s pezinsko-perneckým kryštalinikom tvorí jednu samostatnú geologickú jednotku, ale bratislavský masív

vedno s ostatným kryštalinikom druhú, pričom jedna je voči druhej pootočená približne o 90 stupňov.

Pri metamorfovaných horninách sa dokázala zhoda magnetickej foliácie s metamorfnou bridličnatosťou, čo poukazuje na synmetamorfnosť ich vnútornej magnetickej stavby, ktorá v priebehu výzdvihu Malých Karpát len pasívne rotovala okolo osí vrás.

V rokoch 2001–2002 sa v Malých Karpatoch odobrali vzorky na 105 lokalitách prevažne v kryštalinickom jadre a v jeho obalových jednotkách. Výsledky meraní AMS odhaľujú oveľa komplikovanejší obraz vnútornej magnetickej stavby tohto geograficky neveľkého, ale geologicky rozmanitého pohoria so zložitou stavbou.

Aj keď sa žuly bratislavského typu priraďujú k typom S a granodiority až tonality modranského masívu k typom I granitoidov, rozdiely v objemovej susceptibilite nie sú také výrazné, ako by sa dalo očakávať – priemerné hodnoty pri žulách sú $1{,}3\times10^{-4}$ [SI] a pri granodioritoch $7{,}9\times10^{-4}$ [SI]. Nositeľom magnetickej susceptibility je najmä biotit a v granodioritoch a tonalitoch nestechiometrický magnetit.

Anizotropia magnetickej susceptibility skúmaných hornín nie je vysoká. Maximálny stupeň magnetickej lineácie granitov bratislavského masívu v niektorých prípadoch kolíše okolo 1,05, ale pri väčšine vzoriek neprekračuje hodnotu 1,03. Magnetická foliácia je o niečo výraznejšia, ale nie vyššia ako 1,20, pri väčšine vzoriek iba 1,10. Pri granodioritoch modranského masívu sú hodnoty len o málo vyššie, ale aj tam má magnetická lineácia vyššiu hodnotu ako 1,05 len v niektorých prípadoch, maximálne do 1,26. Miera foliácie je veľmi podobná ako v žulách bratislavského typu. Vo všetkých – nielen v granitoidných typoch skúmaných hornín Malých Karpát – prevláda planárna magnetická stavba nad lineárnou.

Hoci magnetická stavba je na väčšine miest preukázateľne výsledkom alpínskych deformačných procesov, vylúčiť nemožno ani prítomnosť predalpínskych reliktov, a to najmä v interných častiach bratislavského príkrovu (bratislavský masív, pezinsko-pernecké kryštalinikum, baďurská časť modranského masívu). Alpínska štruktúrna stavba je najmä v oblasti modranského príkrovu interferenciou viacerých deformačných režimov (nonkoaxiálny strih pozdĺž násunových plôch, koaxiálna deformácia v systémoch makrovrás) a štruktúrotvorných procesov (nasúvanie, transpresia) v niekoľkých deformačných štádiách a výsledkom toho je aj pomerne zložitý obraz orientácie a intenzity magnetickej stavby.

Podrobnejšia analýza orientácie magnetickej stavby pôvodný predpoklad o vzájomnej rotácii obidvoch granitoidných masívov nepotvrdila ale poukázala na určité rozdiely. Magnetická lineácia ani magnetická foliácia v bratislavskom masíve nemajú jednoznačnú orientáciu. Prevládajú dva smery magnetickej lineácie, a to SZ–JV a Z–V. Póly magnetickej foliácie sa spájajú do neúplného pásu smeru S–J s jedným výraznejším maximom, charakteristickým pre subhorizontálnu foliáciu.

Pezinsko-pernecké kryštalinikum a prevažná časť granodioritov modranského masívu majú oveľa jednoznačnejšie definovanú orientáciu. Magnetická lineácia má smer ZSZ–VJV a smery magnetickej foliácie varírujú najmä v rozmedzí ZSZ–VJV a SZ–JV. Sklon foliačných plôch v jv. časti modranského masívu je mierny až stredný a smeruje prevažne na JZ. V sz. baďurskej časti masívu, ktorá je súčasťou bratislavského príkrovu, je sklon strmší.

Výrazne odlišné smery magnetickej stavby sa zistili v žulových telesách v jz. časti Bratislavy. Na lokalite na Devínskej ceste, na Patrónke a v Lamači (teda v čelných, zvrásnených častiach bratislavského príkrovu) má magnetická lineácia aj magnetická foliácia veľmi podobný smer, a to SSV–JJZ až S–J, čo v predpokladanom koaxiálnom režime poukazuje na pôsobenie maximálnej kompresnej zložky napätia v smere približne V–Z.

Podobný tektonický režim – kompresiu v smere približne JV–SZ – potvrdzuje aj tektonická a magnetická stavba triasových kremencových telies vystupujúcich v jadrách veľkorozmerových ležatých vrás a tvoriacich v mapovom obraze pásy tiahnuce sa v smere približne JZ–SV v jv. časti modranského masívu (modranský príkrov). Aj orientácia magnetickej stavby granodioritov v blízkom okolí kremencových telies zodpovedá vplyvu takejto koaxiálnej deformácie. V južnej časti modranského príkrovu medzi Hrubou dolinou a Modrou má však už magnetická stavba dominantne smer SZ–JV, čo sa dá vysvetliť ako vplyv prevládajúcej nonkoaxiálnej deformácie v strope modranskej jednotky pod násunovou plochou bratislavského príkrovu alebo aj ako vplyv naložených alpínskych deformačných štádií s transpresným charakterom. Výrazne odlišnú a jednotnú magnetickú stavbu majú doteraz zhodnotené vzorky metamorfných hornín subautochtónnej orešianskej jednotky, kde lineácia aj foliácia naznačujú pôsobenie maximálnej zložky kompresného napätia v smere JJV–SSZ.

Paleomagnetizmus terciérnych sedimentárnych jednotiek vnútorných Západných Karpát

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Systematický paleomagnetický výskum paleogénnych a neogénnych sedimentárnych jednotiek slovenských Západných Karpát prebieha už viac ako 20 rokov. Prvé výsledky sú zo začiatku 80. rokov 20. stor. z Malých Karpát a z jablonickej depresie. Výskum potom pokračoval v Bánovskej kotline a v slovensko-maďarskej časti severného okraja panónskeho bazéna. Neskôr sa študovali sedimenty Lučenskej a Rimavskej kotliny, ako aj východoslovenského neogénu. Posledné výsledky sú z centrálnokarpatského paleogénu Oravy a z Liptovskej kotliny. Väčšina výsledkov sa získala v spolupráci dvoch paleomagnetických laboratórií, a to paleomagnetického laboratória Geofyzikálneho ústavu SAV v Bratislave (I. Túnyi) a paleomagnetického laboratória ELGI v Budapešti (E. Mártonová). V geologickej časti výskumu bola najintenzívnejšia spolupráca s M. Kováčom, D. Vassom a E. Köhlerom. Skúmanou horninou bol pieskovec, ílovec, siltovec, sliež, vápenec a vulkanoklastiká. Vek vzoriek varíroval od eocénu po vrchný miocén. Horniny prejavovali normálnu aj reverznú magnetickú polarizáciu. Odobrali sa vzorky z viac ako 100 lokalít a odkryvov, ale po testoch stability sa ukázalo, že paleomagnetické parametre spoľahlivosti z nich spĺňa len asi tretina.

Paleomagnetické smery. V západnej časti centrálnych Západných Karpát poskytli relevantné výsledky vzorky desiatich lokalít (Lieskové, Vlasáčka, Naháč, Hradište, Sobotište, Podbranč, Krajné, Soľošnica, Roh a Omastiná). Všetky vzorky vykazovali západnú rotáciu (proti smeru hodinových ručičiek, ďalej CCW rotácia – *counter clock wise*.) Keď sa odhliadne od extrémnej CCW rotácie vrchnopaleocénnych až spodnoeocénnych pieskovcových telies lokality Roh (116°), spôsobenej zrejme tesnou blízkosťou bradlového pásma, najväčšiu CCW rotáciu vykazovali pieskovcové telesá egenburgu lokality Sobotište (82°) a najmenšiu pieskovce karpatu Vlasáčky (17°) (Kováč et al., 1989; Túnyi a Kováč, 1991; Márton et al., 1992; Kováč a Túnyi, 1995; Túnyi a Márton, 1996).

Zo severného Maďarska sa získali paleosmery zo vzoriek sedimentov eocénu a oligocénu troch lokalít (Lábatlan, Esztergom-Vár hegy a Esztergom-Bassa út). Všetky mali CCW rotáciu, najväčšiu siltovcové oligocénne vzorky lokality Esztergom-Vár hegy (67°) a najmenšiu oligocénne slieňové vzorky lokality Esztergom-Bassa út (45°; Márton et al., 1992; Túnyi a Márton, 1996).

Na južnom Slovensku boli pozitívne výsledky zo sedimentov šiestich lokalít Rimavskej a Lučenskej kotliny (Čakanovce 1, Čakanovce 2, Lipovany, Veľké Straciny, Tachty a Tornaľa). Všetky mali CCW rotáciu, najväčšiu ignimbrity egenburgu z Lipovian (94°) a najmenšiu vzorky šlíru egeru z Tornale (56°; Márton et al., 1996; Vass et al., 1996).

CCW (západnú) rotáciu terciérnych sedimentárnych panví južného Slovenska potvrdili aj vzorky sladkovodného vápenca eocénno-oligocénneho veku lokality Drienovec, a to približne 90° (Túnyi et al., 1999).

Zaujímavý výsledok poskytli vzorky z kontaktného dvora andezitu a tepelne metamorfovaného pieskovca lokality Šiator pri Fiľakove. Horniny nevykázali nijakú rotáciu. Keďže sa vek intrúzie datuje do bádenu, možno predpokladať, že sa rotácia blokov južného Slovenska skončila pred bádenom, najneskôr v spodnom bádene (Orlický et al., 1995).

Na východnom Slovensku sa získali paleorotácie z deviatich lokalít (Hrádok pri Michalovciach, Lesné 1, Lesné 2, Oreské, Kučín, Nižný Hrabovec, Lada, Slančík a Svinica). Potvrdila sa CCW rotácia (najväčšia pri strednobádenskom zeolitickom tufe z Nižného Hrabovca), ale na rozdiel od stredného Slovenska, kde sa rotácie skončili v bádene, vykázal andezit stredného sarmatu lokality Slančík CCW rotáciu 22° a až vrchnosarmatský tuf lokality Svinica a postsarmatský ryolit lokality Hrádok nevykázali nijakú rotáciu. Z toho vyplýva, že vo východoslovenskej neogénnej panve prebiehali rotácie ešte aj v sarmate (Márton et al., 2000).

Zložitejšie paleorotácie poskytli vzorky pieskovca typových lokalít centrálnokarpatského paleogénu Oravy. Najstaršie, z lokality Borové (stredný – vrchný eocén), potvrdili miernu CCW rotáciu, mladšie, zo Zuberca (vrchný eocén), miernu východnú rotáciu v smere pohybu hodinových ručičiek; (CW – *clock wise*) a najmladšie, z Bieleho Potoka (spodný oligocén), nevykázali prakticky nijakú rotáciu (Túnyi a Köhler, 2000).

Podobné, ale doteraz nepublikované výsledky naznačuje aj paleomagnetický výskum desiatich lokalít centrálnokarpatského paleogénu Liptovskej kotliny (získané pri riešení úlohy Tektogenéza Západných Karpát). Ukazuje sa, akoby bloky z J kotliny mali východnú (CW) rotáciu a bloky zo S kotliny západnú (CCW) rotáciu.

K terciérnym CCW rotáciám centrálnych Západných Karpát možno pripočítať paleosmery triasových vápencových telies piatich lokalít silického príkrovu (Silica, Silická Brezová, Čoltovo, Hrušovo a Drienčany). Pri všetkých sa zistilo postmezozoické premagnetovanie a CCW rotácia varírovala medzi 30 a 40° (Kruczyk et al., 1998).

Pre úplnosť treba dodať, že sa paleomagnetickému výskumu terciérnych hornín slovenských Západných Karpát venovali aj iní autori. Paleosmery z vonkajšieho flyša duklianskej jednotky a Oravskej Magury publikoval Koráb et al. (1981) a Krs et al. (1991). Stredoslovenské neovulkanity skúmali Pagáč (1986) a Orlický et al. (1996) a neovulkanity východného Slovenska Orlický et al. (1970, 1974). Ich výsledky poukazujú na nijaké alebo len mierne CCW rotácie skúmaných jednotiek.

Paleomagnetický výskum terciérnych sedimentárnych jednotiek centrálnych Západných Karpát zistil ich generálnu CCW rotáciu. To naznačuje, že mechanizmus spôsobujúci rotáciu blokov spočíva v regionálnej tektonike. Západné rotácie sú v zhode s ideou presunu horninových más počas tektonického úniku v smere JZ–SV.

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Geologická a tektonická stavba severozápadného okraja Lúčanskej Fatry

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Na geologickej stavbe skúmaného územia sa zúčastňujú tektonické jednotky tatrika, fatrika a hronika. Stratigrafický rozsah tatrika je spodný trias až spodná jura. Vyčlenila sa nová litostratigrafická jednotka *súvrstvie Slávikovej doliny,* ktorá zahŕňa sedimenty najvyššieho triasu (?) až spodnej jury. Granitový masív Malej Fatry v profile prieskumnej štôlne Višňové – Dubná skala nie je homogénnym telesom, aj keď v profile tunela dominujú tonality. Vek granitoidov sa Rb/Sr rádiometrickým datovaním stanovil na 337 Ma. FT analýzy akcesorického apatitu preukázali vek schladnutia pod teplotu 100–120 °C okolo 14,5 Ma. Vek schladnutia pod 60 °C je medzi 3,6–8,8 Ma.

Fatrikum sa skladá z dvoch čiastkových štruktúr. Spodnejšiu tvorí komplex hornín ďurčinskej sekvencie (mladšie paleozoikum – spodná krieda). Do ďurčinskej sekvencie fatrika zaraďujeme mladopaleozoické sedimenty tzv. antiklinály Kozla. Vyššiu štruktúru tvoria horniny zliechovskej sekvencie (stredný trias – stredná krieda). V rámci ďurčinskej sekvencie sa vyčlenili nové litostratigrafické jednotky. Kamennoporubské súvrstvie reprezentuje sedimenty permu. *Jedľovinské vrstvy* je nový názov pre bazálnu časť súvrstvia karpatského keuperu reprezentovanú karbonátovými brekciami. Ďurčinské vápence sú telesá svetlého masívneho vápenca stratigraficky sa viažuce na vrchnú juru až spodnú kriedu.

Hronikum sa vyskytuje iba v denudačných reliktoch na sz. okraji skúmaného územia.

V horninách lúčanského komplexu kryštalinika tatrika sú zachované relikty hercýnskej tektonickej stavby modifikované alpínskymi tektonickými deformáciami. Paleoalpínske deformácie prebiehali v strednej až vrchnej kriede. Hlavným prejavom je presun príkrovov v smere od JV na SZ. Neoalpínske deformácie mali podobu kompresie a sinistrálnej transpresie smeru SZ–JV v spodnom miocéne. Vo vrchnom miocéne dominovala extenzia smeru SZ–JV. Neotektonická etapa (pliocén? – recent) sa vyznačuje extenziou v smere SV–JZ. Odraznosť vitrinitu reflektuje rozličnú premenu horninových súborov z hľadiska ich tektonickej histórie. Ako významná sa ukazuje miera teplotnej premeny neogénnych sedimentov pri západnom okraji Turčianskej kotliny, čo potvrdil aj výskum FT vekov.

Geológia a tektonika Turčianskej kotliny

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Sedimentárna výplň miocénu Turčianskej kotliny sa člení do viacerých novodefinovaných súvrství a vrstiev, ktoré sa spoločne označujú ako turčianska skupina (?sarmat až pliocén). V sedimentárnej výplni Turčianskej kotliny možno na báze sedimentov spodného miocénu rozlíšiť diskordanciu D_1, ktorú reprezentuje rakšianske súvrstvie egenburského veku, diskordanciu D_2, znamenajúcu začiatok sedimentačného cyklu turčianskej skupiny, diskordanciu D_{2a}, sčasti sledovateľnú v rámci turčianskej skupiny, a na rozhraní pliocénnych sedimentov turčianskej skupiny a sedimentov pleistocénu diskordanciu D_3.

V čase sedimentácie hornín turčianskej skupiny bola Turčianska kotlina izolovaným sedimentačným bazénom s jazernomočiarnou sedimentáciou, čo potvrdzujú nálezy endemickej fauny *(Kosovia, Papyrotheca, Pyrgula, Congeria),* litologická povaha sedimentov a bohaté nálezy flóry. Prepojenie so širším okolím – opätovne potvrdené faunisticky – bolo len vo vrchnom panóne až ponte.

Subsidencia Turčianskej kotliny sa začala v (?)sarmate, keď bola kompresná os paleonapätia orientovaná v smere SV–JZ. Najvýznamnejšie boli poklesové zlomy pri jej západnom okraji, ony spôsobili výraznú deniveláciu reliéfu a smerom do kotliny bol zo Z prinášaný hruboklastický materiál v podobe veľkých výplavových kužeľov. Litologické zloženie materiálu odráža litologický charakter zdrojových oblastí klastík. Osová časť kotliny sa naopak vyznačovala pokojnou sedimentáciou len s občasnými vpádmi hruboklastického materiálu. Na dlhodobú tektonickú aktivitu zlomov pri západnom okraji kotliny poukazuje uniformné uloženie sedimentárnej výplne so sklonom na Z resp. SZ.

Sekvenčná analýza magurského bazéna z pohľadu smerov turbiditných prúdov

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Analýzou smerov turbiditných prúdov a sedimentárnych štruktúr možno zistiť dynamiku lalokov, vejára aj bazéna. V sekvenčnej analýze lalokov sa pracuje s dohora hrubnúcimi a dohora sa zjemňujúcimi cyklami.

Terénne pozorovania ma priviedli k zavedeniu klastických cyklov, pri ktorých sa hrubnúci či zjemňujúci trend dá sledovať, ďalej pelitických cyklov, kde takýto trend nebýva sledovateľný, a nepravidelných cyklov, ktoré sú kratšie a vyvinuté nepravidelne. Pri určovaní cyklov používam parametre, ako je hrúbka vrstvy, pomer pieskovec/ílovec, vyvinutie sedimentárnych štruktúr (Boumove intervaly), erózia bázy, výskyt sklzov, slieňovcov a i., ale pohľad do priestoru umožňujú iba smery prúdov.

Klastické cykly sú produktom plynulej laterálnej migrácie laloka. Masívne Ta – Tab pieskovce sedimentovali z hustejšej časti blízko osi prúdu (laloka). Stenčovanie vrstiev je výsledkom vzďaľovania sa osi laloka, čo býva pozorovateľné aj pri plynulej zmene smeru prúdov.

Pelitické cykly prevažne tvorí tenkovrstvový a pelitický flyš. Časté sú pelagické polosiderity a slieňovce. Smer prúdov je výrazne stabilný, ale väčšinou iný ako pri tenších vrstvách klastického cyklu, pri ktorých sa aktívny lalok výrazne vzdialil, čo dokonca môže súvisieť s eustatikou alebo klímou. Ílovcová poloha hrubá až niekoľko metrov môže pri úplnom odklonení laloka prekryť suprafán.

Zo štúdia mi vyplynuli nasledujúce všeobecné závery: vo vejári je jeden alebo viac lalokov; os laloka (koryto) sa rozvetvuje do slabších radiálnych vetiev s odlišným smerom, ako mala os laloka; laloky laterálne migrujú, môžu náhle zanikať „uškrtením" alebo vznikať pretrhnutím hrádze.

Na väčšom území v oblasti Javorníkov som analýzou smerov turbiditných prúdov a sedimentárnych štruktúr sledoval, ako v magurskej jednotke v čase (kampán – mladší eocén) vnikali do bazéna laloky a vejáre z rozličných strán bazéna a s rôznym petrografickým zložením, ako aj priestorové a časové rozšírenie. Navzájom sa stýkali a prestupovali. Prúdové smery umožňujú lepšie chápať rozloženie a migráciu vejárov v bazéne.

Slovenská geologická spoločnosť pri SAV

Súhrnná správa o činnosti za rok 2002

Pobočky: 3 (Bratislava, Banská Bystrica, Košice)
Sekcie: 13 odborných skupín podľa špecializácie (geofyzikálna, geochemicko-mineralogická, hydrogeologická, inžinierskogeologická, ložisková, paleontologická, sedimentologická, štruktúrno-geologická, vulkanologická, ropnej geológie, uhoľnej geológie, zberateľov nerastov a skamenelín a gemologická)
Komisie: 1 (pre mineralogickú nomenklatúru a terminológiu)

Organizačné akcie

V roku 2002 zasadal rozšírený výbor SGS dva razy a užší výbor (podľa potreby) viac ráz.

Výbor SGS:
doc. RNDr. Dušan Plašienka, CSc. – predseda
doc. RNDr. Peter Reichwalder, CSc. – podpredseda
RNDr. Ladislav Šimon, PhD. – vedecký tajomník
RNDr. Ľubica Iglárová – hospodárka
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RNDr. Pavel Uher, CSc. – člen
RNDr. Milan Kohút, CSc. – člen

Na zlepšenie komunikácie s členskou základňou (informácie o akciách, perspektívne adresár, diskusné fóra) má SGS www stránku http://dionysos.gssr.sk/sgs.

Odborná činnosť

Vedecké konferencie

SGS sa v roku 2002 zapojila do organizovania niekoľkých medzinárodných vedeckých akcií, najmä 17. kongresu Karpatsko-balkánskej geologickej asociácie, jej členovia sa zúčastnili na príprave a realizácii radu ďalších vedeckých podujatí na Slovensku aj v zahraničí a boli autormi alebo spoluautormi veľkej časti na nich prezentovaných odborných referátov alebo posterov.

Semináre a prednáškové popoludnia

Základom vedeckej aktivity SGS boli jednodňové tematické odborné semináre, prednáškové popoludnia a individuálne prednášky. V roku 2002 bolo 26 akcií tohto druhu, predniesloa sa na nich 58 prednášok autorov alebo autorských tímov a v auditóriách sa vystriedalo vyše 450 účastníkov. Organizátorom boli odborné skupiny a pobočky SGS (prehľad akcií je v prílohe).

Ostatné odborné akcie

SGS bola spoluorganizátorom študentskej exkurzie na talianske sopky 11.–24. septembra 2002, na ktorej sa zúčastnilo 47 univerzitných študentov a geológov.

SGS sa s geologickým oddelením Prírodovedného múzea Slovenského národného múzea zapojila do organizovania 19. medziná-

rodného stretnutia zberateľov nerastov a skamenelín, ktoré sa konalo 7. decembra 2002 v Bratislave. Zúčastnil sa na ňom rekordný počet vystavovateľov (77, z toho 57 zo Slovenska, 18 z Českej republiky a 2 z Maďarska) a okolo 1000 návštevníkov. Takéto akcie významne pomáhajú pri propagácii geologických vied medzi širokou verejnosťou.

Zahraniční lektori

V rámci akcií SGS boli v roku 2002 prednášky 15 zahraničných lektorov (z Českej republiky, USA, Rakúska a Nemecka).

Edičná činnosť

SGS sa rovnako ako v predchádzajúcich rokoch zúčastňovala na vydávaní časopisu Mineralia Slovaca, periodika SGS a slovenských geologických organizácií. V roku 2002 vyšlo šesť čísel jeho 34. ročníka. Časopis publikuje vedecké štúdie a odborné články z geovedného výskumu na Slovensku, ktorých autormi sú väčšinou členovia SGS. Prílohou periodika je Geovestník, informačný spravodajca pre geológiu, baníctvo a životné prostredie, ktorého veľkú časť tvoria aj informácie o SGS – polročné harmonogramy akcií pobočiek a odborných skupín, správy o činnosti, informačné a koncepčné materiály, zdravice jubilantom, nekrológy, informácie o medzinárodných podujatiach, recenzie, abstrakty z odborných akcií SGS (konferencie, semináre, prednášky a pod.), náučno-populárne príspevky z geológie, informácie o trendoch jej vývoja doma a vo svete, ako aj rozličné geologické zaujímavosti.

Keďže periodikum Mineralia Slovaca je geologickej verejnosti na Slovensku známe už vyše troch desaťročí a prístupné – jeho predplatitelia členovia SGS majú výraznú zľavu, hodnotíme formu publikovania materiálov SGS a komunikácie s členskou základňou za stále najvýhodnejšiu. Oceňujeme aj to, že hoci časopis aj v roku 2002 zápasil s finančnými ťažkosťami, má stále vysokú odbornú úroveň, výbornú techniku tlače a väčšinou aj periodicitu.

Príspevok SGS na jeho vydávanie vo výške 8000 Sk bol v roku 2002 uhradený z dotácie RSV pri SAV.

SGS bola aj spoluvydavateľom (bez finančného príspevku) konferenčných materiálov (osobitné číslo časopisu Geologica Carpathica, exkurzný sprievodca) 17. kongresu Karpatsko-balkánskej asociácie.

Členská základňa

Počet členov SGS dlhodobo mierne klesá. Ide zväčša o dôsledok útlmu aktivity najmä v oblastiach pôsobenia mimobratislavských pobočiek. To je príčina, pre ktorú sa zrušila žilinská aj spišsko-novoveská pobočka SGS. Nezáujem o ďalšie platené členstvo sa prejavuje najmä u členov odchádzajúcich do starobného dôchodku alebo prechádzajúcich do iných profesií. Utvorilo sa aj viac profesijných geologických asociácií, v ktorých je organizovaná aj väčšina členov SGS, a tak časť z nich (najmä pôsobiacich v súkromnom sektore) stráca o členstvo v SGS ako vedeckej spoločnosti záujem. Preto sa zrušilo členstvo ďalším členom, ktorí dlhodobo neplatili členské príspevky. Prijímanie nových členov hlavne z radov univerzitných študentov a absolventov univerzitného štúdia doteraz úbytok členov nekompenzuje. Dobrým konštatovaním je, že sa pokles počtu členov SGS na jej odbornej aktivite doteraz záporne neprejavil. Je to signál, že SGS opúšťajú najmä pasívni členovia.

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SGS je od roku 1993 členom Asociácie európskych geologických spoločností (AEGS), ktorej hlavným cieľom je upevňovanie kontaktov, výmena skúseností a myšlienok medzi európskymi geologickými spoločnosťami, ako aj spolupráca s mimoeurópskymi organizáciami. Plenárne zasadnutia AEGS sa konajú každé dva roky a spájajú sa s vedeckými konferenciami.

Členský príspevok SGS v AEGS je 100 EUR a za rok 2002 sa uhradil prostredníctvom RVS pri SAV z prostriedkov MŠ SR.

Bratislava 24. januára 2003 *Doc. RNDr. Dušan Plašienka, CSc.*
predseda SGS

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