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COVER: A panoramatic view on the Gemeric unit in the area of Dobšiná town – the childhood place and initial research area of Prof. Ing. L. Rozložník, DrSc. The isolated hills – like Radzim hill at the horizon – belong to Silica nappe klippes. The Kohút zone basement rocks of the Veporic unit form the right side of the shot. Photo by T. Sasváry.

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Foreword

The present issue of the Mineralia Slovaca contains the short communications and papers as well as posters presented at the international Conference devoted to "Geology and prospecting in the Carpathians".

The Conference was held from 4th to 6th September 2000 in Herľany. It was organised by the Department of geology and mineralogy of the BERG Faculty, Technical university Košice in co-operation with Geological Survey of the Slovak Republic, Slovakian Geological Society, Slovakian Mining Society and Association of Metallurgy, Mining Industry and Geology of the Slovak Republic. The conference was organised within the framework of the 50^{th} anniversary celebration of the establishment of the Dept. of geology and mineralogy. The Department was established in Bratislava and subsequently transferred to the newly re-established Polytechnics in Košice that later has become the Technical university in Košice.

The Conference was also dedicated to the honour five founder members of the Department – Professor Ján Šalát, Professor V. Zorkovský, Professor L. Rozložník, Professor V. Radzo and Assoc. Prof. R. Marschalko. Their work in conjunction with the work of other members of the Department – who worked there at that time – has laid the groundwork for the research and teaching in knowledge areas selected as leading subjects of this Conference.

The aim of the conference was to present the latest results in the area of geological research and prospecting in the Carpathians. The Conference and the excursions were attended by 80 participants from 7 countries. The participants presented 48 papers and 15 posters.

The conference had 3 sessions. The first was devoted to the Western Carpathian Internides (dedicated to the memory of Professor Rozložník), the second to Carpathian Neovolcanites (dedicated to the memory of Professor Šalát) and the third to Eastern Slovakian Tertiary Basins (dedicated to the work of Professor Zorkovský, Assoc. Prof. R. Marschalko and Professor Radzo). The first session, chaired by S. Jacko, M. Grecula and T. Sasvári) has 3 subsessions (Tectonometamorphic evolution; Origin of mineralised structures, their spatial and temporal relationships; Economic potentials for the coming millenium). The second session (chaired by F. Zábranský, M. Kaličiak and J. Lexa) consisted of 3 subsession – Internal structure and geophysics of volcanoes; Magmatic processes, their products and temporal relations of the volcanism and Causes of mineralisation variability and deposit perspectives of volcanoes. The third session (chaired by M. Zacharov, J. Janočko and S. Karoli) was subdivided to the following subsessions: Geodynamic evolution of basins; Sedimentology of basin fills and Economic potential and perspectives of the basins.

There were 3 excursions linked to the Conference. One (managed by T. Sasvári, M. Grecula and Z. Németh) dealt with the mined deposits of the Gemeric unit, the second (managed by B. Žec, P. Bačo and M. Repčiak) dealt with the Neovolcanites of Slánske vrchy and Vihorlat, the third (managed by J. Janočko, S. Jacko Jr. and S. Karoli) went to the Neogene and Paleogene of the E. Slovakian region.

The Proceedings contains also the short biographies of Professor Šalát, Professor Zorkovský, Professor Rozložník, Professor Radzo and Ass. Professor R. Marschalko.

The organizers like to express their thanks for the financial support to Slovak VEGA grant Agency (Grant No. 1/7389/2) and to the following organizations: Association of Metallurgy, Mining Industry and Geology of Slovak Republic, Geological Survey of the Slovak Republic, Slovak Geological Society, Management of TU Košice, SAPTU Foundation of TU Košice, Betox JSC. Košice, SMW JSC. Jelšava, Uranpress Ltd. Spišská Nová Ves, TESCO Košice, ŽELBA-Siderite JSC. Nižná Slaná, GEOLOGIA JSC. Spišská Nová Ves, MASEVA JSC. Košice, Slovak Mining Society, Slovak Mining JSC Hodruša-Hámre and ŽELBA JSC. Spišská Nová Ves.

I hope that this Special volume of the Mineralia Slovaca will bring you a lot of new information concerning the geology of the Carpathian region and will stimulate further researches in these areas.

Stanislav Jacko

Professor Ladislav Rozložník DrSc.

Professor Rozložník was born in Rákoš, situated in the Central Gemer in 1930 into a teacher's family. He was one of the founders of the Department of Geology and mineralogy and of the Mining Faculty, Košice Polytechnics. His career was also linked to this Department, where – apart from his engagements abroad – he worked up to his untimely demise on the 8th of October 1990.

Professor Rozložník finished his secondary school education in Rožňava in 1948. Influenced by the mining tradition of the Gemer region, he started his university studies in 1948 at the Slovak Polytechnics in Bratislava. He graduated from that HEI as a mining engineer in 1952. After graduation, when the Polytechnics was re-instituted in Košice, he joined it as a lecturer at the Dept. of Geology. In 1962 he became a reader. In the period of 1964–1966 he was the Head of the Department of Geology and Mineralogy. He became a full professor in mining geology in 1969. In 1976 he successfully completed his DrSc. Thesis – at that time the highest science degree available to senior scientists. From 1973 till 1974 he was the Director of the Mineral Research Laboratory of the Mining Faculty. He was twice the Vice-dean for science and research and in the 1971–1972 period was the Dean of the same Faculty. He served also two terms (1965–1966 and 1972-1985) as a Vice-chancellor of the Polytechnics in Košice.

He was a hard working researcher and devoted much of his time to the development of geology. He also participated in the organisation of conferences such as the Conference of the Slovak Geological Society in Košice (1975), the "Mining and Geology Days" in Zlatá Idka (1979, 1981, 1984). He was an appointed expert of the Commission for the classification of mineral deposits since 1972 and he was also its Vice-president. For long years he was the member of Slovak Geological Board, of the Council of the Slovak Academy of Science for the Earth and Planetary Sciences and in the period of 1979–1990 he was the chairman of the Committee for the presentations of DrSc. dissertations in the area of geology, deposits and geophysics.

Though Professor Rozložník founded the application of petrostructural methods in the analysis of poly-stage genesis of metamorphosed complexes of Western Carpathians (1961, 1965), and authored a number of papers on petrography, petrophysics and metallogeny, his main area of scientific interest was the interpretation of the development of ore field structures. On the basis of complex analysis of ore structures and ore fields of the Gemericum unit, he formulated an objectively conceived model of the poly-phase development of the mineralised structures and of its specific traits in the Internides of the Western Carpathians. An analogous approach to the investigation of the development of the Schemnitz (Banská Štriavnica) Ore Field resulted in a scientifically grounded discovery of a new i. e. impregnated vein-type mineralisation.

Professor Rozložník and the team of his co-workers contributed significantly to the elucidation of the genesis of the tungsten mineralisation in the Low Tatra Mts. (1990). He concluded his research on his native Gemer as a co-author of two chapters in a monograph "Gemer – Malohont" (1990).

Professor Rozložník was active also in the field of international projects. He was active in the Task force IX – Multilateral cooperation between the Academies of the Socialist countries, in the International Association for the Genesis of Ore Deposits (IAGOD) and he worked also as a chief geologist of the Cuban mines (1963–1964). There he made the inventory of the mineral resources of Cuba. He participated also in mobilities to USSR, Hungary, Bulgaria, Yugoslavia, Sweden, Austria, Spain and Mexico.

He has a list of more than 100 research papers, he was the chief co-author of the textbook "Mineral deposits and their survey" (1972). He successfully guided 30 PhD students. For his work in science he was awarded a number of distinctions: "For exceptional work", "For loyalty in work", the "Gold medal of D. Štúr", "For merits in development" and "Klement Gottwald State price" (1982).

His legendary modesty, his perseverance, energy for work, his high standards for work quality, understanding for his co-workers and their research problems makes him a model scientist and teacher for the generations to come.

Stanislav Jacko

Professor RNDr. Ján Šalát

Professor Šalát was born on 9 May 1919 in Udavské, Distr. Humenné. After finishing his secondary school studies in Michalovce, in 1940 he started his studies at the Faculty of Natural Sciences of the Comenius University in Bratislava. Due to family reasons he had to partly break his studies and up to 1946 to work as a secondary school teacher in Dolný Kubín. In the mean time he finished his university studies extramurally. In 1946 he returned to the Mineralogical an Petrological Institute of the Comenius University and worked under supervision of Professor Lukáč. Along with his teaching work, he started also his research activity and he was awarded the degree of Doctor of Natural Sciences in 1949. In 1952 he was appointed as a deputy reader. In the same year he went to the newly reestablished Polytechnics in Košice, where he was appointed as a reader and Head of the Dept. of Mineralogy and Petrology.

At his new workplace whe started to build the Department with huge investments of energy and skills. He made the Department functional and recruited a very able team both in research and teaching. The Department started educating a new generation of geologists and mining engineers. They did research oriented to the investigation of petrological and mineralogical problems of the Western Carpathians. He coordinated a number of state research projects in those areas. In 1956 the Dept. of Mineralogy and Petrology was forced to merge with the Dept. of Geology. In 1957 however, he established the Mineral Research Laboratory of the Mining Faculty of the TU Košice. He was the Director of that Laboratory up to the end of his life. He was always willing to support new lines of research and to share his knowledge and resources with his colleagues and specially with those in whom he sensed deeper interest in his science area. Between 1957–1961 he served a Term as a Vice dean for international relations and in 1958 became the Dean of the Faculty. At the same year he became a full professor of mineralogy and petrology.

During his work at the Faculty of Natural Sciences of the Comenius University in Bratislava and then at the Mining Faculty of the Technical University, he was a member of the Czechoslovak society for mineralogy and geology and was one of the founding members of the Slovak Geological Society in Košice. He was the Chairman of the latter society since 1952. Since 1962 he was an extra-ordinary member of the Geologische Gesellschaft der DDR. He was also the member of a number of committees, science councils like that of the Slovak Academy of Science in Bratislava, of the Carpathian and Balkanian Geological Association and others. Under his chairmanship, the 10th Conference of the Czechoslovak Society for Mineralogy and Geology was organised in 1956. The conference was very well received by the professional community.

Professor Šalát was above all a very inspiring and enthusiastic teacher. He liked very much the work with students. He understood them, their problems, was willing to make fun when appropriate, but he had a prodigious memory (he monitored the professional development of all his students) and demanded a high level of knowledge from them. He himself was a very active scientist and literally lived with his research. Later he has led a number of prominent scientists and researchers within the whole Slovakia. He had a very good feel for starting new lines of research. Even under those difficult times, he managed to attract leading scientists from all over the globe to Košice. He had a great number of study trips to various parts of the COMECON and also to some parts of Western Europe. Thus he made his Laboratory and the Faculty a place well recognised abroad. As early as in 1967 he started supporting computer related petrological research at his own Institution.

The name of Professor Šalát is this indelibly written into the history of development of the mineralogical and petrological research in Slovakia. He had an extensive number of published and unpublished works. They were oriented mainly to the petrological and mineralogical research of the Neogene volcanism of the Western Carpathians. His groundbreaking works in the Schemnitz Mts (Štiavnické pohorie) as well as in the area of East Slovakian neovolcanites, laid the foundation of modern, systematic petrological research in those areas. He has publications also related to the Čierna hora Mts., Spiš Gemer Ore Mts. and much of his efforts went also to the area of petrological classifications, where he was the first in Slovakia to use also computer classifications. He had led a number of industry related projects both for the geological and mining industry. It has to be noted that in the early 60-ies he did a research into the properties of perlites and published a book on them and thus helped a significant industry to start. An overview of his research papers is given in Mineralia Slovaca, 5, 4, 589–591.

As a professor of Mineralogy and petrology he skilfully selected gifted students and gave them special attention. Some he oriented to applied research and some to scientific research. From among his students Ján Slávik DrSc. deserves special mention. He was a leading person of the geological investigation of the Western Carpathians and also founder and founder-director of the Slovak Geological Office in Bratislava (1969).

Professor Šalát was an outstanding member of the mineralogical and petrological science community in Czechoslovakia. He was known at home and abroad through his numerous contacts and publications. He was known by scientists and industrial professionals as well. He educated generations of engineers. At the beginning of 70-ies the heavy load of problems related to the spirit of the time made him gravely ill. In spite of that he still inspired and overviewed the 1st International Symposium on Inter-science applications in mineral science and technology (1972) where pecialists from Czechoslovakia, Hungary, Poland, Romania, USSR, UK, Japan and other countries attended. He continued to work up to his demise on 12 November 1973 at the age of 54 years. Many of his visions remained unfinished, but nevertheless, his accomplishments command true respect.

Jozef Slavkovský

Professor RNDr. Vojtech Zorkovský

Professor Zorkovský was born on 6 January 1920 in Dulice, District of Martin. He completed his secondary-school education in Martin and he graduated therefrom in 1939. Between 1939–1943 he studied at the Faculty of Natural Science of the Comenius University in Bratislava. After graduation he began working as a lecturer at the Geological Institute of the Slovak Polytechnics in Bratislava. Here, under the guidance of Prof. D. Andrusov, he intensively participated in pedagogic work and also in scientific research of basic or applied character. The results of the scientific research concerning "petrography and petrochemistry of basic rocks of the Mesozoic series" was compiled in his viva-voce by which dissertation in 1947 he was awarded the title of Doctor of Natural Science. During the period of 1947–1952 he participated in research aimed at the survey and evaluation of clay, bauxite and other deposits.

In 1952, on the basis of the assessment of his achievement, he was appointed as a Senior lecturer assigned to lead the Department of Geology at the newly reestablished Faculty of Mining of the Polytechnics in Kosice. After his arrival to Kosice he started with a great zeal to build a new workplace which, in a very short period of time, took a dignified position among other geological institutions in Czechoslovakia. Later his Department united with the Department of Minerolgy and Petrology. In 1958 he became a full professor of the geology of mineral deposits. Apart from pedagogic work and research he took active part also in the management of the Faculty of Mining of the Polytechnics in Kosice, where he was a Dean of the Faculty for two terms- between 1954–1957 and 1959–1960.

The research and pedagogic activities of Prof. Zorkovský cover a wide spectrum. Research-wise he aimed at investigating the problems of petrology of Mesozoic and Tertiary volcanic rocks. He was the first to give a petrologic characteristic of Permian and Mesozoic basic rocks of the Western Carpathians. He began applying the garnet research in his work on petrologic problems related to andesites and rhyolites of Western Slovakia. Next of his research interests was the investigation of metallic and non-metallic mineral resources. His role in developing general maps of mineral resources of Slovakia has been also important. An evidence of the extent of the research work of Prof. Zorkovský is given in the bibliographical survey that is attached to the papers dedicated to his jubilee by Professor Rozložník. – "To the sixtieth birthday of Prof. RNDr. Vojtech Zorkovský" (Mineralia Slovaca, 12 (1980) 1, 91–94) and "To the seventieth birthday of Prof. RNDr. Vojtech Zorkovský" (Mineralia Slovaca, 22 (1990), 89–90).

As a university teacher he lectured for 46 years, out of which he was in charge of the Department of Geology and Mineralogy at the Faculty of Mining of the Polytechnics in Košice for 31 years. For a period of time his Department belonged to the Faculty of Civil Engineering. In education of the young generation of civil engineers, mining engineers and geologists, he did a lot of work. He was the advocate of visual aids and care for teaching aids was exemplary. He wrote 32 textbooks and was the chief author of the national textbook "Deposits of industrial mineral resources". A number of researchers and teachers at the Faculty of Mining and elsewhere have grown up under his professional guidance. His name is closely connected with the beginnings of the geological branches of learning at the newly established Faculty of Natural Science of P. J. Šafárik University in Košice, which in 1998 celebrated the thirtieth anniversary of its existence. From 1964 till 1966 he taught at the Havana University and in 1969 he lectured also in Santiago de Chile.

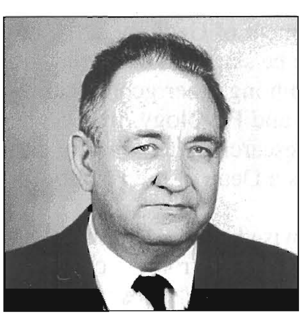
One of Prof. Zorkovský's unique interests was the popularisation of geology. Through books, popular science articles, lectures, radio and television programmes he raised public interest in geological problems of Slovakia and of those parts of our planet that he became acquainted with during his trips abroad. At the same time he popularised the works of great personalities of Czechoslovak and world geology. Professor Vojtech Zorkovský is a member of the generation that at the end of the forties and at the beginning of the fifties, guided by Academician D. Andrusov, laid the foundation of modern geological research of the Western Carpathians and contributed to the education of geologists and mining engineers in Slovakia.

For his work in the area of geology, mining industry and for the results of his teaching work, Professor Zorkovský was awarded many medals and distinctions. Although his greatest honour has been the fact that his former students have achieved exceptional results in their research as well as in geology or mining. His students always had him for a strict task-master. During the alumni reunions, when they were recalling their student years and problems connected with studies of geology, they were – as mature persons – able to see the positive imprints left by the pedagogical and managerial work of Professor Zorkovský. We are thankful to the doyen of our department for his work. We, his students, colleagues, but also the younger generation, that has no experience of him, thank him for his lifelong work which we will try to carry on for the benefit of the further generations. In 1989 he concluded his work at the Department of Geology and Mineralogy of the Faculty of Mining and retired. He still lives in Košice.

His students, colleagues, friends and the participants of our conference wish him all the very best for the coming years of his life, happiness in his family and delight in the results of his followers.

Jozef Slavkovský

Professor RNDr. Vendelín Radzo, CSc.



Professor Radzo was born on 16 July 1929 in Hruštín, District Dolný Kubín. After the graduation from grammar school in Dolný Kubín he started his university studies at the Faculty of Natural Science of the Comenius University in Bratislava in 1949. He graduated from the Department of chemistry and mineralogy in 1953. He started working as an lecturer at the Department of mineralogy and petrography of the Faculty of Mining of the Polytechnics in Košice under the guidance of Professor Šalát.

Between 1956–1968, after the establishment of the Mineral Research Laboratory of the Faculty of Mining, he became a Research associate at this Laboratory and at the same time acted as a university teacher. After attaining readership in mineralogy in 1969 he left the position of the Research associate and became a full-time teacher and apart from mineralogy and geochemistry he worked on the methods of laboratory research. On the basis of the assessment of his achievements in science and pedagogy, he was appointed a full professor of mineralogy in 1981. Between 1984–1989 he acted as the head of the Department of geology and mineralogy of the Faculty of Mining.

Professor Radzo worked in the area of applications of methods of physical chemistry in mineralogical research of non-metallic mineral raw materials. This was also the subject of his PhD Thesis (1965) and reader's Thesis (1969). He was one of the pioneers of mapping the mineral row material assets of Slovakia, particularly of minerals for the ceramic industry. He participated in the research work connected with the discovery and research of the mineralogical and technological quality of bentonite deposits near Fintice, Nižný Hrabovec and Tepličany, as well as of clay minerals and bauxite in Eastern Slovakia. A great number of his publications is dedicated to the investigation of the character of hydrothermal changes around the mineralisations in the Schemnitz-Hodruša region, in the Zlatá Baňa Ore Field and elsewhere. On the mentioned localities he was the first to describe a whole range of clay materials (illite, montmorillonite, hydromuscovite, halloyzite, kaolinite and others), but also other minerals like jarosite, gibbsite, etc. At the same time he participated in the identification of some new mineral discoveries in the Western Carpathians, that engaged him in topographical mineralogy of Slovakia. A great part of his publications is dedicated to the development of physical and chemical methods of analysis, especially X-ray diffractometry, DTA and spectrophotometry.

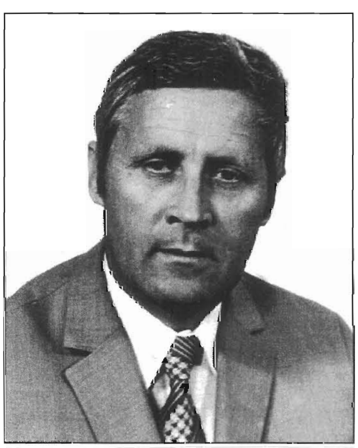
Professor V. Radzo has developed the techniques of mineralogical research at the Mineral Research Laboratory and Department of Geology and Mineralogy. He took an active part in the work of many professional committees, was a member of The International Committee for Mineralogy at Czechoslovak Academy of Science, a member of the Committee for PhD thesis presentations, was a supervisor of a number of PhD students and moreover, was an excellent teacher. He taught students of geology, mining and metallurgy at the Polytechnics (which later became the Technical University). His name is connected with the beginning of teaching mineralogy and geochemistry at the Faculty of Natural Science of the P. J. Šafárik University in Kosice, where he worked since 1968 as an external teacher. His like for teaching is reflected also in writing a number of educational texts in mineralogy, which he constantly updated. He represented the Department, the Faculty and the Polytechnics as well as the level of our mineralogical research on national and international conferences. He had a number of colleagues at home as well as abroad with whom he exchanged results. In this way he presented our research results related to clay materials on a number of forums.

For the results achieved in his pedagogic and research work, for the work dedicated to the education of the intelligentsia and for the development of mineralogy, Professor Radzo was awarded many medals and honours. He entered the history of the department where he had worked for the whole of his productive age, and contributed to the development of knowledge on clayey materials in Slovakia. In 1994 he retired from the position of professor at the Department of Geology and Mineralogy. He continues to live in Košice.

His colleagues, students and the participants of our conference greatly appreciate his contribution to the development of Slovak geology and wish him well-being as well as optimism whilst enjoying his life as a senior.

Jozef Slavkovský

Assoc. Prof. Ing. Róbert Marschalko, DrSc.



Sedimentology became one of the basic buttresses of geologic sciences in the last decades not only in the field of basic research, but also in the area of applied geology. The sedimentological results help to understand sedimentary processes in original sedimentary environments and they show spatial distribution of sedimentary facies which is mostly important for mineral deposit exploration.

The founder of this modern science and especially of its modern trends in the Slovakia is without doubt Róbert Marschalko. His studies on gravity flows in the Western Carpathians belong to basic works on this topic and have worldwide importance.

Róbert Marschalko graduated at the Technical University in Bratislava in the specialization mining engineering. Probably the study at this university endowed him by ability of descriptive seeing and ability to physically analyse sedimentary processes. This unconvential approach enabled him to outpace his time and distinctly advance knowledge of many geologic rules not only in the Slovakia.

After the studies he worked at the Mining Faculty of the Technical University in Košice where he lectured basic geology, stratigraphy and sedimentary mineral deposits. In 1956 he left to Dionýz Štúr Geological Institute. He worked in the field of sedimentary geology, sedimentology and regional mapping of Mesozoic and Tertiary basins. Here he gained his Ph.D. title by the thesis "Geology and sedimentology of flysch marginal facies in the Central Carpathians". Just the results of this work met with high response and became well known in the world. They were tested in orogenic belts of the Alps, Appenines, Dinarides, Caucasus, Ands and Appalachian Mts. The model he presented predicts geometry, structure and bathymetry of basins, helps to find source areas of sediments and to do basin restorations.

In 1965 he joined the lithological department of the Geologic Laboratory of academician Andrusov and since 1966 he has worked at the Geological Institute of Slovak Academy of Sciences. In 1984 he got academic title DrSc. by his scientific work "Evolution and geotectonic importance of Central Carpathians Cretaceous flysch". He also lectured Special methods of sedimentary rock research and sedimentology at the Faculty of Science of the Comenius University where he got degree of associated professor.

Róbert Marschalko took part in several study stays and scientific expeditions during his fruitful career. I would like to mention at least his stays at several places in the Italy, works in the Eastern Carpathians (Romania, Ukraine), Bulgaria, several places in Alps and participation in expeditions to Caucasus, Tan San and Pamir.

The main topic of Róbert Marschalko's work is geology and sedimentology of sedimentary basins in the terminal stages of orogen. Already in 70-ties he described transformation of gravitational flows and practically he worked with system tracts a long time before discovery of sequence stratigraphy. On the base of synsedimentary folds he defined angle of original depositional slope. He belongs among the pioneers introducing mapping of oriented sedimentary structures in flysch basins in order to get palaeoflow directions. He always emphasized physical processes in sedimentology which help to reconstruct sedimentary paleoenvironments. He defined sedimentary features like olistostromes and sedimentary klippens and melanges in the Cretaceous flysch of the Klippen Belt originated by event sedimentation in forearc basins and he showed differences between these melanges and tectonic melanges originated by subduction processes. His research represents an important contribution to many fields of applied geology, especialy in the area of hydrocarbon exploration.

He published his works in two monographs and 113 original scientific papers. All of them have a wide cite response in sedimentological literature. The data published in these papers were used by such grand oldmen like Bouma or Walker.

He was many years member of editorial board of the Sedimentary Geology. Since 1991 he has been a member of editorial board of the Geologica Carpathica. He is honorary member of the Slovak Geologic Associations.

Róbert Marchalko is still active and still deeply involved in the research. He solves scientific problems with this same enthusiasm and charm like many years ago. We wish him good health and many years of his fruitful activity.

Juraj Janočko

BERG Faculty
Technical University
Košice

Geological Survey
of the Slovak Republic
Bratislava

Conference

GEOLOGY AND PROSPECTING IN THE CARPATHIANS

September 4–6, 2000, HERĽANY, SLOVAKIA

Editors

Stanislav Jacko, Juraj Janočko, Jaroslav Lexa

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GENERAL SECTION

PROCEEDING OF THE CONFERENCE GEOLOGY AND PROSPECTING IN THE CARPATHIANS,
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GEOLOGY AND PROSPECTING IN THE CARPATHIANS

Edited by

Stanislav JACKO
Juraj JANOČKO
Jaroslav LEXA

Mineralia Slovaca, Bratislava, 2000

INTERNIDES

NEOVOLCANICS

Mineralia Slovaca, 32 (2000), 155–156

Geosciences at the beginning of the 21st century: desirable trends of future activities

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Abstract

Mankind at the beginning of the new millenium evaluates all fields of human activities and try to define the most important problems which ought to be solved in future. It is clear that successful solution of global problems needs broad international as well as interdisciplinary approaches. For geosciences offer to collaborate seems to be one of those which should keep its prestige in society as well as to offer new nontraditional jobs for young geoscientists.

Key words: new millenium, geosciences, nontraditional application in society

Geological sciences (or geosciences in 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 formerly positions. Such unfavorable development is based namely 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 hardwer, chips, electronic communication network etc.

As the direct consequence of lower demand of young geologists/geoscientist numerous departments of geological sciences at various universities round the world have been closed, or their staffs have been reduced. The most sensitive aspect of the discussed problematic is that for geological research (survey) of state territories (geological mapping included) in the majority of countries by state quaranteed budged have 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 writer of this remarks, that there exists - at least partial, solutions. I will try to pointed on some of them.

Education in earth sciences

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

For modern educated societies appropriate knowledge on abiotic 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 keeping in mind that economic and from environmentalistic point of view non harmful exploitation of abiotic sources is a fundamental aspect for progressivelly developing communities in the 21st century.

Namely in our country, as the relic from the past, during the secondary school study our young generation is supplied by top level scientific knowledge dealing with abiotic nature in very restricted amount only. Short course (half a year) of abiotic nature and the basic aspects on 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 higher level of abiotic nature understanding by the prevailing part of the society.

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

"Penetration" 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 is till now seldomly realised. 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 example. Modern archaeology 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 archaeological artefacts should be defined in details: the raw materials of chipped and polished implements and settlements construction materials, types and provenances of clays for ceramics 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 example of interdisciplinary approach to solve the above problematics.

Based on the fact that archaeological objects differ in physical properties (electrical conductivity, density, susceptibility, radioactivity and the others) from the sourounding 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 finnacial cost and time needed. Geophysical methods have been used during last sixty years for prospecting and location of aerchaeological objects of interest mainly in the northern Europe. Later on these methods have been applied all over the world.

But geosciences have tremandeous application also in practical technologies and human activities. Permanent problems in abiotic environment should be monitored and problems solved using geoscience methods, for example problems of the soil erosion, overflows, landlisdes and rockfalls, prediction of earthquakes and volcanic eruptions, location of the radon risk areas, in solving problems of ancient mine wastes, undergound 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 (artificial 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 neccessity of educated crossdisciplinary specialist trained both in museology as well as in geosciences. Such museum custods are completely missing in our country though several museums are concentrators of artefacts from abiotic character. Translators into leading international lanquages educated in geosciences should get jobs in leading publishing houses, press, TV and radio but they ought to try to get such positions!

Mineralia Slovaca, 32 (2000), 157–164

Geodynamic evolution of the Western Carpathians: an overview

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Abstract

Both the basic geodynamic events and products of Hercynian, Mezozoic and Tertiary polystage evolution of the Western Carpathians which relate to global tectonic processes in the ALCAPA realm are outlined in this contribution.

Key words: Western Carpathians, Hercynian, Mesozoic and Tertiary tectonic evolution

Introduction

Current results of research projects focused to the clarification of basic stages of the Western Carpathian development has brought series of original knowledge which helpfully assisted at explanation of geological evolution of this the ALCAPA realm from plate tectonic principles. In this paper we chronologically summarize fundamental development features of the Western Carpathian geodynamic history and their relationship to adjoining ALCAPA domains.

Main features of the Hercynian development of the Western Carpathians

Both an impact of polystage Hercynian geotectonic processes into structural and petrological record and the inverted tectonic superposition of the Western Carpathian basement complexes became the key for recognition of the main Hercynian litothectonic units (Bezák et al., 1997). In the internal i.e. Tatric – Veporic basement domain four the following lithotectonic units have been distinguished (Fig. 1) (i) – The low-grade (mainly phyllitic) metamorphites in the uppermost position, (ii) – the Upper (gneissic – amphibolitic – granodioritic) one, (iii) – the Middle unit predominantly composed of micaschists and amphibolites, (iv) – the Lower unit consisting of greenchist facies metamorphites.

The external – e.g. Gemeric part of the Western Carpathian basement, comprises from the top to the bottom three basement units (Fig. 1): (i) – the Klatov group formed by high grade metamorphites – probably of island – arc provenance (Hovorka and Spišiak, 1997), (ii) – slightly metamorphosed back – arc basin (Hovorka et al., 1988) basic volcanites and psamopelites of the Rakovec group, (iii) – Early Paleozoic volcanosedimentary fore – arc flysch sequences (Vozárová, 1993) of the Gelnica group metamorphosed under green – schists facies conditions.

High – grade metamorphites of the Zemplinic unit located at the eastern part of the Slovakian – Hungarian borderland by their composition and metamorphic T – P conditions (Faryad and Vozárová, 1997) remind the mentioned Upper lithotectonic unit of the Tatric – Veporic basement.

Based on the structural, geochronological and petrological data Hercynian tectonometamorphic development of the Western Carpathians may by divided into three principal evolution stages:

– *Paleohercynian stage* (430–380 Ma): The oldest subduction processes are indicated in this stage. Their typical features are the higher pressure metamorphism, and the overthrusting of the lower crustal sheets into the middle-crustal metamorphic ones. The high-grade assemblages created during this stage, were incorporated into the Upper lithotectonic unit during the superimposed developmental stages (Bezák et al., 1998). The age of the older, high-pressure event, is not clear. Its cooling age determined by Ar/Ar dating of amphiboles is 375–380 Ma (Kráľ et al., 1996). Some geochronological results indicate the interval 420–390 Ma (e.g. Cambel et al., 1990).

– *Mesohercynian stage* (380–340 Ma): Comprises the

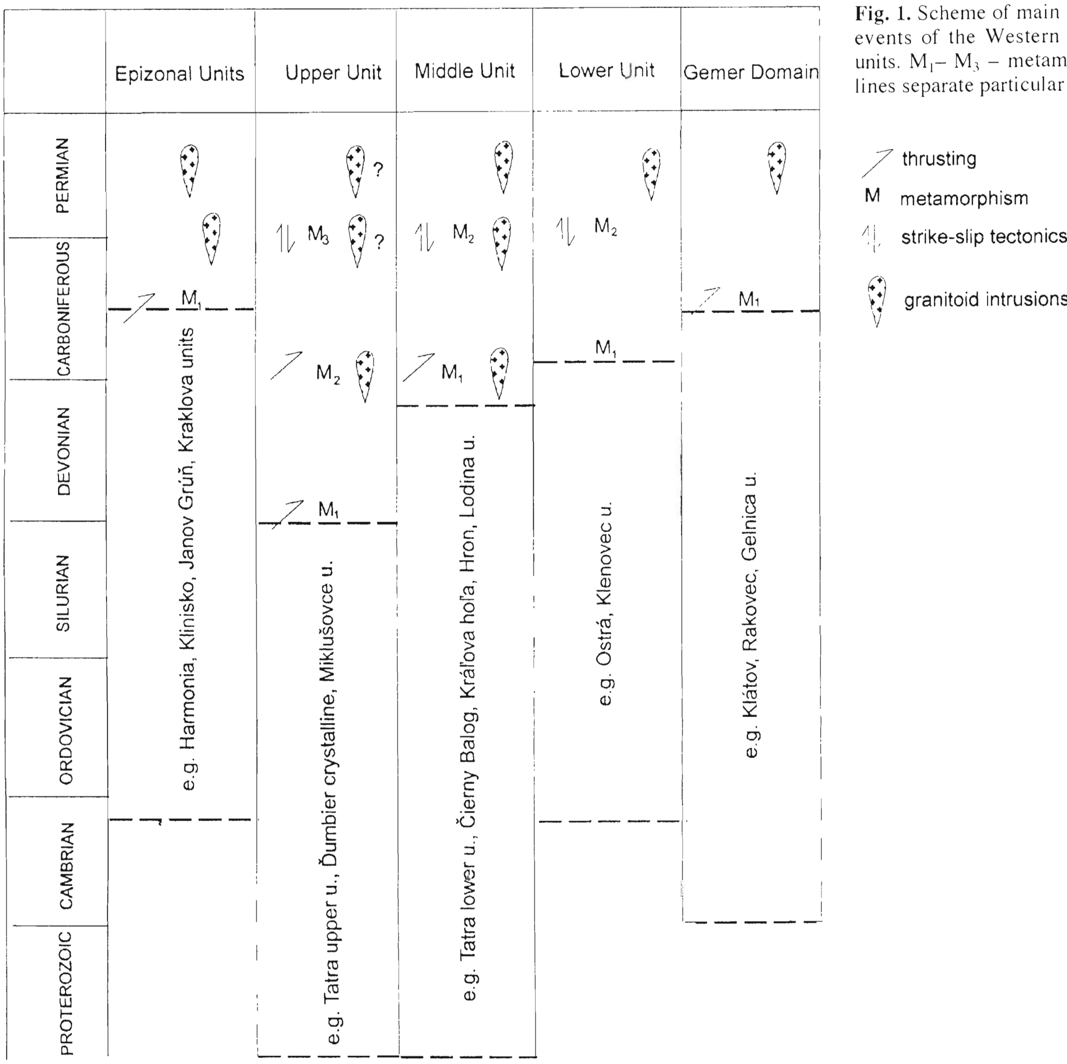


Fig. 1. Scheme of main Hercynian geodynamic events of the Western Carpathians basement units. M_1– M_3 – metamorphic events. Dashed lines separate particular development stages.

southvergent stacking of middle-crustal nappe piles (i.e. main Hercynian lithotectonic units) in the internal basement zone during this, structurally the most significant, Hercynian collisional stage (Fig. 1). Syntectonic metamorphism has reached the medium pressure conditions (Barrowian type). The collision ceased by intrusions of syntectonic granitoids. The structural observations indicate thrusting under ductile midle-crustal conditions.

– *Neohercynian stage* (340–260 Ma): During this tectonometamorphic event the collision in the external Hercynian (e.g. Gemeric) domain was finished (i. e. closure of the Rakovec oceanic realm) and was accompanied by transpressional regime in the inner zones. This process probably coincides with the Ar/Ar age of 330–312 Ma obtained from two localities of diaphtorized gneisses of the Veporic Lodiná complex of the of the Čierna hora Mts. (Dallmeyer et al., 1996). Pebbles of diaphtoritic gneisses among clasts of Carboniferous cover sequence of the Čierna hora Mts. Veporic unit (Korikovskij, et al., 1989) and Westphalian sediments transgressively overlapping the Klatov unit nappe sole within Gemeric domain confirm the whole Western Carpathian impact of this event. A post-collisional evolution is represented by transtensional to extensional processes, accompanied by the formation of the molasse basins, volcanism and by intrusions of post-collisional A-type granitoids.

Granitoids intruded in several pulses into various units (Fig. 1). Substantial part of granitoids intruded mainly into the already formed Mesohercynian structure. U/Pb zircon data from the S-type granitoids range between 350–360 Ma, I-type granitoids yielded 300 Ma. Small occurrences of A-type granites (Gemeric granites and, a part of the Veporic granites as well) have Permian ages, i. e. 270–235 Ma. (cf. also Poller et al., this volume).

Structure and Mesozoic evolution of the Central Western Carpathians

The Central Western Carpathians (CWC), located between the Meliata and Penninic-Vahic oceanic sutures, originated by shortening and stacking of a continental domain which was related to Europe during the Late Paleozoic and Triassic and to Adria during the Cretaceous and Tertiary. The crustal-scale basement/cover sheets (Tatric, Veporic and Gemeric superunits) and detached cover nappes (Fatric, Hronic and Silicic systems) build up altogether the Slovakocarpathian tectonic system that is well correlable with the Austroalpine system of the Alps. The Oravic units of the Pieniny Klippen Belt, along with the surrounding Vahic and Magura oceanic units are ranged to the Penninic tectonic system (Plašienka, 1999).

The poorly consolidated epi-Variscan crust in the southern part of the CWC suffered the Late Permian to Scythian rifting and the Late Anisian break-up of the Meliata ocean, followed by its Middle to Late Triassic spreading (Fig. 2). Opening of the Meliata ocean is attributed to back-arc rifting and extension triggered by the northward subduction of Paleotethys (Stampfli, 1996). The northern, Slovakocarpathian shelf was still attached to the stable North European Platform and shows zoning from slope facies deposited on a transitional crust, carbonate reef bodies on a subsiding distal passive margin, and lagoonal to terrestrial environments landwards.

Southward, partly intraoceanic subduction of the Meliata ocean commenced in the latest Triassic (Kozur, 1991), but the contraction belt was restricted only to a narrow accretionary wedge (the present Meliatic and Turnaic units, see Fig. 2). The first manifestations of the southward subduction of the Meliata ocean are coeval with rifting within both the Slovakocarpathian and Vahic domains during the earliest Jurassic. Rifting caused segmentation of the Triassic carbonate platform into longitudinal subsiding basins and elevated swells marked by syn-rift sedimentation. The "wide - rift" mode of extension focussed in break-up of the Penninic-Vahic oceanic realm at the Early/Middle Jurassic boundary. Extension is tentatively attributed to the passive rifting of the lower European plate due to the southward pull exerted by the negative buoyancy of the Meliata slab, augmented by the eastward drift of Adria. This event separated the Austroalpine-Slovakocarpathian realm from the North European Platform.

The Meliata ocean was gradually closing during the Jurassic, but the Szarvaskő back-arc basin opened in its place (Fig. 2). The closure of the Meliata ocean during the Late Jurassic welded the Slovakocarpathian domain with the Adria-related Hungarocarpathian tectonic system located presently southwards of the Meliatic suture in the Internal Western Carpathians (IWC; Transdanubic and Bükkic terranes). Initial collision and synorogenic sedimentation dominated by olistostromes affected areas within this zone.

The Cretaceous growth of the West Carpathian orogenic wedge shows a northward progradation from the Meliata suture and an episodic accretion of crustal material from its northern foreland. The first, latest Jurassic – earliest Cretaceous episode directly followed closure of the Meliata ocean. It was associated with an exhumation of the Meliatic blueschists and a deep burial of the Veporic domain below the accretion/collision stack. However, the northern lower plate was still subjected to post-rift thermal subsidence and mostly pelagic sedimentation. Episodic extensional events are ascribed to the B-subduction and persisting southward slab-pull of the Meliata oceanic lithosphere attached to the European lower plate.

The second, mid-Cretaceous episode of the CWC wedge growth was accompanied by crustal thickening and eo-Alpine metamorphism related to underplating of the Veporic wedge by the buoyant Tatric-Fatric crust that triggered the vertical extrusion of thermally softened material in the rear of the wedge. The inferred P-T-t path of the Veporic metamorphic core complex, which is based on petrologic and structural studies, indicates its exhumation from lower crustal levels (peak metamorphic conditions: T about 600 °C, P up to 10 kbar – Plašienka et al., 1999) and cooling ages between 88 and 75 Ma (Fig. 2). The foreland Tatric-Fatric area was seized by synorogenic flysch sedimentation during the Albian and Cenomanian followed by cover nappe emplacement during the Late Turonian.

During the Late Cretaceous, the rear of the orogenic wedge cooled and contraction prograded to the zones at the northern Tatric (continental) and Penninic-Vahic (oceanic) interface, marked by commencement of synorogenic flysch in the subducting Vahic realm during the Senonian. However, only indistinct crustal thickening is indicated there and the northern Tatric edge became to act as the rear buttress of the developing External Carpathian accretionary wedge during the Paleogene.

Paleogene development of the Western Carpathians

Evolution of the Western Carpathians during the Paleogene was closely related to the convergency between the European Platform and Carpathians (e.g. Royden et al., 1983; Sandulescu, 1988; Decker and Peresson, 1996)) as well as lateral escape of internal units from the Alpine collisional zone (e.g. Csontos et al., 1992; Csontos, 1995). Isostatic adjustment as a result of CWC cover nappes also played an important role in formation and migration of major depocentres during the Paleogene. In relation to the subduction zone between the European Platform and Carpathian Block the Paleogene sedimentation in the Western Carpathians occurred in foreland basins (e.g. Miall, 1995) represented by our "flysch basins" and basins in the Penninic – Vahic realm, piggyback (e.g. Bentham et al., 1992) or in-wake (Ricchi Lucchi, 1986) basins represented by the Central-Carpathian Paleogene Basin and retroarc basins (e.g. Tari et al., 1993) comprising the Buda Paleogene Basin having only a small extent in the Slovak territory.

Sedimentation in foreland basins continuously evolved from the Mesozoics when initial opening of the basins commenced. Progressive subduction stimulated outward migration of depocenters with gradual younging of deposits. The low-energy hemipelagic and pelagic deposition of dark and variegated shales with minor sandstone layers represents the lowermost deposits of the basin and represents typical initial deposits of peripheral foreland basins described elsewhere (e.g. Ricchi Lucchi, 1986; Miall, 1995). The fine-grained sedimentation was replaced by typical gravity flow deposition in the Paleogene. It indica-

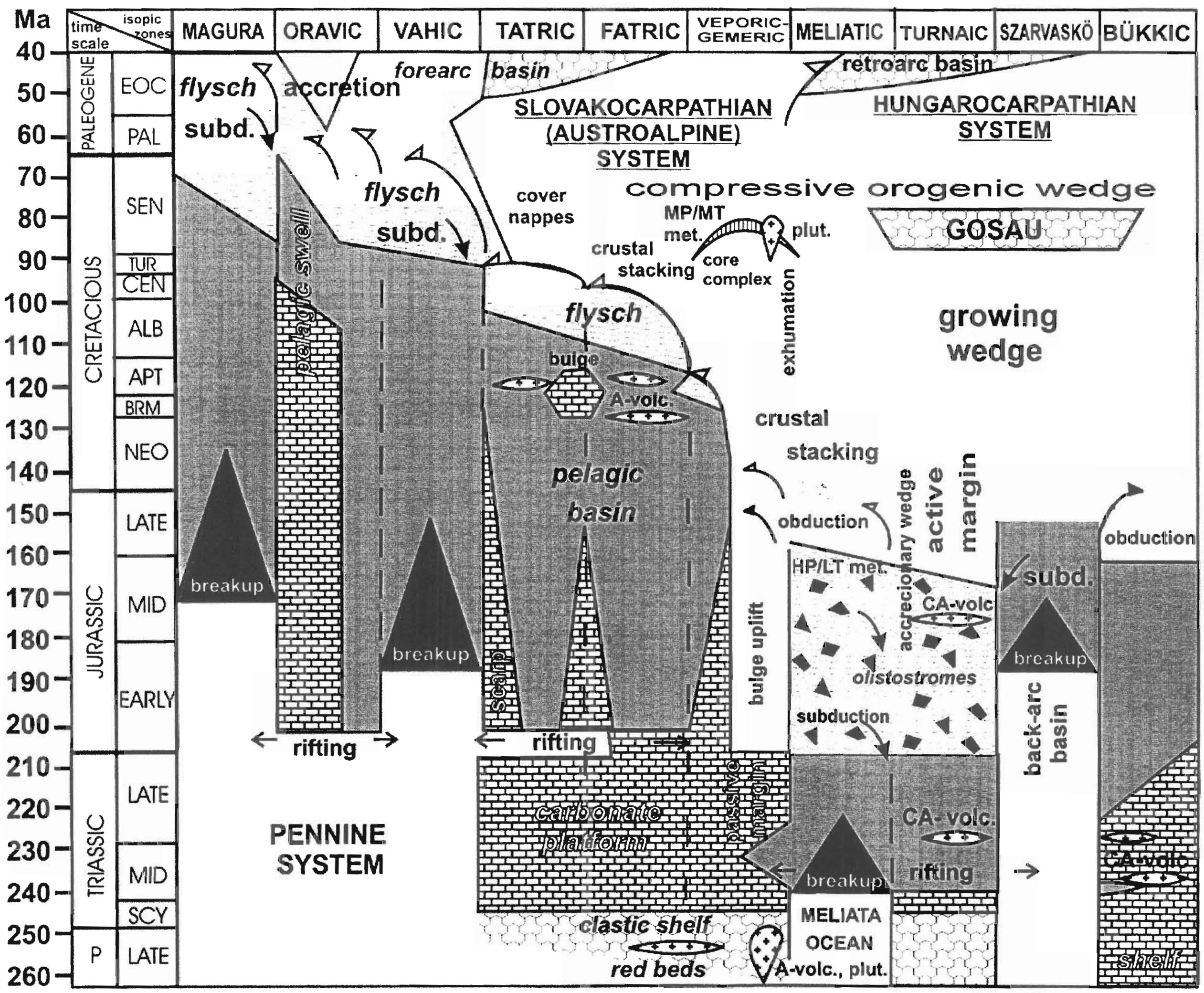
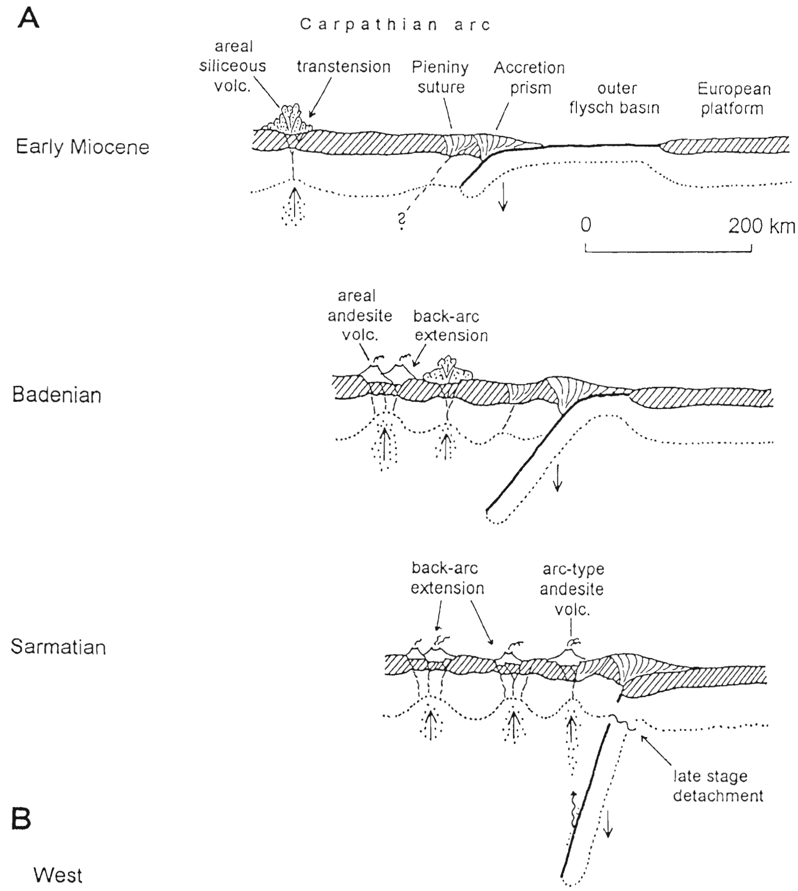


Fig. 2. Synoptic overview of the Mesozoic orogenic processes in the Western Carpathians. Sedimentary record is ornamented, non – deposition is blank.

tes rising of thrust folds and subsequent generation of large source areas. During the Paleogene deposition was mostly controlled by high mobility of the area governing change of subsidence rate, basin topography, bathymetry and sediment input as well as eustatic sea level fluctuations. Mobility of the area determined high facial variability in individual basins. On the contrary, eustatic sea level fluctuation resulted in deposition of sediments common for all individual basins. The facies architecture reflects deposition in the basin floor fan and slope fan systems separated by time of low sedimentation rates (e.g. globigerina marls).

Initial stage of inversion and shortening of foreland flysch basins is already recorded in the Paleocene, however, the age of youngest sediments involved into the individual tectonic units of the flysch belt suggests the main deformation phases of foreland basin after the Early Oligocene. The process of sediment offscrapping and accretionary wedge formation was diachronous and can be still observed in the seismically active Vrancea zone in the Romania.

Central-Carpathian Paleogene Basin is a piggyback or in-wake basin (Miall et al., 1992) developed above the CWC crystalline and Mesozoic units behind the foldthrust belt generated by convergence of the North-European Platform and the CWC. Recent results hint at connection between the basin and foreland "flysch" basins in some phases of the Paleogene evolution. The basin fill, thick up to 4000 m, shows typical example of sediment architecture controlled by subsidence, sediment input and sea level fluctuation. The fill consists of several sedimentary sequences composed of terrestrial, shallow-marine and deep-marine deposits. They were formed during transgressive and high-stand (mainly low-sediment rate mode of deposition, hemipelagic sedimentation) and low-stand (slope fan, basin floor fan, canyon) phases of relative sea level position. The oldest deposits are of the Paleocene age and the youngest ones indicate the Late Oligocene – Early Miocene age (nanoplankton NN-1 and 2 zones, e.g. Molnár et al., 1992; Janočko et al., 1998; Soták and Starek, 1999). However, vitrinite-reflectance data and clay mineral analysis suggest at least 2 km overlying sedimentary sequences



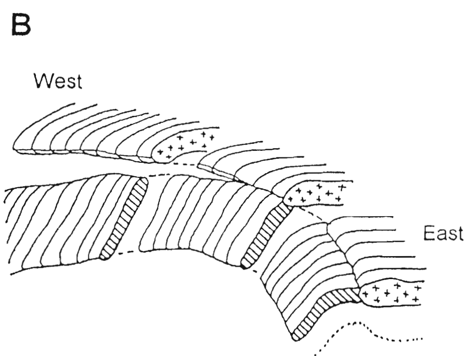


Fig. 3. Geodynamic model for the Neogene calc-alkaline volcanic rocks of the Western Carpathians (Lexa and Konečný, 1998). A – proposed relationship to subduction and back-arc extension. B – probable progressive detachement along the Carpathian arc

(Kotuľová et al., 1998) indicating a continual transition to the Neogene sedimentation.

The basin was predomintly filled along its axis, however, smaller depositional systems entering the basin laterally played also an important role during the basin evolution (e.g. Marschalko, 1968, 1978, 1982; Janočko and Jacko, Jr., 1999). Analysis of system tracts revealed contemporary shallow-water, slope and basin floor deposition in individual sedimentary sequences (e.g. Janočko and Jacko, Jr., 1999; Soták and Starek, 1999) and migration of depocenters during the basin evolution connected with opening of the basin.

Development of the Western Carpathian neovolcanites

A preferred geotectonic model of Tertiary volcanic rocks in the Carpatho-Pannonian region (Lexa and Konečný, 1998) is shown schematically at the Fig. 3. The model accepts the idea of Sandulescu (1988) about two Tertiary suture (subduction) zones in the Carpathian arc separated by remnants of the Silesian cordillera (see above). So the younger subduction in the Silesian/Moldavian flysch zone is not considered as a direct continuation of the preceeding subduction in the Pieniny/Magura zone, but rather as a new subduction zone formed by following accretion of the Silesian Cordillera to the upper plate (Carpathian arc). Owing to the overall compression (and – presumably, low angle geometry) during the first stage of subduction in the Pieniny/Magura zone, no extension related diapiric uprise in the mantle could take place to generate contemporaneous magmas. Our model relates to all Miocene to Quaternary calc-alkaline volcanic rocks affiliated to the younger stage of subduction in the Silesian/Moldavian flysch zone. The Early to Middle Miocene *areally distributed silicic volcanic rocks* associated in space and time with the initial stages of back-arc transtension and extension, which were contemporaneous with the initial stages of subduction in the Silesian/Moldavian flysch zone. As newly initiated subduction could not reach appropriate depth and distance in such a short time, our model advocates back – arc extension induced diapiric uprise of enriched (by previous subduction processes) asthenospheric mantle as principal mechanism leading to magma generation. Silicic character of volcanism at this stage is attributed to relatively thick crust, which had not been thinned yet by continuing back – arc extension.

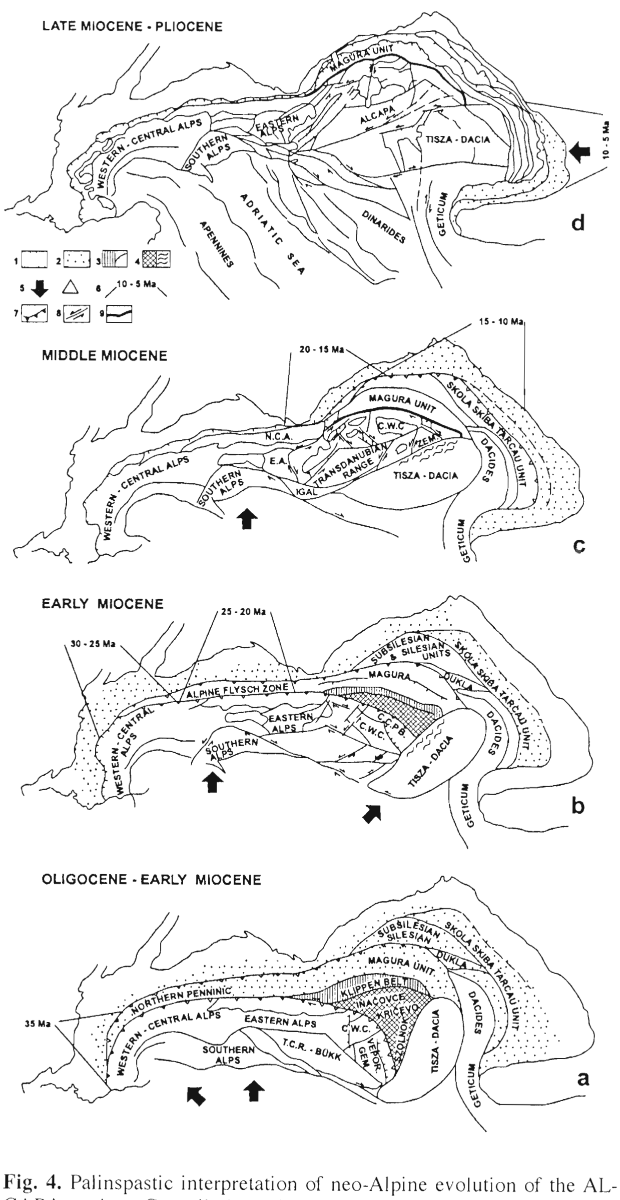


Fig. 4. Palinspastic interpretation of neo-Alpine evolution of the ALCAPA region. Compiled on the basis of the following data: Balla (1984, 1987), Jiříček (1979), Horváth (1984), Kováč et al (1989, 1994, 1998), Royden (1988), Sandulescu (1988), Seifert (1992). 1 – Neogene basins, 2 – The ALCAPA Foredeep, 3 – The Pieniny Klippen Belt, 4 – The Szolnok flysch basin, 5 – main compressional orientation, 6 – final stage of nappes emplacement onto foreland units, 7 – emplacement of nappes, 8 – strike – slip movements. Other explanations see in text.

The Middle Miocene *areally distributed andesite volcanic rocks* associated spatially and temporary with intense back – arc extension processes, up to 150 km in hinterland of the arc, lead to the evolution of the horst/graben structures, which were contemporaneous with more advanced stages of subduction in the Silesian/Moldavian flysch zone. As in the case of the areal type silicic volcanic rocks, not enough time had elapsed for subducted lithosphere to reach appropriate depth and extent. However, back – arc extension zones correspond to zones of thinned crust and/or lithosphere. So back – arc extension induced diapiric uprise of "fertile" asthenospheric material accompanied by decompression melting is envisioned as a principal process of initial magma generation. Progressive thinning of the crust is reflected in andesitic or even basaltic composition of magmas reaching the surface or undergoing further differentiation in shallow magma chambers.

The Middle Miocene to Pleistocene *arc – type basaltic andesite to andesite volcanic rocks* follow closely geometry and timing of the Carpathian arc and our model assumes a direct relationship to ongoing subduction in the Silesian/Moldavian flysch zone in the same way as it is known from active island arcs. In individual segments of the arc – volcanic rocks of this type post-date initial stages of subduction by 8–10 Ma. This is the time needed by sinking lithosphere to reach the depth of "magma generation" around 120–150 km, implying subduction rate at 1.5–2 cm a year. Alignments of the arc – type andesite volcanic rocks are rather close to the trace of the related subduction zone, indicating that "magma generation" depth had been reached in time, when the subduction zone was almost vertical. Very short duration of volcanic activity in individual segments (with exception of the segment between the Western and Eastern Carpathians) may imply, that volcanic activity actually took place in the stage of subduction slab detachment (Nemčok et al., 1998).

The Pannonian to Pleistocene *alkaline basaltic volcanism* post-dates the convergence in closely situated segments of the arc, however, they reflect the extension environment due to continuing subduction in the Eastern Carpathians during the Pliocene to Pleistocene time (Nemčok et al., 1993). Their geochemistry indicates involvement of depleted asthenospheric mantle (e.g. Dobosi et al., 1995), brought into the region perhaps by asthenospheric flow compensating subduction rollback.

Miocene development of the Western Carpathians

In the Early Miocene after the Alpine collision with the North European plate, generaly northeastwards drift of the Alcapa microplate continued – passing the corner of the Bohemian massif on the NW (Fig. 4, Conthos et al., 1992). The Magura nappe stack in front of the Western Carpathian Internides started to be totaly unrooted and was thrusted over the Silesian ramp which collapsed as a result of continental litosphere flexure caused by the load of overriding nappes. After that event the Outer Carpathian flysch basins attained features of relatively deep water foreland basins with turbiditic sedimentation in axial part (residual flysch basins), while on platform margins molasse deposits acumulated.

The Eggenburgian marine transgression flooded the uplifted parts of the Outer Carpathian accretionary prism (e.g.Vienna Basin), frontal part of the Central Carpathian orogen (e.g.Vah river walley, East Slovakian Basin), as well as the South Slovakian – North Hungarian Pétervására retroarc basin (Kováč et al., 1993). The Ottnangian development is characterised by isolation, decrease of salinity or formation of coal seams. However compressional tectonic prevailed, initial back – arc extension appeared along the suture zone between the "Intra-Carpathian" microplates (Midle – Hungarian line) associating with acid volcanic activity.

The **Karpatian to Early Badenian** time is characterized by extrusion of the Alcapa (Western Carpathians) lithospheric fragment northeastwards, as a result of Alpine collision and subduction pull in front of the Carpathian orogene (Kováč et al., 1998). Interaction between the Bohemian massif and Western Carpathians led to counter – clocwise rotation of microplate (at the end of the Ottnangian cca 40–50° and at the end of the Karpatian cca 30°).

Active thrust front of the Carpathian accretionary vedge mooved to the edge of Krosno – Menilite nappe stack thrusted over the Carpathian foredeep situated on platfom margin. Extension of the overriding microplate, led to inicial rifting in the back – arc region. Crustal thinning iniciated uplift of the astenospheric mantle acompanied by acid and calc – alkaline volcanic activity. At the boundary between the Eastern Alps and Western Carpathians the Vienna pull – apart basin was opened in NE–SW trending sinistral wrench zone (Kováč et al., 1997). At the Western and Eastern Carpathian boundary East Slovakian pull – apart basin created in NW–SE trending wrench zone (Kováč et al., 1995).

Karpatian marine transgresion via "transdinarid corridor" situated in Slovenia flooded back – arc region (Styrian, Novohrad, Vienna and East Slovakian basins) and penetrated to East Alpine and Western Carpathian foredeep. Later on, during the Early Badenian also the sea connections opened to the southeast and full marine conditions are documented in the whole Carpathian foredeep.

The **Middle Miocene** collision related compressive tectonic regime continued only in front of the Western Carpathians. The Outer Carpathian accretionary prism started to be uplifted and in front of its external zone foredeep has been developed (Meulenkamp et al., 1966). Subduction of the Krosno – Menilite flysch through basement induced island-arc volcanic activity in the Eastern Slovakian Basin (NW part of Transcarpathian depression) related to melting of downgoig plate.

Extension in back-arc region assoctiated with uplift of astenospheric mantle masses and voluminous areal type acid and calc – alkaline volcanic activity (Lankreier et al., 1995). The back – arc basin system (Vienna, Danube and East Slovakian Basins) was flooded by epikontinental sea with characteristic island archipelagos, built – up by emerged parts of various tectonic units (Kováč et al., 1995). Badenian sea was marine, Sarmatian become a brackish character due to isolation from the Mediterranean.

During the **Late Miocene** the evolution of Carpathian loop come to its final stadium. Active subduction is reported only from the Eastern Carpathians during this time. Similarly as in the Western Carpathians it associated with calc – alcaline volcanic activity in Transcarpathian and Transylvanian basins.

The Pannonian back – arc basin system was at the beginig of this period structuraly rebuilt by wide rifting (opening of depocentres in Danube and Great Hungarian plain basins) and passed to thermal postrift subsidence stadium Lnakreijer et al., 1995). Kaspi – brackish character of the semiclosed sea gradualy changed to lacustrine. The turbiditic deep water sedimentation turned to shallow water deltaic to fluvial at the end of the Late Miocene. During the Pliocene started tektonic inversion of the back- arc basins (Kováč et al., 1998).

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New trends in the Western Carpathian lithosphere research

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Abstract

In recent years great attention was paid to the study of deep crustal and lithospheric structure of the Western Carpathians within geodynamic investigations of the evolution of these mountains. These studies have been based upon complex geophysical and geological interpretations. The results yielded a handful of new information on the crustal and lithospheric structure of the Western Carpathians mainly on ranges of crustal thickness, the position of the lithosphere/astenosphere boundary, the distance and the deep of underthrusted European platform beneath the Carpatho-Pannonian plate, the influence of extensional processes and the predisposition of the older basement structures on the development of younger structures. This paper tries to show new trends mainly in the research of the Western Carpathian lithosphere thickness, structure and rheology.

Key words: Western Carpathians, lithosphere, European Platform, Carpatho-Pannonian Plate

Introduction

A new approach combining results from seismics, seismology, gravimetry, magnetometry, magnetotelluric sounding, geothermics as well as tectonic considerations were applied to determination of a geophysical-geological cross-sections of deep lithosphere structure and its geodynamics in the Western Carpathians and its vicinity (Šefara et al., 1996, 1998; Bezák et al., 1997a; Bielik et al., 1998). It has been shown that the principal role for the present lithospheric structure of the Western Carpathians has relationship between the European platform and the Carpatho-pannonian block (ALCAPA and TISZA megablocks) and interaction between lithosphere and asthenosphere. The results has documented differences between the western, central and eastern parts of the Western Carpathians, mainly in platform configuration, deeping of the subducted-underthrusted European platform, position of the subduction zones, configuration of crustal slab, composition of crustal fragments, various influence of extension processes and relief of the lithosphere-asthenosphere boundary.

On the lithosphere thickness issues

Determination of the lithosphere-asthenosphere boundary is very important for study geodynamic evolution of the Western Carpathians. Up to date this boundary is the least known. This boundary is not very often considered when interpreting density models. Maybe it is due to the fact that unlike the statistical proof of the Moho as a density boundary (by the correlation with the map of the Bouguer gravity anomalies), such proof does not exist. It can be considered only in terms of calculations (Šefara, 1986; Lillie et al., 1994; Bielik, 1998).

The physical rationale for this boundary is a depth in which the temperature reaches the point of melting of the upper mantle masses. Based on this assumption a thermal lithosphere is defined (e.g., Čermák et al., 1992). The melted materials have lower seismic wave velocities (low velocity layer) and a very large conductivity. It enables to determine the thickness of seismic (e.g., Babuška et al., 1988) and geoelectrical (Praus et al., 1990) lithospheres. All determinations of the lithosphere-asthenosphere boundary have their own limitations. One of the main ones is a very small amount of observations. From this point of view it is necessary to use interpolation to very large distances. Moreover, in geothermics it is necessary to consider the convection heat flow transfer (including volcanism). This process can reach the surface. For the purpose of density modelling a density contrast of -0.03 g/cm^3 on the lithosphere-asthenosphere boundary was specified based on modelling with help of isostatic balancing (Lillie et al., 1994). It can be regarded as conventional rather than proved.

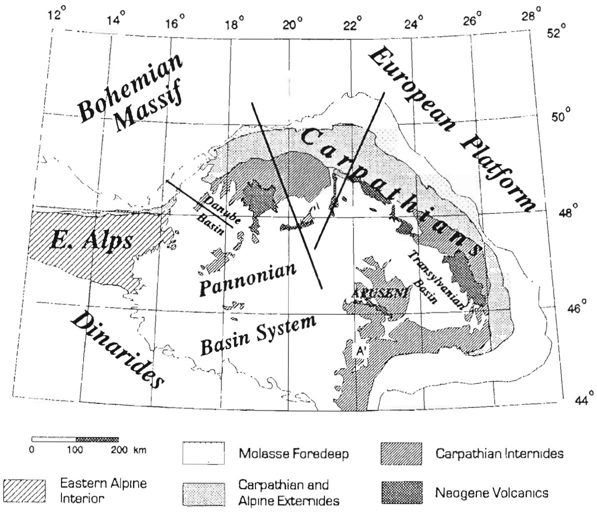

Fig. 1. Tectonic map of the Eastern Alpine-Carpathians-Pannonian basin region (modified after Lillie et al., 1994). The three cross-sections of the geological and geophysical study mentioned in the text are shown by bold lines.

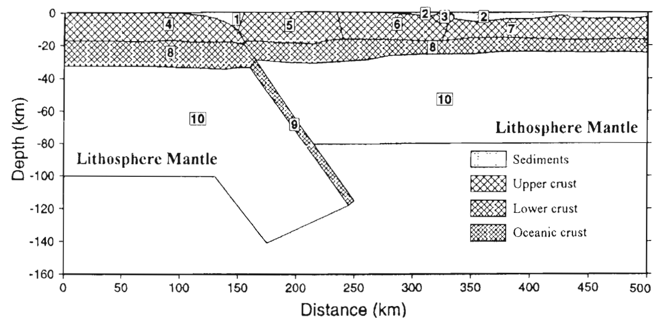

Fig. 2. Geophysical model of the lithosphere structure calculated by means of integrated interpretation combining gravity, surface heat flow and topography.

First seismological studies of the lithospheric thickness were performed by Babuška et al. (1987, 1988) through the interpretation of teleseismic P-wave delay times. In their model, the thickness of the lithosphere decreases from 200 to 140 km when passing from the central East European Platform to ist borders. In Poland, southwestern from the TTZ and northeastwards from the TTZ (northern European craton) lithosphere thicknesses of 100 km and 200–250 km respectively were defined (Čekunov et al., 1993a, b). In the Bohemian Massif the lithosphere thickness varies from about 80 km to some 140 km. The Western Carpathians just lie over the maximum gradient of shallowing of the lithospheric-asthenosphere boundary (LAB) from TTZ towards the Pannonian Basin. In contrast, a relatively thick lithosphere (100–120 km) was suggested extending from the Outer Western Carpathians into the northeastern part of the Pannonian Basin. Also results obtained at individual magnetotelluric sounding localities (Praus et al., 1990) indicated in this region a thick lithosphere (150 km). However, other magnetotelluric measurements which were published in the papers of Ádám et al. (1990, 1996), Ádám and Bielik (1999) and Ádám (1996) gave only a 50–70 km thick lithosphere in this region. The results of Babuška et al. (1987, 1988) and Ádám et al. (1990) were used in the lithospheric map of the Pannonian Basin and surrounding areas published by Horváth (1993). A thinning of the lithosphere to about 60–70 km under the Pannonian Basin was also obtained in a delay time tomography by Spakman (1990). Geothermal models (Čermák, 1982, 1994) resulted in a lithospheric thickness of 100–130 km under the East-European Platform, about 100 km under the Western Carpathians and a minimum thickness of 60–80 km under the Pannonian Basin. The results of stationary geothermal modelling (Majcin, 1994; Majcin et al., 1998) along a profile crossing the Western Carpathian arc near the seismic profile 2T showed similar differences between the results of seismic and geothermal methods. On the basis of the current knowledge on this boundary we can claim that the accuracy of its real position is about 30–50 km.

The analysis of the above mentioned differences led us to the application of integrated lithospheric modelling of the surface heat flow, Bouguer anomalies and topography (local isostasy) determine the continental lithospheric thermal structure along the profile going through the East European platform, the Western Carpathians and the Pannonian basin. The main goal using the integrated algorithm was to improve determination of this important boundary, when the calculation was controlled by means of two different geophysical fields (gravity and surface heat flow density) and real topography.

The integrated modelling was carried out along profile 1-1', which crosses the European platform, the Western Carpathians and the Pannonian basinin NNW–SSE direction. The length of the profile is 500 km. The results of this approach were calculations of the relief of the thermal lithosphere-asthenosphere boundary (defined as the 1300 °C isotherm) and the actual temperature distribution as a base for geodynamical reconstructions of the Western Carpathian-Pannonian basin region.

Tab. 1
Density and thermal properties of the different bodies used in the model

Nr	Unit	HP	TC	$ń_0$
1	Outer Flysh and molasse	1.5	1.5	2660
2	Sediments	2.3	2.5	2510
3	Volcanics	2.0	3.0	2700
4	Upper crust (European Platform)	1.2	2.5	2820
5	Upper crust (Tatricum)	1.5	2.5	2720
6	Upper crust (Veporicum)	2.1	2.5	2760
7	Upper crust (Pannonian)	2.8	2.5	2740
8	Lower crust	0.2	2.0	3000*
9	Oceanic crust subducting	0.2	2.0	3100
10	Mantle	0.05	3.4	3325*

Nr. Reference number in Fig. 2, HP· Heat production ($ěW/m^3$); TC: Thermal conductivity (W/m*K), $ń_0$, density at room temperature (kg/m^3)

*· The densities of lower crust and mantle depend on the temperature by $ń(T)= ń_0*(1-3*10^{-5}T)$

The new model (Fig. 2 and Table 1) shows a relatively thin lithosphere underneath the Polish foreland (100–120 km) with indications for a flexural foreland bulge. The lithosphere underneath the European platform reaching about 100–110 km in our model is much thinner than previously modelled. The first results of integrated modelling in the Western Carpathian mountains also indicate the presence of a lithospheric root beneath the highest topography with a maximum beneath the Pieniny Klippen belt - perhaps as a result of suggested small remnants of a south-dipping subduction zone that resulted in continental collision. In this area also a slight thickening of the crust up to about 35 km is required in our model. The data of the Pannonian Basin cannot be completely explained with a standard uppermost mantle. Possible lithosphere-asthenosphere configurations include surprisingly thick lithosphere (110–120 km), a lithosphere which has recently been rapidly thinned from underneath or an uppermost mantle being 5–10 kg/m^3 denser than usual suboceanic mantle which may be explained by enrichment due to a plume. The thickness of lithosphere on average of 80 km in the Pannonian basin is predicted.

Problems of the lithosphere structure analysis

The Western Carpathians belong to the Alpine orogen, formed during the Mesozoic and Tertiary. It contains large remnants of the Paleozoic basement, which constitutes dislocated parts of the European Hercynides. Lithosphere of the Western Carpathians is composed by various Cadomian (e.g. Brunnian, Oravic basement) and Hercynian (principal Hercynian lithotectonic units in the sense of Bezák et al., 1997b) fragments and Alpine units (Flysch belt, Tatricum, Veporicum, Gemericum, Mesozoic nappes, Neogene volcanics and sediments). The long term tectonic processes result in a variegated mosaic of apparently disconnected fragments in the Western Carpathian lithosphere. The analysis of the Western Carpathian lithosphere structure have necessary to take into account the presence of all events in the geodynamic evolution, mainly:

– Building of a Hercynian orogen, resulting from the collision between the Laurasia and Gondwana continents: this tectonics is followed by rifting, nappes stacking, strike-slip fault movements, resulting in a first destruction of the consolidated Hercynian lithosphere.

– Jurassic rifting: oceanic domains formed (Meliaticum, Penninicum), separating continental microblocks.

– Paleoalpine collision of microcontinents and the European platform: crustal tectonic units (Tatricum, Veporicum, Gemericum) collided and developed large north-vergent imbricate structures.

– Oblique collision during the Tertiary: the uplift and movements of Paleoalpine blocks along horizontal strike-slip faults towards NE are dominant.

– Final extension and collapse of the orogen: developed large Neogene sedimentary basins, volcanism and horsts and grabens, exhibiting various structural levels of the crust.

Rheology of the lithosphere

Spatial variations in recent lithospheric strength help us to examine the existence of a rheological control on the tectonic evolution of the Western Carpathians and surrounding tectonic units. Study of the rheological variations (Lankreijer, 1998, Lankreijer et al., 1999) was based on previous geophysical-geological interpretation of deep lithospheric structure, and extrapolation of microphysical models from laboratory scale to a lithospheric one. Rock failure can occur either by brittle or plastic deformation. While brittle failure is mainly controlled by lithostatic pressure, ductile flow depends strongly on rock-type, strain-rate and temperature (Byerlee, 1978; Carter and Tsenn, 1987; Kirby, 1983).

The mechanical strong core of the Bohemian massif with EET's in order of 20–40 km acted as a rigid anchor, blocking the northward movement of the colliding alpine region, causing, e.i. large scale sinistral stike-slip movements in the Eastern Alps (opening of the Vienna basin) and the moving of the Western Carpathians in NE direction.

The Polish foreland area (Fig. 3) shows a horizontal rheological stratification of the lithosphere. Mechanicaly strong behaviour is predicted for the upper part of the crust, the uppermost part of the lower crust and the upper most part of the mantle. The weak lower part of the upper crust is predicted as the most obvious datachment level. The combined elastic effect of the three strong layers will govern the flexural behaviour of the foreland in this region. An EET of 12 km is predicted on our strenght predictions.

In the Western Carpathians lower crustal strenght completely disappears as a results od the crustal thickening and increased crustal temperatures. The lithospheric strength gradually decreases towards the Pannonian Basin. This is a direct result of the increasing temperatures and decrease of the (thermaly defined) lithospheric thickness. An eet of 15–23 kmit is predicted .

The Pannonian rheological structure including Danube basin as well are characterized by one relatively thin

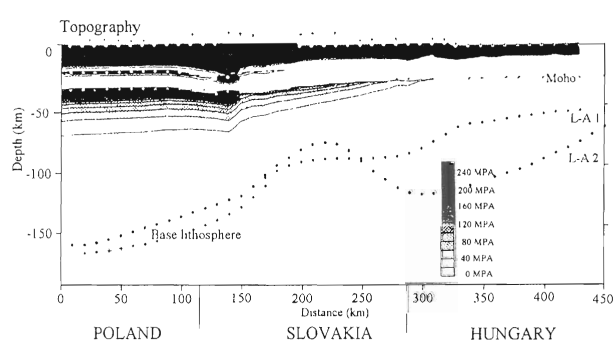

Fig. 3. Rheological cross-section running across the central part of the Western Carpathians (modified after Lankreijer et al., 1998). Yield-strength contour plot for compressional deformation. Rheological stratification is observed. Depth to Moho and the base of the lithosphere is indicated by white and black dots respectively

strong layer in the upper crust and complete absence of strength in the lower crust and lower lithosphere. The extreme weakness of the lithosphere is a direct result of the high surface heat flow density and relatively to the extremely shallow asthenosphere in the Pannonian basin. the eet is predicted at 5–10 km only.

Conclusion

As a research of the deep-seated lithospheric structure and as well as a solving of a problem defining of the real disconituities within lithosphere including also the lithospere-asthenosphere boundary are very difficult it is necessary to go on in multidiscipline geological, geophysical and petrological investigations in order to be able to create reliable improvement geodynamic model of development of the Western Carpathians and its surrounding tectonic units.

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Tectonic evolution of Gemericum (the Western Carpathians) outlined by the results of petrotectonic research

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Abstract

The results of regional petrotectonic research contributed to the new interpretation of tectonic boundary between Gelnica and Rakovec groups of Gemericum which is interpreted as Variscan exhumation zone, as well as to the kinematics of Middle Cretaceous post-collisional unroofing of Veporicum along the Lubeník-Margecany line and to the Bôrka nappe transport. Recent arc shape of Gemericum and Veporicum contact zone is indirectly indicated by the opposite sense of mid-Cretaceous extensional sliding as compared in western and eastern part of the contact as a product of late Alpine brittle-plastic shear zones.

Key words: microstructures, U-stage, textural goniometry, paleopiezometry, Gemericum, Veporicum, Meliatic Bôrka Nappe, Western Carpathians

Introduction

The complex Variscan and Alpine evolution of the Inner Western Carpathians produced three regionally important ductile shear zones in the region of Gemericum. The oldest ductile shear zone, being studied petrotectonically, divides Early-Late? Paleozoic Rakovec group from Early Paleozoic Gelnica group. This zone is supposed to be a product of Late Paleozoic Variscan orogenesis. Next studied shear zone, Lubeník-Margecany zone, recently divides the tectonic units Gemericum and Veporicum. Our research took into scope eastern, Margecany part of the zone, which complex tectonic story has been already known (Jacko et al., 1996; Gazdačko, 1994; Jacko, 1998, a.o.). Study of the northern regional spread of the Cimmerian Bôrka nappe, superficially representing third ductile shear zone, brought some proofs and criteria for further research.

Methodology

Representative samples were taken from three regionally important ductile shear zones which were distinguished by regional geological mapping and structural research. Oriented samples, cut parallel to the XZ plane, were studied by optical microscopy (microstructures, U-stage) and textural goniometry (Siemens D500 reflection X-ray texture goniometer). To obtain exact data about the magnitude of differential stresses distribution during Gemeric tectogenesis we tried mathematically distinguish these by paleopiezometry on marbles. Two used methods, Twinning incidence (T.i.) and Twin density (T.d., Rowe and Rutter, 1990), we have improved and in comparison with our older results (Németh and Putiš, 1999) the final differential stresses we have calculated altogether by six ways for each sample.

Obtained results

1. Tectonic boundary between Early Paleozoic Gelnica and Rakovec groups

Outcrops in the contact zone of Early Paleozoic Gelnica and Rakovec groups of Gemericum demonstrate moderate dip of foliation towards N, NNW as well as NNE and generally subhorizontal E–W trends of lineation. In the eastern part of Gemericum, where the contact zone of both groups is bended to SE, the above described structural settings follow this bend.

Studied flyschoid sandstones consist of originally alternating psammitic and pelitic layers. Rocks suffered dynamic recrystallization with different effects on psammitic (quartzy) and pelitic layers. Rheological differences between both types of layers caused preferred kinematic activity of former pelitic layers (phyllosilicates). The prevailing deformational mechanism of quartzy layers was dislocation creep leading to grain boundary migration and later polygonization of quartz grains. The origin of synthetic and antithetic microshears in former pelitic layers containing asymmetric recrystallized quartz porphyroclasts, mantled porphyroclasts of harder phases, rare strain fringes on pyrite and microfolding indicate non-coaxial deformation regime.

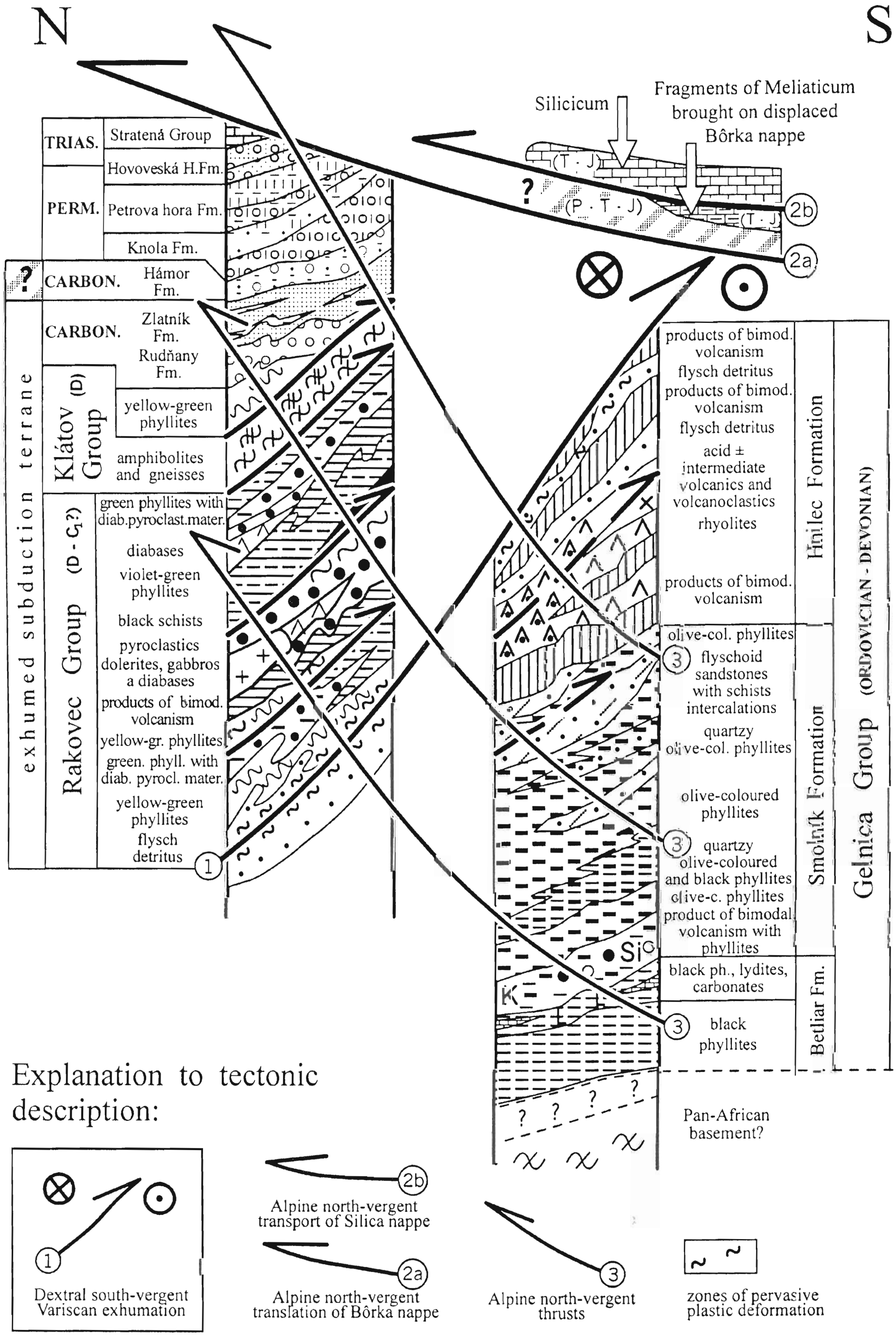

Fig. 1. Lithotectonic column of the North-Gemeric zone depicting the tectonic evolution related to Variscan subduction and exhumation processes as well as Alpine nappe transport and north-vergent thrusting.

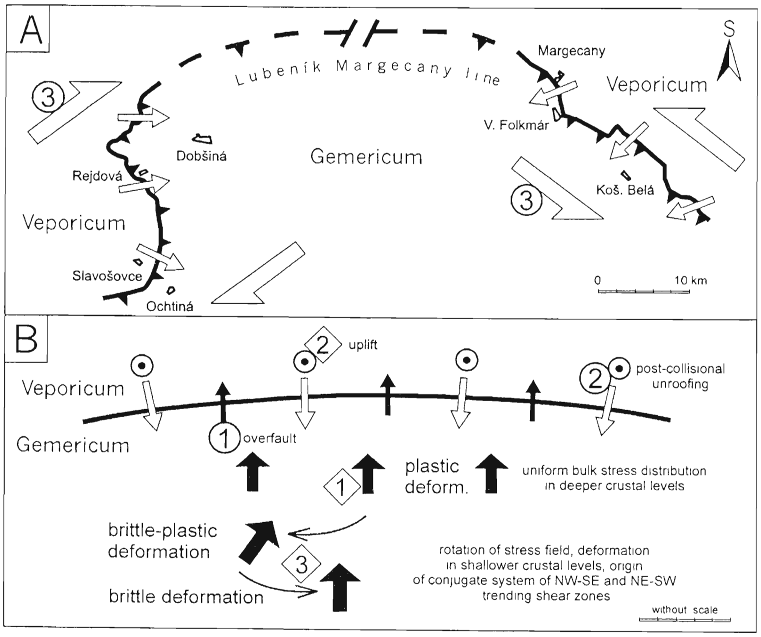

Fig. 2. A – Opposite direction Alpine extensional unroofing in the contact zone of Gemericum with Veporicum and its arc shape. B – Process of formation of arc shape which preceeded the final situation depicted in A. The numbers in squares list reasons, numbers in circles list consequences. The numbering gives the succession of events.

Asymmetric microstructures of mylonites studied from the contact zone between Gelnica and Rakovec groups demonstrate top-to-the-ESE (SE) hanging wall transport direction. In the eastern part of the contact zone (wider area of the Vyšný Klátov village) there was found also transport top-to-the-S, SW (and locally to the W), which corresponds to spatial change of mezoscopic planar and linear characteristics (prevailing moderate dip of foliation to NNE and NE). U-stage measurements, done selectively on quartzy layers, behaving as harder and kinematically less active phase, demonstrate low temperature of deformation and very weak asymmetry spatially corresponding with those of distinct asymmetric structures. Because of unsuitable lithology the textural goniometry and paleopiezometry has not been recently applied. Differential stresses have been calculated from the deeper lithostratigraphic horizons of the Gelnica group (Holec beds) marble samples at locality of Gočovo (87–110 MPa by T.i. and 168 MPa by T.d.) as well as Holec elevation point – sample of yellow marble (208–210 MPa by T.i. and 231 MPa by T.d.) and grey marble (141–155 MPa by T.i. and 197 MPa by T.d.).

2. Tectonic boundary between Gemericum and underlying Veporicum tectonic unit

The Alpine age of overthrusting of Gemericum on Veporicum along Lubeník-Margecany line is derived mainly from its tectonic and metamorphic effects on Mesozoic Federata Group. In the eastern, Margecany part of the contact zone it was proved by structural research (Jacko et al., 1996; Gazdačko, 1994; Jacko, 1998, a. o.). Younger, Middle Cretaceous post-collisional unroofing was reconstructed in the western part of the contact zone between Gemericum and Veporicum by numerous authors (e.g. Plašienka, 1993; Hók et al., 1993; Kováč et al., 1994; Putiš et al., 1999). Our research not only fully confirmed former findings in the western contact zone, but brought new astonishing microstructural evidences of the same processes in the eastern contact zone of both megaunits. Into scope there were taken quartzites and marbles of the inferred Veporic cover in the Čierna hora Mts. area.

The quartzites contain dynamically recrystallized flattened grains, often obliquely oriented to metamorphic/mylonitic foliation. Low viscosity contrasts between quartz-clasts and quartzose matrix is observable according to stretched and strongly dynamically recrystallized clasts without any sharp boundaries to matrix. Few present clasts of feldspars behaved as a brittle phase. Textural patterns from U-stage and textural goniometer document dislocation creep on basal <a> and less prism <a> and rhomb slip systems at estimated temperatures between 400–500 °C.

The calcite marbles show dynamically recrystallized layers (medium to fine grained) alternating with layers of flattened, elongated twinned grains. The textural patterns reflect both combined dislocation creep and mechanical e-twinning as the plastic deformational mechanisms. Pole figures proved medium and low temperature top-to-the W and SW extensional sliding. Recalculated paleopiezometrical results from Košice-Diana locality are 221–276 MPa (T.i.) and 228–254 MPa (T.d.).

3. Bôrka nappe

Samples of quartzy tectonites (sandstones, arkoses, conglomerates) were taken from the Bôrka outliers in the Nižná Slaná Depression. Oriented samples were taken from marbles on the south of Gemericum.

Quartzy tectonites in relation to character and granularity of protolith display strongly dynamically recrystallized quartz, boudinage of quartzy layers and σ and δ porphyroclasts. Typical is synkinematically grown tourmaline either conformable with foliation planes or with synthetic and antithetic shears.

Pole figures of psammitic quartzy tectonites from the higher levels of the Bôrka nappe are asymmetric with low temperature basal <a> and prism <a> slips reflecting the last stages of tectonic evolution. Quartz of samples directly neighbouring with the thrust plane is totally dynamically recrystallized having polygonal fabric. The shear deformation is indicated with penetrative foliation planes as well as synthetic microshears with newly generated white mica. Green glassy material, present in sediments in app. 5–20 cm thick attitudes unconformably with layering, displays pole figure with relatively equally distributed clusters reflecting combination of low temperature basal and rhomb <a> slips with maxima on prism <a> slip. This finding do not contradict to former findings of presence of products of synsedimentary rhyolite volcanism (e.g. Vozárová and Vozár, 1988). The activation of low temperature slips of quartz of glassy material reflects younger stages of tectonization of volcanic protolith. Because green glassy material gradually passes into ultramylonitic matrix with fragments of recrystallized coarser material wrested in glassy matrix, green glassy material represents strongly softened parts of the shear zone with gradual transitions through ultramylonites towards lower temperature mylonites.

Marbles demonstrate transition from metamorphic to deformation process. The result of metamorphic recrystallization is their coarse-grained character (usually up to 2 mm), migration of grain boundaries, lobate shape of grains and the origin of thick, usually bended, e-twins (>200–250 °C), interpreted as transitive between growth and deformational twins. Development of another twin system, containing tens of e-twins (up to 50) equally distributed in the grain, indicates higher temperature intracrystalline deformation of the "soft" material under medium differential stresses. Youngest system of deformation e-twins is narrow and sharp (<200 °C). Pole figures show a uniform low temperature N-ward thrusting.

The results of paleopiezometry from the type localities of the Bôrka nappe on the south of Gemericum: Šugov valley – 193–195 MPa (T.i.) and 187 MPa (T.d.), Zádiel valley – 258–259 MPa (T.i.) and 277 MPa (T.d.). The results from marbles of so-called Jaklovce Meliaticum (Kozur and Mock, 1995), studied for comparison, are 351–352 MPa (T.i.) and 396 MPa (T.d.). Recrystallized carbonates of the Murovaná skala hill, newly interpreted in relation to the Bôrka nappe (Németh, 1996), accomodated differential stresses 341–342 MPa (T.i.) and 273 MPa (T.d.).

Discussion

Regional petrotectonic research documented kinematics and character of plastic deformation on three regional ductile shear zones. Documented tectonic evolution starts with Variscan exhumation of subducted parts of the Rakovec group (interpreted as volcanosedimentary sequences of active type back-arc basin) over Gelnica group (marginal parts of the basin in the earlier period of its development). Next there was highlighted the role of Alpine unroofing of Veporicum along the Lubenik-Margecany zone which was traced not only in the western contact zone, but in the eastern one as well. In the frame of synchronous postcollisional unroofing of both marginal parts of the zone (recently displaying opposite sense of movement), the model of relatively younger age of arc-shaping of the Lubeník-Margecany line (and in broader sense the whole Western Carpathians) was microtectonically proved. Finally, there was characterized plastic deformation related to transport of the (Cimmerian) Bôrka nappe and compared with the new indices of this nappe in the North Gemeric zone. In this case the most instructive were the extraordinarily high differential stresses found by paleopiezometry from so-called Jaklovce Meliaticum (Kozur and Mock, 1995) and the Murovaná skala marbles (Németh, 1996), which support their allochtonity and probably indicate the frontal parts of the Bôrka nappe.

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Tectonic slices with amphibolite facies assemblages: a further member of the Meliata unit

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Abstract

Metamorphic rocks with relic amphibolite or epidote-amphibolite facies mineral assemblages, related to the Meliata unit, occur in four localities in the southern parts of the Gemericum. As relic phases they contain muscovite, tschermakite or pargasite and rutile. A younger metamorphic overprint was in blueschist facies or in greenschist facies conditions, in the latter case they occur in the vicinity of blueschist facies rocks. Based on their metamorphic characteristics, the investigated rocks represent fragments of an older basement unit, which was involved in subduction zone.

Key words: amphibolite facies rocks, Meliata unit, Western Carpathians

Consistently with some new results of petrological study the Meliata unit represents an accretionary complex between footwall of the Gemericum and hangingwall of the Silica nappe and it is characterized by the presence of different metamorphic rocks. Blueschists and very low-grade rocks with ophiolites, which are known for long time in this area, were formed by closing of Triassic-Jurassic Meliata oceanic basin and their subduction with adjacent continental crust materials during Middle Jurassic time. In order to find possible litho-stratigraphic relations and geotectonic position of the Meliata rocks exposed on surface, different models have been proposed to reconstruct their metamorphic history (Mello, 1996; Faryad, 1998; Ivan, 1999). Since the blueschists were derived from different lithologies (basalts and various kinds of sedimentary rocks), and form tectonic slices, which are mostly surrounded by very low-grade sequences, we classify the rocks based on their metamorphic characteristics. Besides well-investigated blueschists and associated very low-grade rocks (Faryad, 1995; Ivan and Kronome, 1995; Mazolli and Vozárová, 1998) we found metabasites and micaschists with amphibolite or epidote-amphibolite facies mineral assemblages. The first occurrence of gneiss and amphibolite with relic hornblende and garnet was reported from the eastern part of the Meliata unit, near Rudník (Fig. 1; Faryad, 1988). Indication of earlier amphibolite facies rock was latter found in micaschists from Zadiel valley, in which relic muscovite gave Early Paleozoic age (Faryad and Henjes-Kunst, 1997). In both cases there are clear evidences of blueschist facies overprint on medium-grade assemblages.

Metabasites and micaschists with amphibolite facies mineralogy were recently found in two localities in the western parts of the Meliata unit. They occur NW from Rožňavské Bystré and west from Nižná Slaná (Fig. 1), the second occurrence was partly investigated by Ivan (1999). In both localities, metabasites and micaschists associate with blueschists facies rocks. The investigated metabasites and micaschists are mostly well foliated and contain more or less of the following minerals: amphibole, epidote, white mica, albite, quartz, rutile and titanite. In some cases they are coarse-grained with large crystals of amphibole, white mica and chlorite. Amphibole, forming up to 5 cm long grains may cross foliation in the micaschists. It is usually completely replaced by chlorite. Relics of biotite were found in some chlorite crystals from Rožňavské Bystré. Rare rutile forms relatively large crystals or aggregates.

Based on microprobe analyses the amphiboles, including megablastic variety, correspond to tschermakite in Nižná Slaná and to pargasite in Rožňavské Bystré. Both amphiboles are rich in Al with maximum Al_2O_3 = 15 wt % and have XMg = 0.6–0.7. The Na^{M4} position is occupied by 0.25–0.34 Na atoms. This amphibole is partly rimmed or replaced by actinolite, but mostly by chlorite. White mica has composition near to muscovite with maximum Si content of about 3.15 a.f.u. Analysed epidote has 38–48 % zoisite content, calculated based on $(100[Fe_{tot}/(-2+Al_{tot}+Fe_{tot})])$. Plagioclase is albite in composition with low An = 3 % content.

The metabasites and micaschists from Rožňavské Bystré and Nižná Slaná occur in the vicinity of blueschists, but for the lack of outcrops it was difficult to find their relationships. The blueschists are characterized by the presence of glaucophane, epidote, albite and phengite. Some phyllitic rocks may contain garnet and chloritoid. In the

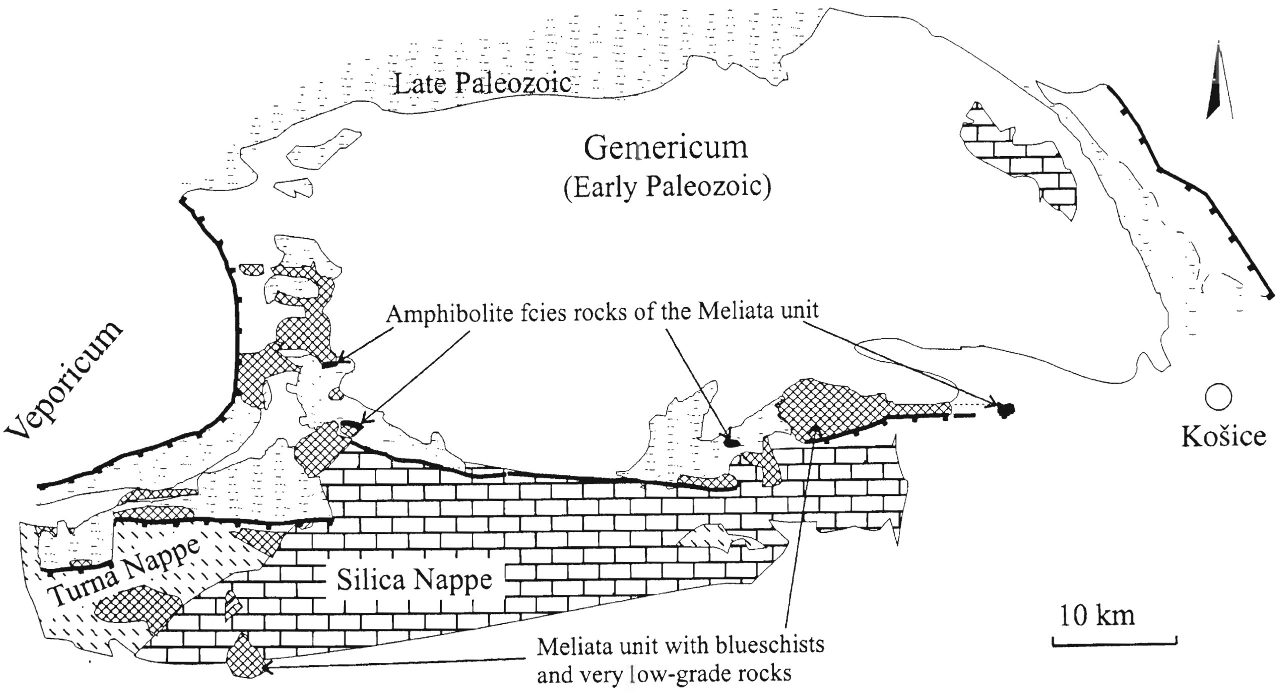

Fig. 1. Medium-grade metamorphic rocks with blueschists or greenschist facies overprint and related to the Meliata unit.

Rožňavské Bystre actinolite rimming glaucophane and accessory winchite was also found. Although no glaucophane or high Si-phengite was found in nearby metabasites and micaschists with tschermakite or pargasite, blueschists overprint on earlier amphibolite facies assemblage is well known in micaschists from Zadiel locality, where muscovite is crossed by glaucophane. The common feature of micaschists from Rožňavské Bistré and Nižná Slaná with Zadiel is the presence of coarse-grained muscovite and relatively large rutile crystals. The investigated rocks from all four localities, including Rudník, (Fig. 1) contains medium-grade mineral assemblages that were overprinted either by blueschist or greenschist facies metamorphism. Based on position and metamorphic characteristics, the investigated metabasites and micaschists can be interpreted as a fragments of older basement unit which were involved in subduction zone and underwent blueschist to greenschist facies metamorphism. Although some analogies of relic phases and rock fabrics occur between gneiss-amphibolites at Rudník with gneiss-amphibolite complex occurring along the eastern and northern boundary of the Gemericum, the micaschists from the rest three localities are exotic in this area. By my experience, such rocks are not known from the Gemericum or Veporicum.

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Tertiary semi-ductile shear event within Margecany and related shear zones

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Abstract

NW–SE trending shear zones belongs to the most pronounced structures of the eastern part of the Western Carpathian Internides. The most significant of them is the Margecany shear zone delimiting the Gemericum unit against the Veporicum of the Čierna hora Mts. one. The last unit comprises several shear zones of the same spatial position.

Activity of the zones have been documented from the Early Cretaceores up to recent period. Tertiary development of the zones has been up to now associated with a brittle regime. Presented semi – ductile deformations are clearly superimposed onto Cretaceous ductile tectonites of shear zones. They prevailingly have sinistral oblique strike – slip kinematics and they are principally associated with E–W orientation of tensional component of the paleo – stress field.

Key words: Western Carpathians, eastern Gemericum and Veporicum units, shear zones, Tertiary semi-ductile deformations

Introduction

NW–SE trending Margecany shear zone (MSZ) separates the crustal – scale basement/cover sheets (Gemeric and Čierna hora Mts. Veporic units) at the eastern part of the Western Carpathian Internides (WCI). Gradual ceasing of rhytmically developed subparallel shear zones in both mentioned units as well as results of gravity sounding indicate spatial extensiveness of the Alpine shortening within the MSZ. Noteworthy great temporal activity of the zones (Early Cretaceous/Quarternary), their variable tectonic and deformation regimes during this time (cf. Jacko et al. in Polák et al., 1997) cause several difficulties even in recognition of succesive position, kinematics and regional significance of individual tectonometamorphic events in the zones. The aim of this paper is to demonstrate the presence, type and kinematics of the Tertiary semi-ductile tectonites in the MSZ and related (i.e. Bujnisko and Rolová) shear zones of the Veporic unit of the Čierna hora Mts. associated up to now with Cretaceous tectonometamorphic development of the region.

Geological setting

The Čierna hora Mts. (Čh. Mts.) Veporicum unit forming the eastern edge of the WCI consists of crystalline basement, Late Paleozoic to Mezozoic cover formations and some isolated klippes of Choč nappe sequence. Margecany shear zone detached the unit from Paleozoic seque-nces of southwardly situated the Gemeric unit. The eastern and southern margin of the Čh. Mts. is transgressively covered by the Paleogene and/or Neogene sediments respectively.

The crystalline basement of the Čh. Mts. consists of three lithotectonic complexes. From the bottom to the top these are (Fig. 1), the Lodina complex, the Miklušovce complex and the Bujanová complex (Jacko, 1985). The last two belong to the Upper lithotectonic unit (ULU) of the Variscan structure of the WCI sensu Bezák (1994), the first one is a part of the Middle lithostructural unit. (MLU,l.c.). The Lodina complex principally consists of strongly diaphtoritised gneisses and tiny amphibolite bodies. The Miklušovce complex is formed by migmatites and intrafolial aplitic granites and the Bujanova complex – the top subsheet of the Variscan nappe suite, is composed of gneisses, migmatites, amphibolites and granodiorites.

The cover sequence of the Čh. Mts. Veporicum unit starts with Late Carboniferous and Permian clastic formations, comprising rhyolitic volcanics within the later. Triassic to Late Jurrasic part of the sequence is mainly composed of carbonates. Choč nappe klippes – flately overriding Jurassic cover carbonates in the region, are formed by Late Carboniferous and Permian clastic stratas includingly tiny sill-like dolerite bodies in the Permian formations.

Geometry of the shear zones

All three the mentioned shear zones have NW-SE direction and a medial inclination to SW (Fig. 1). These up to 400 m wide shear zones extending to several tens km emphasize boundaries between the units, among their lithostructural complexes or (in the last case) they cut the sequences longitudinally. Comprising NE vergent lithostratigraphically different horses of tectonically stacked sheets the zones show a distinctive imbricated structure. The most significant one – the MSZ, contains also slices of the Choč nappe (Jacko et al. in Polák et al., 1997).

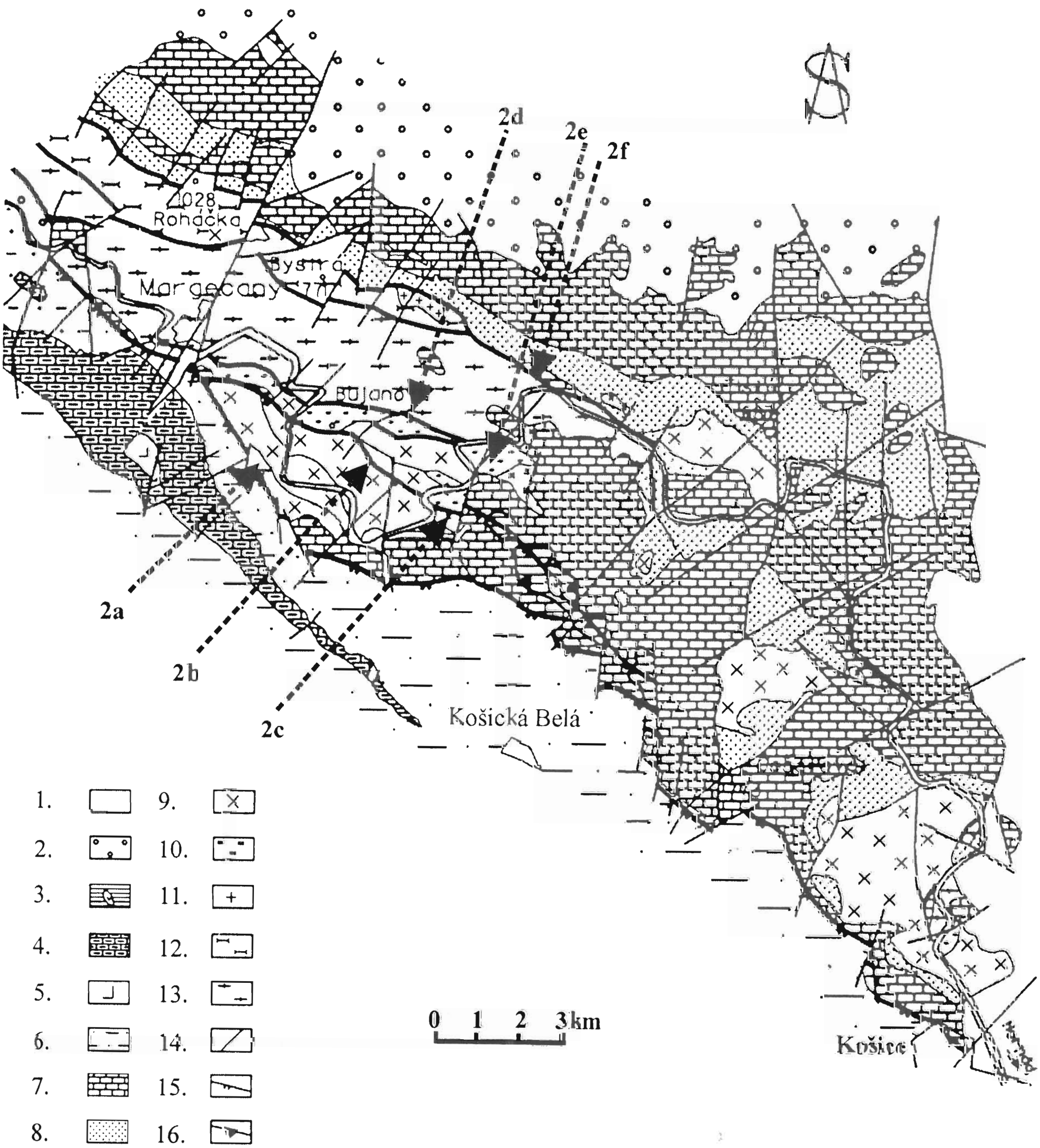

Fig. 1. Schematic geological map of the Čierna hora Mts. Veporic unit and adjacent part of the Gemeric unit. 1 – Neogene molasse sediments, 2 – Flysh successions of the Intra Carpathian Paleogene, 3 – Choč nappe of the Hronicum unit, 4 – Sediments and metabasites of the Meliata unit, 5 – ultrabasic rocks of the Meliata unit, 6 – Late Paleozoic cover of the Gemericum unit, 7 – Triassic to Late Jurassic cover – prevailingly carbonate successions – Veporic unit, 8 – Permian greywackes, shales and rhyolite volcanites – Veporic Unit, 9–13 – Early Paleozoic of the Veporic unit, 9 – granitoides of the Bujanová complex, 10 – greisses of the Bujanová complex, 11 – granitoides of the Miklušovce complex, 12 – migmatites gneisses and amphibolites (Bujanová and Miklušovce complexes), 13 – diaphtoritised gneisses and amphibolites of the Lodina complex, 14 – regionally significant faults, 15 – shear zones, 16 – soles of the Alpine nappes.

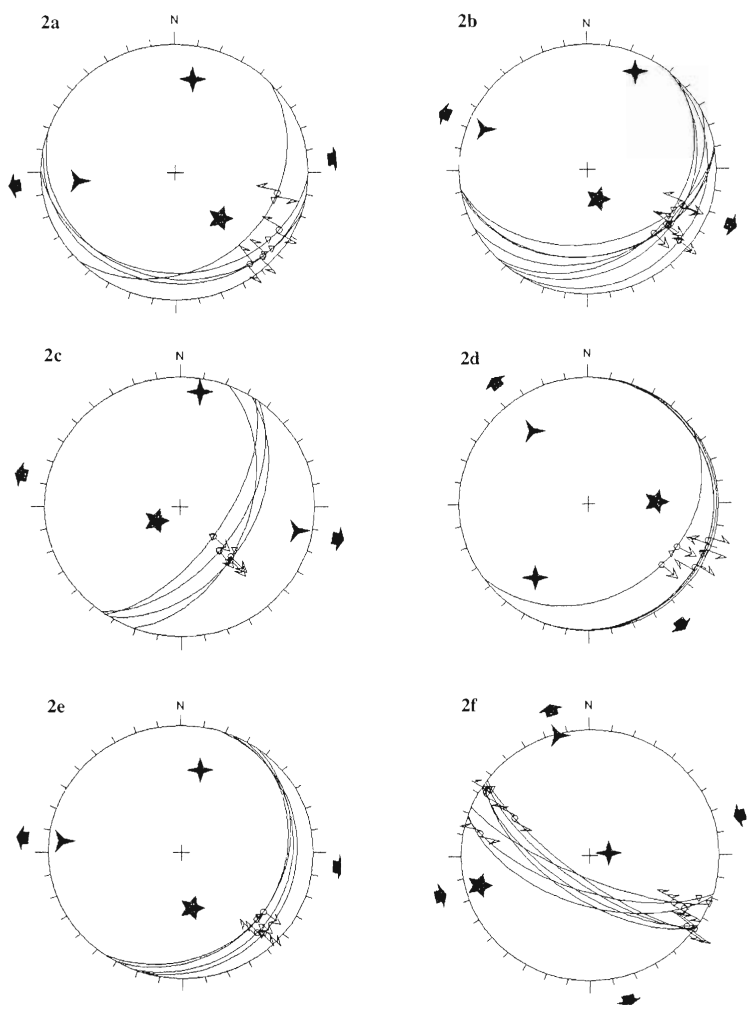

Fig. 2. Maximal horizontal stress axes constructed from C – planes and striations of semi-ductile Tertiary deformation event of the region, lower hemisphere projection. Location of 2a–f data cf Fig. 1

All the zones are displaced by more or less significant NE-SW trending subvertical faults.

The Bujnisko shear zone (BSZ) located approx. 2 km NE from the MSZ (Fig. 1) interrupts basement rocks of the Bujanova complex as well as jointly folded cover formations of Čh. Mts. and Choč nappe klippes. The Rolová shear zone (RSZ) emphasizing contact of basement units of the Čh. Mts. (i.e. the Bujanová complex and Lodina one) is marked similarly as the BSZ by rooted lensoidal bodies of the Permian and Triassic formations.

Methods

Structural observations and microtectonic measurements were carried out at several stations of the zones. Especially ductile to semiductile S/C structures and kinematic indicators on C – planes were investigated in all lithostratigraphical sequences participating in the structure of the zone. From these data paleostress calculations were completed using Stress computer programs (Villemin and Charlesworth, 1991). Microscopic verification of zone movement sense was mainly based on porphyroclasts, domino sets, mica fishes and both antithetic and synthetic microfractures.

Typical features of semi-ductile event of the zones

Despite originally contrasted rock complexes rheology in which the shear zones are developed discussed semiductile deformations at the zones reveal two the following mutual evidences: (i) – they are nearly exclusively limited to the NE-SW planar sets (Fig. 2a–f), (ii) – the deformation event has been generated by top – to – the SE noncoaxial normal fault shearing, (iii) – although deformation structures of the event are continually present at the zones they are most expressively developed at the areas of the subvertical post-Paleogene NE–SW faults.

Except of the mentioned common features the deformations in the particular shear zones comprises in detail some differencies, usually influenced by original rock complexes competences or by a presence of regionally significant NE–SW and/or N–E faults. For example semi-ductile deformations at the MSZ (Fig. 2a), containing at its base incompetent Permian siltstone/shales and/or pre-Tertiary phyllonites of the Čh.Mts. basement rocks, are typical by gently to SE inclined C-plane set and similarly dipping sinistral striations on them.

An analogous C – planes spatial position and movement sense of the event is evident in the RSZ (Fig. 2b, d). The paleo-Alpine phyllonite foliation is sheared by C – plane set in this zone. More steeply dipping normal faulting to the SE at the C – planes of equal spatial position is present at the SE part of the RSZ (Fig. 2e). This distinct normal faulting component probably associates with C – planes reactivation on significant post-Paleogene N-S fault set in this area of the region. At the northern part of this fault system C-planes of this event are steeply inclined to the SE (Fig. 2f). Striations on the C – set reveal however sinistral strike-slip motion. An illustrative linkage of discussed semi-ductile deformations to NE – SW faults display to SE medially inclined C – set containing normal faulting striations (Fig. 2c) which represents waning of deformation on both sides of SE – NW negative flower structure cutting both BSZ and RSZ (Fig. 1).

Discussion and conclusions

Eastern part of the Gemeric unit and Čh. Mts. Veporic unit have principally the same structural pattern as their central area. Both regionally developed Alpine folds and shear zones have however an opposite i.e. NW–SE direction. The folds and NW–SE shear zones deform the whole pre-Paleogene rock complexes. Folded and/or ductilely deformed sequences of the shear zones are transgressively overlapped by Paleogene/Neogene stratas. Brittle deformations within the shear zones or at spattialy related faults are developed in the Tertiary and even Quarternary formations.

The lowest activity limit of the NW–SE shear zones is done by Maluski's et al. (1993) result of 135,5 Ma Ar/Ar obtained from muscovites of mylonitised granodiorite from the BSZ. A probability of this age is also confirmed geologically by the absence of Cretaceous formations in the cover sequence of the Čh. Mts. Veporic unit (Jacko in Polák et al., 1997). The Cretaceous ductile reactivation of the zone indicates mylonites of BSZ dissecting the complete pre-Tertiary profile of the Čh. Mts. Veporic unit includingly Choč nappe klippes emplaced onto Jurassic cover sequence of the unit (Jacko, 1979). Sinistral brittle wrenching on the NW–SE Tertiary faults developed directly in the zones and related consequences of this deformation event have been evaluated by Jacko et al. (1996). The outlined data undoubtedly indicate a poly-staqe reactivation of the discussed NW–SE shear zones.

Presented results reveal both Tertiary superimposed semi-ductile reactivation of discussed shear zones and sinistral mainly strike – slip kinematics of these movements. Although semi-ductile deformations are detectable continually through the direction of the zones the majority of them are clearly aligned to regionally significant NW–SE faults. Prevailingly top – to – the SE sliding of rock segments on C – planes sets have been evidently determined by generally E – W extensional orientation of the stress field of this semi-ductile deformation event (cf.Fig. 2a–f).

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Petrostructures of metadiorites in the Veporic basement

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Abstract

The metamagmatic complex of the Veporic basement shows Meso/Late Variscan postcollisional collapse of the collided Pre-Alpine supracrustal Čierny Balog and Hron Complexes. The metamagmatic complex is mostly represented by layered diorites, often porphyric Qz-diorites to diorites, which are internally differentiated into dark Pyrx-Amph or Amph-rich layers of meladioritic (gabbrodioritic) composicion, or into pale tonalitic-trondhjemitic layers. Layered diorites and gabbrodiorites were emplaced into Pre-Alpine supracrustal gneiss-migmatitic rocks of the Čierny Balog Complex.

Key words: Western Carpathians, Veporic zone, layered magmatites, ductile deformation-recrystallization

Introduction and geological setting

The layered metamagmatic-amphibolitic rocks are dominant members of the layered metadioritic complex within the Veporic basement of the Central Western Carpathians (Fig. 1.) The preserved primary igneous textures such as magmatic compositional layering are not everywhere regularly distributed and they are completely re-equilibrated under metamorphic conditions. Despite it, it is commonly possible to observe straight more-less sharp boundaries among a few dm thick layers of diorites, porphyric diorites, meladiorites, gabbrodiorites, gabbros, hornblendites, tonalites and trondhjemites. For a comparison, the partially melted amphibolites contain only amphibolitic and trondhjemitic/tonalitic layers.

The most probable mechanism of the relic magmatic layering appears to be magmatic laminar flow, accompanying differentiation and alignment of Pl and Am mega- and microcrysts parallel to the direction of flow, e.g. in porphyric (meta)diorites (e.g. Parsons, 1987; Percival et al., 1992; Shelley, 1992; Hall, 1996). The development of layering was influenced by the extensional emplacement conditions of the magmatic sills into the shear zone accompanying an extensional detachment fault. Thus a continuous evolution of the magmatic to subsolidus and solidus foliation might have formed (e.g. Patterson et al., 1989, 1990; Shelley, 1992). The mentioned conditions might cause the thinnig of already magmatically differentiated and mixed sills, controlled by propagation (opening) of an extensional shear zone.

All lithological members were thinned and stretched into straight bands with sharp boundaries, changing the mineral grain size, due to superimposed strong ductile deformation and recrystallization at medium-T conditions within a deep-crustal shear zone.

Mesostructures

Characteristic mesostructures – symmetrical boudins of competent gabbrodioritic/hornblenditic layers in both XZ and YZ planes, surrounded by the ductilely deformed pale trondhjemitic and dark amphibolitic layers, reflect pure shear regime of deformation at the beginning stage of extension connected with the increased heat flow. This is also reflected by superimposed higher-T recrystallization of Hbl1 generation. Brown-green to green Am1 of Mg-Hbl to Ts-Hbl composition is replaced by blue-green Ts to Fe-Ts at the rims, or Am1 is directly replaced by symplectitic aggregate of Ts+Qtz. This process is well discernible e.g. in ultramylonitic layered amphibolites, where the tiny grains of Hbl1 are almost entirely replaced by higher-temperature Ts+Qtz symplectitic aggregates, indicating the temperature increase during and partly after the extensional mylonitic to ultramylonitic deformation.

Microstructures

The microstructures comprise Qtz ribbons surrounded by dynamically recrystallized Pl aggregates. Symmetrical crystallographic preferred orientation patterns (CPO) of Qtz ribbons subgrains and Pl confirm the pure shear regime of mylonitic deformation and recrystallization in the first stage of the uplift. Later, and at a higher structural level, the deformation was transformed into an asymmetric ductile- and ductile-brittle regime.

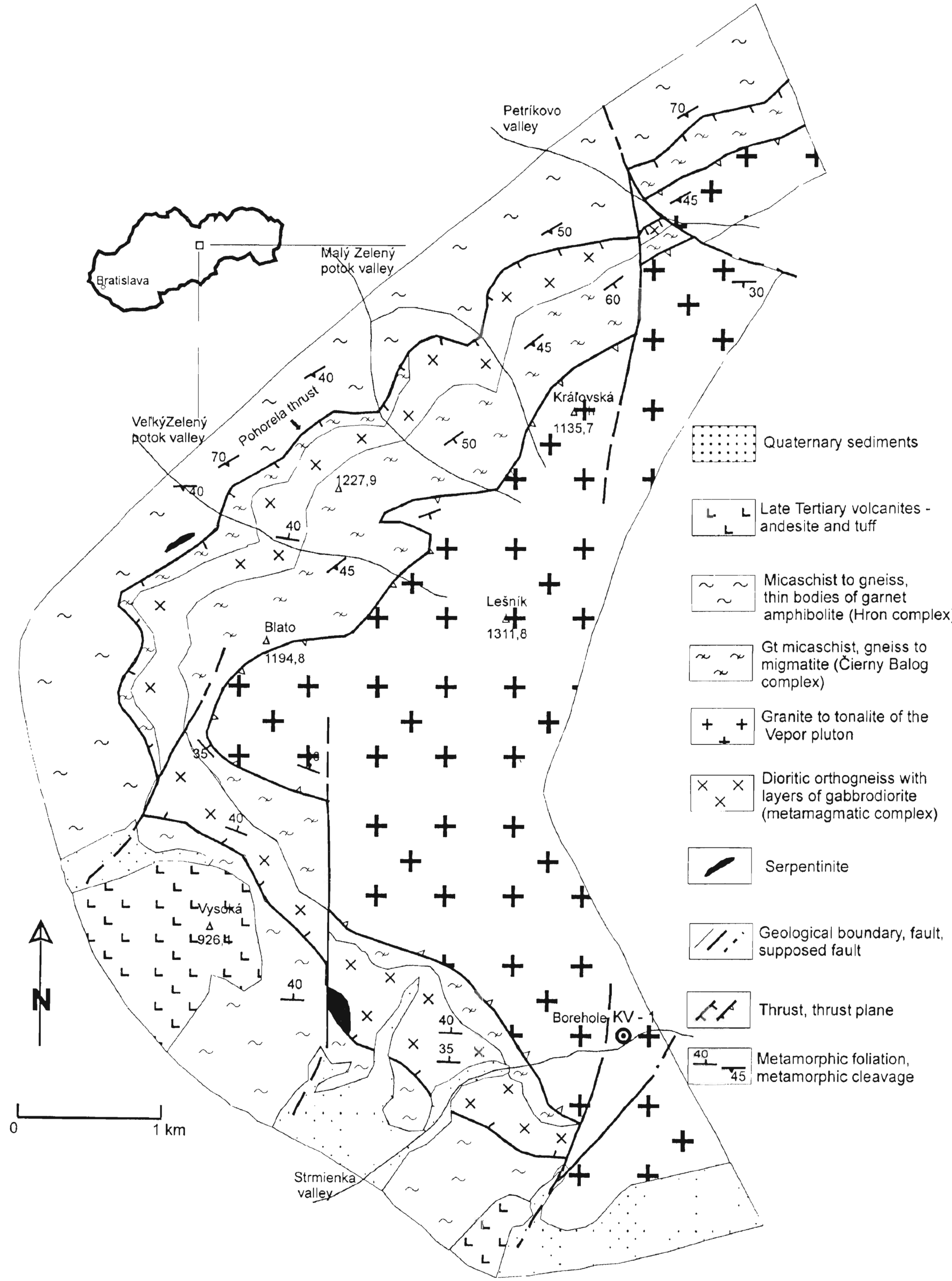

Fig. 1. Geological-structural sketch of the metamagmatic complex in the North Veporic unit of the Western Carpathians (M Putiš and I. Filová, 1996).

Deformation-recrystallization stages

It is possible to distinguish the next deformation--recrystallization stages (mineral abbreviations after Kretz, 1983) in the main types of rocks:

1. metadiorites to metagabbrodiorites

DR_1 (prograde burial, Variscan): Am_1 (Mg Hbl, edenite – pargasite?), Pl, Qtz, Ep-Czo, Grt, Bt_1, ±Ttn

DR_{2-1} (extensional exhumation, Variscan): Am_2 (Ts), Pl, Grt

DR_{2-2} (late Variscan? or Alpine cooling): Am_2 (Act), Ab, Chl2, Bt2, Ms-Phe, ±Cld, Grs

2. layered metadiorites – amphibolites (magmatic, subsolidus and solidus layering)

DR_1 (prograde, Variscan): Am_1 (Mg-Hbl), Chl_1, Qtz, Pl, Bt_1
Moreover, Px – diopside of metahornblenditic lenses is replaced by Mg-Hbl(1).

DR_{2-1} (extensional exhumation, Variscan): Am_2 (Ts), Grt, Czo, Phe

DR_{2-2} (late Variscan? or Alpine cooling): Am_3 (Act), Ab, Ms, Bt2, Chl2, Grs, ±Cld

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Graphitic metaquartzites and magnetite-bearing gneisses: petro- and minerogenetic analysis (Kokava nad Rimavicou, southern Veporic basement)

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Abstract

Carbonaceous substance, forming well-crystallized graphite, preferentially occurs in metaquartzites. There were find out some factors controlling accumulation of graphitic matter· Higher primary concentration of organic matter was deposited in some nearly pure quartzitic domains or nearby pelitic laminae. Later deformation induced secondary enrichment in graphite along the boundary between muscovitic and quartzitic layers. Local passive accumulation of graphite are also caused by ductile shearing in quartz-rich rheology, mostly directed parallel to the sedimentary fabrics. Arithmetic average of $\delta^{13}C$ in graphites give -27.78, which may indicate a bituminous material as the carbon protholite. Magnetite is a frequent constituent in Fe-gneisses with characteristic metamorphic mineral assemblage: garnet (almandine)-amphibole (grunerite)-apatite±biotite (annite), quartz, chlorite (brunsvigite), graphite and allanite. The original Eh of certain beds determine the nature of Fe-phases crystallisation (e.g. ilmenite vs. magnetite or grunerite vs. magnetite) during the regional metamorphism. Black quartzites, chamosite-bearing ferrolites and host psammites shared a common tectonic history and underwent the Hercynian regional metamorphism under the conditions of amphibolite facies. Their deposition indicates a special type of shallow-sea sedimentary facies.

Key words: regional metamorphism, depositional environment, quartzite, $\delta^{13}C$, graphite, ferrolite, grunerite, magnetite, deformation, Hercynian basement, Western Carpathians

Introduction and geological setting

Layers of graphitic metaquartzites and ferruginous gneisses occur aprox. 3km W from the centre of Kokava n./Rim., near the road to Hriňová (Fig. 1). They are associated with various types of high-grade metamorphites, consisting mainly of garnet-biotite gneisses. Investigated area was ranged to "northern migmatite zone" (Šuf, 1938), to "late-orogenic migmatites and granitoids" (Hovorka in Kuthan et al., 1963) or to "hybridic complex" (Bezák, 1988). The magnetite-bearing rocks were examined due potential source of iron but an economic meaning was due to high hardness and irregular occurrence of the raw material doubted (Šuf, 1938; Zoubek and Nemčok, 1951). Petrogenesis of this rocks were studied by Gubač (1957) and Korikovskij et al. (1989). Recently, graphitic material of a high quality was investigated in metaquartzites and gneisses (Pulec, 1989; Petro, 1998; Očenáš in Petro, 1998; Kováčik, 1998), though its low bulk-content needs more effort in looking for a more effective prospecting criteria. The first identification and field distribution of grafitic material were indicated by Zoubek and Nemčok (1951).

Outline of tectonometamorphic evolution

Hercynian regional metamorphic event (M1) constrained by conditions of amphibolite facies represents the basic tectonometamorphic imprint on the rocks under study. The whole metamorphic complex is conformly arranged in ductile deformational structure (generally W–E directed subhorizontal b-axis, foliation planes usually dip to north) which was surrounded with a multi-staged granitoid intrusions of a generally accepted the Carboniferous age. However, before this main granitization period some granitoid remnants, forming mainly budins, were observed in "pre-granitization" deformation fabrics. This older granitoids may represent the climax of the basic regional metamorphism. Processes of migmatitization, partial anatexis or assimilation are connected mainly with the dominant granitoid plutonism (M2). Periplutonic manifestations of a relatively younger leucocrate granites caused locally considerable recrystallisation in adjacent gneisses (e.g. randomly oriended biotite flakes or 1–2cm garnet porfyroblasts). Alpine deformation and/or recrystallization (M3) does not reach such an intensity like in other areas of the southern Veporicum realm. This is presumably due

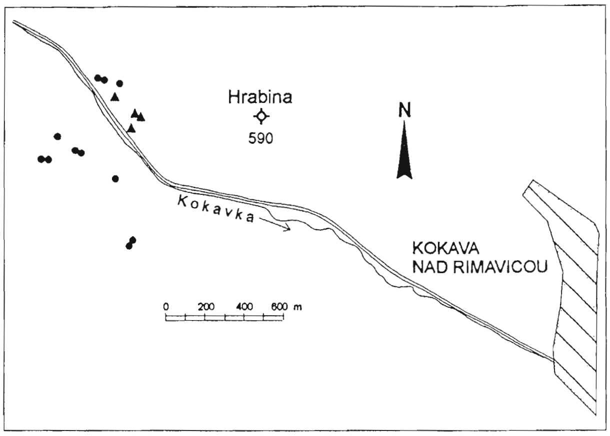

Fig. 1. Location of investigated graphitic metaquartzites (circles) and garnetiferous Fe-gneisses (triangles).

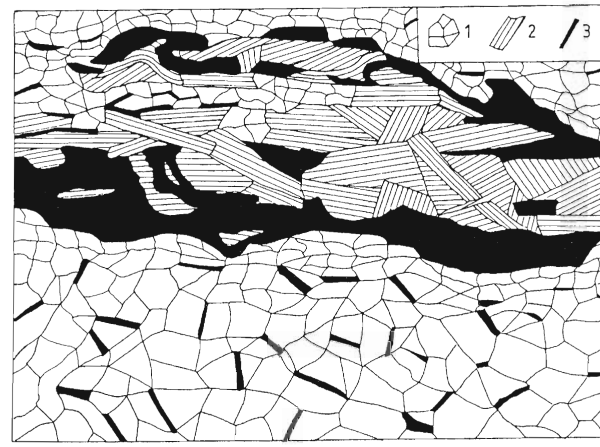

Fig. 2. Microtexture of graphitic metaquartzite (enlarged 35x). 1 – quartz, 2 – muscovite, 3 – graphite. Imposed deformation accommodated between quartzitic material and muscovite strip accumulate graphitic matter The lower part of drawing shows a common distribution of graphite crystals in undeformed domains.

to strong rheology of the investigated rocks (in comparison with micaschists, metavolcanites a. o.), which are moreover, enclosed in big and a relatively iso-tropic granitoid body.

Protolith and minerogenetic contributions

Carbonaceous substance in form of well crystallised *graphite* is preferentially bound on quartzitic lithology. Lensoidal beds of dark *metaquartzites* of X-m to deca-meters in thickness has massive or fine-banded texture. Graphitic matter appears in many of the adjacent rocks; spots of oriented structure marked by graphite was found also enclosed in the granitoids. The monotonous graphitic quartzites are usually composed of 90–95 vol.% of quartz and variable amount of graphite, muscovite (phengite) and also plagioclase in some domains. Minor constituens represent Mg-biotite, apatite, rutile and ilmenite. Signs of sedimentary fabrics are expressed by alternation of tiny quartzitic laminae of various enrichment in graphite, plagioclase and sericite. Generally, the monomineral quartzitic domains contain more carbonaceous matter than the coarser quartz-feldspar one. Scarce narrow stripes of lepidoblastic muscovite reflect a primary clayey admixture. Undistinct metamorphic foliation usually developed parallel to these sedimentary patterns.

Graphite is more/less uniformly distributed in the rock texture (Fig. 2), which indicate a large amount of nucleation centres. Graphite is mostly randomly oriented and grew along the quartz grain boundaries. The average grain-size is 0.2–0.3mm, local coarse-grained crystals (up to 1 mm) appears mainly on the contacts with micas. Tiny irregular increments on flakes of graphite or framboidal needle-like crystals are not rare. Noteworthy is the very fine carbonaceous pigment scarcely inclused in some quartz grains. This textural phenomenon express the relic inclusions of organic matter, which did not migrate during the metamorphism. There were observed some *factors controlling a higher accumulation of graphitic matter:*

– primary organic matter preferentially concentated in some nearly pure quartzitic layers/laminae or on contact with muscovites;
– enrichment in graphitic material along the muscovitic laminae (Fig. 2) was induced by deformation (due to litological inhomogenity between quartz and mica);
– local parallel orientation of graphite crystals, caused by ductile shearing in quartz-rich rheology (due to strong flattening and partial dissolution of quartz grains), led also to increase of graphitic content;

In the microscale, these later deformational processes, presumably of Alpine age, can cause a mechanical enrichment of the prior crystallised graphite grains. Rare periplutonic effects of granitoids (tiny veins and/or coarse-grained feldspars, quartz and micas overgrowing the original rock-textures) did not influence the original size, distribution a. o. of graphite crystals. Moreover, the imput of a "barren" mass from the outside decrease partly the graphite concentration in concerned domains.

Arithmetic average of $\delta^{13}C$ in examined graphites give value -27.78 (n = 11, s.d. = 0.66). Neither the metamorphism nor the local granitic injections changed the C^{13}/C^{12} ratios, which should reflect original isotopic character of the organic matter. Basing on isotopic data (Hoefs, 1973; Hladíková, 1988) and petrographic textures a bituminous material can be proposed as the protholite of carbon. Plankton could form this material, and similarly, the source of phosphorous could be of organic origin, too.

Magnetite is frequent in various types of *ferruginous gneisses* with characteristic metamorphic mineral assemblages garnet (almandine) - amphibole (grunerite) – apatite (1–3 vol. %) ± biotite (annite), quartz, chlorite (brunsvigite), graphite and allanite. There can be assigned at least six basic petrographical rock-types of ferruginous gneisses. Locally, fine-grained magnetite, apatite, grunerite, (biotite, chlorite) inclused in the garnet, can indicate their pre- and/or early-metamorphic origin. Grunerite appears in many petrostructural positions (porphyroblasts, fine-grained aggregates, needless, swarms), which reflect a polygenetic metamorphic reactions. Ferrolites of sedimentary (to diagenetic) mineral assemblage like chamosite – Fe-oxides (incl. magnetite?) – quartz – siderite are presumed as the pre-metamorphic source of these rock. The basic ferruginous mineral assemblages formed during the Hercynian regional metamorphism under conditions of the middle amphibolite facies (cca 600 ± 50 °C, 4–5 kb). Occurrence of magnetite resulted from a complex combination of many factors. A case study of ferruginous rocks show an affinity of magnetite to a more pronounced pelitic character (indicated mainly by higher content of Al_2O_3), which also corresponds to a greater extent of Fe^{3+}. The original Eh of certain beds seems to determine the character of crystallization (e.g. ilmenite vs. magnetite or grunerite vs. magnetite) in the process of regional metamorphism.

Some reflections on sedimentary environment and tectonics

Deposition of sandstones, ferruginous accumulations, black quartzites and occurence of apatite-bearing laminae in these rocks support an idea about a shallow-sea sedimentary facies (e.g. Kukal, 1991). The uniquity of (meta)ferrolites among the more usual rock association in the Veporic basement may indicate a specific depositional environment (a bay or a deltaic system prograding to the shelf area). Generally, the association of Phanerozoic ooidal ironstones with black shales is conspicuous and frequent (Van Houten and Arthur, 1989). This ironstones were especially common in the Ordovician and Devonian time (Petránek and Van Houten, 1997) and are characterised by a high relative rate of marine sedimentation on the continental crust (Ronov et al., 1980). It may be assumed that these rocks marked a regressive phase of the Early Paleozoic sedimentary cycle (Devonian?), as indications of the Caledonian or Precambrian substrate have not been evidenced so far. However, such an uppermost position in the whole sedimentary sequence arrises a question about the lithostatic load, necessary for the Hercynian regional metamorphism. As a matter of fact, any episodal retreat and transgression of the sea might also have created the investigated rock association, and thus, incorporate it into the Early Paleozoic (volcano)-sedimentary sequence.

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Plagiogranite pebbles in the conglomerates of Rudňany Formation: their characteristics and geotectonic significance

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Abstract

Leucocratic rocks called plagiogranites are found in conglomerates of Rudňany Formation. These rocks are composed of quartz and plagioclase, with accessory ferromagnesian minerals. Normal compositional zoning and compositions of granophyric intergrowths indicate that these rocks are the product of igneous processes. Plagiogranites are characterized by unique low K_2O contents and Rb/Sr ratio less than 0.010. The light REE are depleted relative to the heavy REE, and both are enriched approximately ten times relative to the average chondrite.

Key words: Northern Gemericum, Westphalian conglomerates, plagiogranite pebbles

Introduction

Conglomerates of the Rudňany Formation represent basal part of the Westphalian formations defined as the Dobšiná group (former definition according to Bajaník et al., 1981 redefined by Vozárová, 1996), which they are a part of the Hercynian structure of the Northern Gemericum basement. The origin of these sedimentary sequences reflected continental collision stages of the Variscan orogeny. The present surface outcrops of these rocks represent relics of sedimentary filling of a peripheral basin. Sedimentary filling of this basin composed dominantly of siliciclastic sediments, associated in its middle part with subalcalic basalts and their pyroclastic rocks.

The source area of siliciclastic detritus of the northgemeric Westphalian formations was Pre-Sudetian collision suture belt inclusive of slightly metamorphosed Lower Carboniferous turbidites. Pebbles of the Rudňany formation can be correlated to all known rock-types of Klátov and Rakovec groups and Črmeľ formation. Among pebbles only small part of rocks have any surface equivalent. These "exotics" belong the following rock fragments: two-mica metagranites with accessory garnets, white orthogneisses with quartz-hematite rich bands, mica schists, lydites, quartz metasandstones as well as plagioaplites and plagiogranites.

Petrography of plagiogranites

Plagiogranites are medium to fine-grained hypidiomorphic-granular rocks consisting predominantly of quartz and plagioclase (An_{10-25}). Ferromagnesian minerals are altered to chlorite, hence their primary composition are difficult to establish. Common accessory minerals are zircon, sphene, apatite, ilmenite-magnetite, and very scarce garnet. Nearly all of the plagiogranites studied in this investigation showed some effects of hydrothermal metamorphism, and contain secondary epidote, chlorite, albite and albite/epidote symplectites.

A typical textural feature of plagiogranites is an intimate intergrowths of plagioclase and quartz in the mesostasis. Two varieties of quartz-plagioclase intergrowths have been observed in plagiogranites:

1. Vermicular intergrowths in which worm-like blebs of plagioclase and quartz make up much of the mesostasis between euhedral to subhedral plagioclase grains.
2. Graphic intergrowths of quartz and plagioclase in which the plagioclase host contains quartz having triangular or semi-regular boundaries.

Intimate intergrowth of sodic plagioclase and quartz (so-called "graphic" and "granophyric" texture) generally held to be products of simultaneous growths of quartz and feldspar from a magmatic fluid (Barker, 1970). Intergrowths of sodic plagioclase and quartz were reported by Coleman and Donato (1979) from Oman plagiogranites.

Geochemistry

The bulk chemical composition is characteristic by very low content of K_2O (0.08–0.52 %), greater Na_2O (6.20–6.72 %) and lower total iron content (0.94–1.86 %). Rb contents of plagiogranite showed low values (4 and 17 ppm), whereas Rb/Sr ratio varies from 0.036 to 0.068. This data are a bit higher comparing to typical oceanic plagiogranites (0.015 after Coleman and Peterman, 1975). In addition, REE distribution is characterized by small enrichment of light REE and slight Eu anomaly compared with other oceanic plagiogranite. This apparent discrepancy may reflect interaction of the rocks with external hydrothermal fluids possessing fundamentally different chemistries.

Summary

Plagiogranites from pebble material of the Rudňany formation conglomerates have been shown to be chemically and mineralogically more similar to leucocratic oceanic plagiogranites than those formed in "continental" regime. Although local post-crystallization metasomatism has affected the chemical composition, textural and mineralogical evidences show that they are primarily products of igneous processes such as crystal fractionation and crystal-fluid interaction during the evolution of a subalkaline basaltic magma. These type of leucocratic rocks were found in the upper part of gabbros and in sheeted complexes of ophiolite suites and described by many authors.

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Permian age of gemeric granites constrained by single zircon and EMPA monazite dating

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Abstract

The new datings of the Spiš-Gemer granites which were done on zircon and monazite is presented by this contribution. The results undoubtedly show Permian age for the Spiš-Gemer granites. EMPA monazite dating revealed 273 ± 6 Ma for Hnilec and Betliar granite, single grain zircon dating for Zlatá Idka granite shows 265 ± 20 Ma discordia age.

Key words: Spiš-Gemer granites, monazite, zircon, chemistry and isotopic dating

Introduction

The age of several small granite bodies with typical S-type characteristics (Petrík and Kohút, 1997) emplaced into greenschist facies rocks of the Gemeric Early Palaeozoic basement is still discussed. Although some Rb-Sr dating indicated the Permian age of these granites (Kovách et al., 1986; Cambel et al., 1989) the valuable dating of the high temperature minerals like monazite and zircon up to now still missed. A Cretaceous age for this granite is therefore still proposed by some authors due their occurrences in the Alpine structures in the present position. Transparent or indistinct seismic zones in the upper crust were indicated such situation (e.g. Vozár et al., 1996).

In this contribution, we present single-grain zircon dating from the Zlatá Idka (Poproč) granite body and we confront this dating with recent electron microprobe Th(U)-Pb model ages of the two samples from the Hnilec and Betliar granite bodies (Finger and Broska, 1999).

Methods

The EMPA monazite dating were performed on the monazite from polished thin sections at the Salzburg University, Austria. The analytical procedure follows the working routine at the Salzburg University comprising the microprobe analyses on the chosen big monazite crystals using an accelerating voltage of 15 kV, a probe current of 250 nA and counting times of 200 sec. for Pb, 50 sec. for U and 30 sec. for Th.

The zircons for the isotopic single grain analyses were liberated by classical heavy mineral separation from the crushed rocks. Isotopic analyses were carried out at the Max-Planck-Institute of Chemistry, Dept. of Geochemistry, Mainz, Germany. Investigated zircons were studied in cathodoluminiscence to control possible old inherited cores. Only crystals without invisible old cores were used. The U-Pb measurements used the vapour digestion method and ^{205}Pb-^{235}U mix-spike. The analyses were performed in ion counting mode by peak hoping on a Finigan MAT 261 mass spectrometer. Several standards were measured and sample was corrected on common lead.

Results of Th(U)-Pb dating of monazite

Monazite grains in the Spiš-Gemer granites showed relatively high Th concentration, it reaches up to 17 wt. % of Th with medium value 11.8 wt. % for sample GZ-1 from the Hnilec granite or with average value 10.5 wt. % for Betliar granite. Relatively low average concentration was found only in the GZ-3 specimen. Relatively high thorium concentration in the monazites caused the formation of the sufficient amount of the radiogenic lead for its reliable microprobe analytic procedure. The calculated model ages for GZ-1 sample is 272 ± 11 Ma (Hnilec), for GZ-3 sample it is 276 ± 13 Ma (Hnilec) and 273 ± 13 Ma for GZ-15 (Betliar). The results are graphically presented in the Fig. 1. The samples from the Hnilec and Betliar localities show the similar EMPA age and the age for all samples indicated by common isochron is 273 ± 6 Ma (Fig. 1). The drawn isochron refers to the calculated weighted average of all samples and standard data points, respectively (Finger and Broska, 1999).

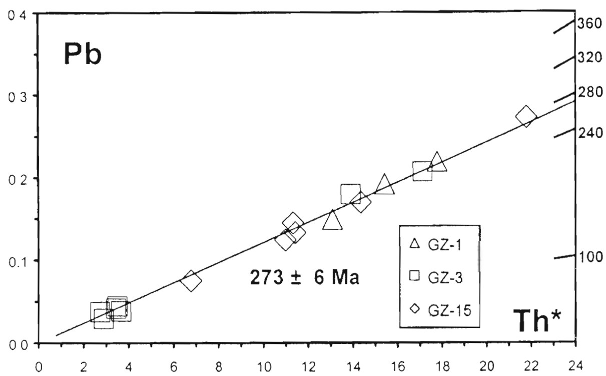

Fig. 1. Total Pb vs Th* isochron diagram of Th(U)-Pb electron-microprobe dating of monazite from the Spiš-Gemer granite according Suzuki et al (1991). The Th* parameter includes the measured Th with certain amount of theoretical Th, that would have produced the same amount of lead as the measured U (at the model age). The recommended age could be perfectly reproduced (weighted average: 342 ± 7 Ma; MSWD 0.54). The Th* and Pb values are in wt % elements. Locations: The GZ-1 sample was taken from Hnilec granite body; cliff 780 m above see level, 800 m NE from elevation point Peklisko; sample GZ-3 Hnilec, outcrop 1205 m a.s.e., 220 m NE from the Surovec hill; GZ-15: Betliar, a cliff 3250 m SW from Mt. Volovec.

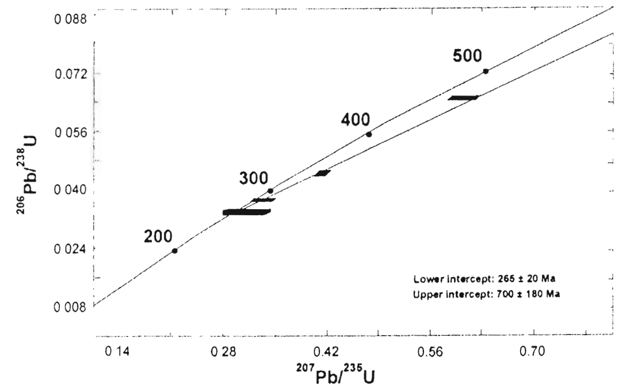

Fig. 2. Isochron diagram constrained for zircon in the Poproč biotite granite (sample GZ-11); 510 m above see level, 1400 m SE from Kojšová Hoľa Mts.

Results of the zircon single grain dating

The crystallization age of zircon from the Poproč granite body by a discordia line, is supported by one almost concordant zircon crystal age and three discordant ages (Fig. 2). The lower intercept age lies at 265 ± 20 Ma (Poller et al., in preparation). The upper intercept age is not well constrained because the zircons are all too close to the lower intercept of the discordia (Fig. 2). However, the upper intercept shows age 700 ± 180 Ma and despite of a wide internal of accuracy, the value could be indicated Upper Proterozoic age of inherited zircon core, invisible by CL-images.

Conclusion

The obtained EMPA model ages on monazites and single-grain zircon age support the Permian age for the crystallization of the Spiš-Gemer granites. Moreover, Upper Proterozoic recycled material is suggest for the Poproč granite formation.

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A comparison of tourmaline composition from the Klenovec and Spiš-Gemer granites

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Abstract

The comparison of the tourmaline composition from the Permian Klenovec and Spiš-Gemer (leuco)granites, Eastern Slovakia, show similar features. The Klenovec tourmaline is represented by high x-site vacant foitite comparable with the tourmaline of Sn-W-Li-Rb rich Spiš-Gemer granites. The high level of Na-deficiency of tourmalines as well as the bulk-rock chemistries suggest analogical metallogenetic features of the Klenovec and Spiš-Gemer granites.

Key words: schorl, foitite, Klenovec granite

Introduction

Two-mica tourmaline- and garnet-bearing leucogranites which have been identified in the area of the Klenovec complex, Veporic Unit (Hraško et al., 1997) show geochemical and mineralogical affinity to the Permian S-type Spiš-Gemer granites, Gemeric Unit (Uher and Broska, 1996; Petrík and Kohút, 1997). The Klenovec granites is characterized by increased content of K, Rb, B, Y, U, Be, Sn, W, low Sr, Ca and Ba and the presence of tourmaline, garnet, monazite and similar zircon typology. Secondary tourmaline remobilization in the form of impregnation and veinlets can be also observed. Preliminary Th(U)-Pb monazite microprobe dating indicates the Permian age of the Klenovec granites ranging from 260 to 270 Ma (Finger, pers. comm.) which is in coincidence with the Permian development of Spiš-Gemer granites (Finger and Broska, 1999; Poller et al., this vol.).

The tourmaline composition of the Klenovec granites from the KS-1 borehole situated near Klenovec has been investigated and compared with the Spiš-Gemer tourmalines granites .

Results

Tourmaline from Klenovec granites forms tiny euhedral crystals (0.1–0.3 mm in size) and it reveals foitite composition with atom. Fe/(Fe+Mg) approx. 0.75 and $^{X}\square$ 0.55–0.70 (Tab. 1). The high level of Na deficiency in the Klenovec granite tourmaline is comparable to the tourmaline from the latest aplitic derivates of the Spiš-Gemer granites (Tab. 1, Fig. 1). There are textural evidences of contemporarily tourmaline and albite crystallization. This fact is probably caused by the formation of Na-deficient tourmaline (foitite) together with albite as essential Na-bearing phase.

Blue disseminated Na-deficient schorl to foitite was firstly found in biotite-muscovite leucogranite near Zlatá Idka village as irregular replacement zones in the tourmaline crystals after primary brown zone (Broska and Uher, 1999). The late aplitic dykes of the Zlata Idka granite body contain common big (1–2 cm in size) crystal aggregates of the dark blue foitite with $^{X}\square$ up to 0.7, which compositionally similar to the investigated tourmaline of the Klenovec (leuco)granites (Tab. 1, Figs. 1, 2). Moreo-

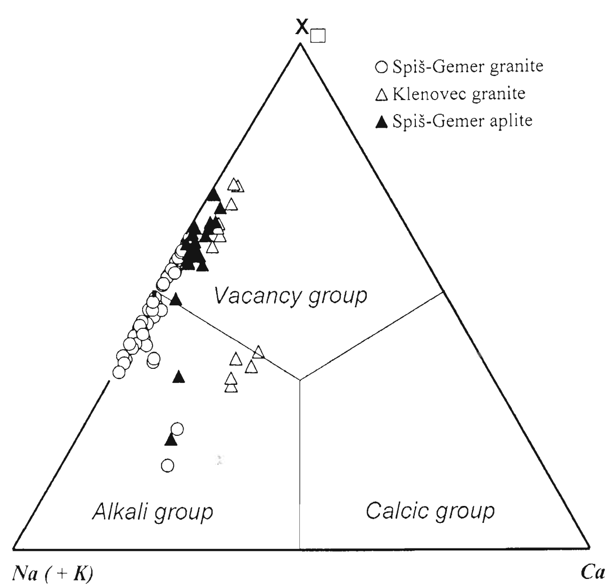

Fig. 1. The major compositional groups of tourmaline minerals after Hawtorne and Henry (1999). Foitite is plotted in the X-site vacancy field.

Tab. 1
Representative EMPA analyses of the Spiš-Gemer (Hnilec and Zlatá Idka) and Klenovec granite (in wt. %)

Anal. #	Hnilec granite GZ-1	Hnilec granite GZ-1	Zlatá Idka granite GZ-12	Zlatá Idka granite GZ-12	Zlatá Idka aplite Z12B-32	Zlatá Idka aplite Z12B-33	Zlatá Idka aplite Z12B-35	Klenovec granite KS121	Klenovec granite KS122	Klenovec granite KS126
Position	core	rim	core	core	center	middle	rim	center	middle	rim
SiO_2	35.45	36.27	33.01	34.56	34.44	34.10	34.19	34.94	35.14	34.98
TiO_2	0.13	0	0.23	0.00	0.25	0.58	0.31	0.56	0.45	0.88
B_2O_3*	10.31	10.47	10.33	10.29	10.37	10.28	10.33	10.38	10.51	10.42
Al_2O_3	34.02	35.14	36.19	34.67	35.25	33.92	35.49	34.10	35.83	34.57
Cr_2O_3	n.d.	n.d.	n.d.	n.d.	0.00	0.00	0.00	0.19	0.16	0.09
FeO_{tot}	13.73	13.1	12.86	15.10	14.10	14.95	13.72	12.89	11.32	11.68
MnO	0.11	0.06	0.12	0.00	0.17	0.32	0.25	0.20	0.17	0.31
MgO	0.34	0.25	1.58	0.55	0.94	0.96	0.81	1.97	2.17	2.31
CaO	0	0	0.32	0.00	0.13	0.10	0.00	0.13	0.18	0.28
Na_2O	2.14	1.62	1.75	1.20	0.96	1.28	1.19	1.28	0.81	1.04
K_2O	0.03	0.03	0.07	0.04	0.00	0.00	0.00	0.06	0.00	0.05
H_2O*	3.56	3.61	3.56	3.55	3.58	3.55	3.56	3.58	3.63	3.60
Total	99.82	100.55	100.03	99.96	100.19	100.04	99.85	100.28	100.36	100.21
Atomic proportions based on the sum of T+Z+Y = 15 cations *calculated from ideal stoiciometry										
Si	5.974	6.020	5.553	5.838	5.771	5.765	5.753	5.850	5.813	5.835
^{T}Al	0.026	0.000	0.447	0.162	0.229	0.235	0.247	0.150	0.187	0.165
Total T	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
B*	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
^{Z}Al	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
Ti	0.017	0.000	0.029	0.000	0.032	0.074	0.039	0.071	0.056	0.110
^{Y}Al	0.787	0.949	0.733	0.737	0.733	0.524	0.791	0.579	0.798	0.631
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.025	0.021	0.012
$Fe^{2+,3+}$	2.087	1.975	1.822	2.125	1.976	2.114	1.931	1.805	1.566	1.629
Mn	0.017	0.009	0.017	0.000	0.024	0.046	0.036	0.028	0.024	0.044
Mg	0.092	0.067	0.399	0.137	0.235	0.242	0.203	0.492	0.535	0.574
Total Y	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
Total Al	6.813	6.949	7.180	6.899	6.962	6.759	7.038	6.729	6.985	6.796
Ca	0.000	0.000	0.058	0.000	0.023	0.018	0.000	0.023	0.032	0.050
Na	0.699	0.521	0.571	0.393	0.312	0.420	0.388	0.416	0.260	0.336
K	0.006	0.006	0.015	0.009	0.000	0.000	0.000	0.013	0.000	0.011
Total X	0.705	0.527	0.644	0.402	0.335	0.438	0.388	0.452	0.292	0.397
Vac. X	0.295	0.473	0.356	0.598	0.665	0.562	0.612	0.548	0.708	0.603
Total Cat.	18.705	18.527	18.644	18.402	18.335	18.438	18.388	18.452	18.292	18.397
OH*	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
O	31.237	30.940	31.135	30.731	30.963	30.947	31.006	31.035	31.034	31.072
Fe/(Fe+Mg)	0.958	0.967	0.820	0.939	0.894	0.897	0.905	0.786	0.745	0.739

ver for a comparison, we presented compositions of late magmatic and probably post-magmatic hydrothermal alkali-deficient blue schorl close to foitite which forms overgrowths on primary brown schorl in the Spiš-Gemer granite near Hnilec.

Consequently, the compositional similarities of X-site deficient Fe-rich tourmalines (schorl to foitite) of the Klenovec and Spiš-Gemer Permian leucogranites, together with their bulk- and trace-element chemistry, could be indicate also possible metallogenetic (Sn, W, Li, etc.) specialization of the Klenovec leucogranites similar like it is known in the Spiš-Gemer granites.

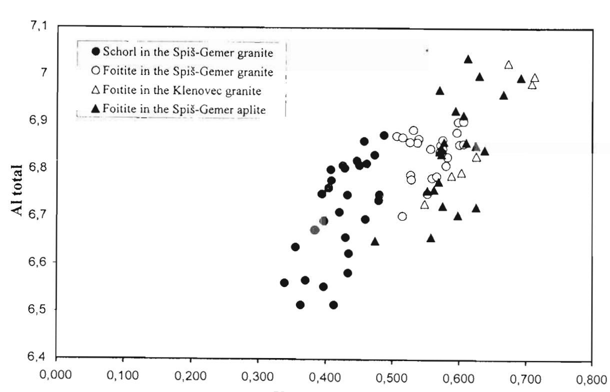

Fig. 2. Al-total vs X-site vacancy diagram tourmalines.

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Structural and geochemical aspects of the Rožňava – Strieborná vein deposit

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Abstract

The Strieborná vein is the deposit in the Rožňava ore area. The vein structure is formed by older siderite and younger quartz – sulphidic mineral association. A prevailing mineral of sulphidic association is tetrahedrite. Economically significant elements are Ag, Cu, Fe. On the basis of valid criterions we presume that it is possible to expect a presence of new vein deposits with industrial qualitative parameters in the ore field.

Key words: Strieborna vein, Rožňava ore area, silver, siderite veins, quartz-sulphidic mineralization.

Introduction

The research of the depthward continuation of the Maria vein on its 13th level (Abonyi et al., 1981), located in eastern part of Rožňava Ore Field, led to investigation of possible parallel veins not reaching the surface. Results of geological investigation and studies suggests presence of new vein structures, the Strieborna vein (1981) and the Pallag vein (1983).

In this contribution we only point at several results related to structural position of the Strieborná vein and geochemical aspects of surrounding rocks. Present knowledge of other autors is not commented, we only quote their results in this study. Detail survey of exploration activities together with calculated resources are published in studies of Mesarčík et al. (1991, 1994, 1998), Sasvári and Maťo (1998).

Structural position of the Strieborná vein in Rožňava ore field

The Rožňava Oore Field is a part of the most southern ore zone located in the central part of the Gemericum Unit, which has been named as Rožňava – Pača – Lucia baňa zone (Rozložník, 1986). Position of the Rožňava Ore Field is illustrated on Fig. 1, which represents geological sketch of Inner Western Carpathian structure. The area is typical for its siderite and baryte – siderite ore zone development with young quartz – sulphidic mineralization occurrence.

From the metallogenetical point of wiev the Rožňava Ore Field is not entirely uniform unit. It is divided by the Slana river into the western part (Turecká massif) and eastern part (Tri vrchy and Rozgang area). This ore field is represented by siderit ore vein formation of epigenetical origin with typical variability of mineral assemblage on siderite veins (Vaček, 1959), Slavkovský (1978). The main vein fill is siderite accompanied by minor presence of quartz-sulphidic mineralization in Turecká massif. Eastern part of Rožňava Ore Field is typical for its main quartz-sulphidic mineralization occurrence.

This vein structures mainly occur in Gelnica Group rocks and its continuation is proved only in upper parts of the Rožňava sequence. From the structural point of view, the interfolial character with strong lens-like development in direction and inclination is typical for these veins (Slavkovský, 1978).

The veins in western part of the ore field (Fig. 2) was exploited as siderite acummulations and the mining activites was stopped in 1993. The veins in eastern part (Tri vrchy and Rozgang area), the Maria and the Strieborná veins, are represented by siderite-quartz-sulphidic mineralization. It is supposed that the veins originated in tectonically restricted zone proved by difference in s_2 – plane evolution of surrounding porphyroids, quartz phyllites and laminated quartzites (Slavkovský, 1998; Sasvári and Maťo, 1998). This veins can by assigned as interlayer-cleavage subtype. Its geological position in geological profile (Fig. 3) illustrates tapering of the Strieborná vein on transition to gray metepellites.

Description of Strieborná vein and results of geochemical research of surrounding rocks

Strieborna vein deposit has been discovered by mining in the beginning of 1981 on 13th level of Maria mine, in the distance 600 m below of the Maria vein. It is the second vein structure in Rožňava Ore Field which does not crop out (7th vein was the first one). From tectonical viewpoint there is a shape analogy between the Strieborná and Mária vein. Structural evolution and deformation stages are described in detail in contribution of Sasvári and Maťo

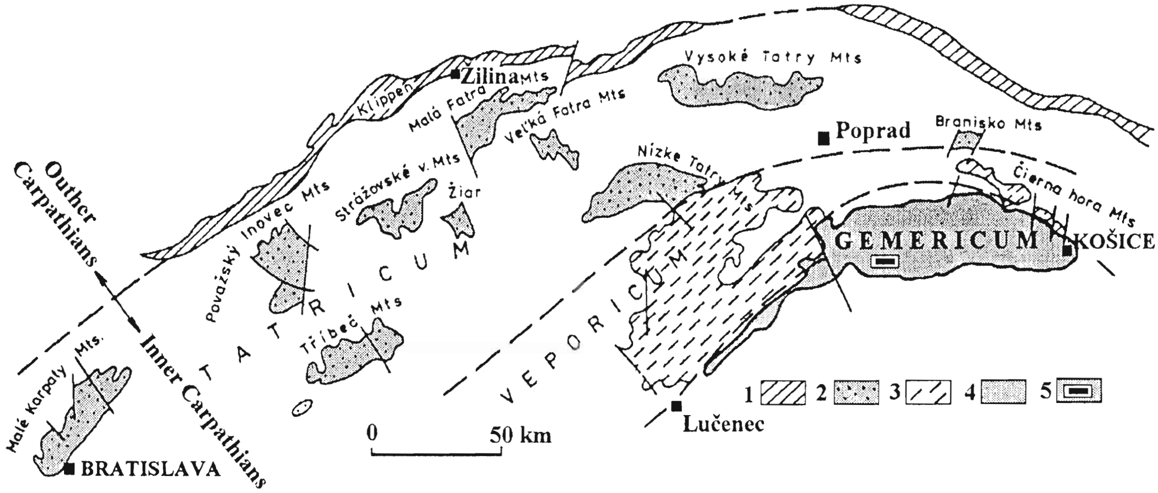

Fig. 1. Position of the Gemericum and the Rožňava Ore Field in the Western Carpathians (Grecula, 1995) – modified. 1 – Carpathian Klippen Belt, 2 – Tatricum, 3 – Veporicum, 4 – Gemericum (pre-Triassic komplexes only), 5 – The Rožňava Ore Field.

(1998). The ore fill in the entire known lenght of the vein is mainly created by siderite and younger quartz-sulphidic mineralization. Both tetrahedrite with high occurence of Ag, Zn, Bi, Hg and chalcopyrite are prevailing minerals in the vein. High content of Ag in tetrahedrite (leading to name the Strieborná vein) is described in Sasvari and Maťo (1998).

The Strieborná vein occurs in three types of surrounding rocks. The lower part is developed in porphyroids and quartz-chloritic-sericite phyllites at 10th level. The boundary is tectonic. Vein structure continues from surrounding quartz-chloritic-sericite phyllites to dark metapellites at the 8th mine level. Contacts among particular phyllite varieties have tectonic character (Kondela, 1998). The vein

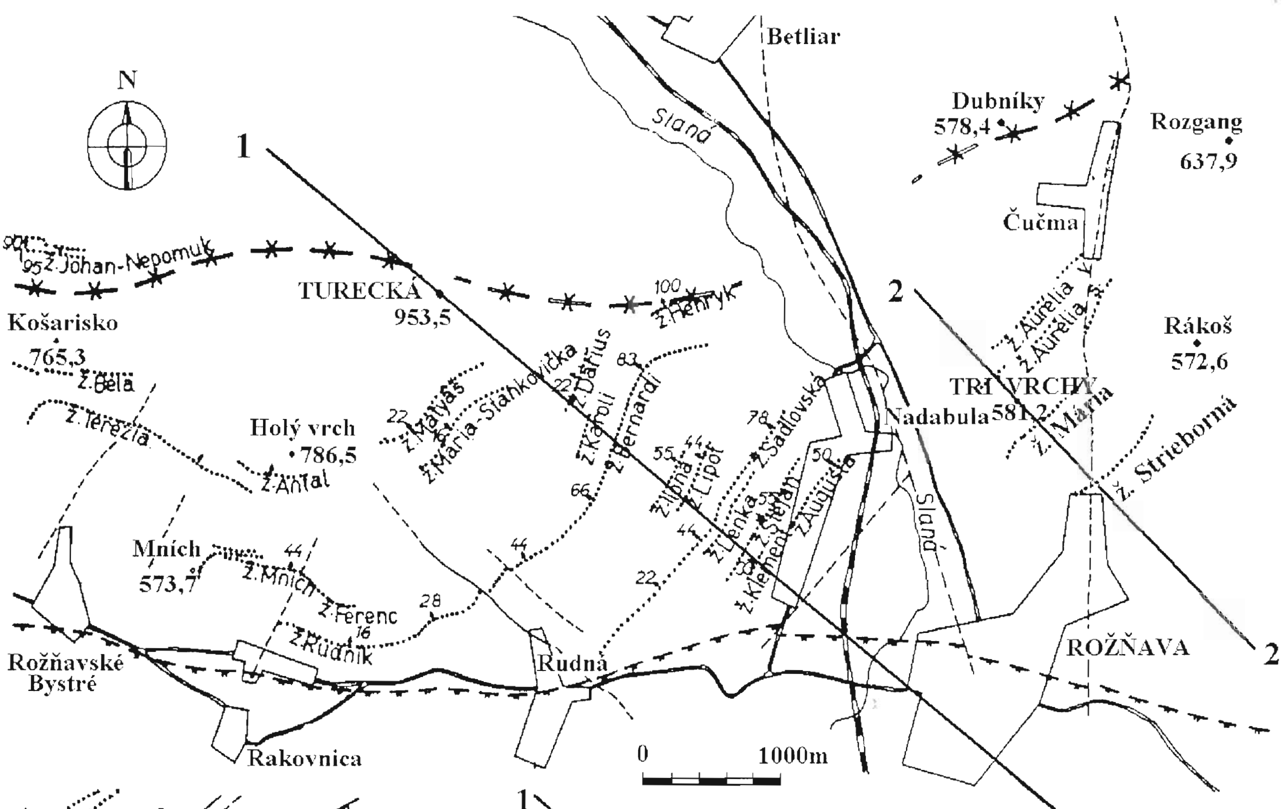

Fig. 2. Map of ore veins in the Rožňava Ore Field. 1 – ore vein structures, 2 – slip and normal slip-faults, 3 – Rožňava fault line. 4, 5 – geological profile.

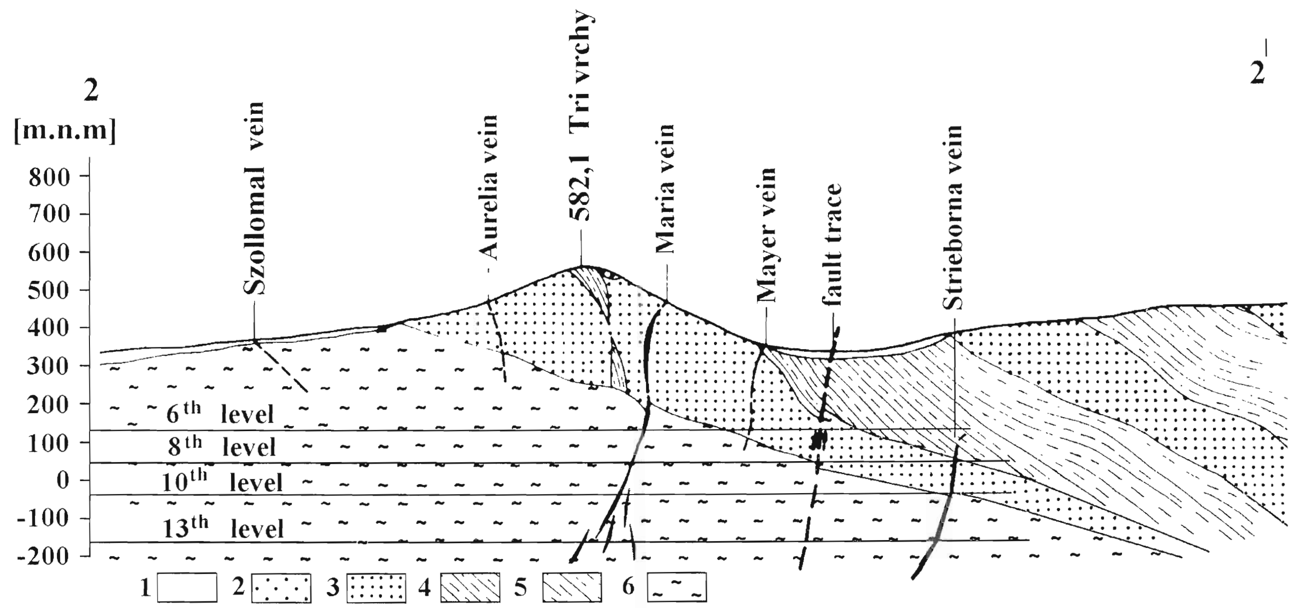

Fig. 3. Geological profile of the Kalvaria – Tri vrchy vein systems. 1 – Quarternary, 2 – conglomerate (the Rožňava type), 3 – quartzites, 4 – dark metapellites, 5 – quartzites in excess or in balance with phyllites, 6 – porphyroides.

thickness reached the maximum 12 m and also maximal content of Ag in tetrahedrite reached 1386 ppm in the place of penetrations (Mesarčík, 1994; Kondela and Blišťan, 1999). Ag distribution in vein structure displays vertical zonality. From 13th to 8th level the content of Ag increases. Reverse zonality is observable in Cu, it means it increases downwards (Jeleň in Mesarčík, 1991; Kondela, 1998). During the geochemical research there was identified primary geochemical aureole of Ag in the environment of dark phyllites. It is located in the 50 m distance from the vein. Also primary geochemical aureole of Cu was similarly identified.

Although the Cu aureole follows the vertical development of the vein in porphyroids and green phyllites, its contrast and range is very small. High content of As in dark phyllites, at mean 8th mine level (maximum 120 ppm, 60 ppm) is quite important and also proved content of Tl in two rock samples. The common sign of surrounding rocks is their silicification. From the 8th to 6th mine level the structure of dark phyllites changes into the stockwork one and it continually tapers upward. Only the quartz lenses with suphide minerals are observed in the 6th level. Also the inclination of the Strieborná vein at the 10th level is directionally similar to NE, but behind the 10 453 point it continues to the dark metapellite layer.

Porphyroids and quartz-chloritic-sericite phyllites have favourable physical influence on the vein structure evolution. This result corresponds to contens and continuations of siderite veins in the Turecká massif. Dark phyllites occur below and not above the veins (e.g. the Rozgang vein). Siderite veins do not occur in dark metapellites at the 35th level, e.g. at the lowest level of the Turecká massif (Radvanec and Bartalský, 1995).

Only increased content of several ore elements was found. In contrast to our findings the mentioned authors suppose that this, i. e. dark phyllite layer is the source of this siderite veins and quartz-sulphide mineralization. Based on the recent results we assume that this formation does not allow origin of suitable open structures. The main reasons are mechanical-physical constrains. Sulphide mineral occurrence in the Strieborná vein is probably caused by overlying of dark phyllite formation. There was not proved dark phyllite occurrence below it (150 m below the 13th level). We suppose that the drilling did not reach the downward tapering of the vein.

Conclusions

Based on the present results from the Rožňava Ore Field, research we come to these conclusions:

1. Structural position of Strieborná vein is similar to Maria vein, it means that it belongs to interfolial vein type and interlayer-cleavage subtype (Slavkovský, 1998).
2. From the metallogenetical point of view the vein belongs to quartz-sulphide veins of estern part of Rožňava Ore Field. In comparison with Maria vein and other veins of western part of Rožňava Ore Field, the vein has higher content of sulphidic mineralization. The most important mineral of the vein is tetrahedrite with higher content of Ag which influences the mining activites.
3. Geochemical research of surrounding rock of the Strieborná vein suggests a possibility to use indicators of sulphidic mineralization also for other, not recently investigated parts of the eastern part of Rožňava Ore Field.
4. From the sulphidic mineralization evolution aspects it is also important to investigate the Tl content in the surrounding rocks of the vein structure.
5. The Rožňava-Strieborná vein deposit together with the Maria vein have conditions for opening and mining

activites. It only depends on technological solution of tetrahedrite concentrate exploatation and the state of word prices of main commodities of Ag, Cu, Sb, Fe ore.

Present knowledges lead us to pay more attention to the Strieborna vein from view point of technological research, world prices of mine commodities observing and suitable investors finding.

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An outline of exploration of the Dúbrava Massif magnesite deposit – Jelšava (Gemeric Unit)

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Abstract

The paper deals with the geology of Dúbrava Massif magnesite deposit – Jelšava and the history of its exploration. The economic relation of exploration and exploitation methods are considered. The most important are the price of geological information, its actual validity and integrity of both quality and time. The markedly advanced exploration before exploitation without the collaboration of explorational geologist and miner looks like less advatnageous.

Key words: magnesite, exploration, exploitation, reserves, Slovak Magnesite Works, Gemeric Unit

Introduction

The magnestite deposits represent the important raw-mineral potential of Slovakia. The amount of reserves, quality and sophisticated dressing rank us among the prominent world producers of refractory material. Vigorousness of production of our raw-material was proved also during evaluation of economic transformation of our JSC in the 1990s. Despite of increasing prices for energy consuming production, our production of refractory material has increased. The Slovak Magnesite Works JSC, owing obtained results, belongs among the prominent industrial plants in Slovakia.

Geology of magnesite deposits

The Slovak magnesite deposits are located on the northern margin of the Carboniferous strip in the Gemeric unit. It spreads from Lučenec, Hnúšťa, Lubeník, Jelšava towards Košice. Surrounding rock sequences of the deposit, the black schists, belong to the upper part of the Ochtiná formation of Dobšiná group. The Viséan age of deposit has been determined according to the trilobites and brachiopodes found in the Ochtiná deposit. Trilobites are present also in the Jedlovec open-pit. The Dúbrava Massif deposit consists from the dark-grey dolomite, locally hydrothermally altered to light-grey crystalline magnesite. Magnesite bodies are irregularly lensoidal having variegated shape and quality. The qualitative specification of magnesite is represented with the CS module above 2. The magnesite occurrences located near surface have the Fe_2O_3 contents above 4 %. Depthwards the Fe_2O_3 content falls down to 3 %. The occurrences with the increased SiO_2 contents are present irregularly. The horizontal length of the magnesite lenses in the east-western direction reaches 3600 m and the non-effective thicknesses in the north-southern course reach 600 m. The magnesite body has been proved by drilling even in the depth 600 m. The magnesite bodies are to a great extent faulted. The more important are youngest faults trending north-southwards. Tectonic lines are often, mainly in the Dúbrava part of deposit, accompanied with caverns containing ochre filling.

Exploration of deposit

Exploration on the Jelšava – Dúbrava Massif deposit started shortly after its discovery in the change from 19th to 20th centuries. The humble works allowed the superficial exploitation of several hundreds and later thousands tons of magnesite annually. Establishment of factory for magnesite firing in the shaft ovens in 1923 required the quaranteed quality of raw-mineral for raising industry of basic refractory material. The field remnants of former exploration are various shallow diggings and eventually short mines. The former documentation is also rarely preserved.

The superficial drilling reaching up to 600–1400 m and larger mining has started by the end of 1950. The first calculation of reserves and the exploration final report, elaborated in 1961, has been accredited by the Commission for classification of reserves. At that time found reserves reached up to 280 million of tons. This calculation of reserves was very successful when taking into account the limited range of workings and small explored space. The calculation discovered and described firstly the most important Miková part of deposit with very limited ouctropping. The successful calculation stimulated further exploration and building of the capacious mine and dressing

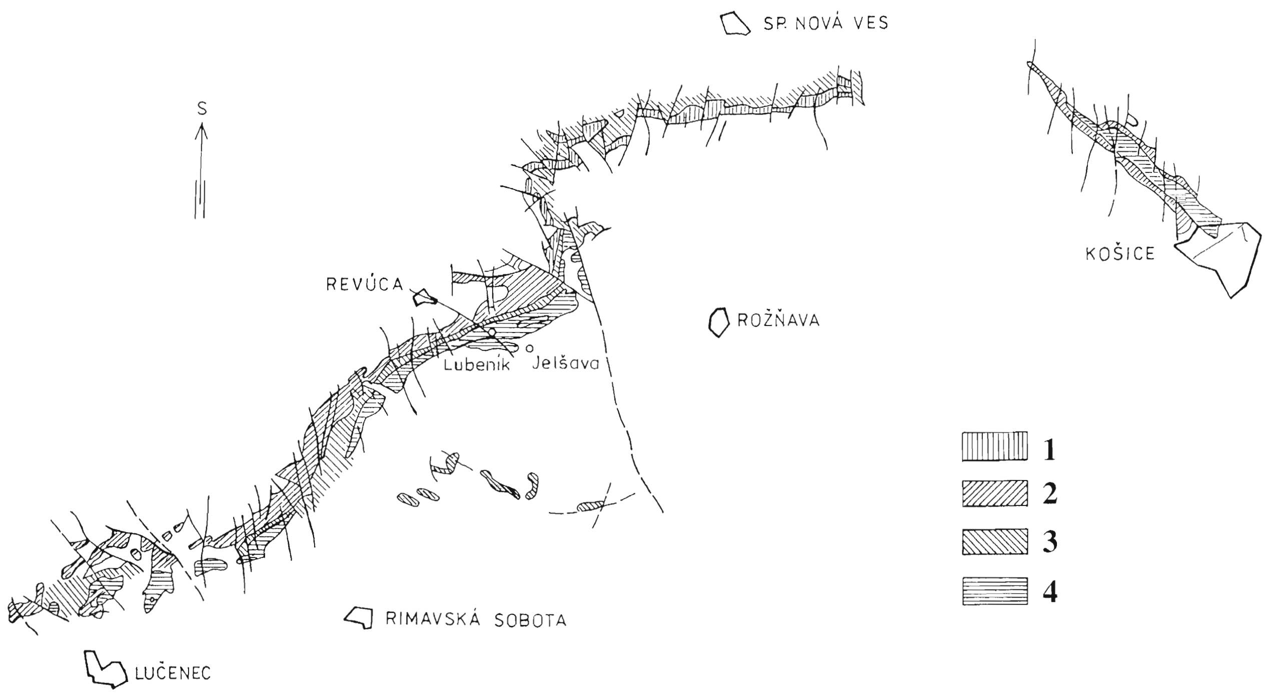

Fig. 1. Late Carboniferous magnesite deposits of the Gemeric unit of the Central Western Carpathians. Compiled according to Geological map of Slovakia in the scale 1:500 000. Explanations: 1 – Late Carboniferous, 2 – Middle and Late Carboniferous, 3 – Middle Carboniferous, 4 – Early Carboniferous sequences containing magnesite deposits.

plant for production of refractory products with annual capacity 280 kilotons of the sinter.

Next reserves calculation in 1972, related to enlarged area with concentrated exploration works, confirmed optimistic assumptions and proved reserves in amount of 600 milion tons. Variance between calculated geological reserves and reserves used for exploration motivated to elaboration of more strict qualitative conditions. The demands were derived from marketing of final refractory cohesionless substances. The exploration was moreover complicated by variability of benefitial component, malignances and by high demands of manufacturers and purchasers for magnesite sinter.

New qualitative demands implemented to the reserves calculation in 1980 reduced the explored deposit reserves from original 600 million to 250 million tons. This change related to revision of technology in the 1970 and the more arduous qualitative demands of customers from the iron metallurgy. The content of the MgO in the final product increased up to 90 % and proportionally increased demands for the bulk density and decreased the content of harmful components.

The new extended exploration focussed for reserves below horizon 300 m above sea level, the mining level 220 m, finished in 1993. Currently the highest overall expenses reaching 215 to 280 millions of Slovak crowns (Sk) brought approval of next reserves of 543 million of tons. This amount supplies magnesite for perspective exploitation in the future.

The financing of the last stage of preliminary exploration has been supplied by the Slovak Magnesite Works JSC with the state participation. The re-organization of the Slovak Magnesite Works JSC caused the discharge of funds and former investments had the company newly create and repay to state. The exploration has not finished yet and use of geological information pushed it till 2010–2015.

Effectiveness of exploration

The first exploration realized in the 1960s had extraordinarily effective expenses reflected in the sum 0.1 Sk per 1 ton of explored reserves.

Dephtward continuation of exploration, using more expensive minings and underground small diameter well cores increases the price of exploration to 0.7 Sk per ton of reserves. This uprise of the price has occurred even in the period of minimal inflation.

The increase of expenses continued during the Preliminary exploration of the Dúbrava Massif in 220 m level, finished in 1993 reaching 1.22 Sk/t. It is interesting, that this cost corresponds with that in the 1970, taking into account the more arduous horizon opening below the local erozive basis as well as the accident caused by the mine water breakout.

The view on effectiveness of exploration expenses through the time factor is more demanding. The most effective are the financial loads we plan to use in the shortest time, the least effective relates to reserves, we do not plan to exploit. Our effort requires shortening the whole cycle of exploration, opening, exploitation and liquidation. There is also important the fact that, according the valid

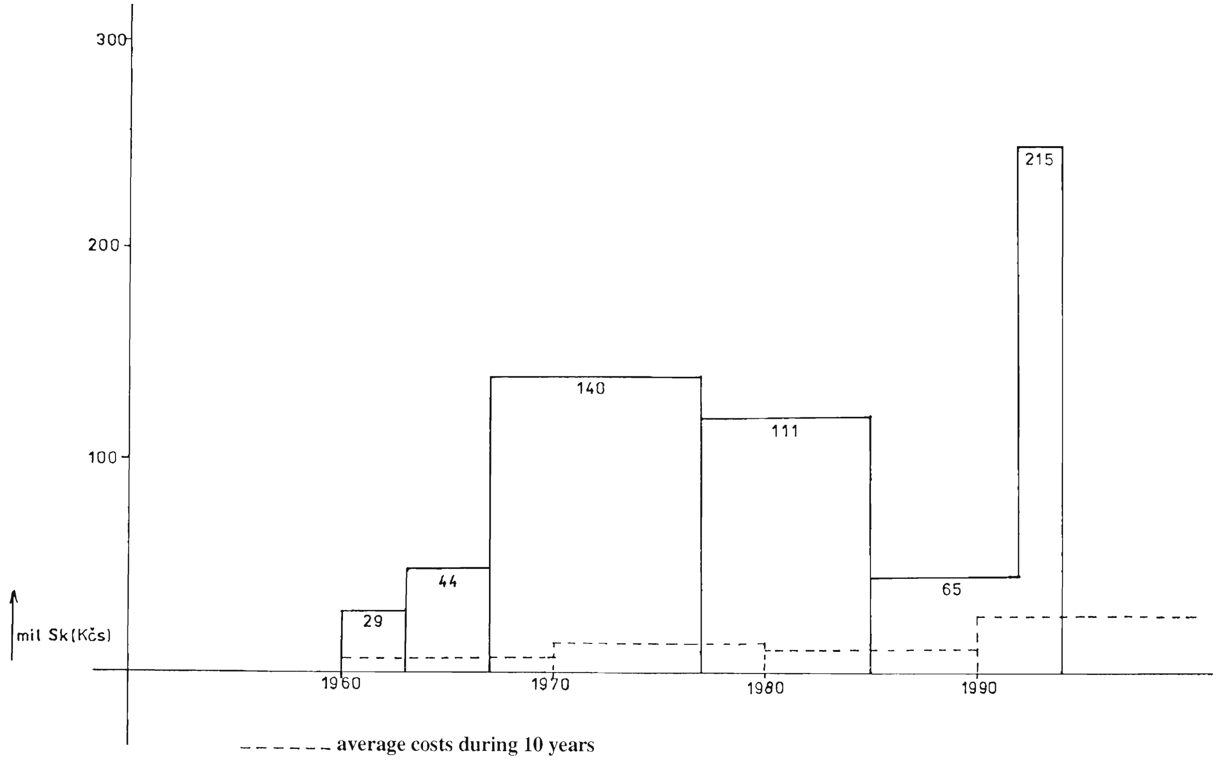

Fig. 2. Financial overview of geological exploration works expences at Dúbrava massif magnesite deposit (average costs during 10 years in mil. Sk).

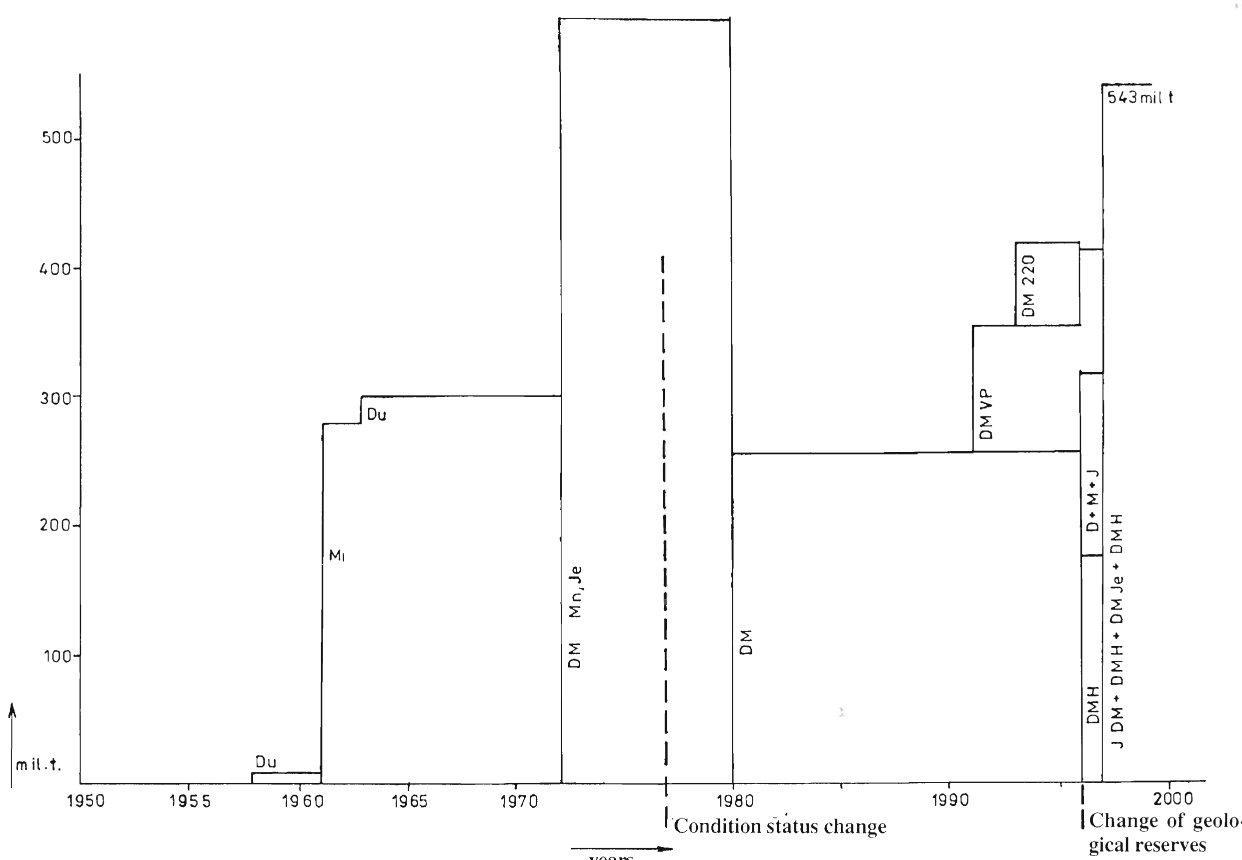

Fig. 3. Approved geological reserves at exclusive deposit (mil. tons/years).

legislative, the results of exploration are publicly accessible after 5 years.

Relations of exploration and exploitation methods

Sufficient amount of geological resources prepared for exploitation and fulfilling the requirements of production has the supreme priority. The whole proportion of expenses relating to the exploration on the price of final product is expressed in the tenths of percents. The constitution of the financial funds for exploration and mine opening is important. The disadvantage is that ten years ago the expenses on exploration were 1 Sk but expenses on exploitation of 1 t of raw magnesite were above 100 Sk.

The exploitation of magnesite relates to the whole amount of exploration. In the 1980 it was 1.8 mil. tons annually. Pale concept of production in the 1990 caused the decrease of exploitation to 0.6 mil. tons. The establishment of Slovak Magnesite Works JSC stopped the market decrease and allowed the exploitation of 1.1 mil. tons of magnesite using the raw-material more effectively.

More complicated there is the question of full use of geological reserves. The concentrated exploitation allows to obtain 60 to 100 % of reserves, but reserves in the marginal parts of horizons remain non-exploited. This fact significantly affects the whole recovery which lowered below 50 %.

Recently we prefer the exploitation by stepping at the expense of open chamber, requiring another system of geological exploration and more information for leading of the long-wall.

Our experience is that the stepping acquires more uniform spatial distribution of exploration works for advancing the obtained information to network of projected pillars.

The whole evaluation and comparison of exploitation methods by both stepping and open pillar exploitation is from the slope stability and environmental viewpoints more favourable for stepping. This method allows to store the non-used raw-material in the exploited spaces, i.e. new dumps do not originate on the surface. This is the positive aspect of the stepping. On the other side, this method requires more precise previous exploration but allows the advantage of the more accurate exploitation supervising.

Results

The effectiveness of exploration is the compromise of more factors. The most important are the price of geological information, its actual validity and integrity in relation of quality and time. The markedly advanced exploration before exploitation without the collaboration of explorational geologist and miner looks like less advantageous.

Above mentioned contradictions there are most frequent mistakes also in our geological and mining practice. Consumptive extended exploration done with the marked time advance before its use can bring even zero effectivity by the threaten of the lost of actuality.

The recent computerized era allows tight collaboration of exploration geologists with miners.

Gold at the Early Paleozoic complexes of the central part of the Spišsko-gemerské rudohorie Mts.

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Abstract

Occurrences of gold have been long known in veins with stibnite content and in stratiform sulphide ores. Lately found U – Au mineralization in quartz veins and stockworks was object of this study. New type of stratiform Au mineralization was found in black sediments of the Betliar Formation and in quartz veins related to sedimentary carbonates. Increased contents of metals in rocks of the Betliar Formation were presumed source of Au mineralization. They were mobilised and concentrated into vein structures due to metamorphic and hydrothermal processes in proximity of the Gemeric granite.

Key words: Spišsko-gemerské rudohorie Mts., stratabound gold mineralization

During 1992–2000, the exploration activities for gold at the Spišsko-gemerské rudohorie Mts. (SGR Mts.) were concentrated into the central part of the SGR Mts., which is built exclusively by Early Paleozoic rock complexes. Some gold occurrences have been known from this area before (several of them even were mined at past), nevertheless, the systematic studies for gold at the SGR Mts. Were missing. By means of the systematic geochemical survey (detailed panning, stream sediments survey, sampling of the old ore mining dumps and surface outcrops of the quartz veins), there have been discovered within this area several unknown occurrences of gold and some new perspective gold-bearing areas have been found (Novotný et al., 1999; Novotný et al., 2000; Háber et al., 2000).

Geology and stratabound gold mineralization at SGR Mts.

The exploration activities were concentrated mainly into sequencies of the Humel nappe (in sense of Grecula, 1982), but some activities were carried out also at Jedľovec, Prakovce and Kojšov nappes (Western part of the area) and Medzev nappe (Eastern one). The most positive results have been obtained from the Betliar formation (especially from Holec Beds), partially also from the Smolník and Hnilec ones.

The Betliar Formation. is characterized by the predominance of the dark lithofacies (laminated graphitic-sericite phyllites, graphitic phyllites, metasiltstones with layers of rudely or thinly laminated up to pelite types of rocks). These rocks and the Holec beds are characterized by higher silicification, presence of silicites (lydites and biogenic siliceous rocks) and various types of the sedimentary, metamorphosed and partially silicified carbonate rocks (limestones, dolomites, ankerites, magnesites).

The graphitic phyllites and metasiltstones are characterized by the presence of the scattered, sometimes more concentrated, impregnations of pyrite, the rocks are often cut by the quartz veins and the unsignificant amount of further sulphides is also there present. For some parts of these rocks the increased gold content is typical. The content of $C_{org.}$ at metasiltstones and graphitic phyllites strongly varies from 0.01 up to 4 %. The products of acid and intermediate volcanism are sporadically found among the lydite bodies.

There are given here some more significant localities, where the presence of gold has been found: Šedlovská skala (black metasiltstones, Au content 0.025 ppm, U – 28.4 ppm, C_{org} – 1.5–4.2 %), Bystrý brook (base-metal Alžbeta deposit, ore-bearing structures Banisko, Joachim-Florián, the samples were taken from the old dumps, gold content 0.14–4.91 ppm, the black laminated metasiltstones and graphitic shales are strongly pyritized and more sulphides are present (pyrrhotite, galena, sphalerite, chalcopyrite, tetrahedrite), Hrelikov brook (a sporadical presence of the microscopic gold grains has been found here, Au content varies from 0.033 up to around 2.5 ppm, Ag – up to 5.6 ppm, Mo – up to 24.3 ppm, Pb-up to 1.100 ppm, C_{org} 0.24–0.47 %) and finally the vicinity of villages Mníšek nad Hnilcom, Hutná dolina, Prakovce and Zlatá Idka (base metal mineralizations with some gold content).

The Alžbeta-Bystrý brook ore deposit represents the characteristic stratabound type deposit at the studied area. The ore mineralization is hosted by the black phyllites developed within the laminated sericite-chlorite shales.

The geological age of mineralization is estimated between 460–570 Ma (Kantor, 1962). The ore mineralization is formed predominantly by pyrite and pyrrhotite and the variable amounts of sphalerite, galena, chalcopyrite, tetrahedrite, chalcostibite, jamesonite, gold, cassiterite, quartz, magnetite, carbonates, cinvaldite, apatite and muscovite (Kantor, 1953; Háber et al., 2000). According to Kantor, the base metal ore contains 1–3 ppm Au, 10–30 ppm Ag and up to 1.06 % Sn. Generally, the gold is very rare and it is usually associated with pyrite of younger generation. The gold is developed as irregular porous grains (size up to 100 μm) at intergranulars, together with guartz. The presence of the gold at deposit is confirmed by the presence of numerous gold flakes at panning samples (up to 23 pieces) and by analysis of the stream sediments from the creaks at vicinity of the deposit (up to 5.2 ppm Au). According to the results of microanalysis, the composition of this gold is 92.15 % Au, 7.36 %Ag and 0.06 % Hg.

It can be supposed, that the origin of this type of ore mineralization is connected with the sedimentary-exhalation proccesses in sedimentary sea-basin within strongly reducted environment, at the black shales facies and following metamorphical remobilization.

The quartz veins hosted in the lens-shaped bodies of the gold-bearing carbonate rocks, can be considered as very interesting. They are narrow connected with an beds of graphitic phyllites and metasiltstones, with the intercalation of lydites (Sedlovská skala locality and its wider vicinity). This type of gold mineralization has been unknown up to now within the SGR Mts. area and its existence is well indicated by an anomalous gold contents at stream sediments (up to 46.5 ppm Au), mainly at Tichovodská valley (from the other side, the presence of gold flakes at panning at this area is very sporadical only). Carbonate rocks are metamorphosed (locally marmoritized) and metasomatically altered to limestone-dolomite-magnesite, sometimes silicified and locally karstered. Mostly at hanging-wall parts along the contact with phyllites, blanket quartz veins are developed, formed by white, glassy-white up to brown coloured quartz, without visible mineralization. Extraordinarily, at brown-coloured quartz, the presence of pyrite and malachite has been found. At carbonate rocks near of quartz veins the sporadical grains of pyrite are present. This type of Au mineralization is represented for example by Pintíková-Šramky locality under Balochova hill (carbonate rocks with Au content 0.005 up to 1.85 ppm), Tichovodská dolina locality (at final parts of valley, occurrences Šedlovská skala and old mining field Christofori-Au content from traces up to 9.75 ppm, As-27 ppm, Hg-0.041 ppm, Sb-1.5 ppm, Cu-292 ppm, Ag-under 0.2 ppm) and Malá Hekerová locality (Mn-carbonate rocks with sulphides hosted by graphitic phyllites, only sporadically with Au content up to 0.15 ppm). However, the presence of visible, resp. microscopic grains of gold, has not been found up to now at the localities.

It is probable, that the spatial position of these veins between carbonate rocks and graphitic phyllites, is influenced by the various level of rocks plasticity. The increased gold content at dark metasediments of the Betliar Formation can represent the source of gold mineralization at quartz and carbonate rocks. The origin of this mineralization is probably connected with metamorphic and hydrothermal proccesses.

The Smolník Formation is formed by the complex of volcanics (basalts, rhyolites and diabases) at its lower part, transiting into the complex of ore-bearing phyllites (the wide scale of chloritic phyllites, psammitic-pelitic and psammitic metamorphites, with low share of the black shales). At the upper parts, the second ore-bearing layer is developed. This upper part is formed by the Mníšek ore-bearing phyllites and by volcanosilicites and various paleovolcanics.

This type of Au occurrences is represented by the following localities: Pintíková valley (the body of basic rocks, formed by dark-green coloured basic tuffs and amphibolites, with clusters of amphibolite, axinite and carbonate rocks, with disseminated pyrite, pyrrhotite, arsenopyrite, chalcopyrite and tetrahedrite, Au content up to 0.6 ppm), Veľký vtáčí hill (layer of sericite-graphitic phyllites with disseminated sulphide mineralization, Au content up to 1.74 ppm) and Trochanka (body of basic rocks and thermally metamorphosed carbonate rocks, Au content up to 0.1 ppm). It is interesting, that at this locality the panning samples from soil contain up to 110 pieces the gold flakes.

The Hnilec Formation is formed prevailingly by the volcanic and volcanoclastic rocks, at central and southern parts of area with predominance of the rhyolite, dacite and andesite rocks (i. e. Gelnica Group), the ore-bearing horizon is developed at upper part of the beds. This type is represented by Hutná valley locality (the stratabound base-metal occurrence with Au content 0.32–0.92 ppm, at stream sediments usually 1–5 ppm Au and up to 0.01 % Ag).

Conclusions

There have been known from the past the two types of gold mineralization at the SGR Mts. The vein-type associated with Sb and the stratabound sulphidic deposits with some gold content (Grecula et al., 1995). The vein-type of Au mineralization associated with U, has been found recently only (Rojkovič et al., 1997). This article deals with disseminated-type of gold mineralization at stratabound ore deposits and occurrences, hosted by black shales. The second type of the disseminated gold mineralization is developed along the contact of quartz veins with sedimentary carbonates of Betliar formation.

The results of geochemical studies of the black shales from Betliar Formation show the primary increased content of metals, including gold. This fact, together with the position of gold occurrences at these formations, can lead to the supposition, that the former source of gold can derive from these rocks. The metamorphical and hydrothermal proccesses were predominantly the main impulse for their remobilization and concentration at present occurrences. However, the influence of intrusive rock (so called gemeric granites), can not be excluded.

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Origin and exhumation of mylonites in the Lúčanská Malá Fatra Mts. (The Western Carpathians)

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Abstract

The Valča Formation formerly interpreted as metamorphosed Devonian sediments has been redefined as mylonite to ultramylonite in the Valča and the Trebostovo valleys in the Lúčanská Malá Fatra Mts. (Central Western Carpathians). The mylonites and ultramylonites have been derived from surrounding granitic rocks under pure shear strain ductile deformation. $^{40}Ar/^{39}Ar$ dating of ultramylonite sericite yielded age 72 ± 3 Ma and muscovite from the granitic rocks 345 ± 2 Ma. Two different phases of exhumation and uplift of the ultramylonites are supposed. Middle Miocene to Pliocene exhumation and Pliocene to Recent uplift. Calculated rate for the exhumation phase is ~ 0,5 mm/yr and for the uplift phase is ~ 1.0 to 1.4 mm/yr.

Key Words: Central Western Carpathians, Lúčanská Malá Fatra, mylonites, $^{40}Ar/^{39}Ar$ dating, exhumation, uplift

Geotectonic aspects of the Neogene volcanism in Eastern Slovakia

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Abstract

Compositional features and space-time distribution of the Neogene volcanic rocks at the contact of the Western and Eastern Carpathians implies their relationship to subduction processes in the Krosno flysch zone as well as to related back-arc and inter-arc extension. Migration of the volcanic arc towards the subduction zone and its timing point to the final subduction zone verticalization and detachment. Bimodal andesite-rhyolite volcanics of the Tokaj-Zemplín-Beregovo-Baia Mare horst system show rather a relationship to back arc extension, reflected now in small thickness of the Crust and Lithosphere. This is confirmed by compositional features of volcanic rocks (medium-K suite), which indicate mostly thin and unevolved crust.

Key words: Eastern Slovakia, volcanism, Neogene, subduction, back arc extension

Introduction

Geotectonic aspects of the Neogene to Quaternary volcanism in the Carpathian arc and Pannonian Basin in general have been discussed recently by Lexa and Konečný (1998). This paper deals in a greater detail with the region at the contact of Western and Eastern Carpathians, using the same approach. The space-time distribution and compositional features of volcanic formations are interpreted in terms of deep processes and crustal structure, which in confrontation with geological and geophysical data serve as a key to understanding of the Neogene geodynamic evolution of the region.

General geotectonic setting

A complex analysis of geophysical, geological, structural and petrological data points to the model, in which the Tertiary evolution of the Carpathian arc and Pannonian Basin is interpreted in terms of a coupled system of the (1) gravity driven subduction of oceanic or suboceanic lithosphere underlying former flysch basins, (2) back-arc extension associated with the diapiric upraise of asthenospheric mantle and (3) lateral escape of lithosphere from the Alpine collision assisted by transform faults and microplates rotation (Csontos et al., 1992; Horváth, 1993; Csontos, 1995; Kováč et al., 1998; Lexa and Konečný, 1998). A subduction zone verticalization and detachment of sinking lithosphere marked the final stage in its evolution (Royden et al., 1982; Wortel and Spakman, 1992; Nemčok et al., 1998), corresponding to the Middle Miocene – Pliocene collision of the arc with the continental margin of the European Platform.

Essential structural subdivision of the region

Fig. 1 and 2 show Tertiary structural units of the region. The *flysch belt* at the NE represents an accretion prism of the Carpathian arc. The accretion prism is build of Early Cretaceous to Early Miocene sediments of basins, whose lithosphere was subducted during the Tertiary evolution of the arc. It is divided into the Magura and Krosno flysch zones, corresponding to two former flysch basins separated by the Silesian Cordillera (Sandulescu, 1988; Potfaj, 1998). While the youngest sediments in the Magura flysch zone are of the Late Oligocene age and the final inversion took place during the Late Oligocene to Early Miocene time, the youngest sediments in the Krosno flysch zone are of the Early Miocene age and the inversion took place during the Early Miocene to Sarmatian time. Overall extent of shortening is estimated at several hundreds kilometers (e. g. Csontos et al., 1992; Potfaj, 1998), the minimum shortening in the Krosno flysch zone alone at 130 km (Roure et al., 1993).

The *Klippen Belt* is a young tectonic element separating the accretion prism from older crustal blocks of the Inner Carpathians. Its tectonisation took place after Early Oligocene, but before Sarmatian (Potfaj, 1998). Structural incorporation into the Magura flysch accretion prism was followed during the Early to Middle Miocene time by the enormous sinistral strike-slip movement, related to the final stage in the lateral escape of the Inner Carpathian units from the domain of Alpine collision.

The *Humenné Unit* makes up a narrow strip between the Klippen Belt at the NE and Transcarpathian Basin at the SW. Its internal structure apparently corresponds to the northern side of the Central Western Carpathians –

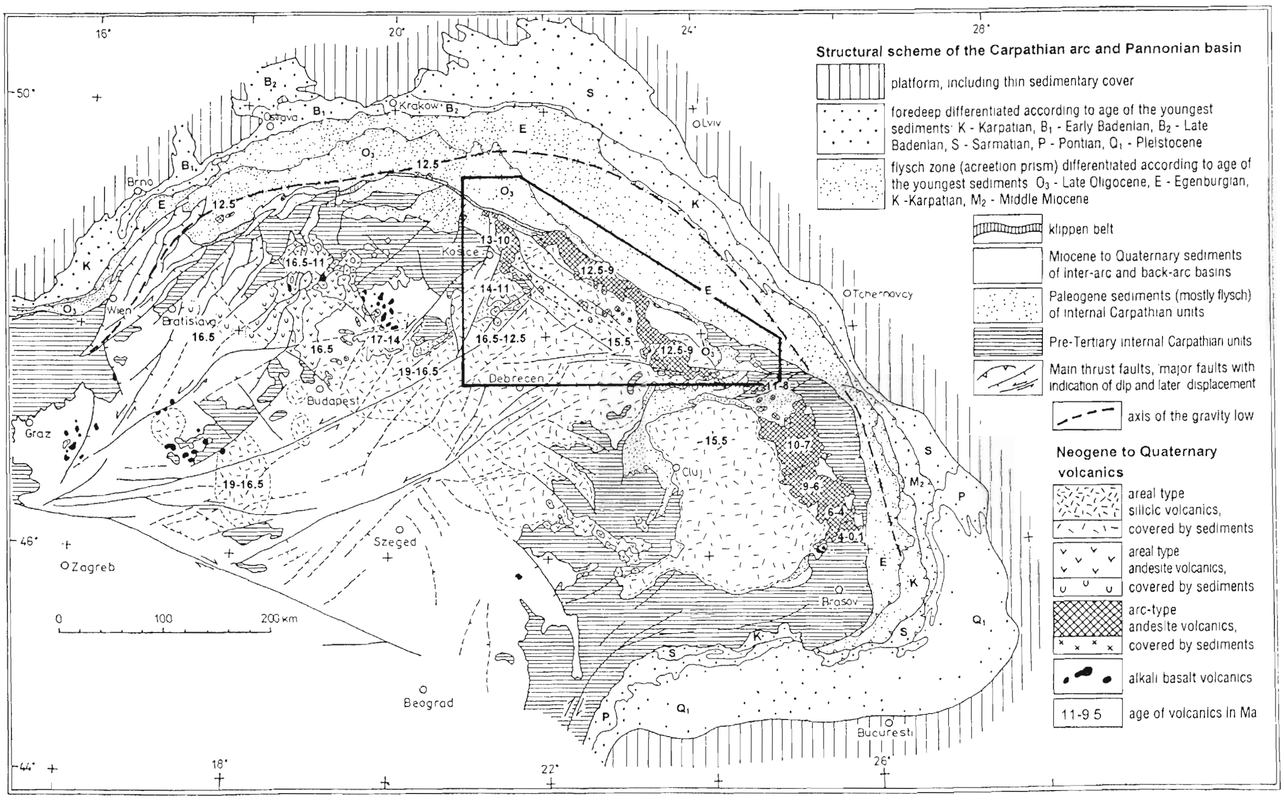

Fig. 1. Position of the region (black polygone) in the structural scheme of the Carpathian arc (Lexa and Konečný, 1998). Based on Pécskay et al. (1995), axis of gravity low after Nemčok et al. (1998).

Tatricum basement and sedimentary cover are overthrusted by the Humenné Mesozoic (Veporicum) and subsequently transgresively covered by sediments of the Central Carpathian Paleogene (Bielik et al., 1998). During Early Miocene the unit was affected by the south-wergent transpressional reverse faulting.

The *Transcarpathian Basin* is filled up by Early Miocene to Sarmatian sediments and volcanics attaining thickness of 6–7 km, younger sediments are of negligible thickness. The basin filling consists of two depositional cycles – the older one of the Karpatian – Early Badenian age corresponds to the pull-apart mechanism (Vass, 1998), the younger and thicker one of the Late Badenian - Sarmatian age corresponds to the inter-arc (back-arc ?) extension mechanism (Kováč et al., 1995) coupled with right-lateral movements (Vass, 1998).

Sediments of the Transcarpathian Basin cover basement units shown in the Fig. 3. Thanks to transform faulting along the southeastern edge of the ALCAPA microplate the basement is represented by a mosaic of blocks of highly variable crustal structure. While Tatricum, Veporicum, Gemericum, and Zemplinicum units are exposed at the surface beyond the limits of the basin, the most interesting Iňačovce-Krichevo unit is completely covered. Metamorphosed Jurassic to Eocene sediments of this unit imply a post-Eocene thrusting with a subsequent exhumation by extension tectonics (Soták et al., 1993).

The *Tokaj-Milič-Zemplín-Beregovo-Baia Mare horst system* separates the Transcarpathian Basin from the main parts of the Pannonian Basin. Individual horsts show an en-echelon arrangement corresponding to the dextral strike-slip component. Their uplift was contemporaneous with the basins subsidence.

The NE part of the *Pannonian Basin sensu stricto* with subsided Early and Middle Miocene volcanics and sediments underneath a thick cover of Pannonian to Quaternary sediments. While the Early to Middle Miocene subsidence was controlled by coupled extension and pull-apart mechanisms, thermal subsidence was responsible for the younger sedimentation (Vass, 1998).

Space-time distribution of volcanic formations

The apparent N–S alignment of volcanoes in the Slanské Vrchy – Milič – Tokaj mountain range (Fig. 1, 2) is not real – volcanoes in this alignment following the eastern edge of the ALCAPA microplate are of the different age and style and in reality they have their equivalents (often buried under younger sediments) southeastward. In the discussed region we are able to distinguish five groupings of volcanic formations showing alignment parallel to the Carpathian arc (Fig. 1, 2): (1) *Areally distributed silicic volcanics* of the Karpatian and Early Badenian age in the Transcarpathian and Pannonian Basins. Their centers have not been identified and their present distribution reflects an extensive reworking. (2) *Bimodal andesite –*

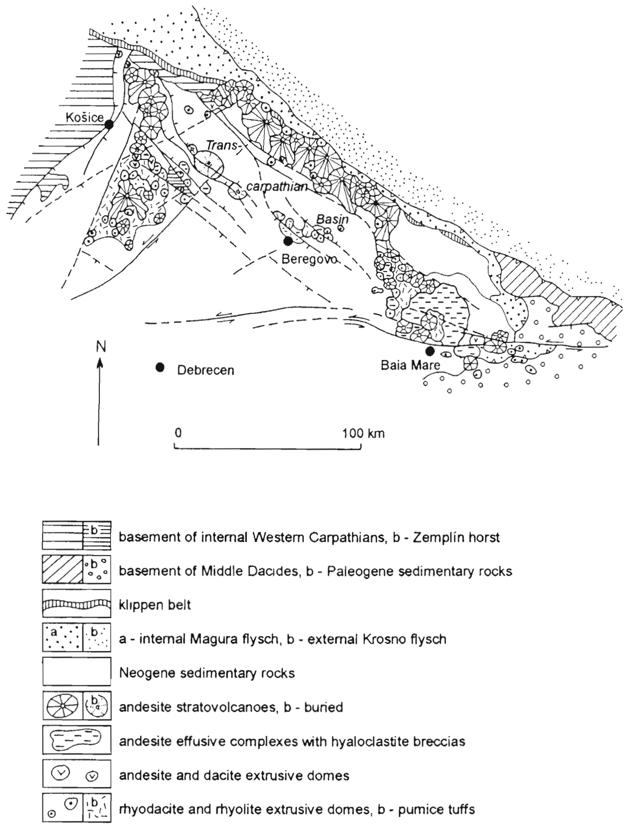

Fig. 2. Structural scheme of the discussed region at the junction of Western and Eastern Carpathians.

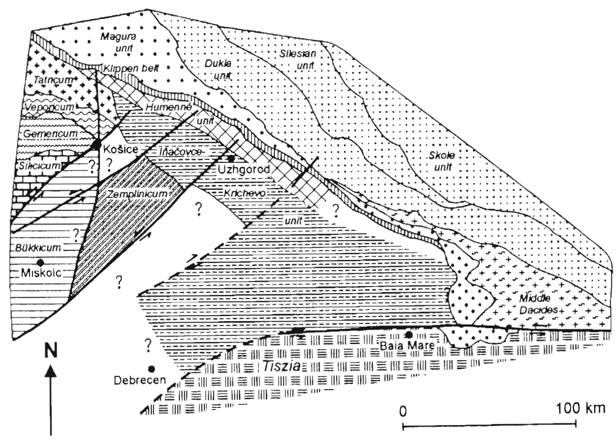

Fig. 3. Extent of basement units in the discussed region (according to Bielik et al., 1998).

rhyolite volcanics of the Late Badenian to Early Pannonian age associated with a system of horsts Tokaj – Milič – Zemplín – Beregovo – Baia Mare south of the Transcarpathian Basin. Volcanic formations evolved in terrestrial and shallow marine conditions. Characteristic there are small andesite volcanic cones and effusive complexes alternating with extensive rhyodacite and rhyolite pumice tuff horizons and less frequent dacite, rhyodacite and rhyolite dome/flow complexes. (3) Mostly *pyroxene andesite stratovolcanoes* of the Early to Late Sarmatian age in the northern part of the Slanské vrchy mountain range and southeastward buried under younger sediments (Malčice, Čop). (4) Mostly *hornblende-pyroxene andesite, andesite porphyry and diorite porphyry* extrusive domes and shallow intrusions of the Middle Sarmatian age in the alignment Kapušany – Vinné – Mukačevo. (5) Mostly *pyroxene andesite stratovolcanoes* of the Middle Sarmatian to Early Pannonian age forming the conspicuous alignment of the Vihorlat and Gutin mountain ranges northeast of the Transcarpathian Basin.

Compositional features of volcanic rocks and applicable petrological models

Using a classical approach, volcanic rocks in the discussed region belong to the calc-alkali association (basalts, andesites, dacites, rhyolites), the orogenic suite in the framework of a geotectonic assignment. Peccerilo and Taylor (1976) divided orogenic suite according to the relative potassium content into Low-, Medium- and High-K suites, indicating, that the relative potassium content reflects thickness and maturity of the Crust. This principle was further elaborated by Bailey (1981) using also other incompatible elements and element ratios. Volcanic rocks of the discussed region belong mostly to the medium-K suite (fig. 4), comparable with the evolved island arc suites in the sense of Bailey (1981). However, the relative potassium content is quite variable, especially in silicic rocks, reflecting probably lateral inhomogeneities of the Crust.

Applicable petrologic models were discussed in detail by Lexa and Konečný (1998). All the models start with a deep reaching subduction responsible for the contamination of overlaying asthenosphere. While in the case of the arc type andesite volcanics diapiric upraise of contaminated asthenosphere is coupled with the subduction, in the case of the areal type silicic and andesite volcanics we assume decoupling from the subduction and initiation of the diapiric upraise by a back-arc extension. Most of the andesite stratovolcanoes show no or limited differentiation and in that way a limited interaction with the Crust. Contrary, the early silicic volcanics and bimodal andesite – rhyolite association of the Tokaj – Milič – Zemplín – Beregovo – Baia Mare horst system points to an extensive involvement of anatectic crustal magmas and their mixing with mantle source andesitic magmas (Lexa and Konečný, 1998).

Relationship of volcanism to subduction processes

Essential aspects of spatial and temporal relationship among volcanics of the discussed region and evolution of the relevant segment of the Carpathian arc are demonstrated in the Fig. 5. Closure of the Pieniny-Magura basin during the Late Oligocene to Early Miocene time preceded the volcanic activity, which has started in the Karpatian time. Related subduction processes have not given rise to contemporaneous volcanic activity, perhaps owing to the overall compression regime. Volcanic activity shows a very close relationship to subduction processes in the Krosno flysch zone. Onset of the areal type silicic volcanism in the Karpatian time corresponds with initial stages of inversion and shortening in this zone (Kováč et al., 1998). Onset of the areal type andesite activity in the Late Badenian time corresponds to advanced stages of inversion and shortening. Onset of the arc type andesite volcanism in the Early Sarmatian time postdates initial stages of inversion and shortening by 5 Ma. A pronounced displacement of volcanic arc towards the subduction zone with time has been observed (Fig. 1, 5). This migration of volcanic activity was accompanied by a narrowing of the zone of compression and an advance of the zone of extension towards the subduction zone (Nemčok et al., 1998). These features point to the subduction zone verticalization from 50° in the Late Badenian time to almost 80° by the end of the Sarmatian. The age of the youngest volcanics corresponds to the age of the last thrusting in the front of the accretion prism – it was roughly contemporaneous with the final slab detachment.

Relationship of volcanism to back-arc and inter-arc extension

The areal type silicic volcanism took place mostly in areas of thick (?) crust during initial stages of back-arc transtension and extension - in our case it accompanied the early "pull-apart" stage in the evolution of the Transcarpathian Basin (Kováč et al., 1995). The areal type andesite volcanism, in our case in the bimodal association with rhyolite volcanics, associated very closely in space and time with advanced stages of back-arc extension, represented by typical horst and graben structures, which resulted also in progressive thinning of the Crust. Grabens associated with the arc type andesite volcanism are parallel with the active part of the arc, reflecting slab pull above the active subduction zone. Evolution of grabens was contemporaneous with volcanic activity. Volcanic alignments in the segment between the Western and Eastern Carpathians migrated in time towards the subduction zone, following migration of the compression/extension boundary in that direction. Subsidence of the Transcarpathian Basin during the second Middle Miocene stage was contemporaneous with volcanic activity and marginal faults of the basin controlled localization of individual volcanoes (Kaličiak et al., 1989). While the older volcanic arc extends along the SW margin of the basin, the youngest volcanic arc extends along its NE boundary faults (Fig. 5). Such the situation qualifies the Transcarpathian Basin as the inter-arc basin.

Relationship of volcanism to crustal structure

As we have mentioned in the part devoted to petrologic models, crust is contributing substantially to the evolution of calc-alkali magmas, with increasing participation of crustal component from andesites towards rhyolites and

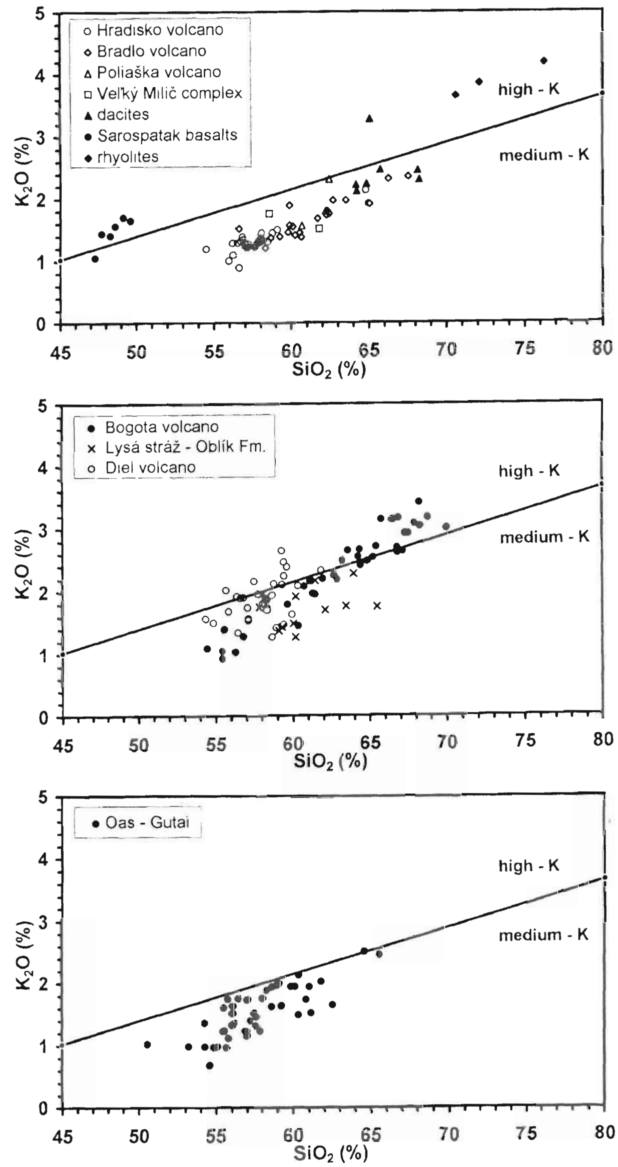

Fig. 4. K_2O-SiO_2 plots of volcanic formations in Eastern Slovakia and neighboring countries (according to Lexa and Konečný, 1998).

from low-K to high-K suites (e. g. Leeman, 1983; Grove and Kinzler 1986; Wilson, 1989). The Crust is involved not only via processes of contamination, but also owing to its function as a density filter for uprising magmas. So the petrographic and geochemical types of volcanics can be used along with isotopic data as indicator of crustal conditions.

Lexa and Konečný (1998) demonstrated, that there is quite a variability of relative potassium contents among volcanic rocks of the Carpathian arc and Pannonian Basin. High-K suites occur systematically in the areas, where geological arguments point to the presence of thicker, consolidated continental crust of Hercynian or even Precambrian age (central Western Carpathians including northern Hungary, the Calimani mountain range, southern tip

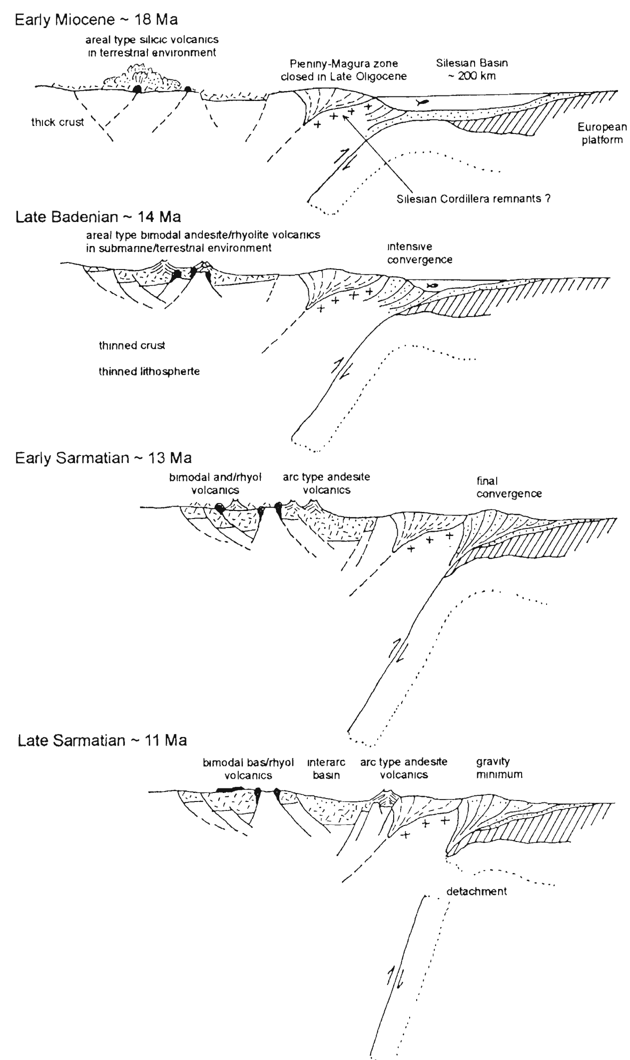

Fig. 5. Schematic palinspastic sections of the region.

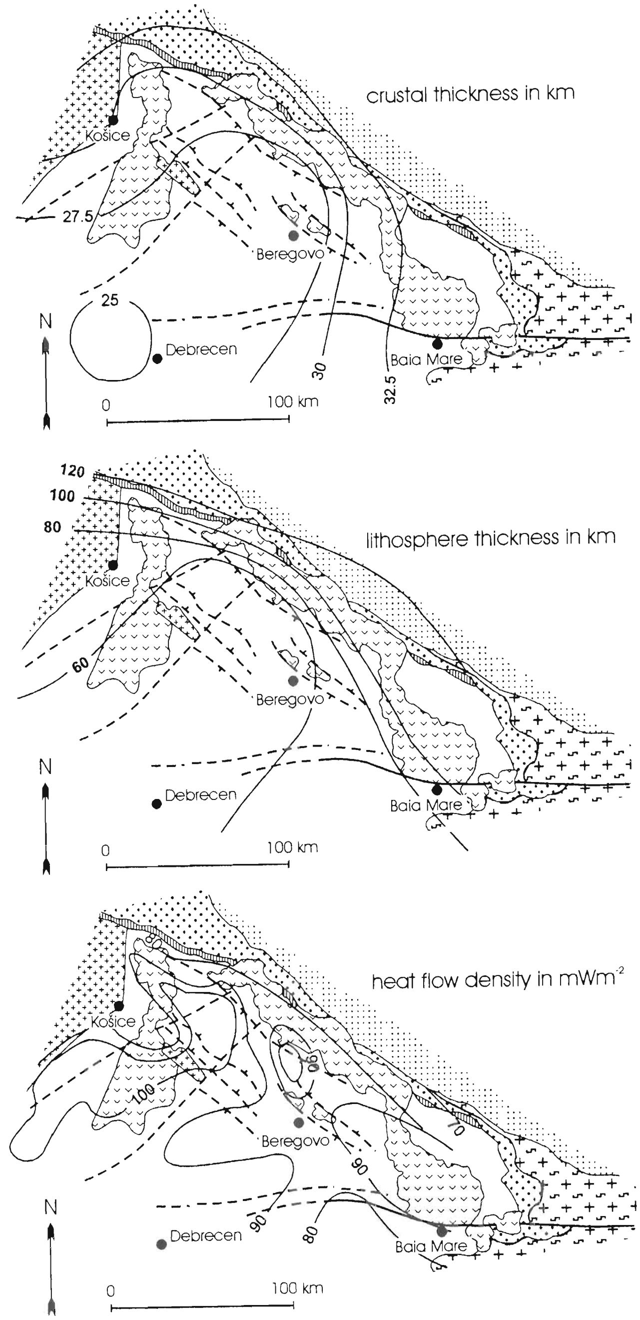

Fig. 6. Crustal thickness, Lithosphere thickness and heat flow in the region (according to Šefara et al., 1996).

of the Hargita mountain range, northern and central parts of the Apuseni mountain range). Contamination of andesites by evolved crust is supported in this case by a fast increase in potassium content with increasing SiO_2 content and by isotopic evidence (Downes et al., 1995; Mason et al., 1996), pointing to contamination by radiogenic crustal material. Isotopic data indicate also a large lateral inhomogeneity of the Crust. The segment of the volcanic arc between Western and Eastern Carpathians from Slanské vrchy mountain range at the West to the Gutai mountain range at the East is dominated by medium-K calc-alkali suites, implying, that we are dealing with a region of relatively thin and unevolved crust. The older Hercynian crust is either absent or present in thin slices only. Such the conclusion is compatible with a recent classification of the Iňačovce-Krichevo unit as the "Penninic type" by Soták et al. (1993). Relatively thin and unevolved crust explains also a generally dominant role of basaltic andesites and low proportion of differentiated rocks. However, a local presence of continental crust slices is indicated by bimodal andesite/rhyolite volcanics with highly variable relative potassium content along the Tokay – Milič – Zemplín – Beregovo – Baia Mare horst system. In this sense, the segment between Western and Eastern Carpathians reminds the active Aegean arc, which contains continental crust slices detached from the continental margin by the process of subduction roll-back and modified by subsequent arc stretching.

Relationship of volcanism to geophysical phenomena

This aspect has been recently covered extensively for the whole Carpathian arc by Nemčok et al. (1998), details of the East Slovakian region were treated by Bielik et al. (1998). Crustal thickness, Lithosphere thickness and heat flow density in the discussed region is schematically shown at the Fig. 6. The Lithosphere/Asthenosphere boundary raises to the depth 60–50 km, the shallowest being in the parts with maximum of Tertiary extension in the Transcarpathian Basin (Bielik et al., 1998). It follows from the assumed petrological model, that the areal type silicic and andesite volcanics extend generally over the areas with a pronounced extension and the most elevated position of the Asthenosphere. A similar correlation exist among volcanics and high heat flow anomalies, as high heat flow reflects especially thinning of the Crust and Lithosphere (Majcin, 1993). As extension affects also thickness of the Crust, areal type silicic and andesite volcanics associate with regions of decreased crustal thickness. Succession of the silicic volcanism followed by the andesitic volcanism might be explained as a progressive thinning of the crust due to contemporaneous extension. Low crustal thickness in the discussed region confirms conclusions from the geochemical character of volcanics.

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Buried Miocene volcanic structures in Hungary

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Key words: paleovolcanic structures, complex investigations, buried regions, lava

IGCP 356 was a project dealing with the connection between plate tectonics and metallogeny in the Carpathian Balkan area. Its 7th work-group has dealt with the Neogene palaeovolcanic reconstruction in this territory. By using its results, OTKA T-030133 project is now editing the map of Neogene volcanites of Hungary at the scale 1:500,000. The area, covered with Quaternary and Neogene deposits, a mounts to more than 2/3 of Hungary's present area and former volcanic explosion centres and volcanic products can only be reconstructed by integrated geological and geophysical investigations. A corelation is necessary among data of several deep drillings, more than 60,000 square kilometres of seismic sections, aerial geophysics and ground petrochemistry, mineralogy-petrology and K-Ar chronology from rock samles of deep drillings. Subsurface geological and structural correspondences of regions are attached to these investigations. Relying upon the above-mentioned, we can state that the position and movement of former microplates greatly determined the evolutionary progress of the Miocene in the Carpathian basin. On these facts, we may say that the Neogene volcanic rocks cover larger area in Transdanubia (the plain in Northwestern Hungary and Somogy-Baranya hill-country), the territory between Danube and Tisza and the Great Plain than well-known surface volcanic rocks in Hungary from Visegrád Mountains to Tokaj Mountains. On the basis of existing integrated data, former volcanic centres are mainly concentrated in the environment of former microplate borders and their lava and pyroclastic products considerably exceed 50 metres thickness in these areas.

Taking its geological structure into consideration, the calc- alkali andesite volcanism started early in the Eggenburgian and the Ottnangian escorted by ignimbrite volcanic centres from Mecsek Mountains to the Salgótarján basin and the southwestern part of the Bükk Mountains. The Carpathian rhyolite and dacite volcanic centres can be found mainly in Transdanubia, while the series of Badenian andesite and dacite volcanic centres forming big stratovolcanos are in the buried regions of the territory between Danube and Tisza and the Great Plain.

In the Sarmatian and the Lower Pannonian dominantly rhyolite, subordinately andesite and dacite volcanic series were born, their tuff covers and lava domes extending in the eastern region of the Great Plain (Nyírség), in thickness several thousand metres thick. There are very thick alkali trachyte (Kisalföld – the plain in Northwestern Hungary) and alkali basalt lava domes and tuff craters in regions of stabilized plates in Transdanubia and the territory of Danube and Tisza.

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K-Ar dating of Tertiary magmatism in Hungary

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Abstract

A detailed investigation of the geochronology of the Tertiary volcanic rocks in Hungary has been carried out using the K-Ar method. Tertiary magmatism can be broadly classified into two types:

1 an earlier phase of volcanism of calc-alkaline affinity,

2. a generally later (though partly overlapping) phase of alkaline volcanism.

Within the calc-alkaline volcanism, two age groups can be distinguished: an older group, Eocene/Oligocene in age (42–25 Ma), and a younger one, Neogene in age (20–9.5 Ma).

It is the purpose of this paper to draw up a reliable picture of the space and time distribution of the Tertiary volcanic activity in the study area.

Key words: K-Ar dating, Tertiary, volcanism, Hungary

Methodology

1. *Analytical work* has been made in the K-Ar laboratory, Institute of Nuclear Research of the Hungarian Academy of Sciences, Debrecen, Hungary.

2. *Conventional K-Ar age determination:*

Ar was measured by mass spectrometric isotope dilution with an ^{38}Ar spike, in static mode, K analyses were made using standard flame photometric techniques, K and Ar determinations were checked by interlaboratory standards: LP-6, HD-Bl, GL-O and Asia 1/65 (Balogh, 1985).

3. *Sampling sites:* -cover the whole Hungary, including outcropping and buried volcanic areas.

4. *Sampled rocks:* rhyolite, rhyodacite, andesite, basaltic andesite, basalt, K-trachyte, ultrapotassic rock, taken from lava flows/domes, shallow intrusions (dyke, sill, stock) welded- and non- welded ignimbrites/tuffs, unaltered massive lithic lava blocks from volcaniclastics.

5. *Measured samples:* whole rock, monomineralic fractions (biotite, amphibole, feldspar), different fractions separated from whole rock based on the different magnetic susceptibility and density.

6. *For stratigraphic classification,* the time-scale of Central Paratethys has been used.

K-Ar dating of Eocene-Oligocene magmatic rocks in Hungary

Eocene-Oligocene magmatism is located along and in the vicinity of the Balaton line, from N Hungary (Bükkszék) to Zala basin, at the SW border of the country (Fig. 1).

In the Mátra Mts. extensive Miocene volcanism rejuvenated most of the K-Ar ages. Biotite age of about 30 Ma is mentioned and it is noted, that amphibole ages, are closest to the real age (35.7 Ma).

Feldspar from andesite tuff reached by the borehole Bugyi-2 shows an apparentage 24.6 Ma, indicating some Ar loss from the altered rock.

Biotite from the borehole Kiscell-1 is well dated by K/Ar method and Ar/Ar age is also available (33.7±1.0 Ma).

Biotite has been dated from two levels of the borehole Alcsútdoboz-3. The sample from the upper level is altered and contains detrital material. The similarity of age data suggest, that K/Ar ages (31.7±0.8 Ma) reflect the time of a secondary event. Samples from the Velence Mts. and its vicinity (Pázmánd, Sukoró, Seregélyes, Gárdony, Várpalota) show Eocene-Oligocene ages. The age of tonalite (30.7±1.6 Ma) from the borehole Balatonfenyves-1 is not secondary, since in a neighbouring borehole Hercynian metamorphics under Badenian volcanites preserved their age. Andesites from Zala basin (Hahót-Ederics, Pötréte, Bak) are regarded as Eocene volcanic rocks, though stratigraphy is uncertain for most of the occurrences. Some rejuvenation of the K/Ar ages is likely, since in the Miocene there was also volcanic activity in this area (Széky and Fux et al., 1991).

K-Ar dating of the Neogene magmatic rocks in the Hungary

Miocene volcanic activity started with high-volume siliceous calc-alkaline explosive eruptions about 20 Ma ago, and ceased around the Sarmatian/Pannonian boundary (11 Ma). The most intense phase of acidic volcanic activity

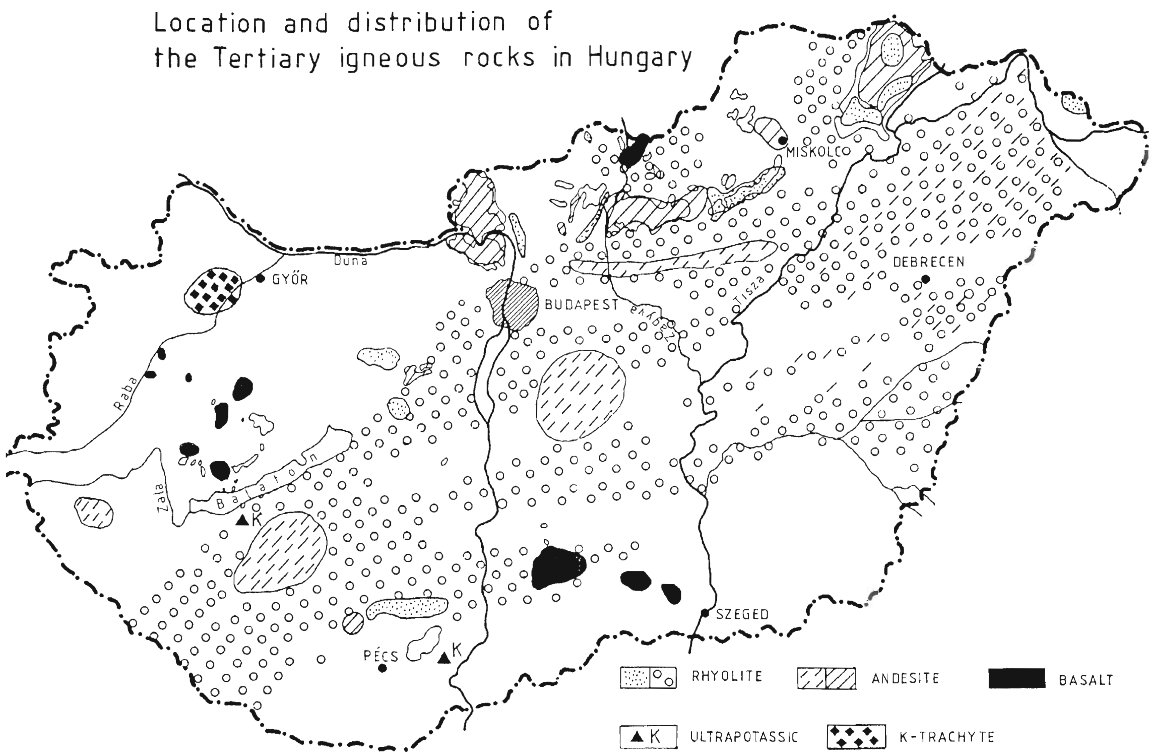

Fig. 1. Location and distribution of the Tertiary igneous rocks in Hungary.

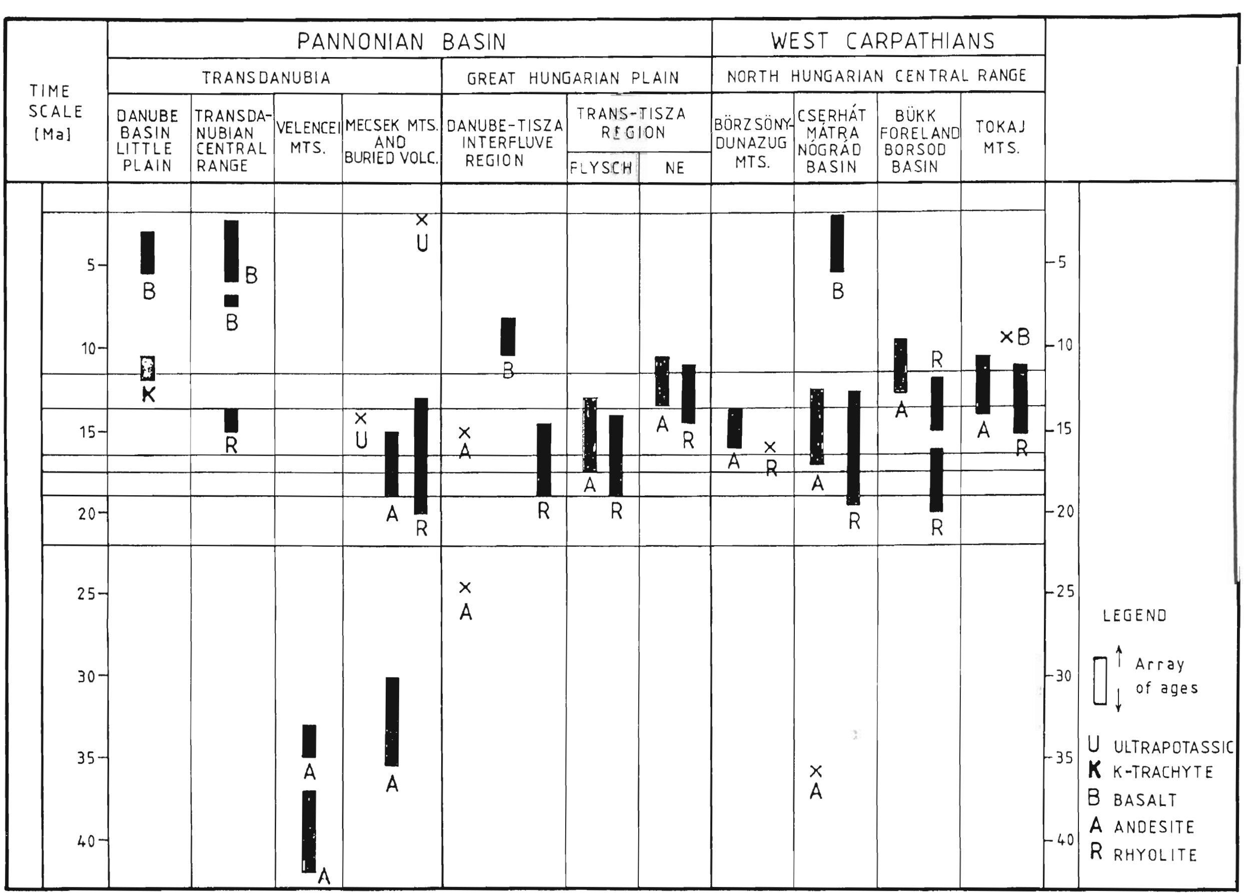

Fig. 2. Synthesis of the extended radiometric data (age intervals for the different rock type groups and considered areas).

took place in the Badenian (16.0–13.5 Ma). Ignimbrites, reworked tuffs and rare domeflow complexes are widespread, extending over most of the Tertiary volcanic fields of Hungary. Their source areas are mostly unknown yet.

Intermediate- and acidic calc-alkaline volcanic activity frequently occurred simultaneously, they can be alternating, however, andesitic volcanism post-dates generally the acidic one (Fig. 2).

A feature of the intermediate calc-alkaline magmatism is the occurrence of rare late-stage basaltic or basaltic-andesitic activity in many areas. Generally, these follow the main andesitic activity.

The oldest andesites (19 Ma) are outcropping in the Mecsek Mts. and buried in SW Hungary, while the youngest eruptions (9.5 Ma) are confined to NE Hungary (Pécskay et al., 1995).

K-Ar data proved, that the oldest extension related alkaline magmas are about 10 Ma old and were erupted just as the calc-alkaline magmatism was waning. Alkaline volcanism in Hungary is dominated by alkali basalts.

Alkaline basalts form significant volcanic fields in the SW part of the Transdanubian Central Range (Balaton Highland and Bakony Mts., 8.0–2.3 Ma), in the Danube basin (5.5–3.0 Ma), in the Nógrád basin (5.4–2.0 Ma) and in the Danube-Tisza Interfluve region (Kecel-Kiskunhalas area, 10.4–8.1 Ma). The youngest alkali basaltic volcanism took place about 2 Ma ago in the Nógrád basin (Balogh et al., 1986).

K-trachytic rocks erupted in the Danube basin (12.0–10.5 Ma), while ultra-potassic rocks at Bár (2.17 Ma) and Balatonmária (14.3 Ma) are represented by a few occurrences only.

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Structure and evolution of the Neogene Štiavnica stratovolcano (Central Slovakia)

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Abstract

The Štiavnica stratovolcano is the largest volcano in the Carpathian volcanic arc. A large caldera, an extensive subvolcanic intrusive complex and a resurgent horst with late stage rhyolite volcanics are the most characteristic features. Evolution of the stratovolcano took place in five stages during the Early Badenian to Early Pannonian time: (1) construction of an extensive andesite stratovolcano, (2) denudation of the volcano and contemporaneous emplacement of the subvolcanic intrusive complex of diorite, granodiorite and granodiorite porphyries, (3) subsidence of the caldera and its filling by differentiated andesites, contemporaneous emplacement of quartz-diorite porphyry sills and dykes, (4) renewed explosive and effusive activity of less differentiated andesites, (5) an uplift of the resurgent horst in the central part of the caldera accompanied by rhyolite volcanism and epithermal mineralization.

Key words: Central Slovakia, stratovolcano, caldera, resurgent horst, andesite, rhyolite, intrusions

Introduction

Systematic geological mapping of the Štiavnica stratovolcano was recently concluded by the compilation of the geological map in the scale 1 : 50 000 (Konečný et al., 1998) and by the synthesis of geological structure and evolution in the form of explanatory text (Konečný et al., 1998). This paper reviews essential aspects of the stratovolcano.

The Štiavnica stratovolcano is the largest volcano in the Carpathian volcanic arc, covering an area of more than 2000 km^2. It is situated in the SW part of the Central Slovakia Neogene Volcanic Field at the inner side of the Carpathian arc. A large caldera, an extensive subvolcanic intrusive complex and a resurgent horst with late stage rhyolite volcanics are the most characteristic features (Fig. 1 and 2). Evolution of the stratovolcano took place in several stages (Fig. 3) during the Early Badenian to Early Pannonian time (16.5–9.0 Ma).

The 1st (pre-caldera) stage

Explosive and effusive activity of pyroxene, hornblende-pyroxene and rare biotite-hornblende-pyroxene andesites during the Early and Middle Badenian time created an extensive stratovolcano 50 km in diameter. Interbedded marine sediments and hyaloclastite breccias at the base of the volcanic pile imply initial activity in a shallow marine environment, which persisted during whole life of the volcano at the South. Alternating andesite lava flows, pyroclastic flow deposits and coarse epiclastic breccias in the form of a stratovolcanic complex dominate in the proximal zone outside of the caldera. Variability of eruptions and migration of eruptive centers resulted in a heterogeneous structure with "effusive" and "pyroclastic" domains. Rocks of the proximal zone pass outward into accumulations of epiclastic breccias (mud-flow and debris-flow deposits), conglomerates and sandstones of the distal zone, laid down variably in the ephemeral stream, fluvial and/or marine environments. In the central zone, exposed due to the uplift of the resurgent horst, there is a complex of propylitized volcanic and intrusive rocks, mostly andesite porphyry sills and laccoliths, emplaced along the volcanic complex/basement interface during the maturity of the volcano. The same rocks as well as minor stocks and extrusive domes occur also at parasitic centers around the caldera.

The 2nd (intrusive and early caldera) stage

Construction of the stratovolcano was followed during the Late Badenian time by a long period of quiescence and erosion – denudation in the central zone has reached the level of andesite porphyry sills and laccoliths. During the same time evolution of magmas in the high level crustal magma chamber lead to a repeated emplacement of subvolcanic intrusive bodies by the mechanism of underground cauldron subsidence, using subhorizontal discontinuities among crystalline basement, Mesozoic rocks of the Veľký Bok Group and Late Paleozoic to Middle Triassic rocks of Hronicum. The early emplacement of diorite in the northern part of the central zone was followed by the emplacement of the extensive granodiorite pluton and later by the emplacement of granodiorite to quartz diorite porphyry stocks and dyke clusters around the pluton.

Late Badenian denudation of the volcano was concluded by the early caldera subsidence, which was contempora-

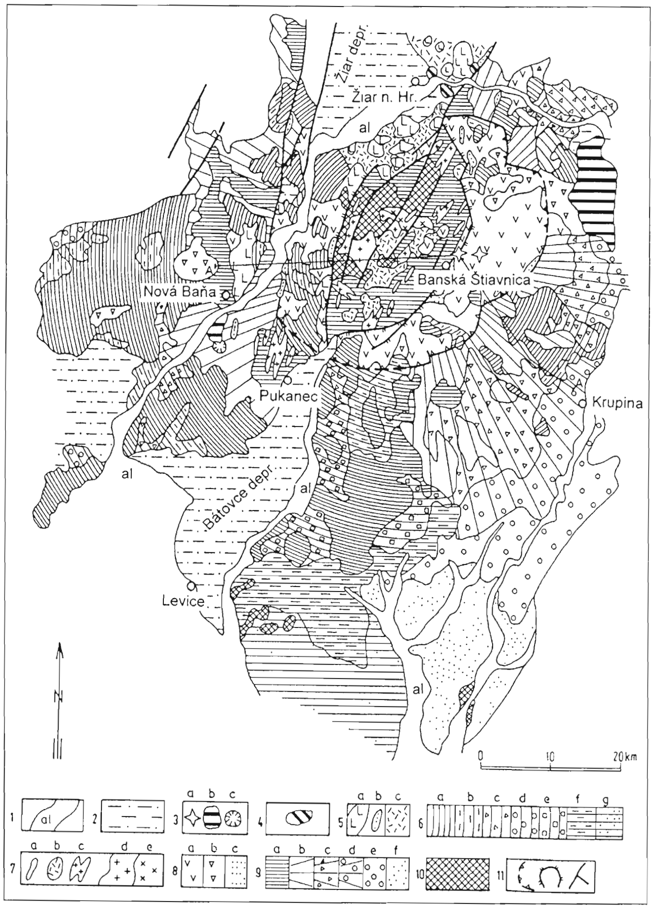

Fig. 1. Structural scheme of the Štiavnica stratovolcano (Konečný et al., 1995). 1 – Quaternary alluvial deposits, 2 – Pannonian to Pliocene post-volcanic tuffaceous sediments, 3 – Late Pannonian to Quaternary alkali basalt lava necks (a), lava flows (b) and cinder cone (c), 4 – Pannonian high-Al basalt/basaltic andesite lava flows, 5 – Late Sarmatian rhyolite extrusive domes (a), dykes (b) and pyroclastic/epiclastic rocks (c), *upper structural level – post-caldera stage (Sarmatian):* 6 – pyroxene, hornblende-pyroxene and biotite-hornblende-pyroxene andesite effusive complex (a), ignimbrites and pumice tuffs (b), epiclastic volcanic breccias (c), conglomerates (d), hyaloclastite breccias (e), marine facies reworked pumice tuffs (f) and marine tuffaceous sandstones and siltstones (g), *subvolcanic intrusions:* 7 – quartz-diorite porphyry dykes (a) and sills (b), granodiorite porphyry stocks and dyke clusters (c), granodiorite (d) and diorite (e) bell-jar pluton, *middle structural level – caldera stage (Late Badenian):* 8 – biotite-hornblende andesite dome/flow complex (a), epiclastic breccias (b) and caldera lake tuffaceous sediments (c), *lower structural level – pre-caldera stage (Early to Middle Badenian):* 9 – complex of undivided propylitised andesite lava flows and andesite porphyry sills and laccolithes (a), pyroxene to hornblende-pyroxene andesite effusive complex (b) and stratovolcanic complex with block and ash pyroclastic flow deposits and epiclastic volcanic breccias (c), epiclastic volcanic breccias/conglomerates (d), marine epiclastic volcanic conglomerates (e) and sandstones (f), 10 – basement outcrops, 11 – caldera fault (a), marginal faults of the resurgent horst (b) and other faults (c).

neous with the subsidence of the Kremnica graben in the northern sector of the volcano. Subsidence of the caldera lead to the deposition of caldera lake sediments in the

thickness up to 100 m and was accompanied only by minor effusive and explosive activity of biotite-hornblende-pyroxene andesites. We assume, that the subsidence of the caldera at this stage was related to a lateral outflow of magma from the high level magma chamber into the Kremnica graben, forming up to 500 m thick effusive complex of hornblende-pyroxene andesites (Lexa et al., 1998).

The 3rd (main caldera) stage

Evolution of magma in the high level magma chamber during the Late Badenian time was concluded by the emplacement of quartz-diorite porphyry sills and dykes and

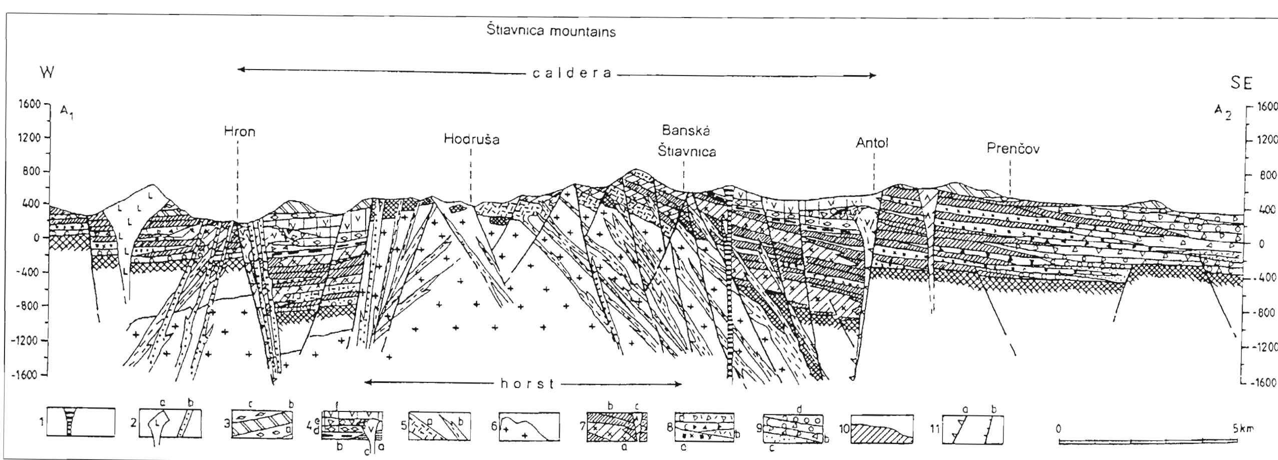

Fig. 2. Schematic section of the Štiavnica stratovolcano (Konečný et al., 1995). 1 – alkali basalt neck, 2 – rhyolite extrusive dome (a) and dykes (b), *upper structural level – post-caldera stage:* 3 – biotite-hornblende-pyroxene andesite pumice tuffs (a), lava flows (b) and ignimbrite (c), *middle structural level – caldera stage:* 4 – biotite-hornblende-pyroxene andesite lava flow (a), caldera lake tuffaceous sediments (b), biotite-hornblende andesite extrusive dome (c), pumice tuffs (d), epiclastic volcanic breccias (e) and biotite-hornblende andesite lava flow (f), *subvolcanic intrusions:* 5 – quartz-diorite porphyry sills (a) and dykes (b), 6 – granodiorite bell-jar pluton, *lower structural level – pre-caldera stage:* 7 – andesite porphyry sills and laccoliths (a), pyroxene and hornblende-pyroxene andesite lava flows (b) and pyroxene-hornblende andesite extrusive dome (c), 8 – block and ash pyroclastic flow deposits (a), tuffs (b), reworked pyroclastic rocks (c) and lahar deposits (d), 9 – epiclastic volcanic sandstones (a), breccias (b), breccias/conglomerates (c) and conglomerates (d), 10 – basement, 11 – caldera fault (a) and other faults (b).

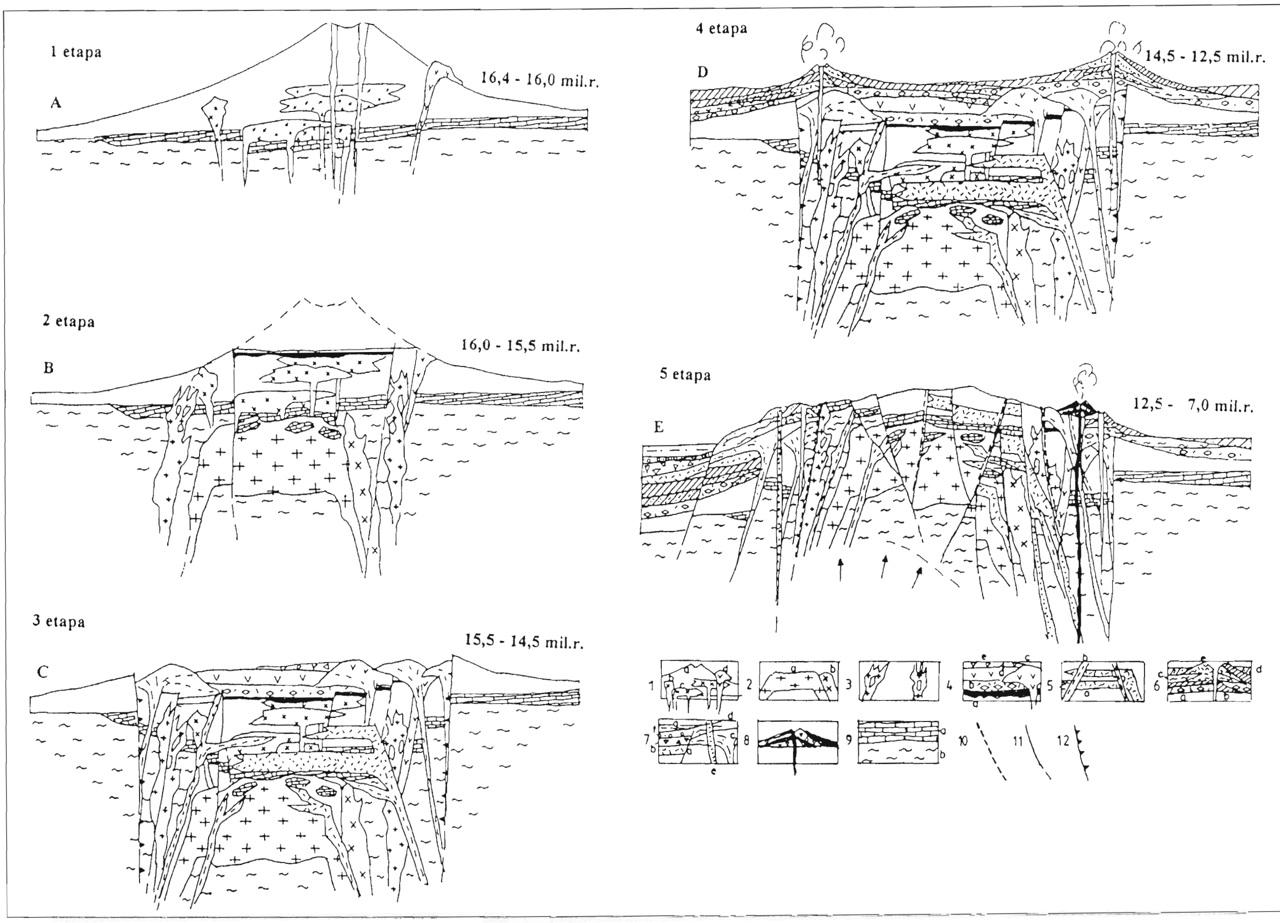

Fig. 3. Evolutionary scheme of the Štiavnica stratovolcano (Konečný et al., 1998). 1st stage (1 etapa), px and hb-px andesite volcanics: 1a – andesite stratovolcano, 1b – andesite to diorite porphyry stocks, 1c – andesite porphyry sills, 1d – extrusive domes. 2nd stage (2. etapa): 2a – granodiorite pluton, 2b – diorite intrusion, 3 – granodiorite to quartz-diorite porphyry stocks and dyke clusters, 4a – early caldera lake sediments. 3rd stage (3. etapa), bi-hb andesite volcanics: 4b – pumice tuffs, 4c – extrusive domes, 4d – lava flows, 4e – epiclastic breccias, 5a – quartz–diorite porphyry sills, 5b – quartz-diorite to diorite porphyry dykes. 4th stage (4. etapa), andesite volcanics: 6a – pumice tuffs, 6b – px andesite lava flows, 6c – ignimbrites, 6d – bi-hb-px andesite lava flows, 6e – pyroclastic breccias and agglomerates. 5th stage (5. etapa), rhyolite volcanics: 7a – pumice tuffs, 7b – epiclastic breccias, 7c – extrusive domes, 7d – lava flows, 7f – epiclastic volcanic conglomerates and sandstones, 7g – tuffaceous sandstones and siltstones in the Žiar depression. 8 – alkali basalt volcano. Basement rocks: 9a – Mesozoic rocks, 9b – Hercynian igneous and metamorphic rocks. 10 – ore veins, 11 – faults, 12 – caldera fault.

more or less contemporaneous subsidence of the caldera 18 x 22 km in diameter. Quartz-diorite sills and quartz-diorite to diorite mostly outward dipping dykes were emplaced by the ring dyke mechanism due to a subsidence of the central block, using discontinuities within the basement, between the basement and volcanic complex and in the lower part of volcanic complex. The main phase of the caldera subsidence was compensated by the explosive and extrusive activity of biotite-hornblende andesites to dacites. Caldera filling in the thickness 350–450 m is represented mostly by a dome/flow complex with related block and ash pyroclastic flow deposits and coarse epiclastic breccias, subordinate pumice tuffs occur especially at the base. At several places the caldera filling passes outward into filling of radial paleovalleys on slopes of the volcano, dominated by thick lava flows and epiclastic volcanic breccias.

The 4th (post-caldera) stage

Renewed explosive and effusive activity of pyroxene, hornblende-pyroxene and biotite-hornblende-pyroxene andesites during the Early and Middle Sarmatian time gave rise to a heterogeneous complex of post-caldera andesite volcanics on slopes of the stratovolcano. Individual eruption cycles produced overlapping domains with characteristic petrographic and lithologic composition. Initial Plinian type eruptions of biotite-hornblende-pyroxene andesite created accumulations of pumice-flow and pumice fall tuffs in the southern sector of the volcano, grading southward into reworked marine facies. Following effusive activity of pyroxene andesites in the SW sector of the volcano formed an extensive lava sheet (plateau), accompanied by hyaloclastite breccias at places, where lava flows entered the coastal zone of the sea. Reworked material in the form of conglomerates, sandstones and siltstones was laid down further southward. Next explosive and effusive activity of biotite-hornblende-pyroxene andesites created accumulations of pumice tuffs and overlying lava flows around caldera margins and in radial paleovalleys on slopes of the stratovolcano, as well as an extensive ignimbrite complex in its western sector. Subsequently, several stratovolcanic and effusive complexes of hornblende pyroxene andesites formed along caldera rim and on its W, NW and N slopes. Youngest there are pyroxene and pheldsparphyric andesite effusive complexes on the SE and W slopes of the stratovolcano. Glassy character of andesites and hyaloclastite breccias imply, that the lowermost lava flows reached a water environment.

The 5th (resurgent horst) stage

An uplift of the resurgent horst (Hodruša-Štiavnica horst) in the central part of the caldera took place during the (Middle?) Late Sarmatian to Early Pannonian time. The horst is asymmetric, exposing due to erosion basement rocks and subvolcanic intrusive complex in its western part. Western and northern marginal faults limit the horst against the subsiding Žiar depression. This fault system, as well as parallel fault systems near Pukanec and Nová Baňa were used for a contemporaneous ascent of rhyolitic magma. Extrusive and explosive activity in the Žiar depression gave rise to a dome/flow complex accompanied by accumulations of pumiceous tuffs and epiclastic volcanic rocks. Solitary extrusive domes and dykes are characteristic for uplifted regions. Dominantly NNE–SSW trending fault system of the resurgent horst hosts also an extensive system of base and precious metal epithermal veins.

Products of the Pannonian calc-alkali basaltic volcanism (dykes, necks, sills, laccoliths, lava flows and phreatic tuffs) around Žiar nad Hronom, Pannonian-Pontian alkali basalt necks near Banská Štiavnica and lava flows south of Zvolen and Pleistocene alkali basalt cinder cone with lava flows near Nova Baňa are not considered as a part of the Štiavnica stratovolcano.

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The Vihorlatské vrchy Mts. volcanic chain, Eastern Slovakia: volcanological features

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Abstract

The Vihorlatské vrchy Mts. volcanic chain forms the easternmost part of volcanoes/volcanic structures in Slovakia and is a part of the longest continuous portion of the Carpathian volcanic arc (Neogene/Quaternary age). This segment of volcanoes basically contains partially overlapping composite volcanoes with a dominant lava-flow activity punctuated by explosive activity and the dome extru-sions. The products of Neogene volcanism of the Vihorlatské vrchy Mts. (~600 km^2) are characterised by the three types of volcanic activity of calc-alkaline composition. The first, the Lower Badenian area type of this volcanism (the Hrabovec rhyodacitic tuffs), scarce, but widely scattered, is represented by the products of dacite to rhyodacite volcanism. The second type of volcanism is represented by the extrusive domes and shallow intrusive bodies (rhyodacite, hornblende-pyroxene andesite, pyroxene andesite, andesite or diorite porphyry) of the Middle Sarmatian age in the alingment Kapušany – Vinné – Mukačevo (Vinné complex). The third type of the volcanism ie characterised by the basalt-andesite to andesite of the volcanic arc type. This activity continued during the Middle Sarmatian – Lower Pannonian and is represented mostly by a considerable number of andesitic stratovolcanoes and volcanoes.

Key words: Eastern Slovakia, Neogene, volcanism, volcanic eruptions, volcanic forms

Introduction

In the north part of the Carpathian Neogene/Quaternary volcanic arc, in the Eastern Slovakia Volcanic Field (ESVF) are situated the Vihorlatské vrchy Mts. (Fig. 1). The synthesis of geological structures and evolution of the volcanoes of this region was concluded in the explanatory text (Žec et al., 1997) and in the geological map in the scale 1 : 50 000 (Žec et al., 1997). This paper reviews important volcanological features of the Vihorlatské vrchy volcanic chain.

The region is represented at the contact of the Western and Eastern Carpathians mostly by a number of andesitic stratovolcanoes calc-alkaline affinity (Kaličiak and Žec, 1995). The products of the Vihorlatské vrchy Mts. volcanic chain are characterized by the three types of volcanic activity of calc-alkaline composition (classified on the basis of distribution of Carpatho-Pannonian volcanic rocks, after Lexa et al., 1993; Lexa and Konečný, 1998). The first is a bradly scattered type of dacite to rhyodacite volcanism (Lower Badenian), the second type is represented by the extrusive/shallow intrusive bodies of the Middle Sarmatian age of the Vinné Complex and the third type of volcanism mostly of the basaltic-andesitic to andesitic volcanism of the volcanic arc type (Middle Sarmatian––Early Pannonian). These composite volcanic structures present a wide range of explosive, effusive and epiclastic products. Genetic types of pyroclastic deposits vary and type of eruptions is characterised mostly by Strombolian to Vulcanian type. The compositional features and space-time distributions individual types of volcanism are presented in confrontation with volcanic aspects of this interesting area.

Geological setting and volcanological features

The products of Neogene volcanism of the Vihorlatské vrchy Mts. volcanic chain (Fig. 2) are characterised by the three types of volcanic activity of calc-alkaline composition (Fig. 3). The Vihorlatské vrchy Mts. volcanic deposits (Žec et al., 1997) range from basaltic andesites to rhyodacites (Gill, 1981) with a predominance of medium K-andesite. Using the classification of Le Maitre (1989) and the AFM plot of Irvine and Baragar (1971) most lava samples reveal calc-alkaline rathern than a tholeitic trend and have a subalkaline character.

The first is a bradly scattered type of dacite to rhyodacite volcanism (Early Badenian) is represented by the fine-grained, predominantly aleuritic-pelitic, light-grey to greenish, the Hrabovec rhyodacitic tuffs (Slávik, 1969) and products are scarce. The volcanic centres of this activity are uknown till now.

The beginning of Middle Sarmatian times was marked by the volcanic activity which products crop out as morphologically distinct, rhyodacite/andesite extrusive bodies of the Beňatina voda member and the Vinné Complex. Another type of volcanism is represented by the basalt-andesite to andesite of the volcanic arc type. One such body occurs north-east of Beňatina. The Beňatina voda of

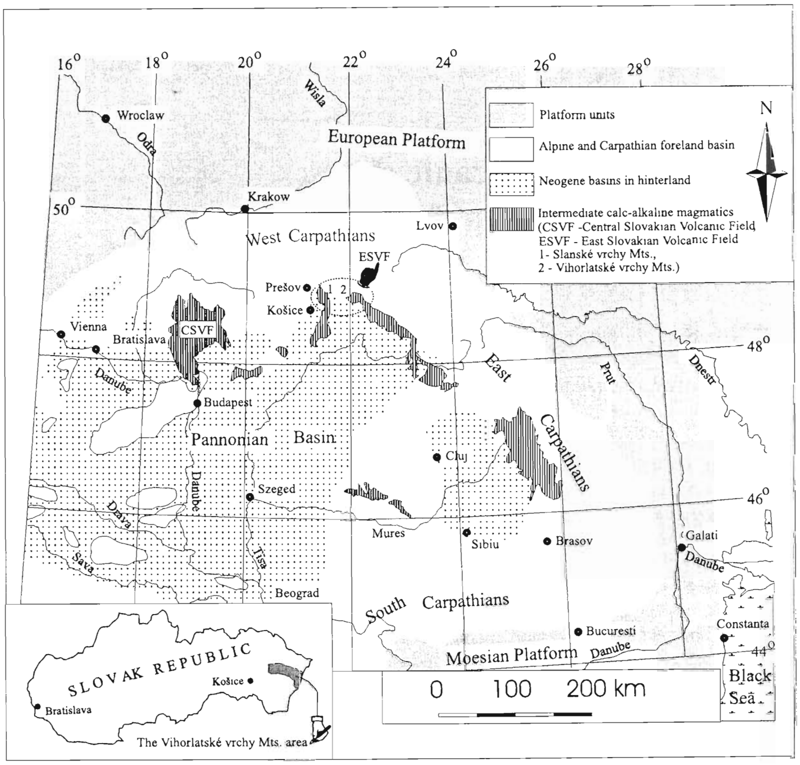


Fig. 1. A sketch of the eastern part of the Alpine–Carpathian–Pannonian area with localization of the Eastern Slovakia Volcanic Field (ESVF) and the Vihorlatské vrchy Mts.

rhyodacite body is made up of pale, autometamorphosed rhyodacite with accessory garnet. The body is enwrapped in a breccia that contains glassy rhyodacite fragments in a clayey-sandy matrix. Morphologically distinct, extrusive bodies of the Vinné Complex are situated at the base of the volcanic suite, at its SW margin (in the surroundings of Trnava pri Laborci – Vinné – Kaluža villages), at its western to north-western margins east of Oreské and south-east of Ptičie villages, as well as at the heads of Konské, Suchý potok and Voňarský potok valleys). The geological structure of the Vinné Complex is composed of several petrographic rock types, which has a common feature – alterations of autometamorphic type, represented by hematitization of mafic minerals and to a lesser extent by chloritization and recrystallization of the matrix. This complex also includes extrusive bodies of amphibole-hypersthene andesites, hypersthene andesites with accessory augite and amphibole, augithe-hypersthene andesites and associating transitions to the extrusive breccias.

The third type is a basaltic-andesitic to andesitic volcanism of an volcanic arc type (Late Sarmatian–Early Pannonian), characterised by a large number of andesitic stratovolcanoes and volcanoes that are related to two fault systems. The Popriečny, Diel and Morské oko stratovolcanoes are situated at the intersections with transversal, north-east striking faults, at the north-eastern side of a graben delineated by a parallel running fault system. To the second fault system are bound the volcanic centres of areally smaller stratovolcanoes called Vihorlat, Sokolský potok, Kyjov and Kamienka. Most of the Late Sarmatian to Early Pannonian times was dominated by the development of andesitic stratovolcanoes (Vulcanian, Plinian, Strombolian type of volcanic activity). A general feature of this volcanic activity is its predominantly explosive onset, which gradually turned into effusive. It was terminated by the intrusions in the central stratovolcanic zones. The discrete stratovolcanoes can well be defined due to the occurrence of central zones with relics of volcanic cones and hydrothermally altered rocks, with andesite and diorite porphyry intrusions, the transitional volcanic zones made up of volcanic mantle and the peripheral volcanic zones, composed predominantly of redeposited pyroclastics and epiclastics. Two distinctive chains of andesite stratovolcanoes developed during the mentioned explosive-effusive activity.

The north-west striking eastern chain includes the morphologically isolated Popriečny, Diel and Morské Oko Stratovolcanoes, each of them represented by the defined volcanic formations. In contrast to the stratovolcanoes of the eastern branch, the western branch stratovolcanoes almost totally lack the differentiated rocks, the spatial similarity and are less extensive. It seems that the aforementioned features were due to the development of volcanic structures beyound the main, graben-like, volcanotectonic zone. The bases of most of the mentioned stratovolcanoes both, in the eastern, and the western branch, are characterised by the products of explosive activity that sedimented in a fluvial-limnic environment and were later overlain by the products of effusive activity (deposited predominantly in a terrestrial environment).

The Popriečny Stratovolcano is composed of the lower Popriečny Formation and of the upper Petrovce Formation. Most of the Popriečny Formation is represented by pyroclastic breccias and autochthonous agglomerates, al-

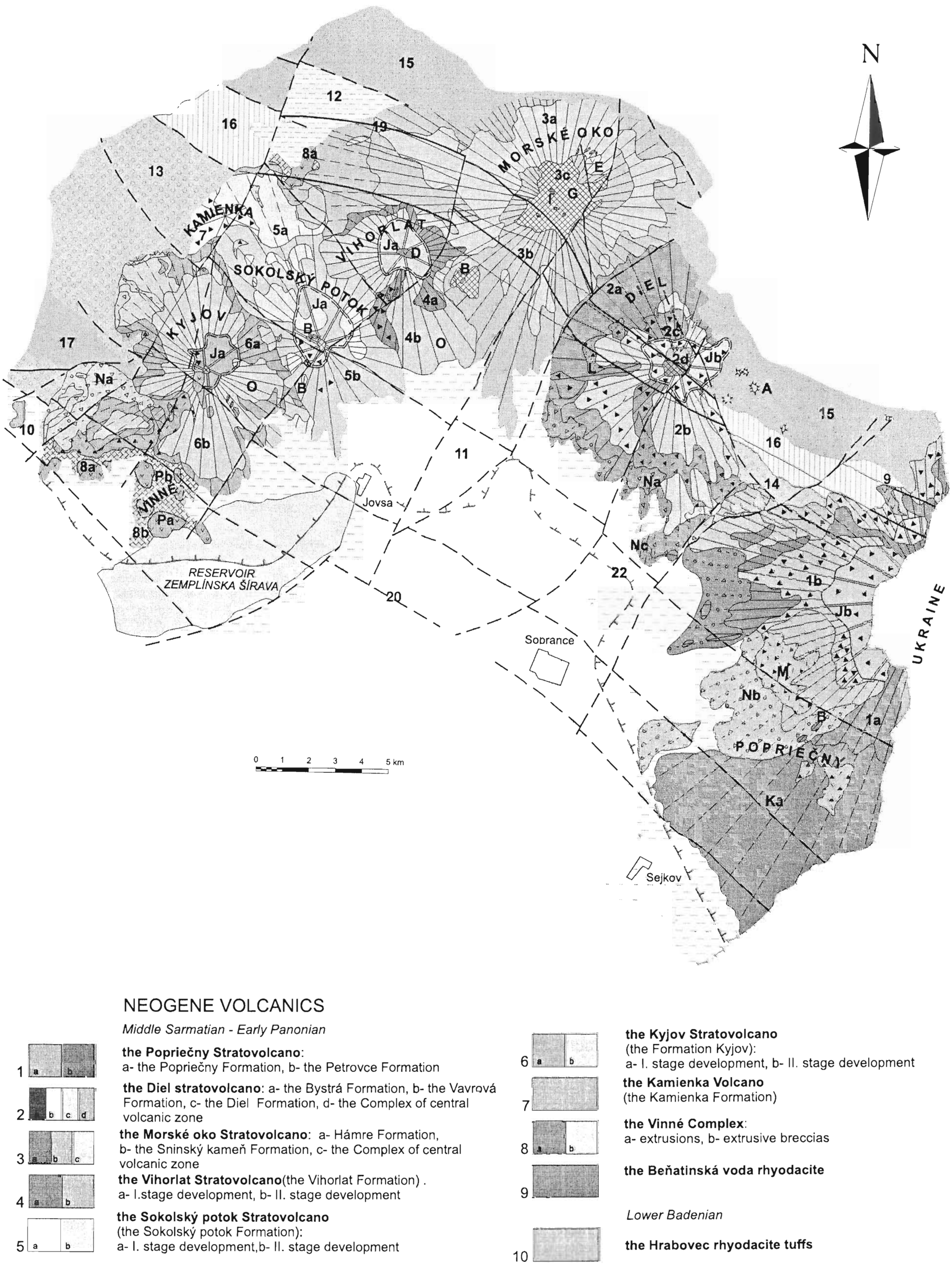
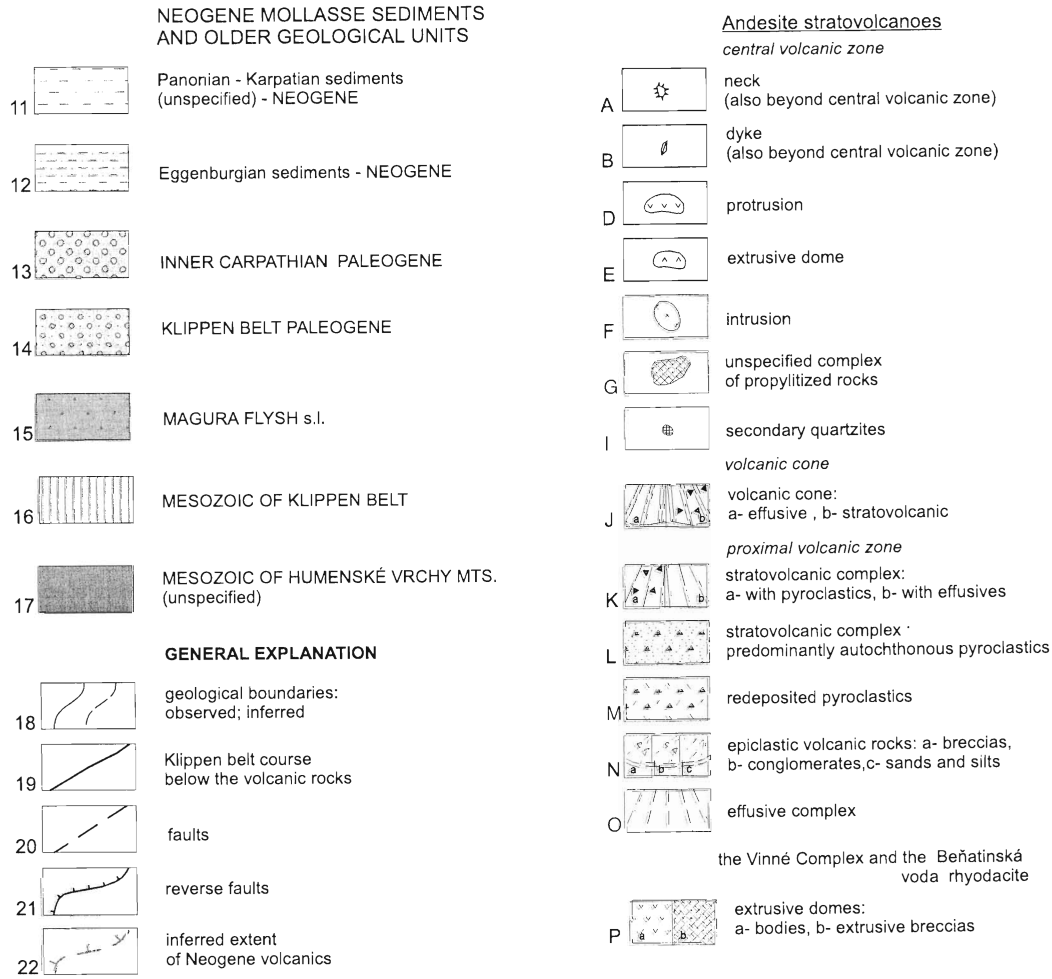


Fig. 2. Structural-geological scheme of volcanoes of the Vihorlatske vrchy Mts. (modified from Žec et al., 1997).



Explanation to Fig. 2.

ternating with lava flows of aphanitic to medium-porphyric pyroxene andesite, but also by redeposited pyroclastics and epiclastics. The upper, Petrovce Formation is mainly a product of an effusive activity, of which the individual lava flows of porphyric pyroxenic and leucocratic andesites make up the south-west running fill of an eroded away paleovalley. The Diel Stratovolcano is composed of the Bystrá, Vavrová and Diel Formations and of Complex of the central volcanic zone. The Bystrá Formation is made up of a medium-porphyric pyroxene andesite lava flows and directly overlies the pre-Neogene basement. In the south most of the Formation is composed by redeposited pyroclastic and epiclastic rocks. The Vavrová Formation, composed mainly of coarse-porphyric pyroxene andesite with large augite phenocrysts and sporadic leucocratic and basaltic andesite lava flows, overlies the denuded surface of the Bystrá Formation. The Diel Formation, represented by the youngest products of stratovolcano volcanic activity, is composed of amphibole-pyroxene andesite lava flows of the relics and of the pyroxene-amphibole andesite dykes and necks. The Complex of central volcanic zone is represented by propylitized pyroxene andesites that are intruded by the diorite porphyry and the dykes of pyroxene andesites. The Morské oko Stratovolcano is composed of the Hámre and Sninský kameň Formations and of the Complex of central volcanic zone. The base of stratovolcano is made up of the Hámre Formation, characterised by pyroxenic lava flows and of a discontinuous bed of redeposited tuffs. The Sninský kameň Formation discomformably overlies the moderately to strongly denudated surface of the Hámre Formation. The base of this formation is made up predominatly of coarse-porphyric pyroxene andesite lava flows and the upper part is made up of medium-fine-porphyric pyroxene andesites, grading to basaltic andesites. The Complex of central volcanic zone comprises of an unspecified propylitized/chloritized sequence of andesitic porphyries and andesites, the intrusions of diorite porphyries, the dykes of andesite and andesite porphyry, the bodies of secondary quartzites and the silicification and argillitization zones.

The western, south-west -nort-east running chain is represented by the Kyjov, the Sokolský potok, the Vihorlat stratovolcanoes, which morphologically merges to join the other volcanic chains at Morské oko stratovolcno. Slightly excentric position occupies the Kamienka explosive volcano, overlapped by the effusive products of the

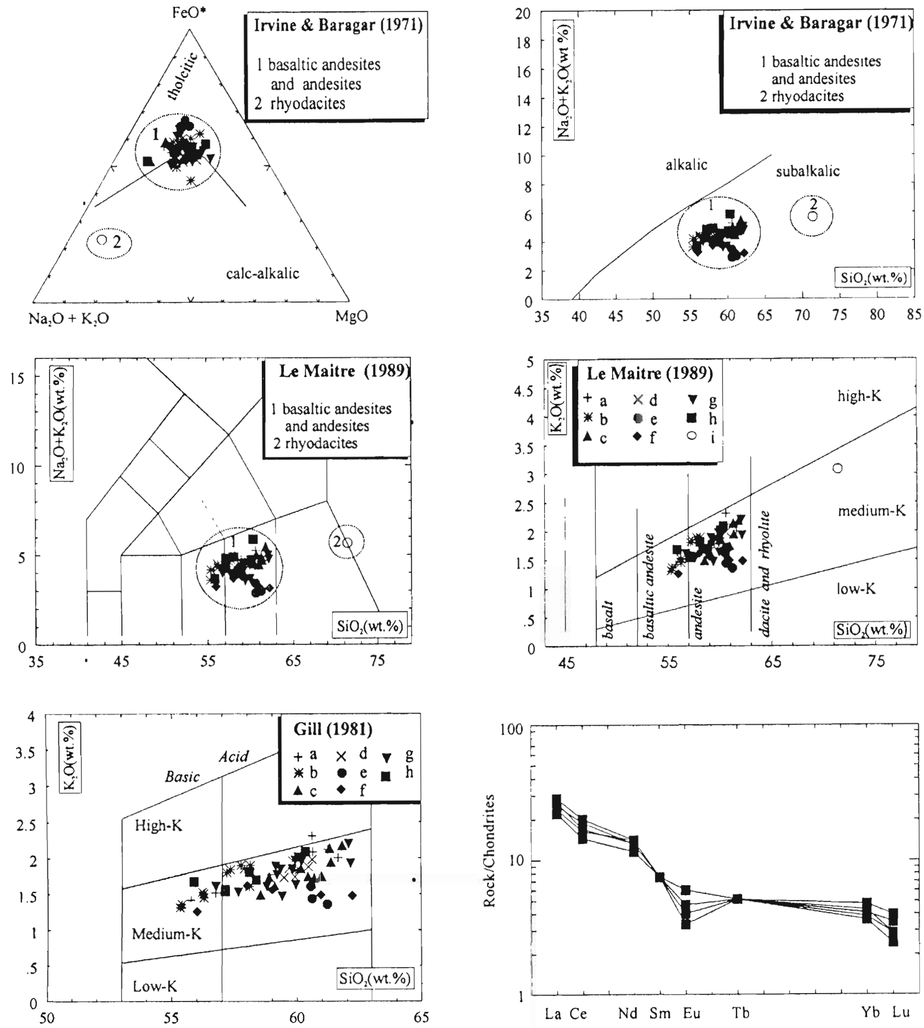


Fig. 3. Taxonomic classifications of the Neogene volcanic rocks of the Vihorlatské vrchy Mts.. a – the Vihorlat Stratovolcano. b – the Popriečny Stratovolcano. c – the Kyjov Stratovolcano. d – the Sokolský potok Stratovolcano. e – the Kamienka Stratovolcano, f – the Vinné Complex. g – the Morské oko Stratovolcano, h – the Diel Stratovolcano, i – the Beňatinská voda rhyodacitic body.

Kyjov, Sokolský potok and Morské oko stratovolcanoes. The lithofacial relationships between the individual andesitic volcanoes of the western chain, which include the interfingering at their junctions, indicates that their formations were approximately coeval. The Vihorlat Stratovolcano is characterised by a periclinal arrangement of the lava flows around the central protrusion (a ?tholoid), located in the area of Vihorlat summit point. The lava flows are composed of pyroxene andesites. The asymmetrical structure of Sokolský potok Stratovolcano strikes north-west, and together with the Kyjov Stratovolcano, they make up a volcanic structure with greater representation of the explosive products in its lower part, and with the lava flows gradually predominating in its higher levels. The pyroxenic andesites predominate over the pyroxene basaltic andesites. The Kamienka Volcano, whose relics are exposed in the Kamenica creek valley, is characterised by the deposits of autochthonous pyroclastic breccias. They are intersected by a number of dykes and necks of pyroxene andesite.

The slope deformations together with erosional trenches represent important geodynamic phenomena in the Vihorlatské vrchy Mts. The Quaternary cover is represented mostly by the deluvial-fluvial, fluvial, eolian-deluvial and proluvial sediments of Pleistocene and Holocene age.

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Evolution of volcanics of the Vtáčnik Mts. in the Central Slovakia Neogene volcanic field

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Abstract

The geological structure of the region incorporates Neogene volcanic and sedimentary rocks. Owing to fault tectonics the geological structure of the region is relatively complicated and characterized by a horst – graben pattern of the Neogene age. The volcanic rocks are Badenian to Pannonian in age (16.5–8.5 Ma).

Key words: Neogene, Vtáčnik Mts., Central Slovakia volcanic field, lava flow, pyroclastic rocks, epiclastic rocks, volcano, volcanic eruptions, lava, ash, bombs

Introduction

The Central Slovakia volcanic field is situated in the inner side of the Carpathian arc. The north-western part of the Central Slovak Neogene volcanic field (Figs. 1 and 2) is mainly represented by a region of the Vtáčnik Mts. (Šimon et al., 1997). The aim of this paper is to present the main volcanological and geological aspects of the region.

Geological structure of volcanics of the Vtáčnik Mts.

Volcanics in this area are resting on a generally levelled and flat surface, built up variably of Mesozoic and Paleogene rocks, indicating erosion and levelling to the end of the Lower Miocene as a consequence of a regional uplift, which preceded the first manifestations of extension and volcanism in the Lower Badenian.

The first manifestations of extension and subsidence in the Lower Badenian were connected with paleogeographical changes, which evoked supply of clastic material from eroded pre-Tertiary formations (Kordíky Formation and the lower part of the Kamenec Formation 500–600 m). Contemporaneously a sea bay penetrated to this area (Lower Badenian marine sediments). In other parts of the region sedimentation was of the fluvial/limnic character.

Almost at the same time also the first andesite volcanism was activated in the Central Slovakia volcanic field (complex of garnet-bearing andesites). It is represented by explosive-effusive volcanism, which produced extrusive domes south of Handlová and near Cígeľ. The products of volcanism of the complex of garnet-bearing andesites were later the source of material for the Kamenec and Kordíky Formations.

Evolution of volcanic activity in the Badenian continued then by formation of large stratovolcanoes of Štiavnica and the Kremnické vrchy Mts. The Štiavnica Stratovolcano (with the centre near Banská Štiavnica) is the product

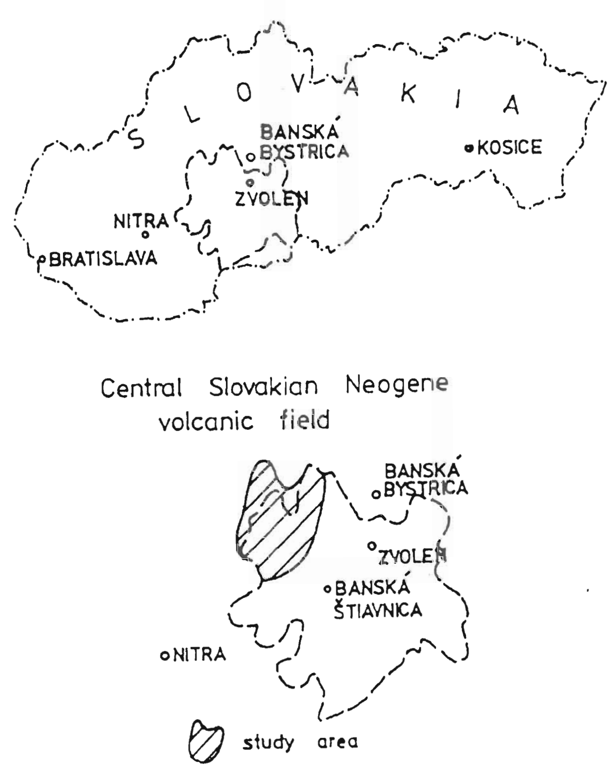
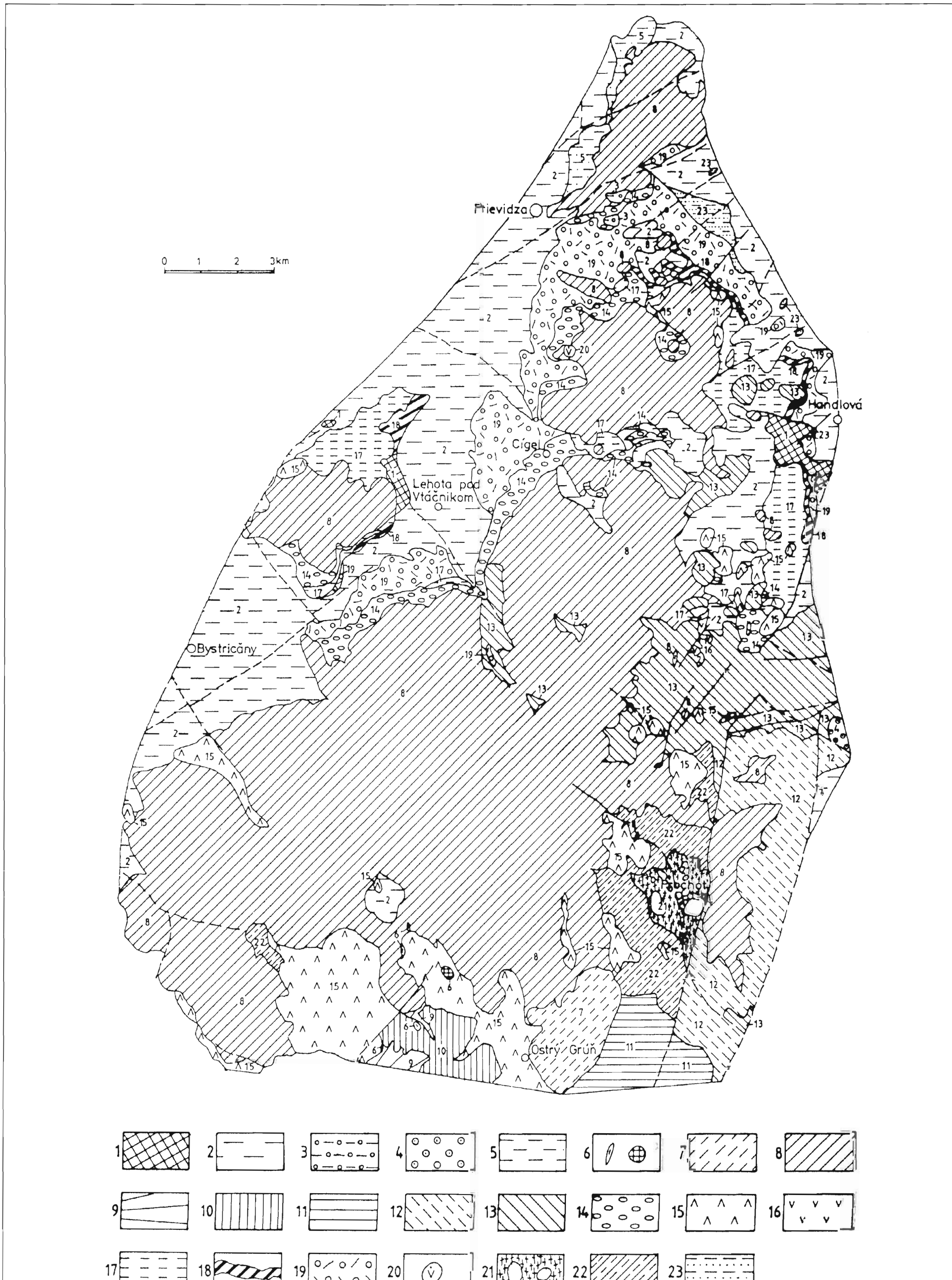


Fig. 1. Location of the study area in the Central Slovak Neogene volcanic field.


0 1 2 3km
Prievidza
Cígel
Lehota pod Vtáčnikom
Bystričany
Handlová
Ostrý Grúň

◀ Fig. 2. Layout of formations and complexes in the Vtáčnik Mts. (Šimon, 2000 complied according to Šimon et al., 1997 Legend: ***Quaternary:*** *Holocene* – 1 – antropogeneous sediments, 2 – Quaternary Unspecified. ***Tertiary:*** *Pliocene: Dacian? Romanian* – 3 – desintegrating conglomerates, gravels and sands, 4 – fluvial blocky sediments of riverine delta. *Miocene. Pontian* – 5 – Lelovce Formation. *Pannonian* – 6 – Ostrovica dykes and neck. *Upper Sarmatian-Pannonian* – 7 – Jastrabá Formation. *Sarmatian* – 8 – Vtáčnik Formation, 9 – Markov vrch Formation, 10 – Žiar Complex, 11 – Upper stratovolcanic structure of the Štiavnica stratovolcano, 12 – Stráň Formation. *Upper Badenian* – 13 – Kľakovská dolina Formation, 14 – Lehota Formation, 15 – Plešina Formation, 16 – Nová Lehota Formation, 17 – Koš Formation, 18 – Handlová and Nováky Formation. *Badenian* – 19 – Kamenec Formation, 20 – Complex of garnet-bearing andesites, 21 – Prochoť intrusive Complex, 22 – Lower structure of Štiavnica Stratovolcano. *Egenburgian* – 23 – Čausa Formation.

of explosive – effusive activity, which reaches the area (SE part of the Vtáčnik Mts.) by the proximal and distal zones with the Prochoť intrusive complex. The Kremnica Stratovolcano (with the centre near Kremnica) reached the area under study by the proximal zone. Mainly at the beginning the volcano was evolving in a subaqueous environment, later in a terrestrial environment.

In the time of the Lower to Upper Badenian the mentioned volcanoes were eroded and we are finding their material in the Kamenec Formation (thickness 300 m) of the Vtáčnik Mts. and Hornonitrianska kotlina depression, where in this time subsidence started, manifested later by the evolution of paludal and lacustrine environment and origin of coal-bearing formations (Handlová, Nováky and Koš Formations).

The subsidence was sporadically accompanied by acid volcanism of extrusive-explosive type, which formed volcanic domes in the area of the Vtáčnik Mts. (Nová Lehota and Plešina Formations).

To the end of the Badenian and in the Lower Sarmatian sudden geological changes were taking place in the region under study. In the area of the Štiavnica volcanic apparatus an extensive caldera formed, which reaches the Vtáčnik Mts. in the southern part.

At the same time a fast subsidence of the Kremnica graben was taking place in the northeastern part of the region. The subsidence was compensated at the beginning by intense effusive and explosive volcanic activity of basaltic, pyroxene and leucocrate andesites of the Kľakovská dolina Formation (thickness up to 600 m) and Turček Formation (in the Kremnické vrchy Mts.), which were developing partly in subaqueous environment.

Later the subsidence was accompanied mostly by effusive activity of amphibole-pyroxene andesites, the Stráň and Kremnický štít Formations (thickness 300–500 m). The subsidence of the graben also evoked paleogeographical changes, which were manifested by erosion in its neighbourhood and by change of rivers flow in direction to the Žiarska kotlina depression, connected with development of fluvial gravels of the Lehota Formation (thickness up to 300 m).

In the Lower Sarmatian volcanic activity of pyroxene andesites was renewed, which formed stratovolcanoes at the marginal fault of the Kremnica graben in the Kľakovská dolina valley and near Remata (Vtáčnik Formation, Remata Formation in the Kremnické vrchy Mts. of thickness 300–600 m). Pyroxene andesites of the 4th stage of the Štiavnica Stratovolcano extend in the southern part of the region.

Younger tectonic movements to the end of the Sarmatian caused rapid erosion of volcanics due to a relative uplift. To the end of the Sarmatian to beginning of the Pannonian extensive rhyolite volcanism of the Jastrabá Formation was activated. With ascent of rhyolite masses a huge fault zone (the Vyhne-Ihráč zone) and marginal faults of the Žiarska kotlina depression were reactivated. In the closing stage of volcanic evolution consolidating block movements with subsidence of partial segments were taking place. As a consequence there was revival of volcanic manifestations. The Ostrovica dykes and necks originated, which are the youngest manifestation of volcanism in the Vtáčnik Mts. (their age is Pannonian).

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Litofacial changes in the products of the Bogota andesite stratovolcano, central part of the Slanské vrchy Mts., Eastern Slovakia

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Abstract

The Products of the Miocene volcanism surface on the NE edge of East Slovakia Neogene Field (ESVF) at the Slanske vrchy Mts. and are represented mainly by andesite polygenetic and monogenetic volcanoes. The central part of the Slanské vrchy Mts. is a dominant by the Bogota stratovolcano. The evolution of this volcano would be characterised by a stratigraphic span mainly from Early Sarmatian to Early Pannonian (13,8 ± 0,5 Ma – 10,3 ± 0,2 Ma), based on radiometric dating. The stratovolcano represents an intricate volcano-sedimentary system, which is typical for the whole range lateral and vertical lithofacia changes, running from volcanoe's center out. The volcano eruption styles include phreatomagmatic, Vulcanian, Plinian and Strombolian one, and further extrusive/efusive activity of lava flows and domes. The central volcanic associations of lithofacies represent mainly subvolcanic intrusive bodies (i.g. laccolith, necks, dykes etc.) and a thin lava flows, fall pyroclastics (s.l.) alongside of the whole range of the secondary volcaniclastics. In the stratovolcano we define the Bogota Formation, the Slan-čík Formation, the Regata Formation and the Nomša Complex. In the range from proximal up to distal associations of lithofacies the change takes place caused mainly by further increase of the whole range of the primary and secondary volcaniclastics, (i.e. hyaloclastics, redeposited pyroclastics, gravity flows, etc.). By an increased distance from its centre, the thick a lava flows occur An initial volcanic activity runs in the Early Sarmatian in a subaqual conditions and was terminated by depositing of the last portions of magma in form of the intrusive bodies of a basaltic andesite composition.

Key words: Eastern Slovakia, Neogene, volcanism, volcano, volcaniclastics, andesite, dacite

Introduction

The andesite volcanoes of central part of the Slanské vrchy Mts. were systematically and comprehensively mapped thruoghout period 80's and evaluated by the beginning of 90's published in print in form of geological maps in 1 : 50 000 scale accompanied by the notes of North and South region of the Slanské vrchy Mts. and Košická kotlina depression (Kaličiak et al., 1991, 1996). The stratovolcano Bogota (Fig. 1) is one of four bigger volcanic structures and by morphology criteria the best preserved volcanic structure (Žec et al., 1990; Žec, 1995, 1998). This article takes in account all obtainable informations and in the same time attempts to characterised selected volcanic formations based on recognition plus to de-scipher the types of each individual eruption activity. This change is responsible for the change in character of each individual volcanic processes and their products.

Geology and tectogenesis of basement

The tectogenesis pre-Tertiary basement had influenced impact of volcano-structural aspects of the Bogota Stratovolcano. The relief of basement is expressively dissrupted having elevation and depression structures. The depth of pre-Tertiary basement in research of western part of the stratovolcano area reaches 2600 m (located by Ďurkov village). The Sečovce deppression, NE area it appears from depth of 4000 to 5000 metres. The older Pre-Neogene rock complexes belongs to many other tectonic units and make this underlayer to re-surface in the Bogota Stratovolcano surrounding where they do not emerge. The sedimentary filler of this basin are made predominantly of the Main Mollase sediments in Eggenburgian-Sarmatian span, and by sediments of Early Mollase (Pannonian--Pliocene) too.

The formation of primary eruption centre (or centres) of the Bogota Stratovolcano did in period of Early Sarmatian. The characteristics of Early Sarmatian environment has been suggested by many authors as being from shallow marine, brackish leading to transition of lacustrinne environment with a presence of delta sediments on its fringes (Vass and Čverčko, 1985; Kováč and Zlinská, 1998). The main tectonic lines of NW-to-SE direction and NE-to-SW even A-to-S direction divide the area to whole range of blocks with different slope angle and differnt vertical level as well supported by evidence obtained during drillings and geophysical research (Tkáč, 1983). From stratigraphic point of spatial expansion and geochemical characteristics, the Bogota Stratovolcano activity belongs to type of volcanic arc from basalt-andesite to andesite volcanism, i. e. sense of Lexa et al. (1993).

Stratovolcano structure and stratigraphic position of the formations

According to the present knowledge, on the base of structural, volcanologic and petrographic data, we devide following formations and complexes within the stratovolcano Bogota (Fig. 2, 3):

1. The Bogota Formation spatially and stratigraphically belongs to the most extensive formations. It comprise up to 90% of the Bogota stratovolcano (the Early Sarmatian-Early Pannonian).
2. The Slančik Formation occurs in the southwestern part of the Bogota stratovolcano - parasitic volcano (the Early-Middle Sarmatian)
3. The Regeta Formation occurs in southwestern part of the Bogota stratovolcano - parasitic volcano (the Early-Middle Sarmatian).
4. The Nomša Complex occurs in the southern part of the Stratovolcano Bogota (the Early-Middle Sarmatian) – besides the discontinuous penetrations of coherent dacite bodies.

The Bogota Formation is the greatest one by the area, which is characterised as a stratovolcano "succession" of basaltic pyroxene andesites, pyroxene andesites and dacites. In the Bogota Formation the spread and representation of each facies and a genetic type of volcanic deposits is not even. The emergence and evolution of the Bogota Formation is as the consequence of explosive-effusive volcanic activity in the subaqual and terrestrial environment as well, which can be characterised by whole range of lithofacies. The association of lithofacies in the central volcanic zone consist of a volcanic cone relict and an inner part of this eroded cone. Each lithofacies comes up to surface in the end of valleys of regions Chlmecký potok creek and Kamenný potok creek, then in the region of the Orechový vrch hill, Poratúnka, Spálený vrch hill with continuation as far as Bogota triangular point. This association contains laccolith intrusive body, dykes, necks and agglomerates, welded fall pyroclastic deposits and thin lava flows. These intrusions are of microdiorite and andesite composition, similar by mineralogy and chemistry to the lavas of volcanic cone of hypersthene-augite andesites, pyroxene andesites and dacites. The character of bodies confirms drilled boreholes from BOG-1, KMV-23 and BOG-2 (in Divinec et al., 1989). The genesis of each particular bodies is connected to dynamics of eruption styles of stratovolcano. Lava effusives represents periclinal deposited thin lava flows with the inclinations up to 30 degrees with unevenly represented autobrecciation. The explosive products represents deposits of agglomerates, volcanic breccias and welded fall deposits created by wide spectrum of pumice and lapily acsending the slopes of a central zone. The substantial part of agglomerate is alteration of coarseblock deposits of andesites between 0.5 to 1.0 metres welded red complection lapilly deposits. The matrix is of ashed substance. Pyroclastic deposits on the slopes of the central volcanic zone represents a change in style of a volcanic activity. That is from Vulcanian type (slopes of the Čertov kameň) to Strombolian type (acsents in the top parts of the Vrchný kameň hill a nd Tereš hill). Besides thin lava flows there in the slope we see acsents of radial direction dykes mainly of andesite composition. The proximal volcanic zone is dominant association of lithofacies with prevailed of block lava flows and lesser contants of pyroclastic fall deposits. By transition to distal volcanic zone the redeposited pyroclastic and epiclastics begins to dominate. Further from centre the characteristic of autobrecciation are on increase in a framework of lava flows. On N and W side of a proximal

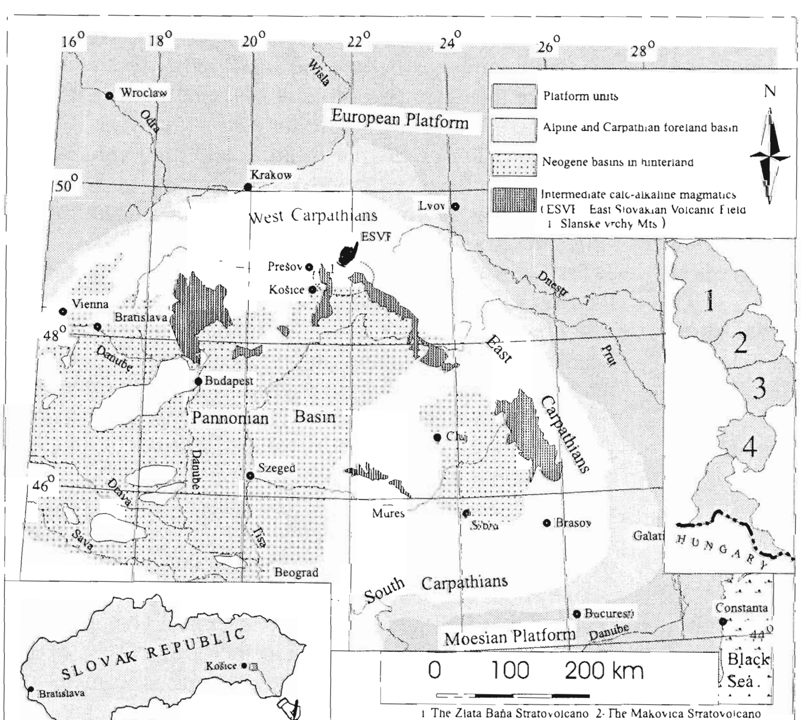


Fig. 1. A sketch of the eastern part of the Allpine–Carpathian–Pannonian are with localization of the Eastern Slovakia Volcanic Field (ESVF) and the Bogota stratovolcano

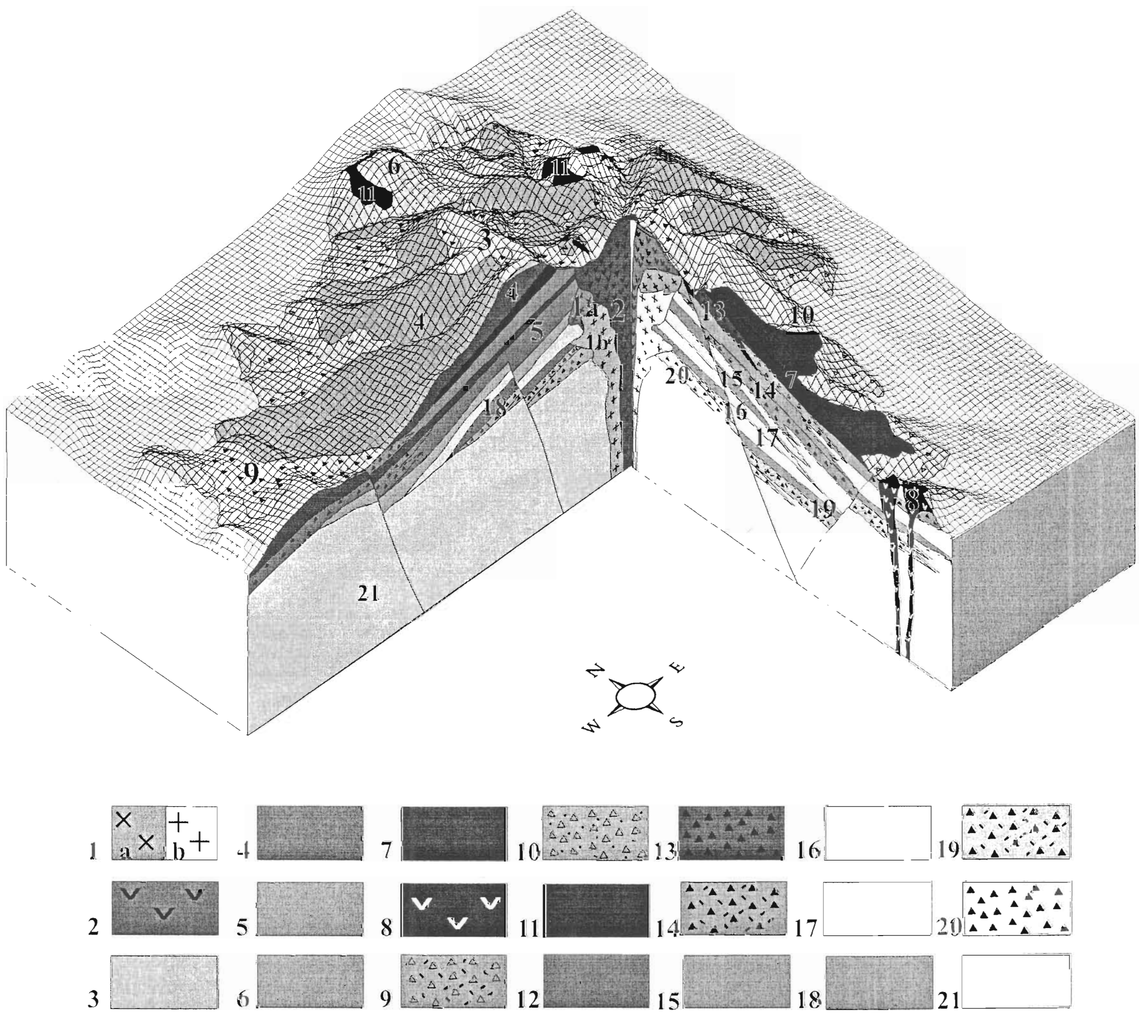
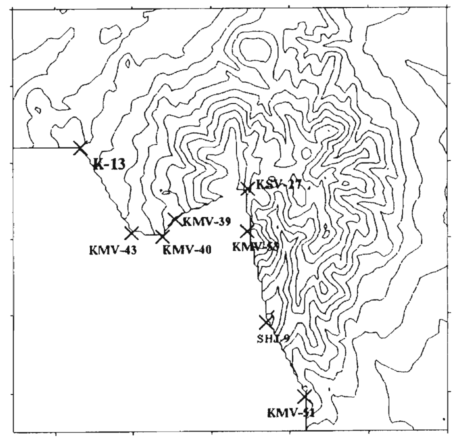
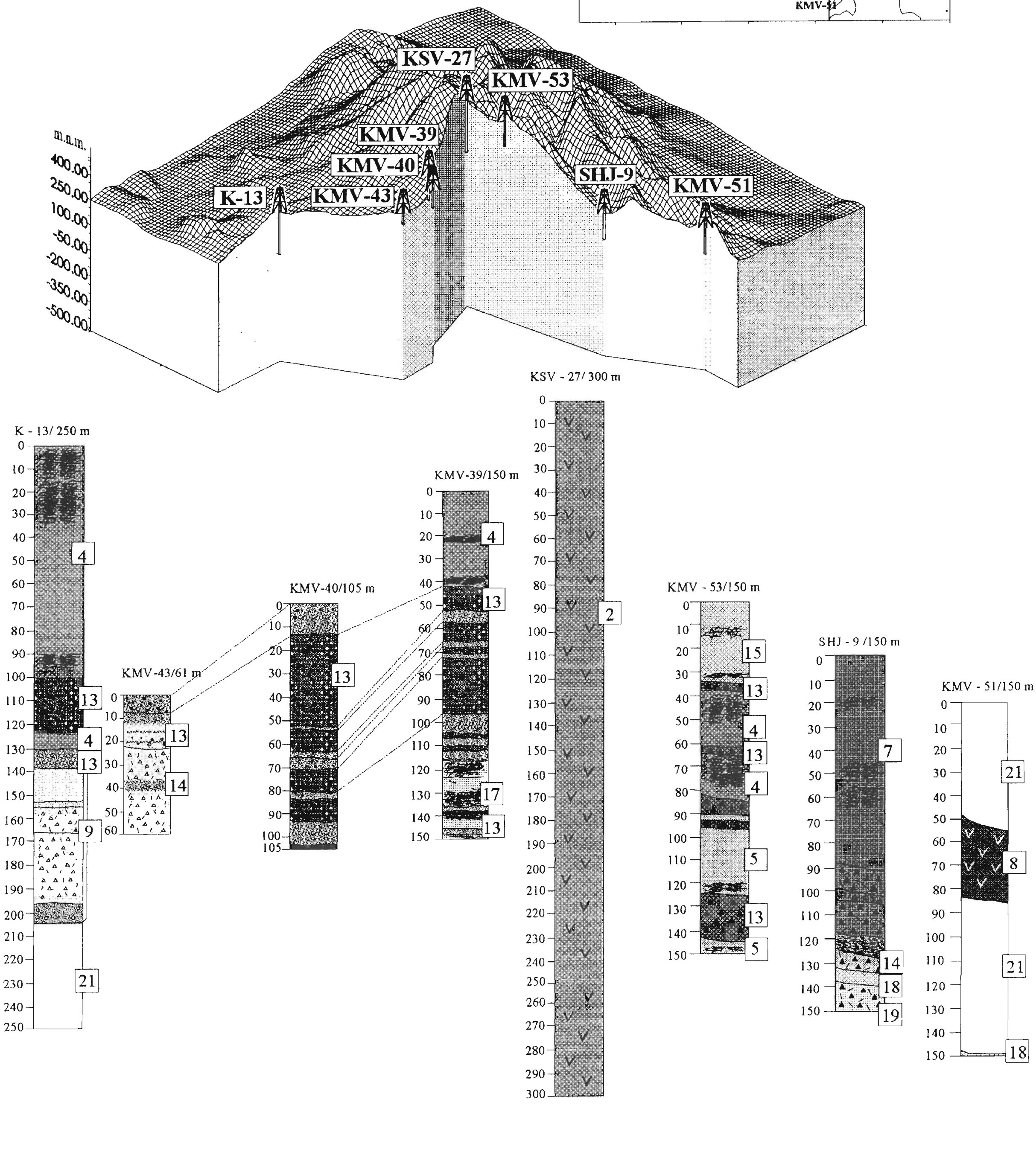


Fig. 2. 3-D model of the stratovolcano Bogota. Explanations: 1 – laccolith (a – diorite porphyre, b – porphyre diorite), 2 – extrusion of augite--hypersthene andesite, 3 – neck of bazaltic augite-hypersthene andesite, 4 – lava flow of pyroxene andesite, 5 – lava flow of basaltic hypersthene--augite andesite, 6 – lava flow of augite-hypersthenee dacite, 7 – lava flow of hypersthene-hornblende dacite, 8 – extrsian (dome) of dacite, 9 – epiclastic breccia (undivided), 10 – epiclastic breccia of pyroxene andesite, 11 – lava flow of hypersthene andesite, 12 – lava flow of augite--hypersthene dacite, 13 – autochtonous pyroclastics, 14 – redeposited pyroclastics, 15 – lava flows of augite-hypersthene andesite, 16 – lava flow of pyroxene-hornblende dacite with biotite, 17 – lava flow of fine-porphyric pyroxene andesite, 18 – lava flow of basalthic andesite, 19 – autochtonous pyroclastics (phreatomagmatic eruption), 20 – redeposited pyroclastics, 21 – clay, claystone, siltstone (the Stretava Formation).

volcanic zone, lava flows of pyroxene andesites dominates. The forefront of the particular lava flows acsents eastwards of Ďurkov and Svinica village, southwards of Košický Klečenov village and nortwards of Zemplínska Teplica village. At the same time they fill up existing paleovalleys. Tha lava flows of pyroxene andesites are accompanied by development of hyaloclastic breccias. Because of a partial tectonic "amputation" of eastern sector of the proximal volcanic zone of the formation and a superimposition by the sediments of the Sečovce Formation (Pannonian age), it is not possible to study in detail the progression of a lava flow on the eastern side of this formation. Besides the lava flows there are present dykes, penetrating basal lithofacies as well and identical in petrographic sense to bordering lavas. Primary fall pyroclastic deposits do contribute on construction of a transition zone, mainly on western and eastern side oh this formation. The important lithoafacies are massive tuff breccias, which were deposited by while spectrum of mechanisms ranging from lahars (in Dehncšov area) to a weaker energetic block flows (in region of the Črepník on western part) plus pyroclastic flows. The distal volcanic zone direction, and chiefly on western and southern side, they ascent to level of redeposited pyroclastics and epiclastic deposits. This formations are typical with irregular alteration of levels of different thickness, grains and classifications. Redeposited pyroclastics are represented by wide spectrum of products as is massive pumice deposits or pumice lapillies up to 1 cm. There are present as well deposits with traces of acretionary lapillies. The presence of

Fig. 3. The selected boreholes in the Bogota Stratovolcano area (explanation – see in Fig. 2).





these lapillies in layer is potential indication of a phreatomagmatic style of eruption seldomly interfingering into deposits of the Bogota Formation those volcanic products of an areal type of volcanism, which is represented region of Dehnešovo, NW from Malé Ozorovce village. Rhyolite pumice flows can reach 0.5 metre thickness, are of great mass and light-white colour. These products is possible to correlate with deposits of Plinian to subplinian volcanic activity of the Tokaj region in Hungary. In the distal zone preserved mainly on SW side of the formation, there is a change of positions of autochtonne and redeposited pyroclastic and epiclastic volcanic deposits. Alteration of positions is irregular having rapid vertical and lateral litological changes. The material deposited in limnic environment in synvolcanic stage of sedimentary formations (The Kochanovce Formation).

As a Slančík Formation we single out volcanic "succession" of basaltic pyroxene andesites emerging on east end of Slančík village. The original form of the volcano (~ 1.5 km sq.) is not preserved in the present. The erosive cut amputated mostly NE and SE part. Only preserved is the central basal part and cone remains with positions of periclinal deposited of autochtonne pyroclastics and hydroclastics. The Slančík Volcano (Formation), is formed of the edge of fault system NW to SE direction and represents a volcanic structure, which evolved in environment of Early-Middle Sarmatian shallow water basin or limnic basins. This formation "lays" on sedimets of Early Sarmatian of the Stretava Formation. The central neck emerges in open quarry, at present dissuted overgrown one, where it is open to massive block jointing pyroxene andesite. The neck area reaches 50x50 metres. The neck breaks through positions of agglomerates and pyroclastic breccias. The NW fringe changes from solid andesite to strongly oxidated autobreccias of rusty-brown colour to red one, and consists of angular fragments of lavas. Based on excavations on NW part of volcano, we guess that a partial flip-over of one of the neck arm took place over the volcaniclastics and consquent change into a lava flow. The position of primary pyroclastics emerging on anticipated base of a volcano, represents a chaotic accumulations of pyroclastic material with no separation attempts, or with seldom indication gradation caused only by local change in the clasts of material. Autochtonne pyroclastics are made by agglomerates are in dominant scale consisted of bombs and juvenile fragments (70–80%). The volume of up to 10–15%, the compositions are made with lithic blocks of andesites. The fragments of juvenile clasts can reach even 3 metres in size. Proportionally, the greater part of autochtonne pyroclastic volume do pyroclastic breccias. The size of breccias varies in average between 20–40 cm. On basis are deposited agglomerates and pyroclastic breccias, which in upper level transform to hydroclastics represented by the finegrain tuffs. The character of volcaniclastics indicates transition from a magmatic to phreatomagmatic volcano activity.

The other form of selection on E and SE edge of the Bogota Stratovolcano are relics of a small monogenetic volcano Regeta (apr. ~ 1 km sq.), which ascends east of Ruskov village, in region called Regeta. The original form of volcano is not preserved. Pyroclastic deposits are formed by positions of phreatomagmatic tuffs (no grades) and agglomerates with the bombs of so called cauliflower impression. The material of agglomerates is made by angular andesite pumice and vesiculate andesite fragments. On the fringes of these fragments are evident traces of a rapid cooling. The ash – alike substance is palagonitized. The andesite neck ascents on the edge of agglomerate deposits (~ 25 metres) and consist of a solid, irregularly separated body of basaltic andesite. The whole sequence of preserved volcaniclastics is clear evidence of a low-energy phreatomagmatic volcano activity.

NW from Zemplínska Teplica village and in the region NE of Roňva potok creek, the region called Nižné Vargovo acsents a Nomša Complex, which contain of extrusive bodies of dacite composition. This is represented irregular penetrating of extrusive bodies, extrusive breccias and hyaloclastite breccias. More widespread is a group of bodies, aprox. three of them or one body in surrounding of triangular point Nomša, where the area reaches approximately 4 km sq. and the thickness is in the range from 30 to 150 metres. The region of Nižné Vargovo has also three bodies is in region of 100 metres. The formation of extrusive bodies run in era of Early-Middle Sarmatian. We can clasified these bodies along side of extrusive domes and also up to endogene extrusive dome, they make a certain transitional type between the extrusive dome and laccolithe. The extrusive form is confirmed by a loaf like form of the body, intensive autometamorphed alteration, a weak argilitization, chloritization, K-metamorhosis and local evolution osteep fluidality. The volcaniclastics representing extrusive breccias are composed of blocks, often of irregular shape, polygonal fragments. Occasionally we can observe the symptomis of autoclastic breccias or from a de-intergrated edge of a body to the hyaloclastics. These bodies are made by dacites and in the most of the cases by block jointing, which seldom transition to pentagonal jointing. The inner body part is made of solid, coherent dacite accompanied by the whole row of autometamorphe changes. By the edge of the bodies the coherent dacite is autobrecciated. An evolution of extrusive bodies took place in the shallow brackish environment. We assume that this took place in the closed water basins or in limnic basins. This is cionfirmed by presence of alterated plants parts in the base of extrusive bodies (drill KMV-51, in Divinec et al., 1989) as well. The bodies that acsented more westwards,i.e. in the region called Nižné Vargovo, were formed on volcaniclastic deposits represented mainly by position od redeposited pyroclastics and epiclastic volcanic sandstones.

Stratigraphic characteristic

Characterization of the Bogota Formation is based on a radiometric dating (K-Ar method) of selected samples and with functioning of a volcanic activity from Early Sarmatian to Early Pannonian (13,8 ± 0,5 Ma – 10,3 ± 0,2 Ma, Žec and Ďurkovičová, 1993). As an outcome of this radiometric dating (13,1 ± 0,4 Ma, Žec and Ďurkovičová, l. c.) the evolution of the Nomša Complex has been supported by biostratigraphic data (Zlinska et al., 1992) taken from sediments acsessing from the Nomša Complex basal layers. The identity of a fauna we categorise these sediments to Early Sarmatian – the Stretava Formation). These sediments were deposited in sublitoral zone in environment of salinity 15–20%. Stratigraphical position of the Regeta Formation and the Slančík Formation we categorise according superposition relations. We talk about the parasitic volcanoes spreading on small area (~ 5 km sq.) Because of superimposition relations with lithofacial members of the Bogota Formation we categorised functioning of their volcano activity to Early Sarmatian – Middle Sarmatian.

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Mineral composition of xenoliths from the Fintice andesite quarry

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Abstract

Compact andesite body in Fintice quarry contains xenoliths of several rock types, even over 30 cm in diameter. Very frequent are the finegrained xenoliths of underlayed sediments. The predominance of plagioclase with pyroxene relates them to older *Neogene* formations. Most relevant to this type of xenoliths are layers of Eggenburgian Čelovce formation. The contact zones between andesite and pelitic xenoliths are narrow, without any obvious changes. Another commonly occuring type of xenolith there are enclaves of magmatic origin, of slightly lower SiO_2 and Na_2O with K_2O contents. The extraordinary one is phlogopitic xenolith, built also of plagioclase and enstatite with random hornblende and spinel (pleonaste). Among suite of secondary zeolithes (chabazite, stilbite...), they are very common along the cracks, the new species heulandite was identified.

Key words: Neogene, andesite, xenoliths, mineral contents, crustal rocks, contact, zeolithes

Village Fintice is situated 7 km to NNE of Prešov. The geological position is on the Sekčov river terrace, built of *Neogene (Karpatian)* and *Quaternary* sediments. To the north they partly cover the volcanic Lysá stráž Formation *(Mid. Sarmatian)*. The expressive group of extrusive domes (to 740 m high) continues from the Fintice area to the east by a ridge of the Kapušany horst. They create the norther-most entity of andesitic bodies, related to semidetached volcanic range of Slanské vrchy Mts., extended to the south behind the Sekčov river valley (Kaličiak et al., 1988, 1991).

Volcanic massifs of the Lysá stráž formation are opened by several rock qarries, all with abundant xenolith occurences. Plenty of xenoliths are in the two Fintice quarries, especially in the upper one, nearly at the top of the prolongued Kapušany horst body. This two-level quarry excavates compact hypersthene–amphibole andesite. Plagioclase (andesine to labradorite) phenocrysts represent 65 % of its volume in cryptocrystaline groundmass. In slightly porfyric structure the portion of dark amphibole (to 7 mm long, 5÷6 %) and orthopyroxene (2÷3 %) crystals is visible. Chemical composition of the Fintice andesite with 62.3 to 65.5 SiO_2 % tends to dacite (Slavkovský, 1977; Kaličiak et al., 1991).

Compact andesite confine mostly xenoliths of sedimentary rocks (even over 30 cm long), quite common there are magmatic enclaves. The frequent xenoliths of underlaying sediments belong to *Neogene* formations, or to *Paleogene* flysh sediments of mostly finegrained texture. Andesite here overlays directly thick *Karpatian* layers, above by *Eggenburgian* ones. The whole sequence of *Neogene* sediments we can estimate (from geophysical map, Šefara et al., 1987) approximatelly to thickness about 0.7 km. The extraordinary one there is micaceous xenolith FHX1, we suppose that it belongs to deeper basement.

Xenoliths of finegrained sediments

Samples of large pelitic fragments are represent by the *FX2* type xenolith, very compact with sharp-edged margins. Typical colour of almost homogeneous xenoliths is light-gray, sometimes with darker concentric zones. Their mineral composition was identified by X-ray analysis and the thin section microscopy. Finegrained plagioclase, pyroxene and quartz are distinguishable only in thin section. The xenolith also comprise about 5 vol. % of apparently larger (0.1÷0.2 mm), dissaminated opaque mineral of irregular shape. From rock powder diffraction analysis we can suppose it is magnetite. Rarely, a clay-mica intergranullar fillings, radial agregates of zeolithe and black dendritic pots are present too. The chemical composition of FX2 type xenoliths (Fig. 1) xenoliths exhibit remarkable contents of 14.5 % CaO and 20.9 % Al_2O_3. Similar xenoliths of sedimentary rocks (sample FX7) are silty, of slightly coarser grain (-0.2 mm). Among these xenoliths colour varies from gray-green, pinky up to ochree shades. The pinky colour is the result of red-brown mica dissamination; the grayish parts contain dark-gray metalic microinclusions (0.1÷0.3 mm). The coarser grains (up to 1 mm), identified as quartz, fill some thin veinlets. The contact zone between andesite and xenolith is very narrow – about 1 mm, without any obvious changes in endocontact or exocontact belt.

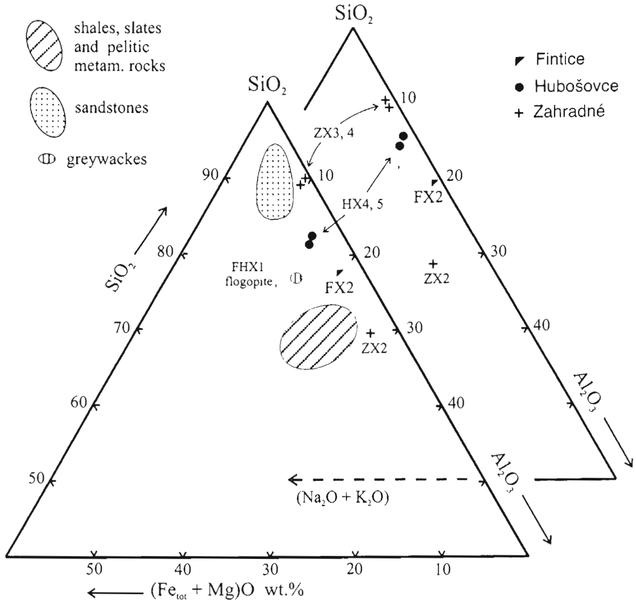

Fig. 1. The bulk rock composition of some sedimentary rocks xenoliths from the Lysá stráž Formation andesites.

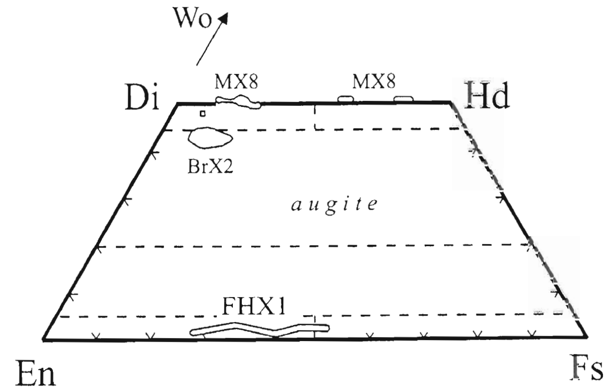

Fig. 2. Composition of pyroxenes from the sample FHX1 in comparison with two xenoliths from Brestov and Maglovec.

Pelitic xenoliths derived from underlaying sedimentary rocks are the most frequent in all the Lysá Stráž Formation andesite bodies (Fig. 1). The predominance of plagioclase with pyroxene is the essential feature, relating them to older *Neogene* formations. In accordance with the basic composition, no broader reaction rim of contact metamorphism products surrounds them. Dry calc-alkaline andesitic magma crystallizes without releasing of larger quantities of volatiles and also xenoliths did not have sufficient residence time in the moving magma for recrystalization or melting. Fragments of pelitic sediments can belong to three formations: the *Karpathian* Teriakovce Formation, built of greenish to gray siltstones to claystones; the deeper but similar is the second one – *Eggenburgian* Čelovce Formation, represented predominantly by pale-gray siltstones to fine-grained sandstones. Most relevant to the FX2 type xenoliths is layer of clayey and micaceous siltstones, slightly calcareous with ~10 % $CaCO_3$, interbeded with some variegated colourfull claystones. The third layer of possible protholite (of FX7) come from widespread Zuberec Formation *(Paleogene)*, which prevailingly extends in the area between Slanské vrchy Mts. and Klippen Belt at the NE. These are typical flysh sandstones of blue-grayish to gray-brown colours, with siltstones and claystones (Karoli and Molnár, in Kaličiak et al., 1991).

Phlogopite and spinel bearing xenolith

Among all crustal xenoliths the only is sample *FHX1*, with micaceous assemblage. Brown vesiculated xenolith is heterogenous, about 20 cm in diameter. In comparison with biotitic xenoliths from Maglovec and Brestov, this type contain more plagioclase. Minerals were identified by X-ray diffraction analysis of separated minerals and with microprobe analyses. Except for common plagioclase and phlogopite, the ortopyroxene with less abundant amphibole, spinel, ilmenite, apatite and zircon were proved. Phlogopite crystals (about 2–3 mm) are fresh, lustrous, with little extent of alteration visible along cracks. Dissaminated dark-violet spinel grains was determined by X-ray analysis. Small radiating agregates of younger epistilbite, penetrated with rhomboedric crystals of chabazite, fill some xenolith cavities. The contact with andezite represents a thin brownish zone of mostly plagioclase composition with phlogopite and zeolitization. The surrounding andezite endozone is porphyric with pyroxene and amphibole crystals.

The chemical composition of the xenolith's minerals was measured by electron microprobe Jeol 6310. Among them the most common are *plagioclase* grains. They show the scope of heterovalent Na ↔ Ca substitution of Ab vs. An molecules between the range of following chemical formulas:

from $Na_{0.394} K_{0.011}Ca_{0.592})Al_{1.542}Si_{2.442}O_8$ to $(Na_{0.019}K_{0.000}Ca_{0.989})Al_{1.943}Si_{2.044}O_8$

With one exception, where plagioclase is much acidic, all are of the *labradorite* to *anorthite* composition. The profile across a 2 mm plagioclase grain reffers to lovering of An component from the core to rim, followed by increasing of albitic one.

Acording to microprobe analyses ortopyroxenes do not contain Ca and after Morimoto's clasification (1988) all are *enstatites*. The composition of measured grains forms a bottom field in Di-Hd-En-Fs diagramme (Fig. 2). By the formerly used pyroxene nomenclature they are equal mostly to hypersthene. Similarly as plagioclase, enstatite also show signs of zoning – core contain more Mg against rim with higher content of Fe.

Relatively scarce mineral there is amphibole. In accord with Leake (1978) formula $A_{0-1}\,B_2\,C_5\,T_8O_{22}\,W_2$, calculated classification criteria $(Ca+Na)_B = 2.00 > 1.34$; and $Na_B < 0.67$ allow to consider it as Ca-amphibole. By its atomic Si contents close to 6.50; and the ratio $Mg/(Mg+Fe^{2+}) = 0.754$ or 0.813, analysed amphibole was determined as *ferri-magnesio hornblende*.

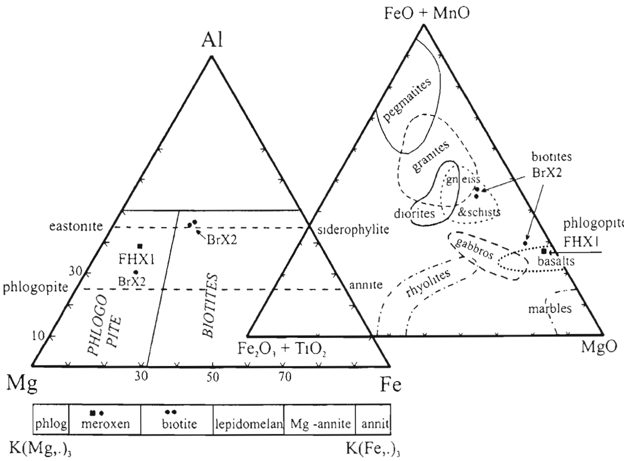

Fig. 3. The ternary diagrams Mg-Fe-Al (by Szabo and Taylor, 1994) and FeO+TiO_2-MgO-FeO+MnO of phlogopite from the FHX1 xenolith, both with respect to biotites bearing xenolith from Brestov

Another minerals in the FHX1 xenolith there are spinel, flogopite and random ilmenite with compositional variation to Ti-hematite. The chemical formulas of spinel and phlogopite are:

$(Mg_{3.526}Fe_{4.408}Mn_{0.035})_{7.97}(Al_{15.607}Fe_{0.303})_{15.91}O_{32}$ – spinel
$(K_{1.718}Na_{0.166}Ca_{0.024})(Mg_{4.214}Fe_{0.942})Ti_{0.115}Al_{2.683}[Si_{5.812}O_{20}](OH)_2$ – phlogopite

From the significant substitution of Fe^{2+} for Mg^{2+} in the spinel structure we can consider it for *pleonaste* member. Its composition is quite far off spinels in xenolithes of mantle origin. The *phlogopite* composition shows Fig. 3. Its identity confirms 81.73 % share of Mg, in oposite to iron in Y^{2+} position, although it has excessive Al portion apart of T_8. We suppose this flogopite (and also the plagioclase) to be original, inherited from the protholite of this micaceous sample. The effect of magma was not high enough for a complete breakdown of phlogopite, although pleonaste and ilmenite are probable products of it.

Xenoliths of hornfelses

The darker *FX4* type xenolith is of elongate shape, slightly stripped, with homogeneous grains (~ 0.3 mm). The colour is variable, with keen rusty shades in the core-belt and dark-brown margin. X-ray analysis revealed that it is formed mostly of *clinopyroxene* with *plagioclase*. The angular positions of diffractive lines shows, that brown--green pyroxene is close to Fe-diopside. Additionally, medium-grained (0.5÷1 mm) quartz is present – in cracks also as chalcedony. Two distinguished zones in xenolith, exposed by X-rays are of simillar composition. Dark-brown margin differs by higher content of plagioclase at the expense of pyroxene, in accordance with influence of surrounding andesite magma. Keen rusty belt is hereby affected by zeolitisation (secondary chabazite) and carbonisation (calcite was proved). The contact is concealed by limonite, locally with inner yellowish-white rim, built of quartz, zeolithe and rare flattened grains of rosy garnets up to 2 x 1 mm in diameter. Despite of comprising quartz grains, chemical composition of the xenolith is rather basic (SiO_2 = 56.8 %); the sample has strikingly higher contents of CaO (20.86 %) and FeO (5.74 %). A similar *FX5* xenolith is of the same origin. It is relatively homogeneous, dark-brown or black, with slightly greenish, paler exocontact zone. Porphyroclasts are absent; the dark gray matrix is formed by graines of pyroxene with light-coloured plagioclase (?) at intergranular position. Between the andesite and xenolith there is a hardly visible rosy contact belt. Both samples are supposed to be altered contact pyroxene hornfelses.

Xenoliths of magmatic origin

This type of xenoliths are of coarser structure (0,X mm), if compared with sedimentary ones. Xenoliths are of brownish colour (type *FX1*), though predominantly built of white to glassy plagioclase. Colouring comes from a dissaminated clay alteration product, with accessory dark mica confirmed by X-ray pattern. Xenolith also contain minor amounts of *montmorillonite*, rarely quartz, biotite and hematite. Thin section of confined rock fragment reveal the uniform size of euhedral plagioclase phenocrysts (0.25÷0.5 mm) as opposite to andesite groundmass with graines 10 times smaller. But xenolith's plagioclases are 1/4 or 1/3 of the size of large plagioclase phenocrysts, comming from andesite. Intergranular space is filled by yellowish-brown clay matrix, with rare oval quartz grains (0.15÷0.2 mm). The sharp contact comprises only a thin reaction rim –not over 1 mm thick. The bulk composition of the FX1-type magmatic enclaves is more basic, comparing to host andesite. The FX1-xenolith contain lower SiO_2 (56.8 %), also the Na_2O and K_2O contents are lower (0.66 % respectivelly 0.40 %). The higher Ca and Al contents are a conseqence of more basic plagioclase. The structure and composition of the FX1 similar xenoliths resemble to altered chamber cumulates, contamined with little portion of surrounding rocks material.

The *FX6* sample bears some resemblance to the described xenolith, with some striated to brecciated structural coherence to andesite. This dark-gray zone in andesite is sharply bordered, with transient line not over 1 mm. Dark matrix contains porphyroclasts of pyroxene and also light-coloured altered phenocrysts, filled with yellow unidentified (sulphate?) phase. According to X-ray diffraction analysis this dark zone is formed predominantly by plagioclase with quartz as a consequence of intense silicification. The gray to black colour is due to disseminated *marcasite* alteration. This sample is not a typical xenolith, but only andesite from tectonic zone, enriched with quartz and marcasite. The probable source of marcasite were some younger (postvolcanic) luquids enriched in sulphuric fluids.

Postvolcanic zeolithe mineralization

Both Fintice quarries are well known for postvolcanic *zeolithe* occurence. Zeolithe minerals were found not only along cracks, but with calcite in some brecciated xenoliths too. Crystal drusy of stilbite with chabazite frequently cover surfaces of cracks. Rarely mesolite, epistilbite and garronite were described (Ďuďa et al., 1981; Koděra et al., 1990). Secondary zeolithes were analysed by X-ray diffraction analysis. Apart of easily distinguishable rhomboedric crystals of chabazite, ball-like agregates of stilbite and mesolite, the brand new zeolithe was determined. It forms glassy to yellowish rhomboedric like crystal ovegrowths. The new species was identified as *heulandite* in assemblage with Na-stilbite and brown epistilbite balls. In succesion heulandite and stilbite are the youngest. Their composition follows decreasing concentration of solutions, which influence the Si content in zeolithes too. Succession from the oldest mesolite to heulandite is followed by an increase of bonded molecular H_2O in the structure. Chemical composition indicates, that they formed at temperatures below 400 °C (Deer et al., 1987), with the higher presence of $Na^+ \pm Ca^{2+}$ ions and relatively low Al^{3+}– Si^{4+} substitution, coming into SiO_4 tetrahedra in hot hydrous solutions.

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Volcanic structure of the youngest volcano in the Western Carpathians – the Pútikov vŕšok volcano

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Abstract

The volcanic activity of the volcano is the youngest of its kind in the Western Carpathians. The volcano was formed during the Pleistocene (Late Riss), this time span having been inferred from a detailed lithostratigraphy of Quaternary sediments, overlapped by lava flows of the volcano. The volcanic rocks have been classified as alkali basalts and/or nepheline basanites.

Key words: Quaternary volcano, lava flow, pyroclastic rocks, volcanic eruptions, ash, bombs, alkali basalts, nepheline basanites

Introduction

The Pútikov vŕšok volcano (Fig. 1a, b) is a discrete space- and time-bound volcanic body (see geological map) situated in the Central Slovakia volcanic region. It is, in fact, the youngest volcanic feature in the Western Carpathians and if it was not for the volcanoes of the southern end of the Hargita Mts. in Romania it would be the youngest in the whole Carpatian-Pannonian region. This paper describes character of volcanism, lithologic features and origin of volcanic rocks.

Volcanic structure of the Pútikov vŕšok volcano

As an independent space-and time-bound volcano, composed of a succesion of lava flows and pyroclastic rocks, the Pútikov vŕšok volcano marks the latest volcanic activity in the Western Carpathians spanning the time between 140 000–130 000 years ago (Late Riss, Pleistocene stage) (Šimon et al., 1996).

The volcano is made of 2 lithogenetic types of volcanic rocks, represented by : 1) lava flows and 2) pyroclastic rocks. Lava flows have variable lengths and thicknesses ranging from short, through medium long to very long.

The longest flows encroach as far as the area of Brehy village, with total lenght of up to 3.2 km and maximum thickness of 15 m. Individual flows of variable thickness and length overlap and/or intermingle with each other, making the distinction of individual lobes, or counting precisely their numbers, impossible.

The main flows are emplaced in a fan, from which the side lava lobes branch out to make, what we call, the lava plateau sequence. The entire mass of the lava flows extends over the area of roughly 4 sq.km. It fills some 500 m wide valley located below the cinder cone and overlies Quaternary deposits in the valley, which opens downwards to form a plateau measuring 1.5 km across.

Pyroclastic rocks of the volcano developed in a process of explosive eruptions. The cinder cone, situated in the central zone and composed of fallen pyroclastics, has been piled up during the early Vulcanian type and later Strombolian and Hawaiian type eruptions. The deposites cinder cone is made of non-consolidated to welded pyroclastic rocks.

Recent works at the western edge of the quarry Brehy-Nová Baňa exposed phreatomagmatic pyroclastic rocks overlying the lava flows. These pyroclastic rocks might be interpreted as secondary cones (pseudocraters) which formed where lava flows entered into the paleo-Hron river.

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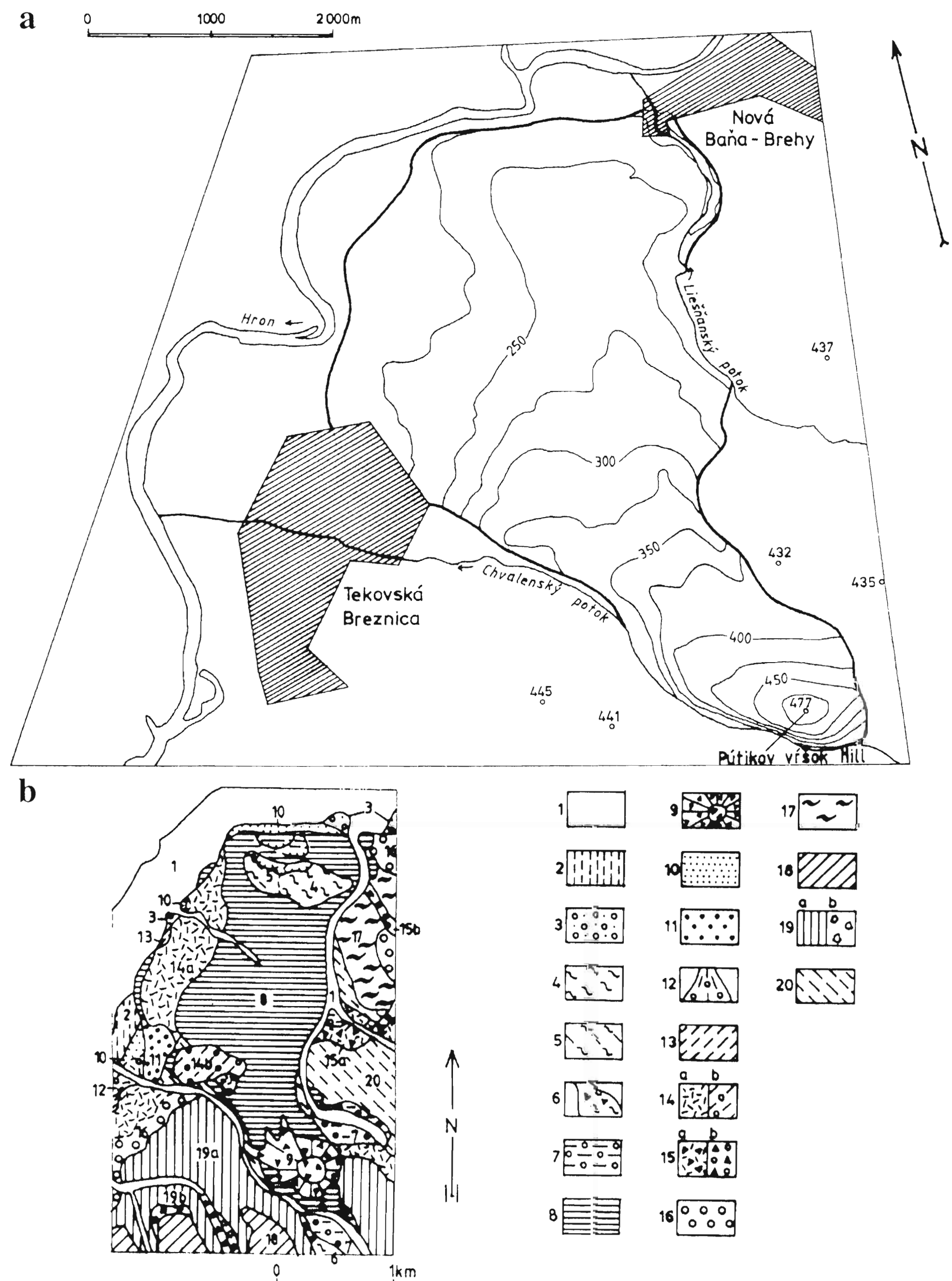

Fig. 1. a – Morphology of the Pútikov vŕšok volcano between Nová Baňa-Brehy, Tekovská Breznica and Pútikov vŕšok Hill (477 m) (Šimon, 2000). b – Geological map of the Pútikov vŕšok volcano (Šimon and Halouzka, 2000). Legend: ***Quaternary:*** *Holocene* – 1 – fluvial, flood plain, mostly loams and sandy loams. *Pleistocene* – Würm(Vislan), 2 – fluvial loams, 3 – fluvial sandy gravels (of bottom accumulation), 4 – eolian (subaeric) calcareous loesses (Pleistocene, unspecified, or Würm). -5- eolian-deluvial, calcareous loess loams and their series. -6- periglacial soliflu-ction-scree-stony flow (mostly basalt fragments in Tekovská Breznica). *Riss/Würm-Würm* – 7 – fluvial-limnic loamy sands and gravels (series in Tekovská Breznica). *Late Riss-base Riss/Würm - the Pútikov vŕšok volcano* – 8 – nepheline basanite lava flows, 9 – cinder cone pyroclastics. *Late Riss (Vartan)* – 10 – fluvial sandy gravels (3rd middle terrace accumulation). *Early Riss (Saale s. s., Drent)* – 11 – fluvial sandy gravels and gravels (the 2nd , i.e. the main middle terrace accumulation) with younger outwash cover, 12 – proluvial loamy gravels with rock fragments (alluvial fan). *Quaternary, Unspecified* – 13 – deluvial-fluvial outwash (run-off) loams, sandy loams, 14 – deluvial sediments-polygenetic: a) slope loams, b) slope, loamy gravels (resedimented), 15 – deluvial sediments-a) screes, mostly loamy-stony and stony, b) stony-gravely screes. ***Tertiary:*** *Pannonian-Pontian* – 16 – coarse to blocky conglomerates, mostly with rhyolitic material (fluvial sadiments within paleovalley fills). **Štiavnica Stratovolcano:** *Sarmatian* – 17 – Drastvice Formation - welded pumice flows, 18 – Sitno Complex- lava flows of the amphibole-pyroxene andesite. *Early to Late Badenian* – 19 – a) lava flows of the unspecified pyroxene andesite, b) epiclastic volcanic breccias-conglomerates (coarse to blocky), 20 – unspecified pyroxene andesite.

Effects of volcanism on coal beds in the Upper Nitra Basin

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Abstract

Approximately 70 % of coal and lignite consumed in Slovakia comes from the region of the Upper Nitra Basin. The kaustobiolite reserves occur in Neogene formation, their exploitation being carried out in the Cígeľ, Handlová, and Nováky mines. Their present geological position is a result of volcanic acitivity in the Vtáčnik mountains.

Key words: Upper Nitra Basin, coal beds, volcanism, structure

Introduction

The Upper Nitra Basin represents one of the major fuel – power centres in Slovakia, spreading over the Prievidza district in the county of Trenčín. The deposits of kaustobiolites – brown coal and lignite, represent a substantial potential source of raw material. The kaustobiolites orrespond to medium quality sapropel coal of ortho to metaphase coalification. The brown coal is to be found in the locality of the Handlová deposit (average thickness 4–11 m), and lignite in the deposit of Nováky (6–10 m).

The first observations about the occurrence of coal here, are dated from 1825. Exploitation attempts began in 1860, but it wasn't until 1912 that prospecting and mining activities commenced. The real exploitation boom however, did not come until after 1945, with exploitation work currently experiencing a period of stagnation. The area of the valley belongs to the complex of inland basins of the Western Carpathian mountains. The north-east and west boundaries of the basin are represented by the crystalline and Mesozoic complexes of the Žiar and Strážov mountain ranges. To the south, the basin ends in the mountain range of Tribeč, the neogene volcanites of the Vtáčnik mountains, and by part of the Kremnica mountains (Fig. 1. BC – CIGEĽ MINE, BH- HANDLOVÁ MINE, BN- NOVÁKY MINE).

Geological structure of wider surrouding

The oldest rocks in the area are represented by Hercynian granites and crystalline schists, which form the peripheral parts of the basin, with presumed development also in the deep substratum of the valley. The Mesozoic is represented by limestone and dolomite strata of the Krížna and Choč nappe. In the basin, the Choč nappe comprises the pre-tertiary substratum. Paleogene rocks are discordantly settled over the basement in the whole area of the basin. Neogene is represented by sedimentary and volcanic complexes – a varied representation of strata from marine, lagoon, terrestrial and volcanic developments. The youngest layers are post-Tertiary sediments represented by alluvial deposits, taluses, andesite breccia, gravels, and clays.

Formation of coal deposits

Fundamental development of the coal basins started during the lower Badenian. It was in such an environment that a massive complex of epiclastic strata settled, originating from destruction of Badenian bedded volcanoes in the southern part of the basin. The developing fluvial and lacustrine environment created favourable conditions for the origination of rich vegetation, which gave rise to development of the individual coal deposits. Metamorphosis of the layers of vegetation led to the creation of productive coal strata. In the consequent period of basin development sedimentary processes formed grey illite clay (Koš strata). Erosion led to denudation of these strata extending as far as the footwal (kamenské complex), together with coal seams. As a result of such denudation, two individual coal "basins" were formed – the Handlová and the Nováky basins.

Tectonic structure of the coal basins

The current tectonic situation on the coal deposits reflects the volcano-tectonic activity of the whole area. Fig. 2 shows the main tectonic depressions at the surface of the basin, and tectonic breaks in the coal seams.

The tectonic structure of the Handlová coal deposit developed in several stages. Normal faults were generated as a result of dynamic activity of the strata upon subsidence

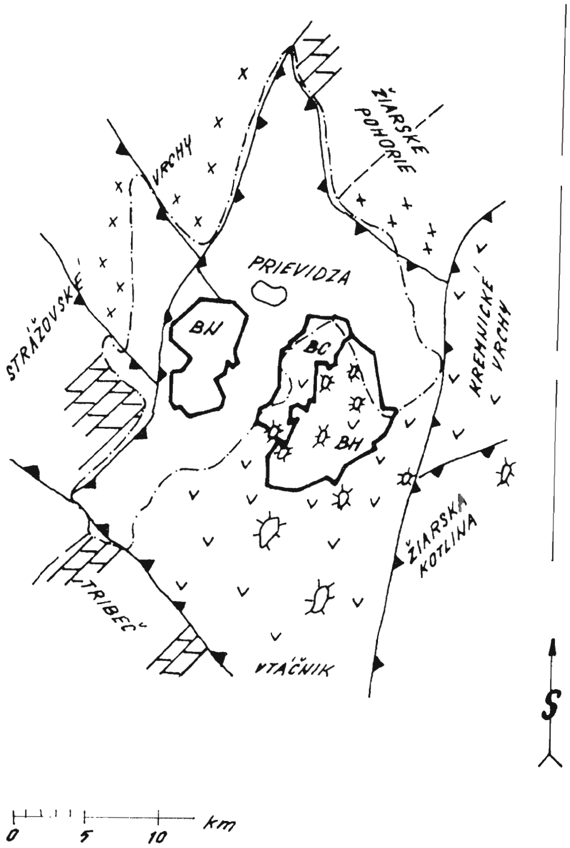

Fig. 1. Geological scheme of the Upper Nitra Basin.

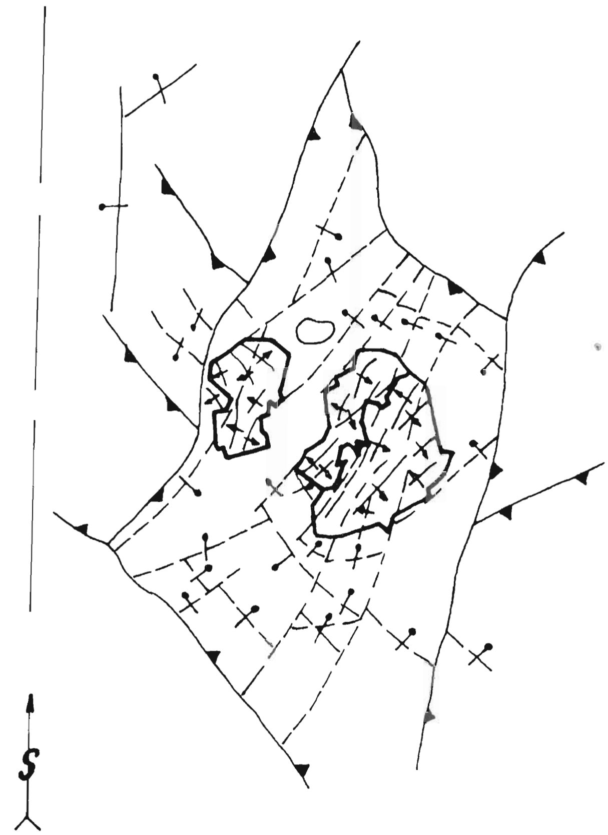

Fig. 2. Structural scheme of the Upper Nitra Basin.

movements of a part of the mountain massif. At certain levels of the deposit, under the influence of volcanic activities, individual parts of the deposit became raised. Separate part of tectonic dislocations is represented by reverse faults in the northern and southern sections of the Cigeľ deposit. Here, magma was actively flowing into the productive strata, while the tangential element of pressure vector caused the overthrust of individual layers.

Development of normal faults in the Nováky deposit also went through several stages. The first stage reflects volcanic activities from the southern part of the basin, with these giving rise to dislocations in the NE–SW direction. The second stage of displacement developed after sedimentation of overburden layers, due to movements of older mountains in the north-west section of the basin. These orogenetic movements resulted in a displacement of strata in the northern part of the given locality, developing dislocation zones in the NW–SE direction, also in the coal seams.

Due to the systems of tectonic dislocations in question, both coal deposits are divided into longer independent blocks, where exploitation mining work is being carried out using various technologies.

Aftermath of volcanism in coal mining

The consequences of volcanic activity are clearly visible when performing direct mining activities underground. In the Cigeľ Mine, there are clear faults dislocating the whole productive strata in a NE–SW direction. Mine workings have exposed smaller apophyses of pyroxenic-andesite in the coal seam and in the subjacent strata. Intrusion of a volcanic body into the productive strata complex led to a discordant rearrangement of the coal layers by 90–120° degrees compared to their original position. The width of this body may be in the range of 15–20 m. In the southern part of the mining area (MA), the coal seam and footwall strata thin out on the andesite body. In this case, it concerns a discharge funnel of magma that extruded on the overlying Koš Formation, and which was later covered by sediments and lava flows (Fig. 3). The surface area of this lava body may be as much as 3–4 km^2. Mine workings in the northern part of Handlová Mine verified a neck of basaltic andesite of 50–200 m thickness. In the subjacent strata in the vicinity of distinct dislocations, increased mineralisation was found.

Mine workings detected significant changes in the faults of the Nováky deposit compared to the general direction of the Handlová deposit.

The coal seams contain tuffaeeous and clay bands, which reduce the quality of mined coal. Development of such barren bands is ascribed to sedimentary and volcanic activity during sedimentation of the coal producing layers. The deree of metamorphosis of the coal mass was higher in the Handlová deposit. In a north-west to westerly direction, the quality of coal seams decreases.

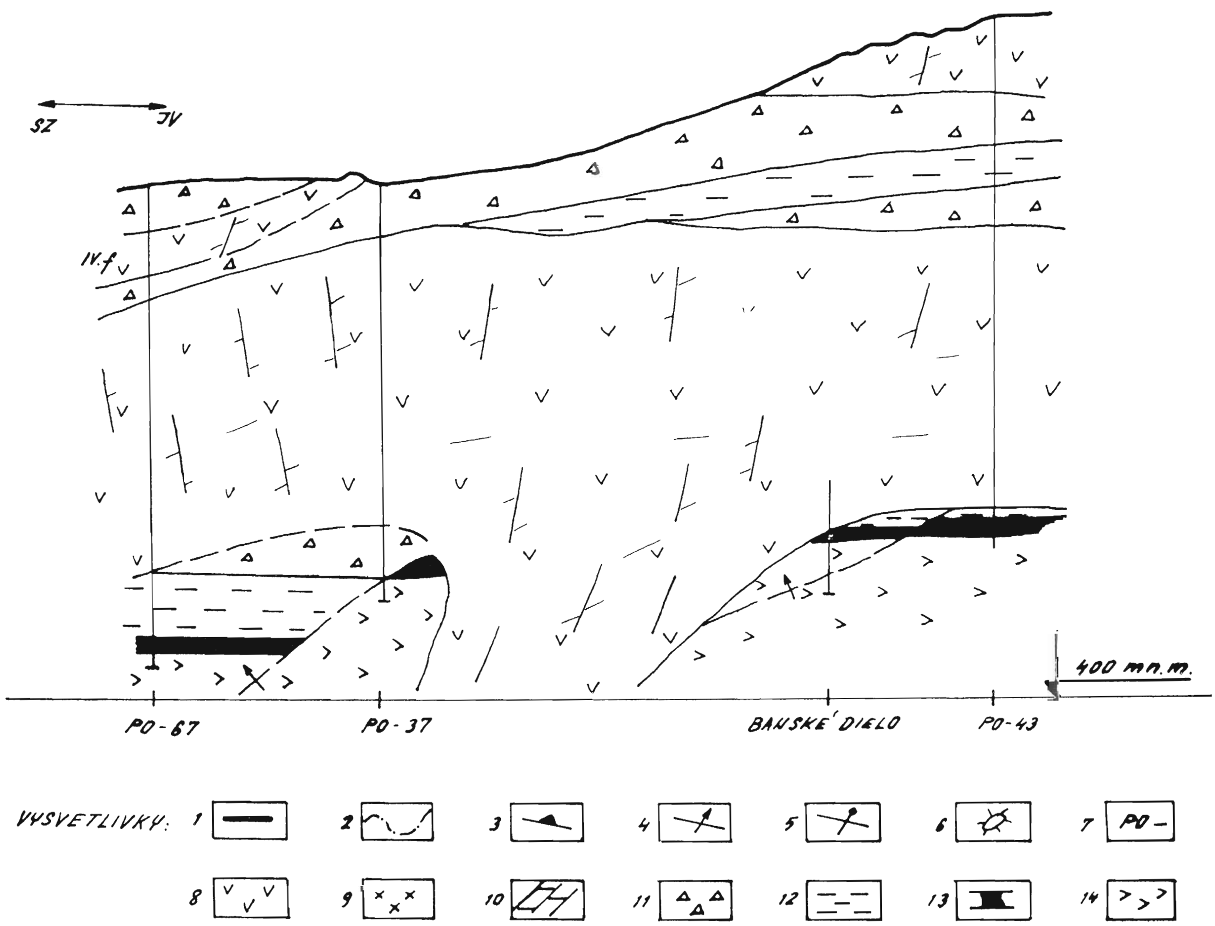

Fig. 3. Section at the southern part of the Cígel' deposit. 1 – mining area of mining plants, 2 – Upper Nitra Basin boundary, 3 – main tectonic-geological lines, 4 – dislocations in productive strata, 5 – dislocations on the surface, 6 – volcanic centres, 7- surface well, 8 – Neogene volcanic rock, 9 – Hercynian basement, 10 – Mesozoic rocks, 11 – andesite breccia, 12 – clays, 13 – coal seam, 14 – subjacent tuffite.

Volcanic activity in the Vtáčnik mountains significantly affected the morphological development of the whole locality. The mountain range has a typical destructive volcanic relief. The volcanic complex has gradually disintegrated and moved gravitationally. Also as a result of these activities, landslides occur on the mountain slopes in individual areas, involving also a reactivation of older tectonic lines in the NE–SW direction. Exploitation of the coal deposits is influenced by gravitational-tectonic activity going on in the mountain massif. With regard to mining work, this results in premature deformations of mine workings, abrupt irruptions of rocks, disintegration of individual fields, and in making reconstruction work on the surface more difficult. All these factors have a negative impact on the mining economy. Systematic mining and research activities provide us with new knowledge however, and on that basis we then carry out mining activities even under such conditions.

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Isotope Rb-Sr and K-Ar time constraints for activity of epithermal fluid-magmatic systems: Banská Štiavnica and Kremnica case

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Abstract

The results of K-Ar and Rb-Sr datings of illites from hydrothermally altered zones, such as those observed in most epithermal fluid-magmatic systems in the Banská Štiavnica and Kremnica stratovolcanoes are reported for the first time. They bring a new information on the time interval of the hydrothermal mineralization. The main stages took place between 12.8±0.6–11.0±0.6 Ma in all important ore districts within the Banská Štiavnica and Kremnica stratovolcanoes.

Key words: Slovakia, Banská Štiavnica, Kremnica, stratovolcano, illite, fluid-magmatic system, epithermal, isotope age

Introduction

One of the basic questions in the problem of the origin of epithermal fluid-magmatic systems (EFMS) consists in the determination of its time parameters: age, relationship of hydrothermal and magmatic activity and duration of ore forming processes. The Banská Štiavnica and the Kremnica represent typical, well-studied world class Au-Ag deposits. This deposits related with like named Neogene stratovolcanos and were generated is response to activity of EFMS. This is why the Banská Štiavnica and the Kremnica isotope geochronological study is a common importance for a progress in EFMS genetic models as well as for EFMS productivity.

In previous works (Bagdasaryan et al., 1968; Konečný et al., 1969; Štohl, 1976; Repčok, 1981; Burian et al., 1985; etc.) isotope dating was done exclusively for magmatic rocks of the Banská Štiavnica-Kremnica ore district. In doing this the K-Ar and fission track methods were used. According these data the evolutionary scheme of the magmatic complexes (Burian et al., 1985; Lexa et al., 1998) includes 5 stages which occurs in the range from 16–17 Ma (1th stage) to 11–12 Ma ago (5th stage). The ore mineralization have not been dated by isotope methods in above cited works. The first data were obtained last time for the Terezia vein in the Banská Štiavnica (Chernyshev et al., 1995) and some vein systems in the Hodruša (Rozália mine) and the Kremnica (Kraus et al., 1999).

The complete bulk of original geochronological data obtained by authors of the present paper with K-Ar and Rb-Sr methods for the Banská Štiavnica and the Kremnica EFMS presents in the following.

Methods

Having regard to young age and low radiogenic ^{40}Ar and ^{87}Sr isotope contents is objects under study the high sensitive low blank (K-Ar) and high precision (Rb-Sr) methods were used. The important features of technique applied in the K-Ar dating are: static regime of argon isotope analysis realized on mass-spectrometer MI-1330, isotope dilution with ^{38}Ar monoisotope, low level of total blank for radiogenic ^{40}Ar analysis (less than 8×10^{-3} ng ^{40}Ar). In the Rb-Sr dating the multicollector mass-spectrometer Micromass Sector 54 was employed. $^{87}Sr/^{86}Sr$ isotope ratio was measured with high precision 0.002 % as 2σ-error. The isochron treatment of Rb-Sr data as well as K-Ar was used to decrease (or eliminate) contribution of an uncertainty of $^{87}Sr/^{86}Sr$ and $^{40}Ar/^{36}Ar$ initial isotope ratio.

Results and disscussion

The problem of the hydrothermal precious mineralization isotope dating in the Central Slovak Neogene volcanic rocks was solved by usage of finely dispersed (<2 μm) K-content clay minerals identified as illite of different polytypes. The last reflect the thermodynamic conditions prevailed during the formation of precious and base metal mineralization. For instance, polytype 1M was dominated in samples prepared for isotope dating of the the Kremnica deposit; samples from the Hodruša (Rozália mine) was composed by illite as a mixture of 1M and 2M1 polytypes.

K-Ar data for the Kremnica deposit obtained according to 6 illite samples from various vein zones lies in the interval of values 10.1–11.7 Ma. In this case the analytical errors of individual dates are ±0.2 ÷±0.3 Ma and the mean value averages 11.0 Ma. Rb-Sr isochron age of the same set of samples is equal to 11.1±0.6 Ma. For the Hodruša deposit (Rozália mine) K-Ar age values of 2 illite samples are 11.9±0.3 and 11.5±0.3 Ma. The Rb-Sr dating of these samples yields value 12.8±0.6 Ma. Set of 4 samples collected from the Banská Štiavnica deposit (Terezia vein) have indicated the K-Ar isochron age 12.1±0.2 Ma coupled with somewhat heightened (328±38) initial $^{40}Ar/^{36}Ar$ isotope ratio.

The magmatic rocks dated represent a greater part of magmatic events (2nd-5th stages) which formed the central part of the Banská Štiavnica Stratovolcano. The K-Ar dating of the magmatic events (intrusion of granodiorite porphyry and quartz-diorite porphyry, eruption of biotite-amphibole andesites, rhyolites and perlites, formation of the Klotilda "rhyolite vein") fit in the narrow range of values 12.7 to 11.4 Ma. A good agreement between K-Ar and Rb-Sr data was found out. For example, K-Ar isotope age obtained for 3 phenocryst minerals (biotite, amphibole, plagioclase) from andesite of the Studenec Formation averages 12.4±0.2 Ma. Rb-Sr examination of these samples yields the same 12.4±0.2 Ma. K-Ar dating using glass and biotite separated from rhyolite of the Jastrabá Formation provided 11.4±0.4 Ma and 12.7±0.4 Ma respectively. Two-point Rb-Sr isochron revealed data 12.1±0.1 Ma.

Consequently, the probable interval of manifestation of all above mentioned magmatic stages when taken in account the most reliable data might be determined as 13–12 Ma ago. The time proximity of the later 5th magmatic stage (the rhyolite formation) and the epithermal Au-Ag-base metal mineralization of the Banská Štiavnica (12.1±0.2 Ma) and the Hodruša (Rozália mine) deposits (probable interval 11.5–12.8 Ma) is evident enough. Thus the time interval of the magmatic rock formation and metal mineralization during the Banská Štiavnica EFMS activity with consideration of the analytical uncertainties is short and does not exceed 1 Ma. It is similar to the time interval of formation for some comparable and geochronologically in detail studied epithermal systems in the word: Emperor- Tavua Caldera, Fiji (Setterfield et al., 1992), Cripple Creek, Colorado, USA (Kelley et al., 1998), Raund Montain- Nevada, USA (Henry et al., 1997), Sleeper – Humbolt County, Nevada, USA (Conrad et al., 1993), Baia Mare, Romania (Lang et al., 1994).

Isotope data obtained for the Kremnica deposit illite samples are 0.9–1.3 Ma younger than data for the Banská Štiavnica deposit. This substantial distinction we suppose provides reason enough to recognize that fluid activity of the Banská Štiavnica EFMS was completed earlier than the Kremnica EFMS. This conclusion is confirmed by known geological evidence: hydrothermal activity produced the Banská Štiavnica deposit was connected with intrusion of the Štiavnica-Hodruša granodiorite and subvolcanic granodiorite porphyry bodies whereas hydrothermal formation of the Kremnica is associated with later rhyolitic magmatism.

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Mineral parageneses, fluid inclusions and stable isotopes studies of Au-Ag-base metal mineralization of Banská Štiavnica and Zlatá Baňa stratovolcanos: A comparison

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Abstract

Banská štiavnica and Zlatá Baňa deposits were formed in different geological settings. They have analogous mineral composition but significantly differ in masstab of mineralization. The ore-forming process at Banská Štiavnica deposit were thus accompanied by concomitant decrease of temperature (from 380 to 100 °C), salinity (from 11.5 to 0.5 wt. % NaCl eq.), oxygen and sulphur activity. The ore-forming process at the Zlatá Baňa deposit have been thus accompanied by contamitant decrease in T (from 300 to 150 °C), salinity (from 12 to 1 wt. % NaCl eq.), a_{O2} (from $10^{-32.5}$ to $10^{+47.5}$) and a_{S2} (from 10^{-10} to 10^{-18}). Zones of relatively richer ores have relatively narrow extension space, which "copy" the fluid boliling level.

Key words: stable isotopes, stratovolcano, fluid inclusion, Au-Ag-base metal deposits, fluid-magmatic system

The problem of productivity of epithermal fluid-magmatic systems (EFMS) in volcanostructures are considered on the example Au-Ag-base metal mineralization of Banská Štiavnica and Zlatá Baňa deposits. The peculiarity of the formation of the ores of these deposits are revealed as the result of detail comparative study of mineral parageneses, fluid inclusions and S, C and O isotopes. These deposits were formed in some different geological settings, have analogous mineral composition, belong to the type of low sulfidation (or sericite-adularia) of epithermal mineralization but significantly differ by the masstab of mineralization. It could be supposed that the specific of the causes enfluicing on the productivity of EFMS. Below will be considered main results of investigations.

The Banská Štiavnica Au-Ag-base metal epithermal deposit is located in Central Slovakia, in the central part of a polygenic andesite stratovolcano. It is characterised also by multiple phase subvolcanic complex with evolution by caldera stage, resurgent horst and contemporaneous rhyolite volcanism. It is limits are more then 100 ore quartz-sulfide and quartz-carbonate veins containing Au, Ag, Cu, Pb and Zn. In ore mineralization is established great number of minerals, including sulfides of Fe, Cu, Zn, Pb, Ag, sulphosalts of systems Ag-Cu-Sb-As-S and Ag-Cu-Bi-S, and tellurides and selenides of Ag, native gold, electrum and quartz, carbonates, barite, adularia, sericite as gangue minerals. The crystallization temperatures of minerals in the beginning of the ore forming process ranged between 380–240 °C and at the end were 225–100 °C. These minerals precipitate from aqueous solutions enriched in Na, Ca and Mg chlorides with of total salinity between 0.5–11.5 wt. % NaCl-eq. The sulphur isotope data indicate that $\delta^{34}S$ values of sulphides (from -9.0 to + 11.8 ‰) and barite (from +17.5 to + 22.5 ‰) are generally representative of the fluids expelled from the uncontamined granitic magmas. The magma-derived fluids were initially characteristic for high oxidation potencial. Oxygen isotopic data on quartz (from -4.0 to 15.2 ‰) and carbonates (from +3.5 to 25.1 ‰), as well as the δD values of chlorite and kaolinite indicate progressively increasing percentage of meteoric waters later mineralization stages (from -52 to -113 ‰).

The ore-forming process at Banská Štiavnica deposit were thus accompanied by concominant decrease of temperature, oxygen and sulphur activity. Authors suppose that on cooling, on the stage of magmatic distillation, excess water and chlorine were expelled from the melt, extracting and concentration in the fluid was initially increasing.

The Zlatá Baňa deposit is located in northern part of Slanské vrchy Mts, in the central part of a monogene andesite stratovolcano with a diorite porfyry subvolcanic stock. The precious metal association is created by gold, electrum, Au-Ag-tellurides, Ag-tetrahedrite, Ag-Sb-, Cu-Sb- and Ag-Pb-Sb- sulphosalts. It was precipitated after dominant base metal sulphides. Ores is created by carbonates and minor amount of quartz, adularia, sericite, chalcedony, fluorite and barite as gangue minerals. Au-Ag-base metal mineralization crystallized at temperatures from 290 to 180 °C from Na-Mg-rich chloride aqueous solutions with salinity from 1 to 12 wt.% NaCl-eq. The $\delta^{34}S$ values in sulphides (from -11.4 to +3.3 ‰) and in barite (+15.9 ‰) indicate the magmatic origin of sulphur in ore-forming fluids. Carbon isotope composition of the oldest carbonates (from – 0.3 to – 8.7 ‰) originate usually at temperatures at above 200 °C indicate juvenile sources of carbon. The composition of C and O stable isotope show that the hybrid character of ore-forming solutions of the youngest stages of mineralization.

The ore-forming process at the Zlatá Baňa deposit have been thus accompanied by contaminant decrease in T (from 300 to 150 °C), a_{O2} (from $10^{-32.5}$ to $10^{-47..5}$) and a_{S2} (from 10^{-10} to 10^{-18}). Zones of relatively richer ores have relatively narrow extension space, which "copy" the fluid boiling level. The main factors of metal precipitation were temperature decrease and increasing of alcalinity of solutions (pH from 3.5–4 at 300 °C to 6.5–7 at 150 °C) that was caused by boiling and has been connected with escape of CO_2. The temperature decrease is accompanied by penetration of meteoric water to ore-forming system and has been connected with cooling relatively smoller magmatic bodies.

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Metallogeny of the Central Slovakia Volcanic Field

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Abstract

Mineralizations of the Central Slovakia Volcanic Field are assigned to 15 genetic types: (1) magnetite skarn deposits and occurrences, (2) porphyry/skarn Cu ± Mo, Au deposits and occurrences, (3) porphyry Cu ± Mo, Au occurrences, (4) intrusion related base metal stockwork/disseminated mineralizations, (5) barren high sulfidation systems, (6) high sulfidation epithermal gold deposit and occurrences, (7) intrusion related low sulfidation epithermal gold deposit, (8) low sulfidation epithermal veins (base metal, silver – base metal and precious metal), (9) base metal replacement deposit and occurrences, (10) precious metal replacement occurrences, (11) barren hot spring type hydrothermal systems, (12) disseminated Hg (Au) mineralization of the hot spring type, (13) sediment hosted base metal deposits and occurrences, (14) sediment hosted Hg (As, Sb) deposits and occurrences, (15) sediment hosted Au mineralization, showing features of the Carlin type. The first seven mineralization types are related closely in space and time to the emplacement of individual subvolcanic intrusions, showing usually evolution in two stages. Low sulfidation epithermal systems are related to extension tectonics post-dating significantly emplacement of subvolcanic intrusions and porphyry copper systems and linked to contemporaneous silicic intrusions and dome/flow complexes. Sediment hosted replacement base metal, precious metal and mercury mineralizations represent a marginal zone to large mineralized volcanoplutonic complexes in grabens.

Key words: metallogeny, ore deposits, Central Slovakia, volcanic rocks, intrusions

Introduction

Volcanic formations, especially central volcanic zones including subvolcanic intrusive complexes, host a number of mineral deposits and occurrences. Essential structural aspects and paleovolcanic reconstruction of the Central Slovakia Volcanic Field (CSVF) has been discussed by Konečný et al. (1995). Relationship of ore deposits and occurrences to a simplified paleovolcanic reconstruction is given in the Fig. 2, while Fig. 3 shows their relationship to morphostructural elements of the prevolcanic basement.

Mineralization types

Using up to date classification principles of volcanic hosted mineralizations (e.g. Hedenquist, 1987; Bonham, 1988; Sillitoe, 1989, 1993; Corbett and Leach, 1996) mineralizations of the CSVF are assigned to 15 genetic types (Fig. 1). Selected references include works, which postdate publication of the Metallogenesis of Neovolcanites in Slovakia by Burian et al. (1985).

1. Magnetite skarn deposits and occurrences related to contacts of the granodiorite/diorite subvolcanic intrusions with Triassic limestones and dolomites (Koděra et al., 1998, 1999).

2. Porphyry/skarn copper ± molybdenum, gold deposits and occurrences related to granodiorite porphyry stocks and dyke clusters emplaced in Triassic limestones and dolomites (Marsina and Lexa, 1998).

3. Porphyry copper ± molybdenum, gold mineralogical occurrences related to diorite (to monzodiorite?) stocks (Štohl et al., 1986; Rojkovič and Rojkovičová, 1999).

4. Base metal stockwork/disseminated mineralizations related to granodiorite and diorite porphyry intrusions (Štohl et al., 1994; Lexa et al., 1999; Koděra et al., 1999).

5. Barren high sulfidation systems related variably to granodiorite, diorite (monzodiorite ?) and granodiorite porphyry intrusions (stocks), representing eventually tops of the porphyry type hydrothermal systems (Štohl et al., 1986; Onačila et al., 1989; Lexa et al., 1999).

6. A high sulfidation epithermal gold deposit and occurrences related to diorite (to monzodiorite?) stocks, showing rudimentary porphyry type mineralization in depth (Marlow et al., 1998; Štohl et al., 1999).

7. A low sulfidation epithermal gold deposit related to granodiorite subvolcanic intrusion (via lateral outflow of fluids from the hydrothermal system of the base metal stockwork/disseminated mineralization ?) (Šály and Kámen, 1992; Maťo et al., 1996; Lexa et al., 1999).

8. Low sulfidation epithermal veins situated in central zones of older stratovolcanoes, however, directly related to local horst uplifts and late stage rhyolite extrusive domes and dykes. On the basis of metal contents there are distinguished base metal, silver – base metal and precious metal epithermal veins, showing a zonal arrangement in the case of coexistence (Koděra et al., 1989, 1990; Knésl, 1990; Lexa et al., 1997; Bartalský and Finka, 1999).

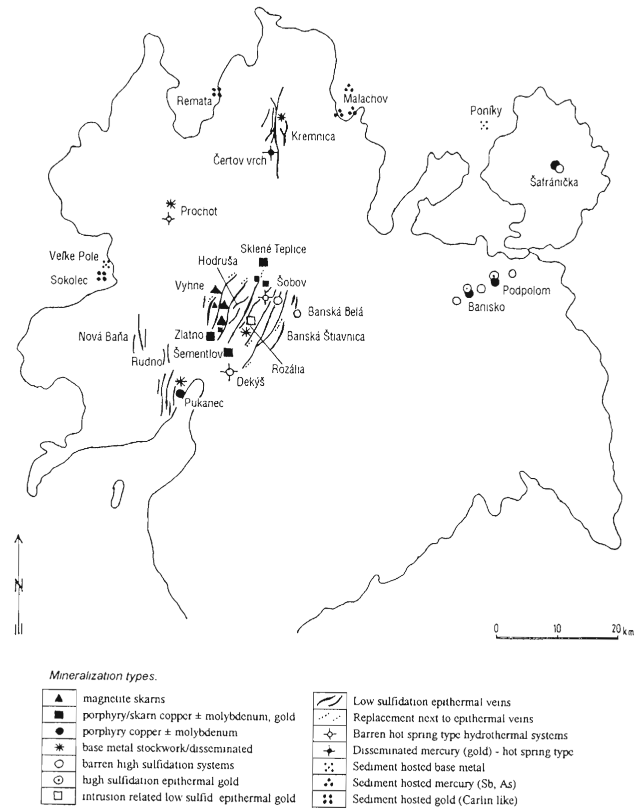

Fig. 1. Spatial distribution of ore deposits and occurrences in the Central Slovakia Volcanic Field.

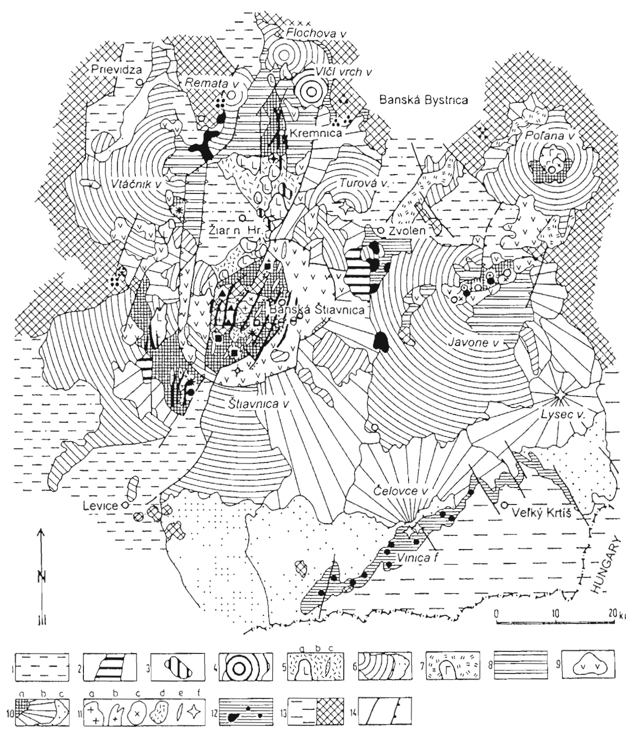

Fig. 2. Relationship of ore deposits and occurrences in the Central Slovakia Volcanic Field to paleovolcanic reconstruction according to Konečný et al. (1995). 1 – sediments of intravolcanic depressions, 2 – alkali basalt volcanics (Late Pannonian – Quaternary), 3 – lava flows and sills of aphanitic calc-alkali basalts/basaltic andesites (Early Pannonian), 4 – stratovolcano of porphyritic calc-alkali basalts/basaltic andesites (Early Pannonian), 5 – rhyolite domes/dome flows (a), dykes (b) and pyroclastic and epiclastic rocks (c) of the Jastrabá formation (Late Sarmatian), 6 – Sarmatian andesite stratovolcanoes and reworked marine facies, 7 – rhyodacite domes / dome flows and related pumice tuffs and reworked tuffs of the Strelníky formation (Early Sarmatian), 8 – effusive complexes of basic to intermediate andesites filling grabens (Late Badenian), 9 – domes/dome flows of intermediate to acid andesites filling grabens and caldera (Late Badenian), 10 – Early to Middle Badenian andesite stratovolcanoes: a – propylitised complex of the central zone, b – stratovolcanic complex of the proximal zone, c – reworked marine or fluvial facies, 11 intrusions: a – granodiorite, b – granodiorite porphyry, c – diorite and diorite porphyry, d – quartz-diorite porpfyry sills, e – quartz-diorite porpfyry dykes, f – necks, 12 – extrusive domes and reworked breccias of garnet-bearing andesites (Early Badenian), 13 – pre-volcanic basement: a – Early Miocene sediments, b – older rocks, 14 – faults: a – normal, b – limiting grabens and calderas. Ore deposits and occurrences as in the Fig. 1

9. Base metal replacement deposit and occurrences next to base metal epithermal veins in Triassic marly shales, limestones and dolomites (Koděra et al., 1989, 1990).

10. Precious metal replacement occurrences next to precious metal epithermal veins in Triassic carbonate rocks (Šály and Veselý, 1997; Lexa et al., 1997).

11. Barren hot spring type hydrothermal systems related to the Štiavnica caldera (Žáková et al., 1995; Lexa et al., 1997).

12. Disseminated mercury (gold) mineralization of the hot spring type at the outskirts of the precious metal epithermal systems (Veľký, 1999).

13. Sediment hosted base metal deposits and occurrences in Triassic limestones and dolomites next to marginal faults of volcano-tectonic grabens (Koděra et al., 1999).

14. Sediment hosted mercury (As, Sb) deposits and occurrences in Triassic dolomites and Paleogene sandstones next to marginal faults of volcano-tectonic grabens (Koděra et al., 1998, 1999).

15. Sediment hosted gold mineralization, showing features of the Carlin type, in Triassic dolomites next to marginal faults of volcano-tectonic grabens (Knésl and Knéslová, 1993; Oružinský et al., 1994).

Intrusion related mineralizations

The first seven mineralization types are related closely in space and time to the emplacement of individual subvolcanic intrusions, showing usually evolution in two stages (Fig. 4, A and B): the first one, prograde stage, corresponding to crystallization and degassing of the intrusion, including evolution of advanced argillic alteration zones; the second one, retrograde stage, corresponding to meteoric water circulation through apical parts of the intrusion, following its crystallization and brittle fracture evolution. Relative magnitudes of the prograde and retrograde stages are highly variable. A large advanced argillic system does not necessarily indicates an extensive mineralization in the depth and vice versa.

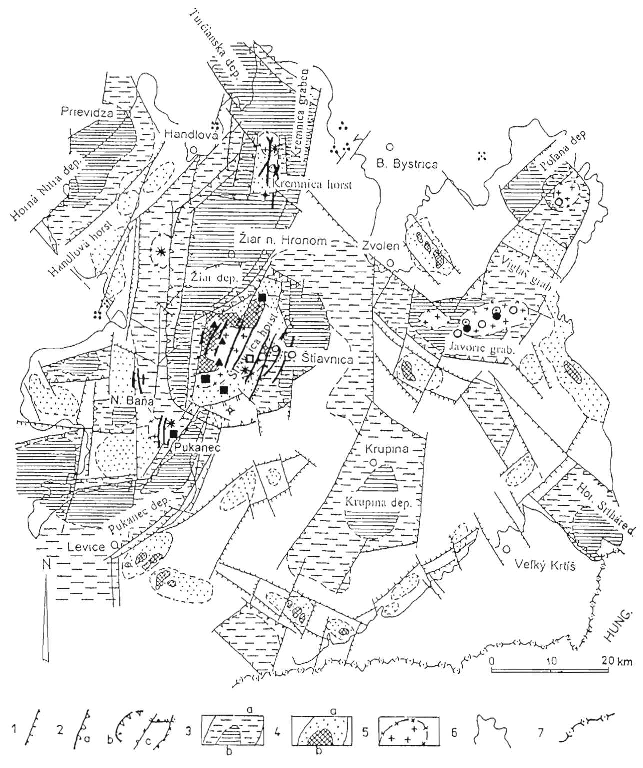

Fig. 3. Relationship of ore deposits and occurrences in the Central Slovakia Volcanic Field to basement structures and subvolcanic intrusive rocks according to Konečný et al. (1995). 1 – faults limiting uplifted and subsided blocks, 2 – faults limiting: a – graben, b – caldera, c – volcano-tectonic horsts, 3 – depressions: a – shallow part, b – deep part, 4 – elevations: a – upper part, b – outcropping basement, 5 – geophysical indications of subvolcanic intrusive complexes, 6 – extent of volcanics, 7 – state boundary Ore deposits and occurrences as in the Fig. 1

Fig. 2 and 3 demonstrate, that mineralized subvolcanic intrusive complexes are usually situated in the central zones of large andesite stratovolcanoes (Javorie, Poľana, Štiavnica, Kremnica) or next to the Štiavnica caldera (Pukanec, Nová Baňa, Prochot). Their emplacement took place following maturity of the early stratovolcanoes, probably as a response to the evolution of magmas in high level magma chambers. A quite good correlation exists among the size and complexity of the stratovolcano and its subvolcanic intrusive complex on one side and the extent of mineralization and alteration on the other side. Simple, monogenous andesite stratovolcanoes without subvolcanic intrusions do not show mineralization, while the most extensive mineralization processes took place in the central zone of the Štiavnica stratovolcano with a multiple stage intrusive complex, caldera and resurgent horst.

Low sulphidation epithermal mineralizations

Low sulfidation epithermal systems (LSED) are interpreted alternatively as: (1) linked to contemporaneous deeper situated porphyry copper systems (e. g. Hedenquist, 1987; Sillitoe, 1989; Corbet and Leach, 1996), (2) related to extension tectonics post-dating significantly emplacement of subvolcanic intrusions and porphyry copper systems (e. g. Mithell and Leach, 1991), and/or (3) linked to contemporaneous siliceous dome/flow complexes (e. g. Hedenquist, 1987; Bonham, 1988).

LSED in the Central Slovakia Volcanic Field (except the one under the number 7) show features of the second and third type. They are situated in central zones of considerably older (by 2.5–4.0 Ma) andesite stratovolcanoes involving differentiated rocks and extensive subvolcanic intrusive complexes (Fig. 2 and 3), hosting intrusion related mineralizations of the Cu-porphyry/skarn, magnetite skarn, disseminated/stockwork base metal, and high-sulfidation type. Epithermal veins are developed on extension faults of local (resurgent ?) horsts, which are a part of the extensive North-South trending horst/graben system (Štohl, 1976), related to lithospheric back arc extension and asthenosphere upwelling (Lexa and Konečný, 1998). The same fault system controls also distribution of rhyolite extrusive domes and dykes, which post-date andesite volcanoes and are roughly contemporaneous with epithermal mineralization (Lexa et al., 1999). However, the extent of epithermal veins is limited to the areas over older subvolcanic intrusive complexes. Andesite stratovolcanoes which are not affected by younger extension tectonics and do not involve substantially the late stage rhyolite volcanic rocks (Javorie, Poľana) do not show low sulfidation epithermal mineralization, despite the presence of intrusion related mineralizations of the porphyry copper and high sulfidation types.

The observed relationships of LSED to the older stratovolcanoes, subvolcanic intrusive complexes, local horsts and late stage rhyolite volcanic rocks are best explained by a model, which combines (1) horst-related extension fault systems creating suitable hydraulic regime and pathways for hydrothermal fluids with (2) high level crustal magma chambers underneath mature andesite stratovolcanoes evolving with time towards siliceous composition as a source of heat and SO_2-poor magmatic fluids (Fig. 4, C). It is the evolving high level magma chamber which relates in space the early intrusion related mineralizations with much younger low sulfidation epithermal mineralizations.

Sediment hosted mineralizations

Sediment hosted base metal, precious metal and mercury (± Sb, As) mineralizations represent a marginal (distal) zone to large mineralized volcanoplutonic complexes in grabens. Magmatic roots of these complexes, including evolving high level magma chambers, stimulated also a regional scale circulation of fluids, marginal faults of grabens serving as upflow zones. If diluted fluids of these systems entered lithologically suitable environment they initiated dissolution phenomena followed by silicification and mostly low temperature mineralization, creating the disseminated and/or replacement type ore deposits and occurrences.

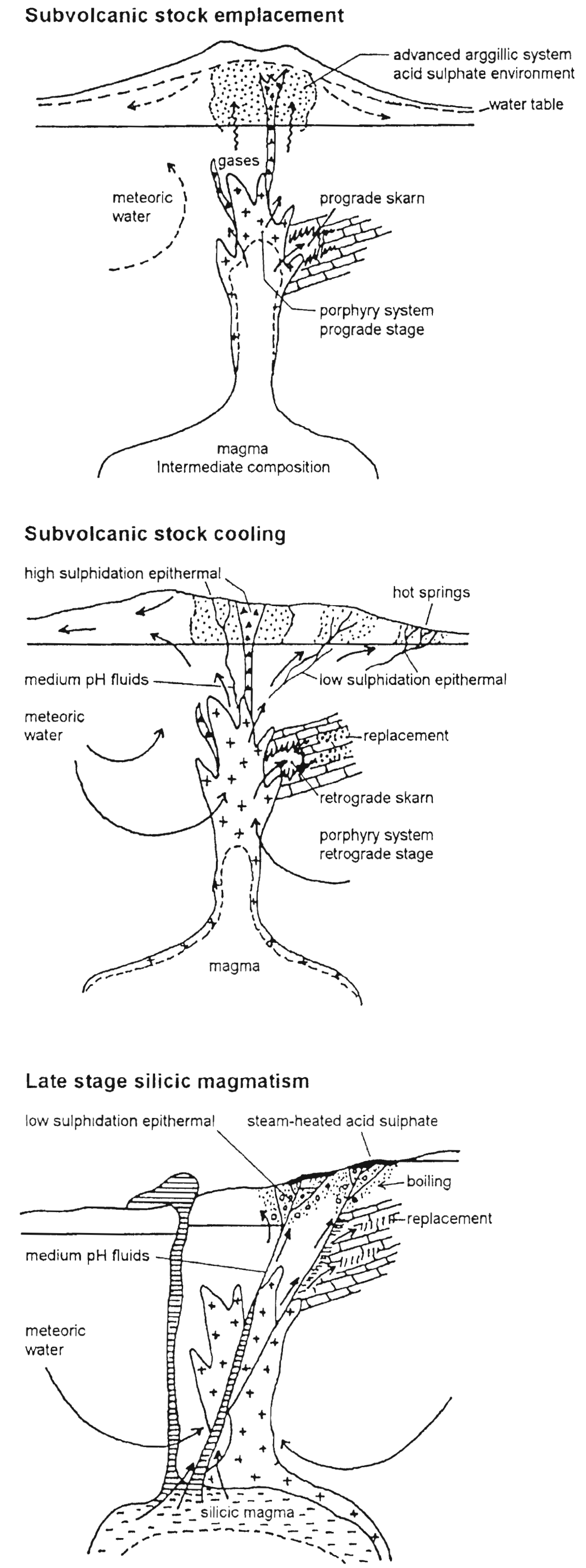

Fig. 4. Evolutionary model of volcanic hosted mineralizations in the Central Slovakia Volcanic Field (Lexa, 1999).

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High-sulfidation of epithermal gold mineralization at Podpolom, Javorie Mts., Slovakia

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Abstract

The Klokoč – Podpolom gold deposit is located in the central zone of the Javorie stratovolcano, at one of the five hydrothermal systems within the NE–SW trending Vígľaš volcanotectonic depression. The system is formed of various facies of residual silica, extensive zones and pipes of hydrothermal-explosion breccias, and surrounding zones of intense argillic alteration. It associates clearly with the apical parts of a diorite to monsodiorite stock, which at depth shows rudimentary but typical features of the porphyry Cu environment. Temperature estimates vary between 280 °C and 350 °C, indicating the depth 1000–1500 m. Primary gold mineralization is related to hydrothermal-explosion breccias and the surrounding shattered rocks that are cemented by massive sulfides along with alunite and pyrophyllite. Pyrite in two generations dominates over pyrhotite, marcasite, luzonite and rare molybdenite. Primary gold has not been found; we assume that it occurs as finely dispersed native gold in sulfides, especially pyrite. The gold deposit with a commercial grade of ore is represented by completely oxidized breccias and shattered silicic rocks, where the former sulfides were converted into hematite, goethite and limonite. Gold of 100 % fineness is present as tiny grains. The oxidized body enriched in gold is about 200 m long. Defined ore body contains from 1 to 2 tons of gold with average grade 1.5 g/t, with peak grades up to 20 g/t.

Key words: High sulfidation epithermal mineralization, gold, advanced argillic alteration, intrusions, Slovakia

Introduction

Conspicuous hills of silicified and altered rocks nearby the Kalinka, Klokoč and Stožok villages in a morphological depression at the northern side of the Javorie mountain range attracted since the Middle Age prospectors looking for gold and silver ores. However, apart of the small native sulfur deposit, which had been mined out during 1840–1862, no other mineralization of economic value has been found. A renewed interest in the area dates back to the fifties. First it was Valach (1966) who identified diorite porphyry intrusions, adjacent argillic alterations with pyrophyllite and alunite and propylitic alteration of surrounding rocks and recognized metallogenetic potential of the area. Such the conclusion was strongly supported by results of the deep borehole KON-1 in one of the hydrothermal centers (Konečný et al., 1977), as well as by geological mapping and paleovolcanic reconstruction of Javorie (Konečný et al., 1975; Konečný and Lexa, 1978), which confirmed, that the area represents a central zone of the Javorie stratovolcano.

The subsequent extensive metallogenetic research involved detailed mapping, ground geophysical survey, drilling, lithogeochemistry, soil geochemistry and mineralogical studies (Štohl et al., 1981, 1985, 1986). The zones of silicified and altered rocks were recognized as advanced argillic alteration zones, reflecting possible porphyry copper systems at depth. Deep drilling confirmed this assumption (Konečný et al., 1977; Štohl et al., 1985), however, mineralization was of no economic interest owing to low grade and great depth. The search for a possible enargite-type Cu mineralization in the advanced argillic zones was except few occurrences also negative (Štohl and Tözser, 1988). Next exploration targeted industrial mineral potential of the advanced argillic zones (Galko et al., 1998).

A recognition of the advanced argillic zones as high sulfidation hydrothermal systems lead in 1996 Rhodes Slovakia Ltd. to the idea of looking for a possible gold mineralization. First positive samples were quickly succeeded by soil & rock geochemistry, geophysics, trenching and shallow drilling, which lead to the discovery of

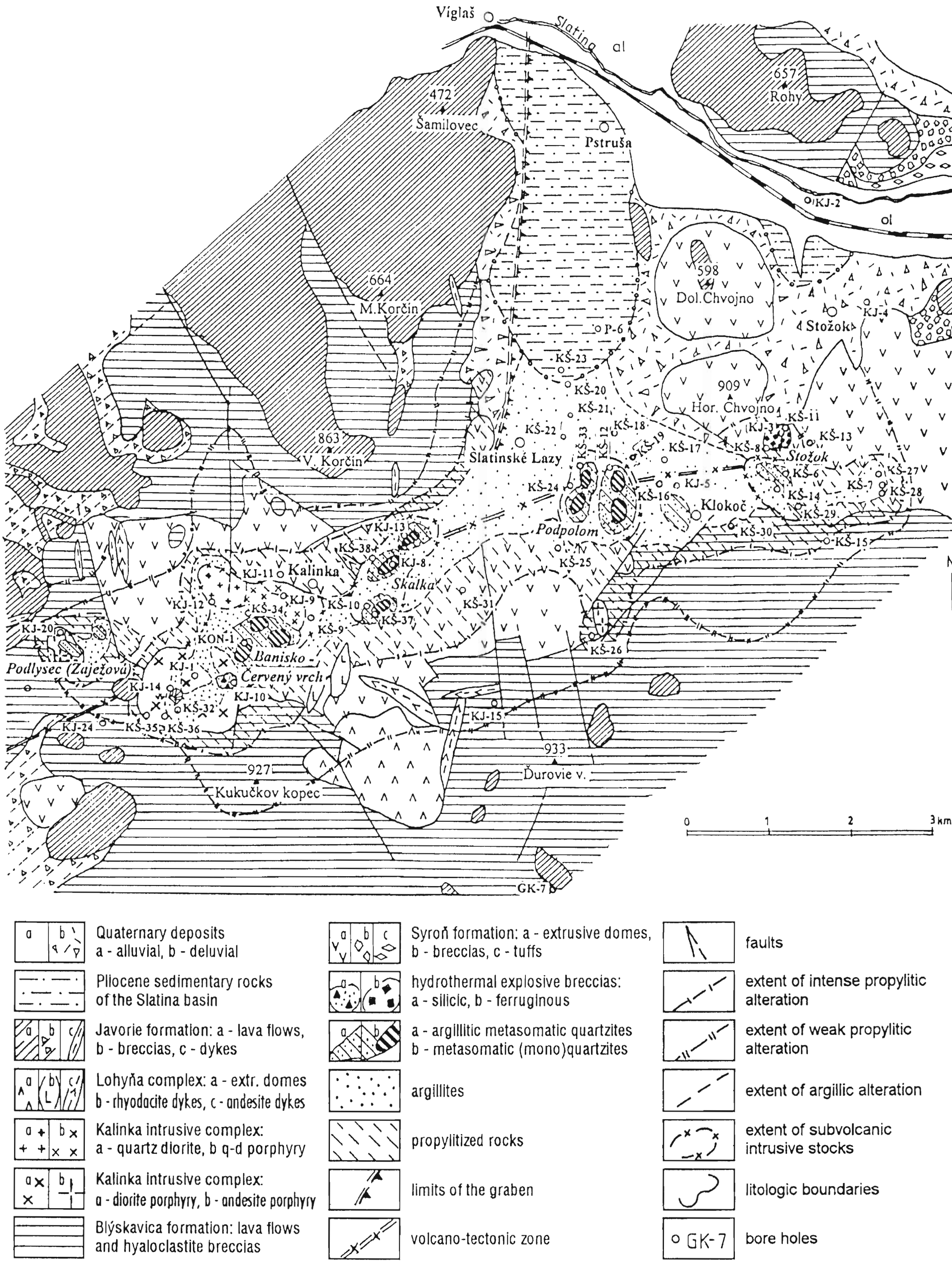

Fig. 1. Scheme of the central zone of the Javorie stratovolcano (Konečný et al., 1998).

a small high sulfidation epithermal Au deposit at the Podpolom hydrothermal system (Onačila and Štohl, 1997; Marlow et al., 1998).

Geological setting

The geology and evolution of the Javorie stratovolcano was described by Konečný et al. (1995, 1998). The Klokoč – Podpolom gold deposit is located in the central zone of the stratovolcano (Fig. 1), within the NE–SW trending Vígľaš volcanotectonic depression (graben). The graben fill consists of a series of hornblende-pyroxene andesite extrusive domes with related coarse pyroclastic and epiclastic breccias (Rohy, resp. Syroň Formations) and a series of basalt to pyroxene andesite lava flows with hyaloclastite breccias (Blýskavica Formation). An approximately 1200-m thick andesite complex of the pre-graben stage, as well as the graben fill was subsequently intruded by a set of "diorite" stocks aligned in the NE–SW direction. The emplacement of intrusions resulted in the generation of hydrothermal systems and related alteration at Zaježová, Banisko, Skalka, Podpolom, and Stožok (Fig. 1). The emplacement of "diorite" intrusions was followed by intrusion of rare andesite to rhyodacite dikes which do not show a clear relationship to mineralization processes. Post-graben andesite lava flows and volcanoclastic rocks of the Javorie Formation are most probably younger than mineralization. Pre-volcanic basement rocks in this region are represented by Hercynian granites and high-grade metamorphic rocks.

Radiometric dating of volcanic, intrusive, and mineralized rocks gives controversial results, incompatible with models of the contemporaneous porphyry/high-sulfidation systems evolution (e. g. Hedenquist et al., 1998). K/Ar and FT ages of the pre-graben stage volcanic rocks and of the graben filling indicate the time interval 16.2–15.5 Ma (Konečný et al., 1998). A K/Ar age of 16.1 Ma is reported on orthoclase from the monsodiorite stock underneath the Podpolom locality, but biotite from the same rock has an age of only 14.0 Ma (Kantor, 1979). The same biotite dated by the FT method has given the result 13.2 ± 0.8 Ma (Repčok, 1978). K/Ar dating of alunite from the advanced argillic zone at Podpolom shows an apparent age of 11.5 Ma (Repčok et al., 1997). One of the late-stage rhyodacite dikes, with an inter- or post-mineralization timing, has an apparent whole-rock K/Ar age of 14.3 Ma, but only 13.6 Ma on biotite (Ďurkovičová in Konečný et al., 1998). K/Ar and FT dating of the post-mineralization andesites of the Javorie formation ranges from 13.7–11.3 Ma (Repčok and Ďurkovičová in Konečný et al., 1998).

Mineralization and alteration

The mentioned hydrothermal centers are autonomous, nevertheless, they generally resemble each other as far as the geological, magmatic, geochemical, geophysical, mineralogical and alteration aspects are concerned (Štohl et al., 1986). Results of mapping, drilling and geophysical interpretations show, that they are related to separate "diorite" stocks, which were the energy and fluids source of mineralization and alteration processes. Stocks have isometric morphology with diameter from 500 to 1500 m. Individual stocks show a moderate petrographic and compositional variability, from diorite porphyries at the top to equigranular diorite and monsodiorite at depth over 1000 m (Fig. 2, 3). This indicates either a multiple phase emplacement or, more probably, emplacement of an inhomogeneous magma. However, a large part of the variability can be assigned to variations in cooling history and subsolidus recrystallization (e. g. potash feldspar enrichment). The late-stage magmatic and immediately subsequent subsolidus processes in the monsodiorite are recorded by irregular aggregates and thin "dikes" of aplitic to pegmatitic differentiates, passing commonly into magmato-hydrothermal breccia with coarse orthoclase and biotite. Thermometry on late stage magmatic feldspars indicates solidus temperature 650–750°C, while Ab content of hydrothermal Ba-enriched K-feldspar indicates temperature of subsolidus reactions around 450–500°C.

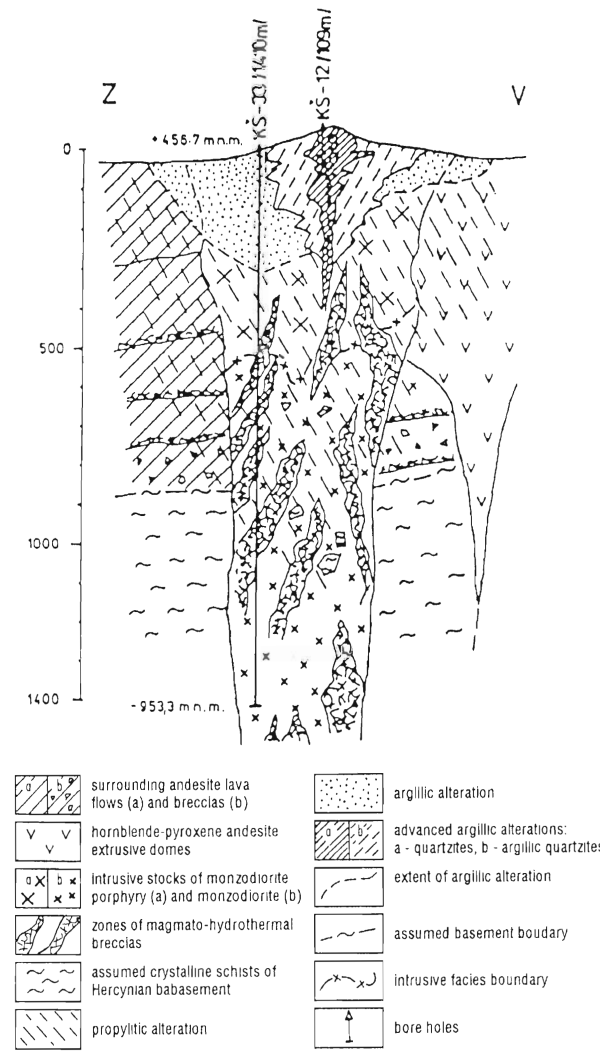

Fig. 2. Schematic section of the hydrothermal center of Klokoč – Podpolom (Konečný et al., 1998).

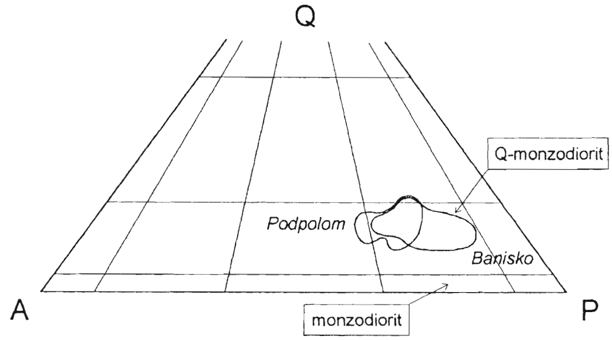

Fig. 3. Composition of parental intrusions in the QAP diagram.

Cu ± Mo porphyry type mineralization dominates at deeper levels. Rare disseminations and veinlets of pyrite, chalcopyrite and molybdenite with hematite, magnetite and pyrhotite are accompanied by secondary K-feldspar, biotite and actinolite. Outward the alteration grades into a zone of quartz-sericite-pyrite replacement and propylitization. Upward it grades into a narrow zone of chlorite and epidote enrichment, before it is overlapped by alterations of the advanced argillic zone close to the surface (0–300 m). The fact, that the advanced argillic alterations descended into the apical parts of intrusive stocks and related porphyry systems points to a progressive downward crystallization of the stocks and a probable syngenetic erosion.

Overlapping advanced argillic alteration zone shows mineral assemblages typical of the highly acid high-sulfidation environment, including quartz, tridymite, lussatite, alunite, pyrophyllite, diaspore, illite, kaolinite, dickite, haloysite, corundum, topaz, rutile, zunyite, tourmaline, fluorite, anhydrite, and native sulfur (Štohl et al., 1986; Žáková, 1988). These alteration minerals are arranged in concentric zones with poorly defined boundaries. In the center and close to the surface there is a body of residual quartz, passing outward into advanced argillic alteration of pyrophyllite, zunyite, diaspore, and alunite. The transition to the outer zone of propylitic alteration is marked by an increased proportion of kaolinite and illite. Due to metasomatic replacement, these mineral zones are irregularly distributed and do not form sufficiently large bodies that would be suitable for the extraction of industrial minerals. The presence of pyrophyllite with quartz, topaz, diaspore and zunyite indicates temperatures above 280 °C. Sulfur isotopes in the alunite-pyrite pairs indicate temperatures 300–350 °C (Repčok et al., 1997). The extensive hydrothermal brecciacion indicates, that hydrothermal systems were at boiling point. The estimated temperature 300–350 °C corresponds in such the case to the depth 1000–1500 m, what is compatible with a paleovolcanic reconstruction of the Javorie stratovolcano (Konečný et al., 1998).

Multistage pyrite, sometimes with admixture of gold, dominates among ore minerals. Other ore minerals occur in very small amounts, anyway, they are typical of the high-sulfidation environment. These are galena, sphalerite, enargite, luzonite, altaite, alabandine, hauretite, bizmutine, Sn - mineral and molybdenite. Characteristic of the advanced argillic alteration zones there is a multistage hydrothermal brecciation. Hydrothermal explosion breccias are composed of angular silicite fragments, variably cemented by silica (massive metasomatic quartzites), rock flour and/or argillic minerals with alunite, rarely also sulfur impregnations (Kalinka deposit) and massive sulfide or limonite in the oxidized zone (Konečný and Štohl, 1991).

Podpolom Au deposit

The high-sulfidation epithermal gold deposit at Klokoč – Podpolom is related to the Podpolom hydrothermal center, about 1 km in diameter (Fig. 2). At the surface and down to a depth of 200–300 m the center is represented by advanced argillic alteration. The center is formed of various facies of residual silica, extensive zones and pipes of hydrothermal-explosion breccias, and zones of intense argillic alteration. Brecciation has been multistage, nature of breccias varying from crackle trough mosaic up to completely shattered types with fluidized rock flour matrix. Fig. 4 shows their distribution at the surface, and Fig. 5 shows a section through the deposit. Hydrothermal breccias are only rarely cemented by quartz to form metasomatic quartzites. Most typically the breccias are cemented by argillic minerals and/or sulfides. Sulfide-cemented breccias and shattered rocks have been converted into hematite, goethite and limonite-cemented breccias due to supergene oxidation that extends to depths of 50–100 m. A large, central portion of the system consists of friable vuggy silica, locally with features of "rock flour". It is not clear to what extent this loose rock is a result of dissolution only, or how much hydrothermal shattering and brecciation were involved.

Bodies of residual silica and breccias are surrounded by irregular zones of advanced argillic alteration (Fig. 4). The contact with residual silica is not sharp; there is a gradual change from silicic alteration through silicified advanced argillic to advanced argillic alteration. Advanced argillic alteration close to silica bodies is dominated by quartz, pyrophyllite, alunite, diaspore and pyrite, with minor zunyite, kaolinite and illite. Kanazirski et al. (1996) report the following paragenetic mineral associations from this zone: quartz – rutile, quartz – pyrophyllite – rutile, quartz – topaz – rutile, quartz – pyrophyllite – topaz – rutile, quartz – pyrophyllite – diaspore – rutile, quartz – topaz – diaspore – rutile, and quartz – pyrophyllite – topaz – diaspore – rutile. These minerals appear to replace early-formed quartz and alunite, indicating a decrease in the acidity of fluids with time. The presence of topaz and zunyite reflects an increased activity of HF in fluids.

Quartz, kaolinite, illite and pyrite dominate further from the silica bodies, implying a decrease in temperature and acidity of fluids, as well as an increase in potassium content with increasing distance from the silica bodies. This argillic zone passes outward into propylitized andesites with chlorite, sericite, quartz, and pyrite closer to the hydrothermal system and chlorite, carbonate, and zeolite further from the system (Žáková, 1988).

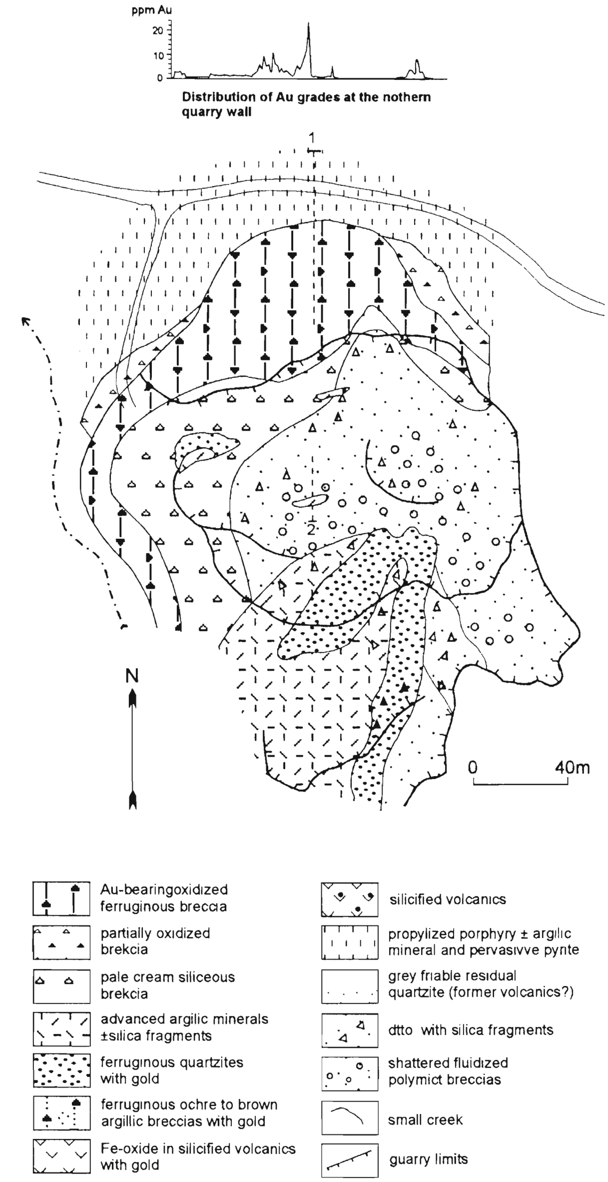

Fig. 4. Surficial map of the Klokoč – Podpolom gold deposit.

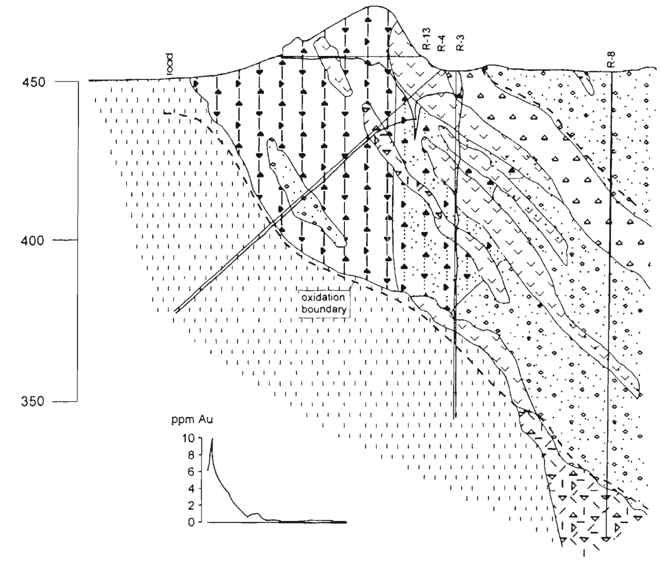

Fig. 5. Section through the Klokoč – Podpolom gold deposit. Legend is the same as in the Fig. 4.

Primary gold mineralization is related to hydrothermal-explosion breccias and the surrounding shattered rocks that are cemented by massive sulfides along with alunite and pyrophyllite (Fig. 5). Pyrite in two generations dominates over pyrhotite, marcasite, luzonite and rare molybdenite. Primary gold has not been found; we assume that it occurs as finely dispersed native gold in sulfides, especially pyrite. Assays of unoxidized mineralized rock at the base of the deposit contain values less than 1 g/t Au. However, we assume that the primary Au content in the upper part of the deposit was higher. There is also enrichment in As, Bi, Cu, Mo and Sn, which is indicative of the porphyry Cu environment (Marlow et al., 1998).

The gold deposit with a commercial grade of ore is represented by completely oxidized breccias and shattered silicic rocks, where the former sulfides were converted into hematite, goethite and limonite. Gold of 100 % fineness is present as tiny grains, mostly in the range of 1–2 microns. The gold content of ferruginous breccias correlates with the proportion of iron oxides and hydroxides, suggesting a possible control by the primary quartz/sulfide ratio (Marlow et al., 1998). The oxidized body enriched in gold is about 200 m long, dips 40° southward, and is exposed in the northern wall of the pit (Fig. 4, 5). Oxidation extends to the depth of 100 m, whereas strong gold enrichment extends only to the depth of 50 m. Defined ore body contains from 1 to 2 tons of gold with average grade 1.5 g/t, with peak grades up to 20 g/t. Gold content sharply drops when passing to unoxidized environment. Economic mineralization is mostly controlled by the zones of brecciation and oxidation (Marlow et al., 1998; Štohl et al., 1999).

Genetic Aspects

Advanced argillic alteration is clearly associated with the apical parts of "diorite" stocks, which at depth show rudimentary but typical features of the porphyry Cu environment (Fig. 2). Their mutual relationship is generally accepted. However, we are aware of several controversial points. Štohl and Tözser (1988) noted the relatively small vertical distance between the advanced argillic system and the porphyry Cu mineralization, i.e., the advanced argillic system evolved in the apical part of the parental intrusion. Such the relationship implies probable syn-hydrothermal erosion, pushing the advanced argillic alteration downward onto the top of the porphyry Cu system. The fact, that the advanced argillic system is eroded down to the level of 1000–1500 m bellow the former surface implies, that we are observing only its lowermost "root" parts.

The gold mineralization at Klokoč – Podpolom evolved in three stages. The first stage was strong acid leaching to form silicic and advanced argillic alteration, which we attribute the outflow of magmatic gases from the freshly emplaced and crystallizing "diorite" intrusion. The second stage was gold-bearing massive sulfide mineralization, with permeable hydrothermal-explosion breccias focusing the ascent of fluids. Breccias with sulfide-bearing fragments indicate syn-hydrothermal brecciation. As indicated by minor elements, this stage may have coincided with the retrograde stage of a porphyry copper system. The third stage was the progressive oxidation of the massive sulfides, concentrating gold of high fineness in the gossan-type ferruginous breccias.

Striking there is also an association of extensive advanced argillic alteration with only minor sulfide/gold mineralization and rudimentary porphyry Cu systems. A possible explanation might involve the impermeable basement of Hercynian granites and high-grade metamorphic rocks. While the extensive advanced argillic alteration is related to magmatic fluids exsolved from the intrusion, the metal-bearing retrograde stage of the system involving meteoric water may not fully develop due to the inpermeability of surrounding rocks at depth.

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The evolution of the magmatic and metallogenetic processes in the Nistru area (Gutîi mountains)

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Abstract

The intrusive magmatic activity from the Nistru area generated a suite of magmatic rocks consolidated at subvolcanic level. The subvolcanic magmatic rocks follow in succession the phase of Sarmatian pyroxene andesites. They distinguish themselves by varied morphological characteristics. There are small stocks and apophyses which vary in composition from quartz-monzodiorites porphyry to quartz-microdiorites porphyry and quartz-microdiorites and small dykes of quartz-andesites and one sill of the micrograbbro. The intrusive rocks are also differentiated by geochemical characteristics of the major and trace elements. The vertical and horizontal zoning of the hydrothermal mineralizations is in connection with the sequential emplacement of the intrusive rocks.

Key words: intrusive rocks, petrographic types, hydrothermal mineralizations, zoning.

Introduction

The metalogenetic activity from Baia Mare area is connected to the Neogene magmatism from the southern part of the Gutîi Mountains. The Oaş-Gutîi Ţibleş Mountains represent the NW segment of the East-Carpathian volcanic mountains in Romania. The Neogene magmatism with the development of the eruptive chain of the Eastern Carpathians is the result of the complex eruptive processes related to the subduction roll back area from the southern part of the East European plate (Balintoni et. al. 1997).

The magmatic activity from the Gutîi Mountains lasted 4-5 Ma. (13.4-9.0 Ma.) according to K-Ar radiometric data (Edelstein et. al., 1992), it generated predominantly or subordinately effusive volcanic sequences accompanied by an intrusive magmatic phase. The Nistru area represents the southern part of the Gutâi Mountains. The products of the Neogene volcanism with maximum development in the Nistru area are as follows: pyroclastic rocks with ignimbritic character, of Badenian age, pyroxenic andesites of Sarmatian age and quartz andesites of Pannonian age. The subsequent intrusive magmatic activity generated a suite of magmatic rocks consolidated at subvolcanic level.

Intrusive rocks

The subvolcanic magmatic bodies from the Nistru area follow, in succession, the phase of Sarmatian pyroxene andesites. They are spatially associated to the volcanic rocks, being distinguished by morphological and structural aspects as well as by petrographic types. The intense erosion of the volcanic structure emphasized the subvolcanic level of consolidation at the surface in the Nistru Valley and its tributaries. They are porphyritic or equigranular and appear as stocks, apophyses, dykes or sills. The relations between the main types of magmatic rocks emphasize their sequential emplacement:

-the first group forms stocks of small sizes with irregular forms represented by porphyric facies of quartz-microdiorites with lateral transitions to andesitic facies (emplaced in the NW part of the Nistru area), and by porphyric quartz-monzodiorites (emplaced in the NE–SE part). These stocks are accompanied by apophyses of quartz-micromonzodiorite which outcrop on the Nistru Valley.

-the second sequence of magmatic subvolcanic rocks is represented by dykes, apophyses and sills of a few meters size that pierce the stocks. These are represented by equigranular quartz-microdiorites in the form of a dyke that pierces the porphyry quartz-microdiorite stock, and porphyry microdiorites in the form of intrusive apophyses included in the quartz-microdiorite porphyry stock. Clear intrusive relantionships are observed between the quartz-monzodiorite stock and the apophyses with composition and texture similar to quartz-andesite lava flows. The porphyry microgabbro forms a small sill occuring within the quartz-monzodiorite stock.

Petrographic types separated within the magmatic sequences distinguish themselves from one to another by the major and trace elements characteristics. Significant differences have been observed in the behavior of SiO_2, Al_2O_3, $FeO + Fe_2O_3$, CaO, K_2O. There are no significant differences observed in the concentration of the trace ele-

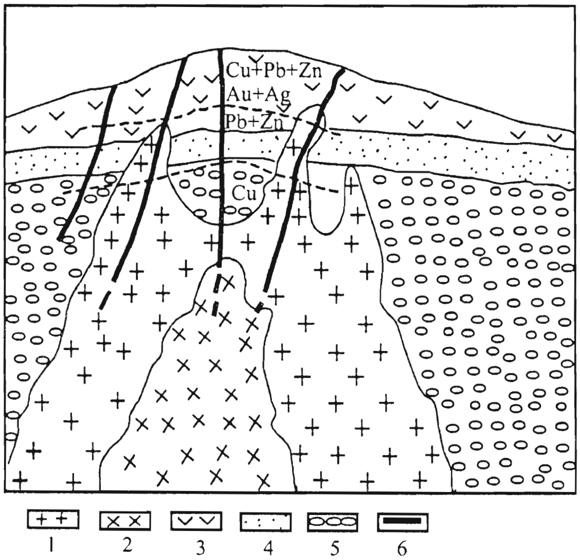

Fig. 1. Vertical zoning of the mineralization associated with the quartz-microdiorites stock. 1 – porphyry quartz-microdiorite; 2 – porphyry microdiorite; 3 – pyroxene andesite; 4 – pyroclastic rocks; 5 – sedimentary rocks; 6 – vein.

ments in rock types. The calc-alkaline and metaluminous character is emphasized by the geochemistry of major elements. The variation of the trace elements and of the rare earth elements within the suite of rocks with subvolcanic character from the Nistru area reflects the characteristics specific to the magmas generated in the subduction areas with affinities towards the calc-alkaline island arc series.

The development of the magmatic intrusions was accompanied by important petrogenetic and metallogenetic processes. They produced important metasomatic transformations that include compositional changes and pervasive alterations which affected sedimentary and eruptive rocks. Magmatic rocks in subvolcanic facies are affected by hydrothermal alterations extremely significant for their role in the metallogenetic activity (propylitic alteration, potassic alteration, phyllic alteration).

Mineralisation zoning

Mineralisations from the Nistru area form vein systems grouped in two distinct vein fields situated in the area of intrusive magmatic rocks. The intrusive rocks exercised control over the zonal distribution of mineralisations. Distribution of mineralisations in distinct vein systems, characterized by paragenetic sequences and vertical and horizontal zoning according to the position of the subvolcanic bodies, suggests their association with two magmatic phases with particular development. So, for the NW part associated to the quartz-microdioritic intrusion vein mineralisatios are developed, with base-metallic character and with typical vertical zoning:

a) the copper zone with development in the interior of the subvolcanic bodies as well as in the rocks around them (in the depth of the structure);

b) the Pb-Zn area situated in the central part of the veins;

c) the base-metal (CuPbZn+AuAg) in the upper part of the veins (Fig. 1).

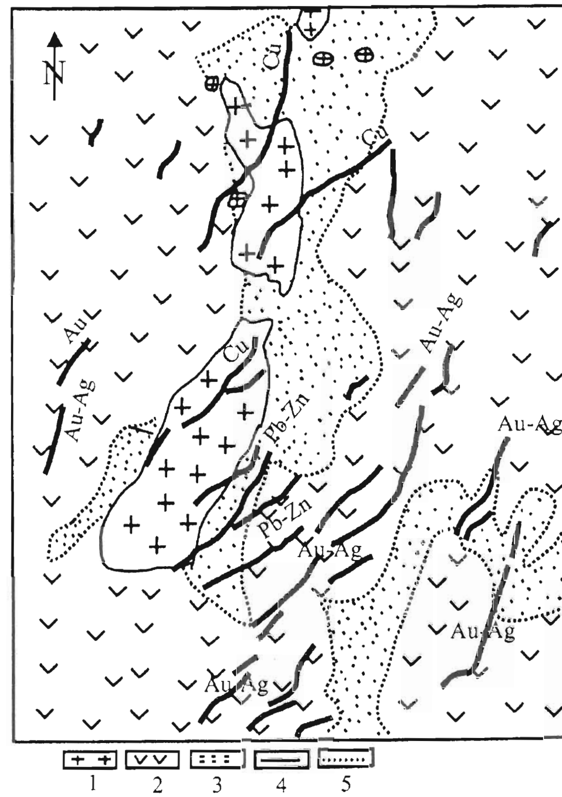

Fig. 2. Lateral zoning of the mineralization associated with the quartz-monzodioritic stock. 1 – quartz-monzodiorite; 2 – pyroxene andesite; 3 – pyroclastic rocks; 4 – vein; 5 – geological line.

For the NE–SE part, the horizontal zoning of the mineralisations around the quartz-monzodioritic stock is emphasized:

a) the central vein area includes the higher temperature mineralisations (copper mineralisations + bismuth sulphosalts) situated inside the stock, and copper mineralisations situated at the contact with surrounding rocks;

b) the external area of the stock is characterized by the emplacement of the Pb-Zn mineralisations with extension in the SE and NE part;

c) gold veins are developed laterally from the margins of the stock. (Fig. 2).

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Geology and mineralogy of the submarine volcanogenic sulphide deposit, near Brehov in Eastern Slovakia: a genetic ore formation model

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Abstract

Volcanogenic, stratabound, polymetallic (Zn, Pb, Cu) and gold sulphide deposit within the Brehov-Sirník interpreted resurgent caldera occur in the volcanic-sedimentary sequence. From mineralogical point of view are present: The upper stratabound Zn, Pb, Fe sulphide matrix-breccia zone; The lower stratabound Cu-Fe sulphide matrix-breccia zone; At the bottom of the deposit is a siliceous stringer and disseminated mineralization with gold (in a intrusive stockwork exfoliation zone). The Brehov kuroko style ore deposit formed from hydrothermal fluids as syngenetic and epigenetic accumulations of sulphide and sulphate minerals near the sea floor Ore accumulations are dominated by low sulphidation mineral assemblages, but less important, smaller high sulphidation mineralization assemblage is present too (In the sense of Sillitoe et al., 1996). In these ore bodies there was ascertained a typical high-temperature hydrothermal assemblage, with such minerals as wolframite, scheelite and specularite.

Key words: Brehov ore deposit, resurgent caldera, volcanogenic – stratabound sulphide mineralization, matrix-breccia zone, hydrothermal vent, exfoliation

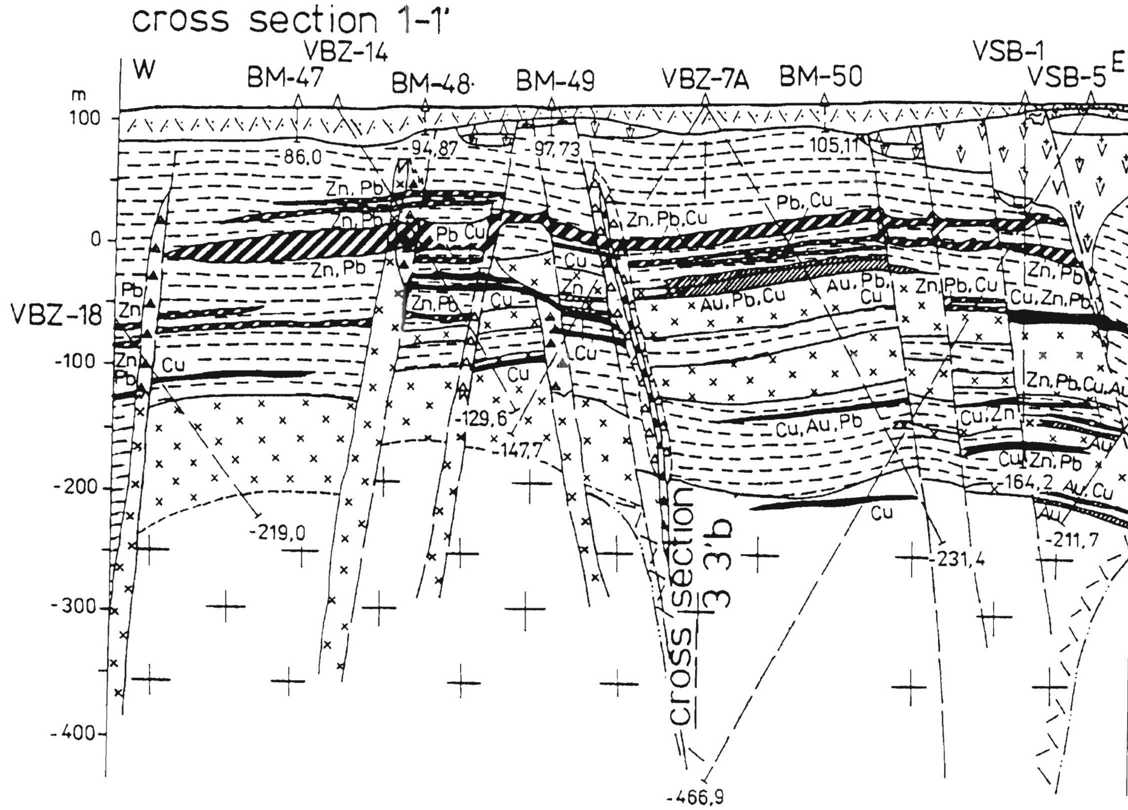
The Brehov-Zemplín area in Eastern Slovakia is characterized by a blockfaulting type tectonic style, with north-south trending faults (Bacsó, 1996). These faults were the pathways for the formation of the resurgent calderas (Brehov-Sirník and Zemplín-Somotor), as well as felsic magma and thus played an important role in the localization of the Neogene kuroko style mineralizations.

Volcanogenic, stratabound polymetallic (Zn, Pb, Cu) and gold sulphide deposit within the Brehov-Sirník interpreted resurgent caldera occur in the volcanic sedimentary sequence (volcaniclastic rocks of the rhyodacitic series, mudstones, intrusive sills and dikes of quartzdiorite porphyry composition). These units comprise the Middle and Upper Badenian Vranov and Lastomír Formations in the north-east transitional zone between the Zemplín Paleozoic-Mesozoic horst and Neogene Prešov-Kráľovský Chlmec graben (in the sense of Pospíšil and Bodoky, 1981). Here, in the Brehov-Sirník interpreted resurgent caldera (36 sq. km), we assume a presence of five mineralized local structures. To this time only the Brehov-West structure was explored by a set of 300–650 m deep drillholes. Bimodal volcanism (rhyodacitic and andesitic) in the immediate hangingwall of the Brehov-Zemplín area suggests that the mineralization took place during an extensional phase of the island-backarc development. The type example, the Brehov-West deposit is a marine volcanogenic, stratabound, felsic type of zinc, lead, copper and gold bearing, not typically massive, but sulphide-matrix breccia and sulphide stringer hydrothermal mineralization. Ages of the hydrothermal mineralizations are from Badenian to Pannonian. – Depositional environment is presented by hot springs, related to marine magmatism, probably with anoxic marine caldera conditions. – Tectonic setting was bild by extensional-orthogonal deep fault activity (in the sense of Favorskaja, 1977) and by creation of a volcanic structure of resurgent caldera, on deep faults intersection.

From the mineralogical point of view there are present: The upper stratabound sulphide-matrix breccia zone (representing "black ore") with higher distributed assemblage of less important barite+quartz, pyrite, marcasite, hematite, rutile±gold and with lower located assemblage of more important main polymetalic sphalerite-galena-pyrite ore. Numerous accessory, systematically distributed minerals, such as chalcopyrite, tetrahedrite-tennantite, sulphosalts (pearceite, polybasite, bournonite) acanthite, Zn-ankerite, chalcocite, greenockite and cinnabar are present too. The gangue minerals are represented by quartz, Mg-siderite, Mg-ankerite, kaolinite and barite.

The lower stratabound sulphide matrix-breccia ore zone (representing "yellow ore"), with higher placed assemblage of chalcopyrite, pyrite dominated polymetallic assemblage±small amount of pyrrhotite, marcasite, hematite, tetrahedrite, bournonite and galeno-bismutine. From gangue minerals there are present, quartz, Mg-siderite, barite, kaolinite and calcite.

At the bottom of the ore-bearing volcanic-sedimentary sequence with kuroko style mineralization is a quartz diorite porphyry intrusion, in a form of a big laccolithic body, sills and dikes, which provided energy for circulating hydrothermal fluids and leaching reactions. Here present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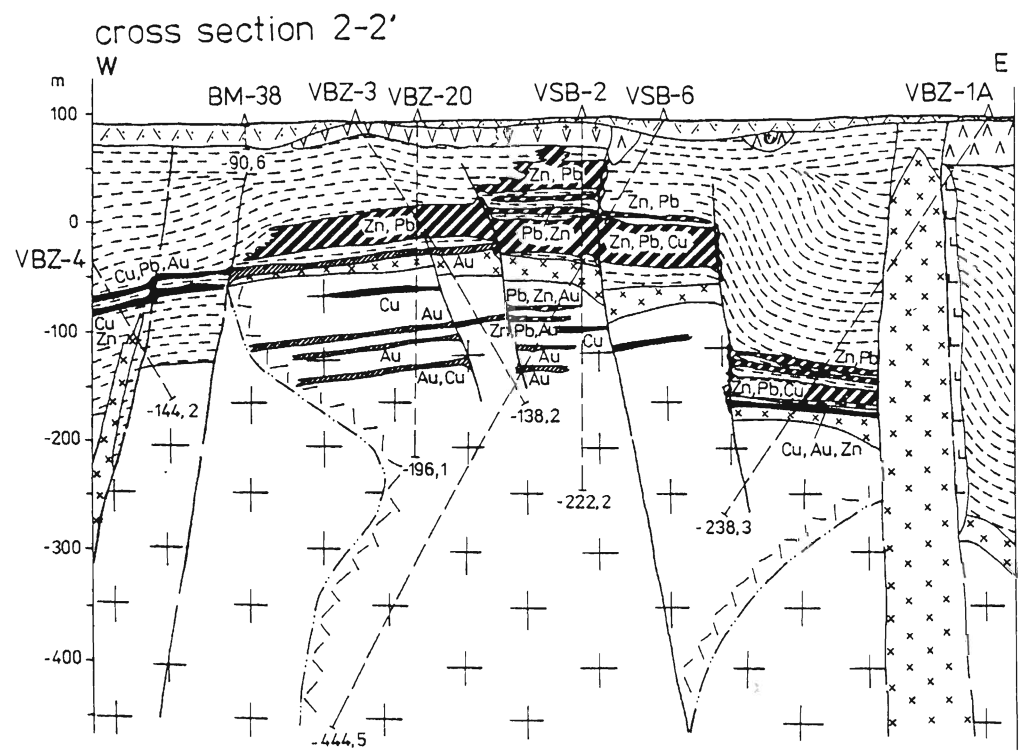
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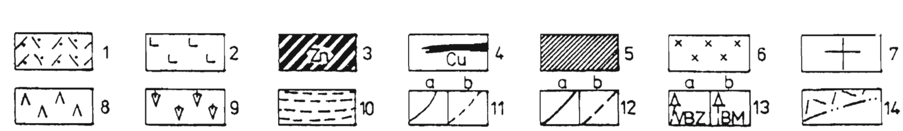
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◀ **Fig. 1.** and **2.** Representative schematic-geological W–E cross-section of the submarine volcanogenic sulphide deposit, near Brehov in Eastern Slovakia. 1 – clays, loams, sands, (Quarternary); 2 – dike body of pyroxene andesite, (Early Sarmatian); 3 – sulplhide-matrix breccia Zn-Pb-Fe (black) ore; 4 – sulphide-matrix breccia Cu-Fe (yelow) ore; 5 – siliceous stringer and disseminated Au-Fe±Cu ore of intrusive exfoliation zones; 6 – transformed quartz diorite porphyry sills, dikes; 7 – laccolithic body of transformed quartz diorite porphyry; 8 – argillizated rhyodacite extrusions and lava flows; 9 – silicified and adularized rhyodacite extrusions and lava flows; (3–9 Late Badenian); 10 – ore-bearing volcanic-sedimentary sequence, (Middle Badenian); 11 – geological boundaries: a - proved, b - assumed; 12 – faults: a - proved, b - assumed; 13 – drill-holes: a - deep: 300–650 m; b - deep: 10–100 m; 14 – brecciated hydrothermal vent (conduit) boundaries.

siliceous stringer and disseminated hydrothermal mineralization is composed of quartz, sericite, Mg-chlorite, adularia, Mg-siderite, pyrite, pyrrhotite, chalcopyrite gold (Bacsó, 1997).

Studies of the volcanogenic sulphide mineralization in the Brehov-West ore deposit define two geochemical, mineralogical and spatial gold associations: (1) Gold with possible economic significance (up to 9 g/t) is concentrated with copper at the base of the Brehov-West matrix-breccia Zn-Pb ore deposit, mostly in the intrusive sill-bodies of quartzdiorite porphyry (in connection with typical high-temperature accessory minerals, such as wolframite, scheelite and specularite); and (2) gold with no economic significance (up to 5 g/t) occurs in auriferous pyrite in the baritic top of the Zn-Pb ore lenses. The first type is localized within a domain covering the central Brehov-Konopiská part of the deposit, which is characterized by an near surface (130–250 m) abundance of intrusive quartz diorite porphyry facies (big laccolithic body, sills and dikes). The paragenesis shows that gold association formed at high temperature (› 300 °C) during the initial phases of kuroko style sulphide genesis. The second type is found near surface, in the south-east Brehov-Trávnický kopec domain of the deposit, where altered rhyodacitic extrusive facies are predominant. The paragenesis shows that gold association formed at lower temperature (› 280 °C), late in the kuroko type sulphide genesis.

Zonation

Vertical and lateral zonation is evident in the Brehov-West deposit. The lowest temperature hydrothermal minerals occurred in the upper zones and the highest temperature hydrothermal minerals in the lower zones. The general metallic trend is: barite-quartz-clay minerals in the near surface upper levels, zinc-lead in the main upper-middle levels, copper-pyrite in the lateral lower-middle levels, and pyrite±chalcopyrite±gold in the central lowest levels (in stockwork intrusive exfoliation zone). This situation is particularly evident in the principal deposit-sections (1–1' and 2–2') of the Brehov-West deposit. Kuroko style mineralization near village Zemplín has no indications of equally well defined vertical zones (see Fig. 1 and 2).

Genetic model

The Brehov kuroko style ore deposit formed from hydrothermal fluids as syngenetic and epigenetic accumulations of sulphide and sulphate minerals, near the floor. Several lines of evidence support this model: the typical stratabound nature, sharp upper contacts, and close association of matrix-breccia sulphide ores with surrounding sedimentary rocks (mudstone) that contain abundant transported products from the hydrothermal vents; and extensive alteration and stringer zones of hydrothermal minerals confined exclusively to the stratigraphic footwall of the Brehov sulphides. Sources of fluids: Two possibilites for sources of fluids there are: (1) circulating seawater and (2) magmatic water. The product of hydrothermal fluids emananted from sea-floor vents there are Mg-chlorites (brunsvigite, ripidolite, pycnochlorite), Mg-carbonates (Mg-siderite, Mg-ankerite, Fe-dolomite) and clay minerals. Sources of heat: The lower half of the kuroko style ore bearing volcanic-sedimentary sequence near vilage Brehov (in the resurgent caldera structure) contains abundant adularized quartz diorite porphyry sills, dikes and near the base of the volcanic-sedimentary sequence is known a big laccolithic body of partly adularized quartz diorite porphyry. Alteration and stringer ore exfoliation zone formation: In the intrusive stockwork, in the footwall of the main stratabound ore bodies, the stringer ore exfoliation zone, beneath the kuroko type subhorizontal ore lenses are enriched in copper. The alteration assemblages associated with the bottom stringer ore zone is presented by silicification, sericitization, Mg-carbonatization, Mg-chloritization, adularization. The abundance of magnesian chlorite and magnesian carbonate may be related to the rate of advection of cold sea-water into the area surrounding the subseafloor hydrothermal conduit.

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Remark: Electron microprobe analyses of monomineralic multigrain aggregates were conducted with a CAMSCAN LINK-AN 10 000 system, at the Research Institute ČSUP, in Stráž pod Ralskem, Czech republic. Analysts: M. Scharmová and P Súlovský. A total of 500 sulphide and gangue minerals were analyzed, in order to obtain quantitative chemical data from mineral grains in Brehov ore deposit.

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The types of the mineralized structures from the Baia Mare ore district, Romania

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Abstract

The Baia Mare district represents the NW part of the Neogene volcanic chain in the Eastern Carpathians. The magmatic rocks have a predominantly calc-alkaline character, and the metallogenesis is a gold and base-metal one. Mineralizations appear as veins, stockworks and breccia columns. The veins are associated with intrusive bodies and stratovolcanic structures.

Key words: Neogene volcanism, gold and base metal mineralizations, polyascendent character, veins, stockwork, breccia pipe

Introduction

The metallogenetic district Baia Mare is situated in the Gutâi Mountains and represents the NW part of the Neogene volcanic chain inside the Carpathian Mountains. The calc-alkaline Neogene volcanism is related to the subduction processes of the orogenic Carpathian chain. This district is the most productive and includes gold and base-metal mineralizations.

Geological seetting

The prevolcanic basement is made out of metamorphic rocks and Paleogene and Neogene sedimentary sequences. These formations were deeply dislocated by longitudinal pre-Neogene fault (Cârlibaba-Carei) that controlled the development of the volcanism and of the metallogenesis (Borcoş et al., 1994). After geochemical features of the Oaş-Gutâi Mountains volcanism, two types of volcanic rocks are observed: calc-alkaline acid and calc-alkaline intermediate. The volcanic activity began with the explosive acid phase (rhyolite-rhyodacite) of Lower-Badenian-Sarmatian age. The intermediate volcanism occurred in the second (Sarmatian-Pontian) and third cycle (Upper Pliocene) (Giuşcă et al., 1973). The recent K-Ar data (Edelstein et al., 1992; Kovacs et al., 1994; Pécskay et al., 1994) indicate the age of the volcanism from Late Badenian to Pannonian for Oaş Mountains and Gutâi Mountains. The intrusive magmatic activity occurred later together with the lava flows of the calc-alkaline intermediate volcanism. The bodies of intrusive magmatic rocks from the Oaş-Gutâi mountains have different morphological characters: stocks, dykes, apophyses, silles, microlaccolithes. These intrusive bodies have an important role ore deposits localisation.

Metallogenetical background

The metallogenetic activity corresponds to three distinct phases (Giuşcă et al., 1973) overlapped over the calc-alkaline intermediate magmatic activity of the second eruption cycle. According to the K-Ar and Ar-Ar radiometric data (Lang et al., 1994) the metallogenetic activity is restricted to the Pannonian level (11.5–7.9 M.a.). Analysing this data we consider that there is a single metallogenetic phase in Oaş and in Gutâi Mountains. Within this metallogenetic phase, three mineralization stages can be separated: a copper stage, a base-metal and a gold silver ones. The upper parts of the copper and base-metal mineralizations have important quantities of gold and silver. Within the base-metal veins the polyascendent character is observed. For the gold veins and veins of small dimensions the monoascendent character is predominant. The structural control, the association with magmatic intrusions, the type of ore deposit, the hydrothermal alterations and the mineralogical composition integrate them to the epithermal and mesothermal type.

Types of mineralized structures

The veins appear in the form of vein systems associated with intrusive or stratovolcanic structures. The gold-silver veins are localized in stratovolcanic structures. In such structures also base-metal mineralizations appear, but they are obviously rich in gold and silver. In the most typical stratovolcanic structure gold mineralizations

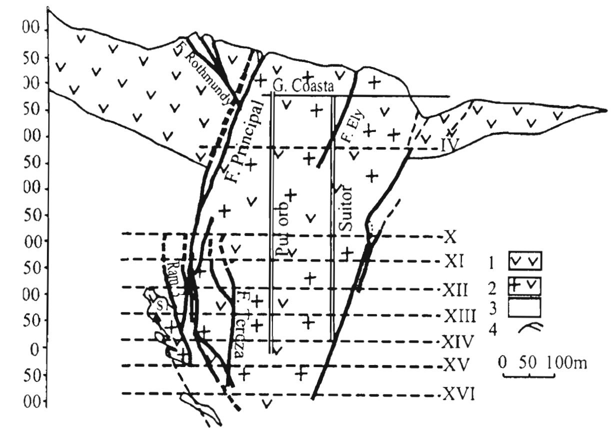

Fig. 1. Cross section through Baia Sprie ore deposit (western part) 1 – Andesite lava, 2 – Dyke, 3 – Pannonian, 4 – Vein.

of Săsar-Propad are developed. The main veins are very extended in the vertical direction and pierce the entire stratovolcanic structure. At Văratec Băiuţ in the eastern part of the district the vein mineralizations also appear in a stratovolcanic structure. The gold base-metal veins are localized in intrusive bodies, lava flows, pyroclastites and Paleocene sedimentary rocks. The central area includes gold-copper mineralizations, and the marginal areas gold and base-metal mineralizations. The vein systems associated with intrusive structures are very frequent in the Baia Mare area. The most representative is the Baia Sprie ore deposit (Fig. 1). The andesitic dyke constitutes the local geological element with an important role in metallogeny. The Main vein is localized on the northern contact and the New vein in the southern contact of the dyke. The Main vein has a great number of branches in both the upper and lower part. Inside the dyke small size veins are present. The vertical silver-gold, lead-zinc and copper zonality is very clear.

A similar structure is the one from Şuior (Borcoş et al., 1973) where the Cremenea vein is situated on the northern contact of the porphyry microdiorite structure. Vein systems associated with intrusive bodies are also found in the western part of the Nistru Valley. In this area the veins are zonally disposed around a porphyry micromonzodiorite intrusion. On the flanks of the body copper veins appear and towards the exterior veins with base-metal and gold mineralizations are also present. There are transitions from structures of stratovolcanic type to the intrusive body structures where the predominantly cupriferous lower parts, are localized within subvolcanic structures. Typical for this model is the vein Bolduţ-Cavnic field. A structure associated with an intrusion of laccolithe type can be found at Ghezuri-Turţ in the Oaş Mountains (Fig. 2). The mineralization is localized on the flanks of a laccolithe with intense potassium altered porphyry microdiorite and has a base-metallic character. The copper veins are entirely localized in intrusive bodies of quartz-dioritic type in the east of the mining district at Toroioaga or they are disposed in the area of the microdioritic intrusive bodies like the ones from Cisma–Poiana Botizei. The vein systems with base-metallic mineralizations are almost entirely situated in intrusive bodies (e.g. Herja).

The stockworks are less known in the Baia Mare area. The reorientation of prospecting and exploration researches in the upper parts of the mineralized structures have emphasized their presence in various areas. In the upper parts of the intensely branched veins gold stockworks could appear predominantly. The most typical body of stockwork type is the one from Borzaş which is overlapped on a vein system and localized in adularized and brecciated quartz andesites. A similar body localized in adularized pyroxene andesite can be found in the western part of the perimeter at Racsa. Gold stockworks are localized in the upper branched parts of the mineralized structures from Şuior, Baia Sprie and Aurum-Săsar.

The breccia bodies are the least known in the Baia Mare

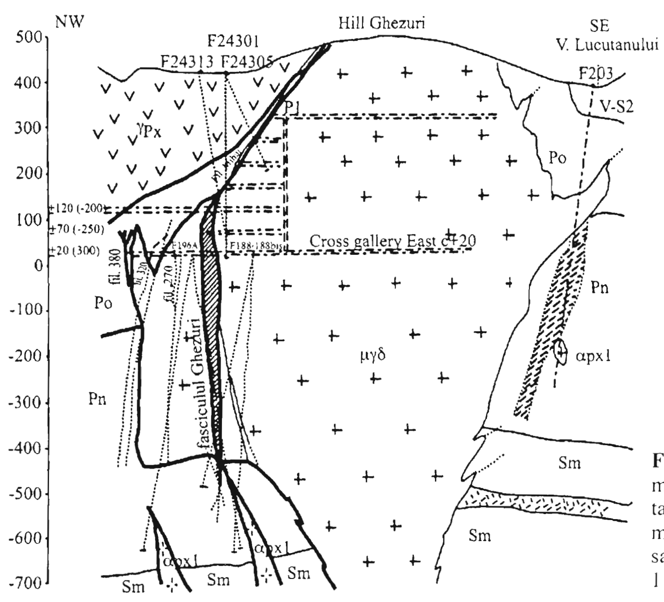

Fig. 2. Cross section through Turt Ghezuri ore deposit. 1 – porphyry micro-diorite, 2 – porphyry micro-granodiorite, 3 – volcano-sedimentary formation, 4 – pyroxene hyalodacites, 5 – Pontian (clays, sands, marls), 6 – Pannonian (marls, sandstones, clays), 7 – Sarmatian (marls, sandstones, tuffs), 7a – pyroclastics, 8 – Veins, 9 – Gallery, 10 – Shaft, 11 – Drillings.

mining district. The main explosion breccia pipe structure from Kelemen Băiuţ is base-metal mineralized. The dyke type breccia are typical for the mineralized shear fault like the very thick veins from Şuior and Baia Sprie. Inside very thick veins and at the vein intersections mineralized breccia of phreatomagmatic explosion appear. The breccia especially from the upper parts of the mineralized structures will be known much better from the ongoing prospecting and exploration carried out in the Baia Mare area for epithermal gold mineralizations.

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New petrological and volcanological data about the Telkibánya epithermal silver-gold mineralization (Tokaj Mts – Hungary)

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Key words: Tokaj Mountains, Hungary, Telkibánya, epithermal low sulphidation, gold mineralizaton, andesite volcanics

History

Telkibánya is a site for mining and ore explorations since the 1400s. Detailed mining records are dated back to 1660. Explorations in the modern times started in 1951, the first stage finished in 1964. After the liberalization of mineral explorations, this area was considered as one of the most promiseful precious metal project target areas in Hungary. RTZ has initiated new exploration efforts in the surrounding areas, and carried geophysics, geochemistry and out reconnaissance drilling. The programme has been stopped in 1998. The works did not extend to the most perspective parts of Telkibánya, but they give useful tools to optimise further explorations in the core of the mineralization. The explorations were complemented by substantial scientific research works, which dealt with the petrology, geochemistry, geochronology, paleotemperature relationships of the area (Molnar et al 1999). The exploration model created from the surface informations is now extended using the infomations obtained from the drillholes and surface explorations.

Local geology

Submarine andesite flows of the Badenian age form the oldest known formations, intersected only by the Tb2 stratigraphic drillhole at 790 m depth. These are covered by shallow marine claystone, siltstone (Badenian), giving way to increasing accumulation of acid pyroclastics and and volcanic sedimentary rocks (Sarmatian).

These rocks are partly overlain and partly intruded by andesite, dacite and rhyolite flows, domes, dikes and shallow porphyric intrusive breccia bodies (11,8-13,13+/-1,2 m.y). The complex forms two caldera structures of which the southern one is centered on the known most perspective mineralization zone (Fig. 1). The rocks show intense hydrothermal alterations. The latest andesite dikes and subvolcanic bodies within the caldera structure (10,6-10,9+/-1,4 m.y) are fresh, and crystallized after the main hydrothermal mineralization.

As the existing gravity and magnetic data and corresponding paleotemperature data indicate, the most intense hydrothermal mineralization coincides with a concealed deep intrusion. Fracture zones of NNW-SSE and N-S strike host the important mineralized veins.

Hydrothermal alterations

The early phase of hydrothermal activity produced intensive propylitisation. This is followed by a pervasive adularia-sericite replacement. A kaolinite (halloysite)-quartz alteration is superimposed onto potassium alteration zones at the mineralization centres. A late-stage (?) alunite alteration progressed along N-S and NNW-SSE fault zones. Pervasive pyritisation is found in brecciated zones, outside of adularia-sericite alteration halo.

Known ore mineralization is found to be related to late vein structures and stockworks. Silver is more related to higher temperature alterations (SE part), in NNW-SSE structures, in closer association with Pb-Zn-Cu geochemical anomalies. Gold is linked to N-S veins, and possibly superimposed onto earlier silver-base metal mineralization. The main silver bearing phase is acanthite, while gold occurs mostly as native free gold.

New data from surface explorations

The geochemical fingerprint of gold and silver elements in the soil geochemistry are markedly different. Gold anomalies are N-S elongated and coincident with known vein structures. Silver anomalies are NNW-SSE elongated and lie on non-vein bearing fault zones. Mineralized veins

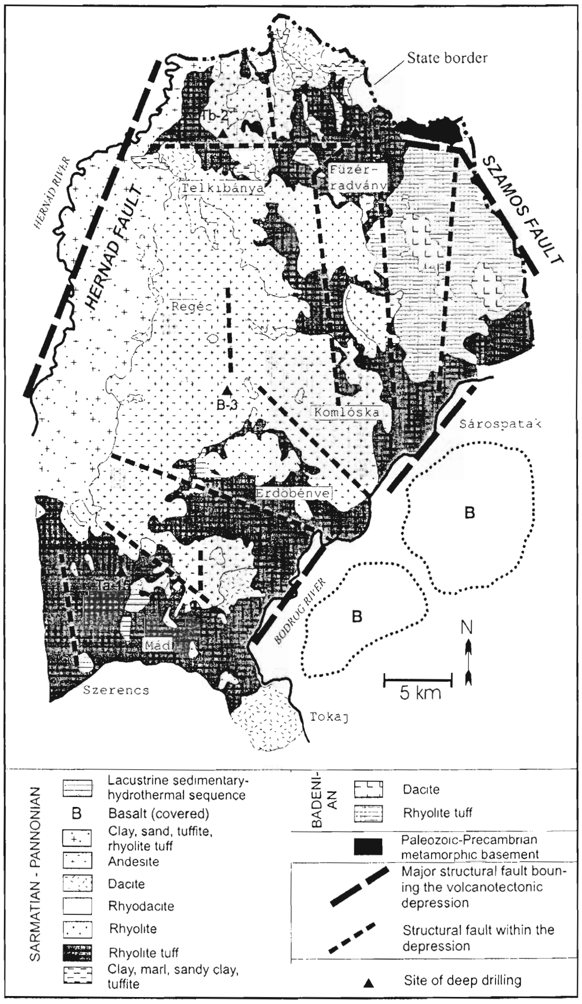

Fig. 1. Geological map of the Tokaj Mts (modified after Molnar et al., 1999).

fall in wider low resistivity zones, representing brecciated linear structures with more pronounced argillic alterations.

Peripherial reconnaissance drilling

In 1997 the TKB1-TKB4 drillholes intersected the interface between the Sarmatian altered andesites and the overlying Pliocene/Pannonian reworked volcanic sediments and rhyolite tuffs. The hydrothermal alterations in the overlying sediments indicate the survival of hydrothermal activities during the accumulation of sediments.

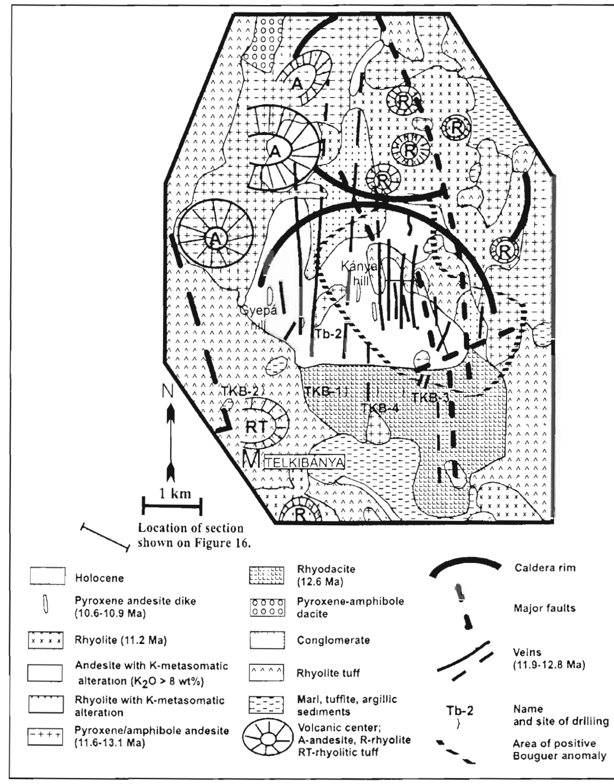

Fig. 2. Geological map of Telkibánya showing the peripherial reconnaissance drillholes (modified after Molnar et al 1999).

The drillholes have proved, that the Sarmatian pyroxene andesites are either submarine flows or shallow subvolcanic bodies, which were emplaced into the submarine volcanics. The drillholes also evidenced that the alterations resulting the potassium enrichment postdate the chlorite-carbonate alterations (propylitic phase) but predate the quartz-kaolinite (halloysite) alterations, which are associated with the gold mineralization.

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Native gold in primary and supergene enrichment zones of high sulfidation epithermal systems – comparison of Lahóca, Recsk (Hungary) and Podpolom, Klokoč (Slovakia) mineralizations

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Abstract

The authors studied the forms and genetic conditions of gold in the Lahóca and Podpolom epithermal deposits. Gold is present in native form in both deposits. In the Lahóca mineralization gold appears in the primary sulfide zone, in form of a few microns to a few tens of microns large grains, mostly in pyrite, subordinately in the silicified matrix. At Podpolom gold enrichment is related to the supergene zone, the 1–2-microns large gold grains occur in the goethite of the matrix of hydrothermal breccia.

Key words: epithermal deposit, high sulfidation system, gold mineralization

Introduction

Both Lahóca and Podpolom deposits are considered as epithermal high sulfidation systems. The Lahóca deposit formed in the Paleogene volcanic unit of the Mátra Mountains, the Podpolom deposit is located in the central zone of the Neogene Javorie Stratovolcano. The gold grades of the two deposits are similar, although economic mineralizations appear in different zones of the systems.

Geology and mineralization of the Lahóca deposit

The Paleogene Recsk unit that encloses the Lahóca mineralization is a smaller part of the Mátra Mountains produced mostly by Neogene volcanism. The pre-volcanic basement of the Recsk area consists of Triassic limestone, quartzite and shales. The Paleogene series starts with Upper Eocene shallow marine sediments. The igneous rocks were developed in both volcanic and intrusive levels. The rocks are of andesitic and dacitic composition with dominantly effusive character.

Besides the Lahóca gold mineralization, the Recsk complex also displays porphyry, skarn and metasomatic mineralizations. The Lahóca epithermal ore appears in the breccia zones of the andesitic series. The breccia has a polymict character with intesive silicification and it is frequently rebrecciated. The breccia bodies are surrounded by advanced argilic alteration with pyrophyllite, dickite, kaolinite and quartz. Outwards, these minerals change into smectite-illite. The most common ore minerals are enargite, luzonite and pyrite. The gold is concentrated in the strongly silicified zones (Földessy, 1997).

Geology and mineralization of the Podpolom deposit

The pre-volcanic basement of the Javorie area is represented by Hercynian granites and metamorphic rocks. Similarly to the Recsk area, the Javorie complex also involves subvolcanic intrusions and a stratovolcanic sequence of andesitic to dacitic composition.

There are two well-defined types of mineralizations in the Javorie complex: porphyry Cu mineralization connecting to the intrusions and high-sulfidation mineralization located at the hydrothermal centers above them.

In the Javorie mineralization, the highest Au grades were found at Podpolom hydrothermal center. The ore is hosted by hydrothermal breccias. The breccia is mostly monomict with multiple brecciation. The silicified breccia particles are cemented by quartz, oxidized sulfides (py-

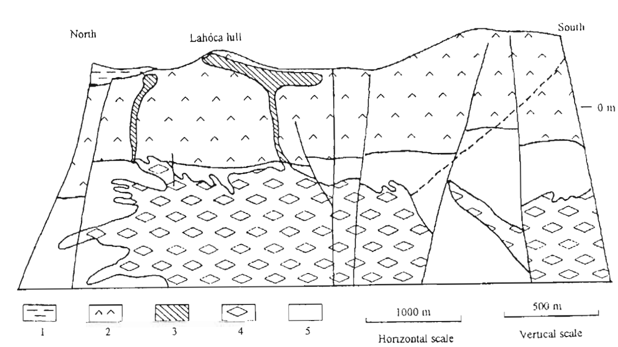

Fig. 1. Schematic section of the Recsk complex. 1 – Oligocene clastics, 2 – Upper Eocene andesite, 3 – gold minerallization, 4 – porphyry copper and skarn mineralization, 5 – Mesozoic basement.

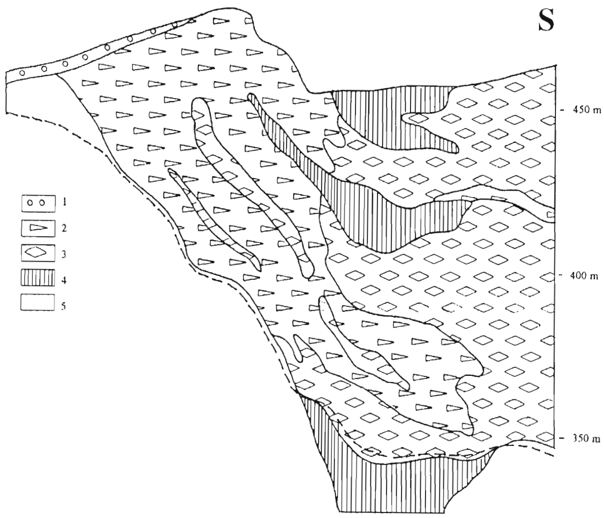

Fig. 2. Schematic section of the Podpolom deposit (After Štohl et al., 1999). 1 – deluvium with rubble ore, 2 – Au-bearing breccias, 3 – Au-free breccias, 4 – friable barren sesidual quartzite, 5 – argillites with pervasive pyrite.

rite) and subordinately argillic minerals. Although primary gold might have been associated with pyrite, the economic gold mineralization is bound to supergene oxidation processes. Gold content drops significantly with the decrease of the ferrugineous to siliceous matrix (Štohl et al., 1999).

Characteristics of gold and associated minerals

Gold assay results extend a few tenth to ten ppm in both deposits. Except a few "larger" grains, gold is not detectable by optical methods. According to the SEM and microprobe studies, it occurs mainly in native form in both deposits.

In the samples from Lahóca gold is associated mostly with pyrite in the form of a few microns to ten microns large rounded inclusions. It is also occurs in the silicified matrix as smaller, irregular grains or aggregate-like structures. Pyrite appears in the euhedral, subhedral, framboidal and amorphous form. Euhedral pyrite is usually free of gold. Enargite and luzonite are frequently present, containing inclusions of different minerals of Sn, Cu, Te, As and Sb.

In the Podpolom mineralization gold grains are smaller than in Lahóca, their sizes are about one to two microns. The gold appears in goethite of the breccia matrix. The silicified breccia particles are barren of gold. Part of the gold is possibly present in solid solution form in the lattice structure of the relatively rare, small, unaltered pyrite crystals. chalcopyrite and less sphalerite were also observed. In both deposits, rutile shows a close correlation with gold content. Prismatic crystals and needles of rutile-usually associated with pyrite – are more abundant in the higher Au-grade samples. As ilmenite is also present, the rutile might have formed by the sollution of Fe-Ti oxides. The iron could possibly appear in pyrite crystals.

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High and low sulphidation epithermal gold mineralization related to the Recsk porphyry complex (Hungary)

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Key words: Eocene, volcanics, low sulphidation gold, high sulphidation gold, Recsk, Hungary

Introduction

The Recsk ore complex is well known for its wide diversity of different mesothermal base metal mineralizations related to diorite porphyry shallow intrusives. This porphyry copper mineralization was used as a guide to explore the unrecognized Lahóca high sulfidation epithermal mineralizations in 1993–1997. The presence of the long known scattered copper-silver veins with sericite-adularia alterations have triggered futher explorations on the peripherial parts. Low sulfidation gold-silver mineralization has been discovered and partly explored in 1996–1997.

Geology

In the Recsk area Triassic carbonate-siltstone-shale series forms the deepest known basement formations. This is overlain by thick submarine andesite flows, later dacite flows and pyroclastics, and the youngest (mostly terrestrial) andesites, andesite tuffs. The sequence represents a continuous regression from closed anoxic shallow marine basine environment (intercalations of bituminous limestones and marls) to open island-like subaerial formation, with remnants of surrounding corral/algae reef limestones. The complex includes several small individual volcanic forms, partly superimposed, partly destroyed by each other. The latest structure of this kind is centred on the Lahóca, and includes several phases of shallower subvolcanic bodies emplaced into the subaerial-submarine volcanics. The succession of intrusive emplacement caused multiple brecciation of former volcanic rocks, later hydrothermal introduction has led to the formation of hydrothermal explosive brecias by the trapped hydrothermal vaporised flluids beneath impermeable rock canopies. The mineralization is related to several stages of becciations, the introduction of gold is dated to the formation of the mentioned hydrothermal explosive breccias (Földessy 1997). The low-sulfidation alterations – Hosszúvölgy mineralization – occur 3 km south from the Lahóca mineralization, and are developed in the middle stage dacite volcanics. The alteration is spatially related to the N-S striking fault structures which have been developed diagonally from a dacite plug. The fault structures host polymict intrusive breccias, as late-stage ingtrusions into the dacite volcanics.

Hydrothermal alterations

The Lahóca mineralization shows zonal advanced argillic alteration. The central parts are characterised by the presence of kaolinite, dickite, illite, quartz (occasional alunite, pyrophyllite), and leached out later to vuggy silica skeleton structures. The outer zones become gradully enriched in montmorillonite, with an outer rim of strong chlorite-carbonate alterations. The highest gold contents are related to the central zone, diminishing outwards. The chlorite-carbonate alteration zone is barren.

The Hosszúvölgy mineralization has been developed in zones of strong quartz-sericite alteration. This is thought to be related to the mesothermal alteration halo of the underlying porphyry intrusions. The superimposed adularia-sericite alteration shows strictly elongated character and close relationship to the N-S fault system. In part it is developed as massive low-temperature quartz veining. The adularia-sericite alteration crosscuts the dacites and the emplaced later intrusive breccia pipe rocks too (Gatter, I. et al. 1999).

Ore mineralization

The high sulphidation gold mineralization appears in thick semihorizontal tabular enrichment zones. Within these zones the gold is dominantly related to pyrite and enargite minerals, and forms few micron sized inclusions in these minerals. Native gold is rare, but recent microprobe investigations evidenced its widespread presence (Földessy and Seresné-Hartai, 2000). Silver is not related to gold, instead, it forms later enrichments along fault structures.

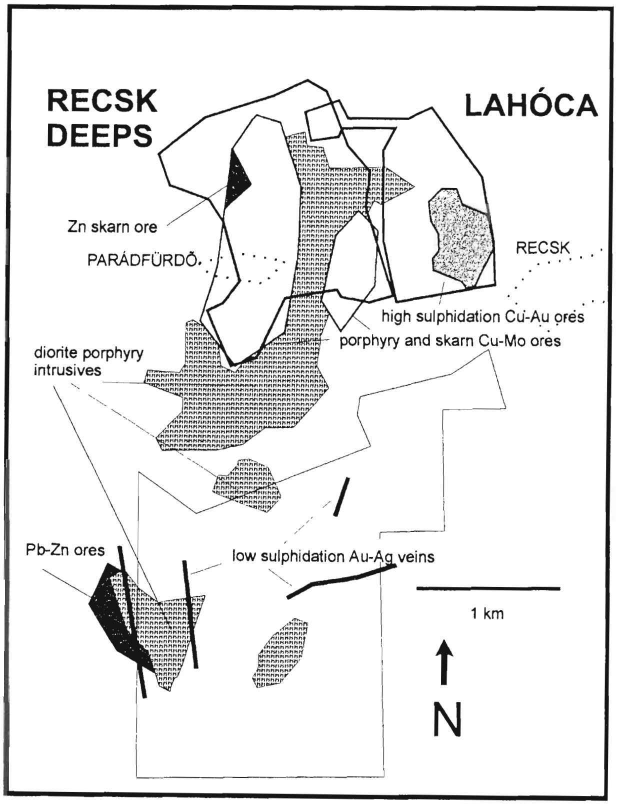

Fig. 1. The distribution of main ore types in the Recsk ore complex.

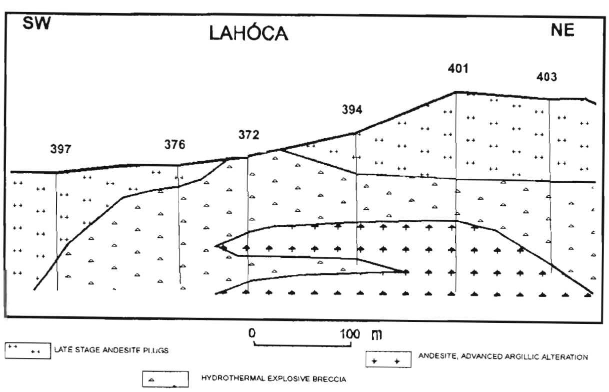

Fig. 2. Geological section accross the Lahóca mineralization.

The low sulphidation gold enrichment occurs mainly in form of finely dispersed native gold in the matrix of the polymict breccia host rock. It is not visually related to any of the sulphide phases. Pyrite, sphalerite, tetrahedrite are associated. The zones have characteristically high silver content.

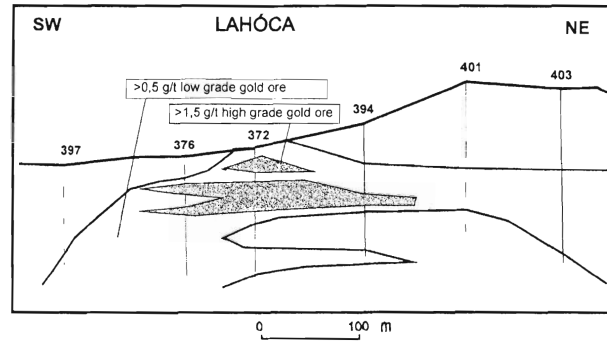

Fig. 3. Gold distribution in the Lahóca orebody.

New exploration model

The low and high sulphidation mineralizations have no proven spatial connection. According to textural evidences the Lahoca gold mineralization is superimposed (later) than the Lahoca enargite-luzonite mineralization. It also occurs in the hydrothermal veinlets which fill fissures of late-stage hydrothermally unaltered andesite volcanics. These late stage volcanics are well identifiable with the post-ore barren diorite intrusions known in the deep levels. In this way the Lahoca gold mineralization is a late stage event, and postdates the porphyry copper (and related other base metal) mineralization. such small subvolcanic bodies were emplaced in the overlying Oligocene sediments. In this case the gold mineralization would span over the Eocene volcanics ant the time of the earliest Oligocene sedimentary accumulations.

The low-sulfidation gold mineralization can well be explained as peripherial counterpart of the high-sulphidation gold mineralization. However, considering its coincidence with the N-S regional fault system (which was active throughout the Neogene), a genesis involving later superposition of Miocene hydrothermal activity can not be ruled out either.

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Eruptive history of the Calimani mountains as inferred from K-Ar geochronology

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Abstract

The Callimani Mountains represent the largest and most complex volcanic structure at the norther part of the 160 km long Calimani-Gurghiu-Harghita chain. 32 new K-Ar ages, besides other 34 published ages, of different types of magmatic rocks (lava flows, intrusions, blocks in volcaniclastics) document the reconstruction of the eruptive history of the volcanic edifice. The new data, integrated in previous volcanological and dating work, show that the interval of magmatic activity took place between 11.3 and 6.7 Ma.

The oldest dated rocks are represented by shallow unroofed intrusions (basaltic andesites, andesites and microdiorites) which pierced the metamorphic and Cretaceous-Tertiary sedimentary basement of the region. The interval (11.3–8.6 Ma) is coeval with the other similar subvolcanic intrusives belonging to the Bargau area (11.9–8.6 Ma). Opened by erosion they also crop out inside the actual volcanic area in the Zebrac valley (10.1–10.6 Ma) or along the Mures valley in the Stanceni quarry (9.5 Ma). In all these occurrences the piercing relationships of the intrusive rocks with Neogene sedimentary strata are obvious.

As inferred from volcanological and petrographical observatons, the oldest stratovolcano was probably centered on the actual main volcanoes of the Calimani Mts.-Rusca-Tihu and Callimani Caldera. We suppose that this volcano, built mostly by basaltic andesites, was very large and voluminous, because it has supplied a huge volume of volcaniclastic deposits, part of them related to a large debris avalanche event. The dating of the debris avalanche blocks show the age interval 10.2–7.8 Ma, also further south in the Gurghiu Mts area. K-Ar data suggest the Rusca-Tihu edifice failure around 8.0±0.5Ma.

After the debris avalanche event, which caused major topographic changes, volcanic activity continued at the same Rusca-Tihu volcano and other peripheral vents, in the age interval 8.2–6.8 Ma. The Calimani Caldera is the most important post debris avalanche volcano. The pre-caldera volcanic rocks show ages 8.2–6.8 Ma, while post-caldera volcanic events are dated at 7.3–6.7 Ma. Post-caldera monzodioritic-dioritic resurgent intrusion exposed in the central part of the caldera shows a large age interval 8.8–7.3 Ma, possibly related to multiple intrusion events. According to K-Ar data, the caldera generation event can be assumed around 7.1±0.5 Ma.

During the generation of the Rusca-Tihu volcano, small-volume effusive and explosive vents were also active, especially in the south-eastern periphery of the Calimani Mts. They belong to the Dragoiasa dome complex (9.3–8.4 Ma), low-K andesite and dacite complex (8.6 Ma), dacite and andesite domes (8.7–7.1 Ma), the Sarmas basalts (8.3–7.3 Ma), suggesting that most of them were active before the debris avalanche event. In the westernmost part, the Budacu andesitic-dacitic complex, dated at 9.0–8.5 Ma, crop out below the Rusca-Tihu debris avalanche depostis, suggesting an older event.

Key words: K-Ar dating, Tertiary, volcanism, Romania

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Tertiary development of the Eastern Slovakia

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Abstract

Tertiary deposits of the Eastern Slovakia are distributed in three basic tectonosedimentary settings represented by the Outer Flysch Zone and Klippen Belt, Central-Carpathian Paleogene Basin and East-Slovakian Basin. The Outer Flysch Zone represents a system of foreland basins prevailingly filled by Late Cretaceous – Oligocene turbidites. The Central-Carpathian Paleogene Basin (CCPB) is a piggy-back basin with prevailingly deep-water sediments deposited from the Paleocene to the Early Miocene. We suggest a gradual transition of sedimentation from the Paleogene and Neogene implying genetic relationship of the CCPB and the East-Slovakian Neogene Basin. The East-Slovakian Neogene Basin is a basin with complex tectonic history. Its sedimentary fill, thick up to 8 km, was deposited in a shallow, epicontinental sea.

Key words: Western Carpathians, Outer Flysch Zone, Central-Carpathian Paleogene Basin, East-Slovakian Neogene Basin

Introduction

Tertiary deposits cover more than three-quarters of the Eastern Slovakia. They occur in three basic tectonosedimentary settings represented by Outer Flysch and Klippen zone, Central-Carpathian Paleogene Basin (CCPB) and East-Slovakian Neogene Basin (ESNB). The basins are filled by tremendous volume of sediments – the thickness of deposits in the Outer Flysch zone attains more than 10 km (Vozár et al., 1998). The deposits filling the Central-Carpathian Paleogene Basin are up to 3 km thick (Gross et al., 1984) and the seismics in the East-Slovakian Basin revealed 8 km thick sediments (Vass et al., in press). The Tertiary deposits are interesting from several viewpoints. The most interesting point is hydrocarbon prospection. Gas is exploited at several places in the ESNB (Ptrukša, Stretava, Senné, Pozdišovce) and some areas in the Outer Flysch zone and CCPB are assumed to have high hydrocarbon potential too. Recently, environmentaly aimed investigation have been started in order to predict areas apt to sliding and to characterize hydrogeologic parameters of rocks in order to predict their behaviour during floods (Janočko et al., 1999a).

The Tertiary tectono-sedimentary history continuously evolved from the Mesozoics. It was closely related to the convergency between the European Platform and Carpathians (e.g. Royden et al., 1983; Sandulescu, 1988; Csontos, 1995; Decker and Peresson, 1996), lateral escape of internal units from the Alpine collisional zone (e. g. Csontos et al., 1992; Csontos, 1995; Potfaj, 1998) and crustal flexure due to gravititional load of the inner Carpathian Mesozoic Nappes. Subduction zone between the European Platform and ALCAPA block is suggested by accretionary wedge consisting of Cretaceous and Paleogene deposits of the Outer Flysch zone as well as by subduction-related Neogene volcanism (Lexa and Konečný, 1998; Lexa and Kaličiak, this volume).

Outer Flysch Zone and Klippen Belt

The deposits of the Outer Flysch Zone comprise the Magura and Dukla Units in the Eastern Slovakia (e.g. Koráb and Ďurkovič, 1978; Nemčok et al., 1993; Biely et al., 1996). Traditionally, the Paleogene deposits overlying the Mesozoic sequence of the Klippen Belt are assigned to the Klippen Belt Paleogene area (Leško and Samuel, 1968). The Paleogene tectono-sedimentary evolution of the Outer Flysch Zone and Klippen Belt continued from the Mesozoics when, besides continuous sedimentation in the Vahic realm, opening of the Outer Flysch Zone peripheral foreland basins commenced. The palaeoflow directions of the deposits, belonging to the Magura and Dukla Units, suggest a common sedimentary basin for these two units (Koráb and Ďurkovič, 1978). Position of the Klippen Zone Late Cretaceous – Paleogene sedimentation area is still unclear and has currently been under research. However, some sedimentologic sequences may suggest its relationship to the Magura – Dukla basin.

The earliest phase of the sedimentation in the East-Slovakian Outer Flysch zone is recorded by the Cenomanian up to Paleocene shales and minor sandstones (Lupkov Fm. of Dukla Unit and Jarmuta Mb. assigned to the Klippen Belt sedimentation area). They comprise typical initial, deep-water, fine-grained deposits of peripheral foreland basin (e.g. Ricchi Lucchi, 1986; Miall, 1995). Increasing sand content in the overlying deposits denotes development of subaerial sediment source, probably connected with emerging of first fold-thrust belts. Compressional regime, connected with thrusting and morphological segmentation of oceanic floor, was already proved in the Paleocene. High tectonic mobility of the basinal and source areas is also recorded by sedimentary sequences showing several types of depositional environments. Basin slope deposits are represented by sediments of Strihov Mb. (Middle to Late Eocene, Marschalko and Koráb, 1975; Biely et al., 1996) belonging to the Magura Unit. Prevailing sandstone deposits, showing normal and reverse grading, sharp bases and floating intraclasts, suggest deposition by high-density turbidites (e.g. Mutti, 1992). They alternate with matrix-supported conglomerates indicating slump deposition on the basin slope. The overlying deposits of Beloveža Fm. (Magura Nappe, Paleocene – Late Eocene, Leško and Samuel, 1968; Biely et al., 1996) consist of alternating shale and sandstone beds. The sharp-based beds are laterally continuous and suggest outer fan or overbank depositional environment. They pass into Makovice Sandstone (Lutetian – Priabonian, Leško and Samuel, 1968; Biely et al., 1966) represented by thick-bedded, amalgamated sandstones of suprafan. Similar transition of outer fan to suprafan deposits can be observed in Middle to Late Eocene sediments of Zlínske Fm.

An abrupt, almost 180° change of palaeoflow direction in the Oligocene, suggests uprise of a new source area in the west. This may be connected with zipping of the suture zone west of the studied area due to oblique convergence (e.g. Miall, 1995).

Central-Carpathian Paleogene Basin

The eastern part of the CCPB extends from the High Tatras in the west to the Vihorlat Mts. in the east. It is bounded to the Pieniny Klippen Belt in the north, pre-Tertiary units in the south and ESNB in the east. The basin fill, stratigraphically ranging from the Paleocene to the Eggerian (planktonic zone NN1-NN2, Gross in Polák et al., 1992; Molnár et al., 1983; Soták et al., 1996; Janočko et al., 1998) is more than 2500 m thick (e.g. Nemčok in Leško et al., 1983). The basin represents a piggyback or in-wake basin developed above the Central West Carpathians crystalline and Mesozoic units behind the foldthrust belt generated by convergence of the North-European Platform and Carpathians. Oblique subduction, pull of the subducted slab and isostatic load of the Mesozoic Nappes were probably main factors determining subsidence of the basin. Deposits show a complex sedimentary history mainly governed by tectonics, sea-level fluctuation and sediment input. The Tertiary succession is marked by an angular unconformity overlain locally by Paleocene and Early Eocene fluvial and alluvial fan deposits (e.g. Gross in Polák et al., 1992). Above this, basal conglomerates, sandstones and nummulitic limestones had been deposited in a wide range of marine depositional systems. Some of them represent typical shallow-water systems recorded by the wave-reworked deposits. Coarse-grained deposits showing features of deep-water fan deltas suggest high-energy (fault-bordered?) coastal relief and narrow shelf passing into basin slope (e.g. Janočko, 1999b). The age of basal deposits is diachronous and ranges from the Middle Eocene to the Oligocene. The marine transgression was not continuous and was governed by the relative sea level fluctuations resulted from interplay among tectonics, sediment input and eustatic sea level fluctuation.

The first significant deepening of the basin in the Eastern Slovakia occurred along the southern part of the Pieniny Klippen Belt at the end of the Middle Eocene. This is suggested by the Late Eocene sedimentary succession in this area, consisting of hemipelagic mudstones, olistostromes, coarse-grained canyon deposits and channel and levee deposits showing typical deep-marine sedimentation. The SE–NW elongated basin depocenter generally migrated southward during the basin evolution and the basin axis gradually rotated to the W–E position. The main sediment palaeotransport direction from NE to SW prevailed in the Late Eocene and shifted to SE–NW at the end of the Late Eocene and in the Oligocene (Marschalko, 1975, 1982). However, north of the Štrba – Ružbachy high (Janočko and Jacko, 1999) opposite palaeoflow direction was observed in the Oligocene deposits. The Late Oligocene and Early Miocene (NP 24-25, NN1-2) coarse-grained deposits with prevailing SE–NW, but also N–S and S–N palaeotransport direction suggest fault-bordered ponded basin. According to the clay mineral analyses and vitrinite reflectance data (Kotuľová et al., 1998) these deposits were overlain by at least 2 km thick sedimentary cover. Based on this as well as on the character of the Eggenburgian deposits in the Čelovce Depression of the East-Slovakian Neogene Basin (Janočko et al., in prep.) we suggest a continual sedimentation from the Oligocene to the Eggenburgian.

East-Slovakian Neogene Basin

The East-Slovakian Neogene Basin (ESNB) is an autonomous part of the Transcarpathian Basin with complex tectonic evolution and high variability in thickness and spatial distribution of sediments complicated even more by intrabasinal volcanics.

The fill of the basin consists of sediments and volcanics stratigraphicaly ranging from the Eggenburgian to the Pliocene. The maximum thickness of the fill is up to 8 km (Vass et al., in press). Most of the deposits are composed of siliciclastics and evaporite and caustobioliths have minor occurrence. Volcanic rocks also comprise an important portion of the basin fill. They are acid (absolutely prevailing from the Eggenburgian to the Early

Badenian) and intermediate (prevailingly from the Badenian to the Late Sarmatian and/or Pannonian).

Kinematic history of the basin is complex and is connected with the convergence of the North European Platform and the Carpathians as well as updoming of the Pannonian asthenosphere (e.g. Vass, 1995). It lies on thinned, about 27 km thick crust thickening toward north and north-west where it reaches about 30 km (Šefara et al., 1987). The lithosphere thickness is 80 km (Babuška et al., 1986). Vass (1998) considers the basin as a forearc and intraarc one in relation to the plate boundary. Kováč et al. (1995) characterized the basin as a back-arc one. However, the clear evidence about the basin position in relation to volcanic arc is only proved since the Late Badenian, when andesite volcanism directly related to the subduction appeared (Lexa and Konečný, 1998). The basin originated in transpressional regime which later changed to compressional and transtensional (Kováč et al., 1995; Vass et al., in press). The most important periods of the basin development are connected with pull-appart regime (Vass et al., 1988). Generally, we can divide two etapes during the evolution of the ESNB. The first etape includes time span from the Eggenburgian to the Middle Badenian when deposition occurred in marine environment. The second etape (Late Badenian – Pliocene) is characterised by gradual decrease of salinity and transition into lacustrine and terrestrial deposition (e.g. Janočko and Šoltésová, 1997). However, considering the recent findings of Eggerian deposits in the neighbouring area of the Inner-Carpathian Paleogene Basin (e.g. Molnár et al., 1984; Soták et al, 1996; Janočko et al., 1998), type of deposition in the Eggenburgian (e.g. Janočko, 1993; Janočko et al., in prep.), results of vitrinite reflectance data suggesting 2 km thick sedimentary cover above the Late Oligocene – Early Miocene deposits in the Levoča Mts. (Kotuľová et al., 1998) and regional hiatus in the Ottnangian, we suggest beginning of a new tectono-sedimentary history of the ESNB from the Karpatian.

The initial etape of the basin evolution is characterized by prevailing marine sedimentation in the fault-bordered basin elongated in NW–SE and WNW–ESE direction. The basin was connected with the Carpathian foredeep from the N and NW (Rudinec, 1989; Vass et al., in press). Sedimentation, occurring mostly in shallow epicontinental sea, was predominantly characterized by mudstone and minor sandstone and conglomerate. However, tectonics and sea level fluctuation occasionally caused change of depositional style. This is the case of Middle Karpatian and Middle Badenian evaporitic sedimentation.

Since the Late Badenian, N–S faults were activated and the basin was opened to the Pannonian Basin in the south and Mukatchevo Basin in the east. The connection with the Carpathian foredeep was gradually interrupted. During the Late Badenian prevailing deltaic deposition occurred in the ESNB. This was changed by shallow-water deposition during the Early Sarmatian. Prevailing lacustrine deposition in various shallow-water and terrestrial depositional systems is recorded from the Late Sarmatian to the termination of the basin evolution in the Pliocene.

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Palaeogeography of the East-Slovakian Basin

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Abstract

The East-Slovakian Basin is a basin with complex tectonic history determined by oblique subduction of an oceanic slab occurring between the North-European Platform and the ALCAPA plate. It is filled by the Neogene clastics, volcanics, caustobioliths and evaporites. Genetic type and spatial distribution of deposits varied during the basin evolution depending on tectonics, volcanic activity, sea level changes as well as sediment input.

Key words: East-Slovakian Basin, palaeogeography, tectonics, sedimentology

Introduction

The East-Slovakian Basin is an autonomous part of the Transcarpathian Basin with complex tectonic evolution and high variability in thickness and spatial distribution of sediments complicated even more by intrabasinal volcanics. Complex geologic evolution is a result of delicate interplay between intra- and extrabasinal processes such tectonics, sediment input, depositional processes, climate and sea level fluctuation. They determined type of deposition, erosion and denudation, position of depocenters and basinal volcanism. Precise definition of basin fill stratigraphy, spatial distribution and type of deposits as well as type of tectonics comprise basis for unraveling basin history. This is the main role of palaeotectonic reconstructions which helps to understand basin history.

Methods

Initial data for palaeogeographic reconstruction in ten time slices were obtained from deep boreholes. Based on this, sediment isopachs assigned to individual time slices were constructed. Borehole cores and drilling logs as well as surface outcrops provided information on lithology, facies types and sequences. This was complemented by analysis of reflection seismic profiles. Biostratigraphic subdivision of the basin fill has been based on foraminifera, nanoplankton, molluscs and ostracods.

Interpretation of main structural elements – faults and overthrusts is based on surface mapping and seismics. Fault characteristics were deducted from palaeostress fields which interpretation was based on analysis of brittle deformation. Sedimentation rate was interpreted on the base of formation thicknesses. Sedimentological analyses were applied for definition of geometry of sedimentary bodies and palaeoenvironmental analysis as well as for definition of sediment input direction. All the data concerning sediment input direction is related to present day coordinates. Radiometric ages of volcanics, which are barren of fossils, enabled their stratigraphic correlation with biostratigraphically dated sediments.

Geological setting

The East-Slovakian Neogene Basin comprises western and autonomous part of the Transcarpathian Basin extending from Košice in the west to the Uzhgorod in the east. The basin is fault-bounded to the Chmeľov-Beňatina Paleogene unit in the north and separated by system of faults from the Šariš – Paleogene unit and pre-Tertiary rocks of the Sľubica, Čierna Hora and Spišsko-gemerské Rudohorie Mts. in the west. To the south it is restricted by Zemplin Horst separating basin from the Nyírseg Basin of the Great Hungarian Plain. The eastern boundary of the basin is expressed by the buried Seredné transverse horst (Vass et al., 1988; Rudinec, 1989).

Striking morphostructure of neovolcanic rocks belonging to the Slanské vrchy Mts. divides the basin into two parts – the Prešov Depression in the west continuing into Moldava Depression in the south and the Trebišov Depression in the east with Roňava "Bay" in the southeast. Both the Moldava Depression and Roňava "Bay" are formally assigned to the East-Slovakian Neogene Basin (Vass et al., 1988) although they are genetically a part of the back-arc depression of the Carpathians.

The kinematic history of the basin is complex. The basin originated in transpressional regime which later changed to compressional and transtensional. The most important periods of the basin development are connected with a pull-appart regime (Vass et al., 1988).

Palaeogeography

Eggenburgian (23.0–19.0 Ma)

The first etape of the opening of the East-Slovakian Neogene Basin occurred during the Eggenburgian (23.0–19.0 Ma). The Eggenburgian basin was relatively narrow wrench furrow continuing from northwest to the Transcarpathian Ukraine in the east. The opening of the basin enabled sea incursion to the East-Slovakian area. The incursion is believed to be strengthened by eustatic sea level rise. The transgression occurred over the partially emerged Outer Flysch Carpathians e.g. over Magura, Dukla, Silesian and Subsilesian Units. The Eggenburgian basin communicated over these units with both the Carpathian foredeep and original sedimentary areas of Skola, Boryslav-Pokuty and Stebnik Units later incorporated into the frontal part of the Flysch Carpathians today. The basin was also opened to the SW where a sea communication with Fiľakovo/Pétervásara basin – bay (e.g. Halásová et al., 1996) existed. We also suggest basin connection to the sea occurring in the pre-Sarmatian Orava Basin. The connection probably stretched further toward the W over the Inner Depressions of the West Carpathians where Eggenburgian deposits were preserved (Turiec, Bánovce, Ilava, Trenčín Depressions) to the Vienna Basin and to the Carpathian Foredeep in the SW of the Moravia. This connection was already considered by Buday et al. (1967).

Ottnangian (19.0–17.5 Ma)

During the Ottnangian the change of palaeostress field resulted in emerging of the area of the future East-Slovakian Neogene Basin above sea level. The pressure generating shear was changed by a pure compression acting in the SW–NE direction resulting in uplift of the area and depositional hiatus (Janočko and Jacko, 2000).

Karpatian (17.5–16.5 Ma)

At the beginning of the Karpatian stage a new depositional area opened in the region of the East-Slovakian Basin. The basin was opened by normal faults parallel to the recent basin axis. The extension was most probably a result of the upheave of the Pannonian asthenosphere (e.g. Vass, 1995). A marine incursion into the opening basin mainly occurred from the NE, i.e. from the basins occurring in the front of the Flysch Carpathians. Sea might also penetrate from the NW direction where Czieszkowski (1992) has suggested a marine basin in the area of the Orava.

Cumulative thickness of the Karpatian deposits shows that the most intensive subsidence and the thickest deposits occurs S of Vranov, SW of Michalovce and SE of Prešov.

Volcanic activity during the Karpatian was represented by acid areal explosive volcanism with crustal origin of magma. The buried products of volcanism occur in the surroundings of Zlatá Baňa (SE of Prešov) where also volcanic centers are assummed (Kaličiak et al., 1991).

Early Badenian (16.5–15.5 Ma)

The sea incursion was from NE, i.e. from the basins located in the Outer Flysch zone or from the foredeep and from the NW (from Orava marine basin). Occurrence of the Early Badenian deposits on the foothil of the Zemplínske vrchy Hills implies possible transgression also from the area of the Great Hungarian Plain or Nyírség Basin.

Middle Badenian (15.5–15.0 Ma)

During the Middle Badenian (Wieliczkan) marine transgression from the Early Badenian continued. Main basin communication with open sea in the outer part of the Carpathians was still a seaway to the foredeep in the NE. Another communication is assumed to the later Orava marine Basin in the NW. After some time in the Middle Badenian, about 15.3 Ma B.P., tectonic activity in the basin ceased and sea slowly retreated giving rise hypersaline lagoons.

Late Badenian (15.0–13.6 Ma)

At the beginning of the Late Badenian (Kosiv), after salinity crisis, the tectonic activity of the basin increased resulting in revitalizing of pull-apart mechanism. The stress field had a maximum compression in E–W direction. The main role in a new basin opening was played by sinistral strike-slips of NW–SE directions and dextral strike slips of NE–SW directions. The faults of N–S direction were normal faults.

During the Late Badenian the basin deposition was accompanied by an important volcanic activity. It started by explosive ryodacite volcanism and was followed by andesite volcanism. The radiometric age of these rocks is 15.0 ± 0.1 Ma (Bagdassarjan et al., 1971).

Early Sarmatian (13.6–12.7 Ma)

During the Early Sarmatian the area of the central Paratethys, including the East-Slovakian Basin, began to be separated from the open sea. The basin was connected with depositional areas in the Hungary and the Transcarpathian Ukraine. The connection to the Carpathian Foredeep terminated and emerged Outer Flysch Carpathians became one of the main source area.

Late Sarmatian (12.7–10.5 Ma)

During the Late Sarmatian brackish deposition continued. High amount of sandy deposits suggess new, intensively uplifted source areas.

The Sarmatian was a period of an eventful volcanic activity. Except above mentioned volcanics, which comprise a part of the basin fill (andesites and rhyolitic tuffs), the main mass of volcanics forming the Slanské vrchy Mts. was formed during the Sarmatian. The radiometric ages of the volcanic rocks from the Slanské vrchy Mts. vary from 10.0 to 13.6 Ma (Bagdasarjan et al., 1991; Slávik et al., 1976; Ďurica et al., 1978). According to radiometric ages the Vihorlat and Popriečny volcanic mountains commenced to form during the Middle and mainly Late Sarmatian.

Pannonian and Pontian (10.5–5.2 Ma)

Termination of the East-Slovakian Basin sedimentation continued during the Late Miocene e.g. during the Pannonian and Pontian. The Pannonian deposits of Sečovce Formation are also slightly folded (Kováč et al., 1994) giving an important information for timing of the stress shock as post-Pannonian.

The Pannonian deposits only extend in the middle and SE part of the East Slovakian Lowland and in the Moldava depression. They transgressively and unconformably overlie deposits of various biozones and lithostratigraphic units of the Sarmatian. The thickness of the Pannonian and Pontian deposits in the SE part of the basin is about 1 300 m. In the partial depression between Sečovce and Trebišov and E of the Zemplínske vrchy Hills the thickness of deposits is maximum 500 m.

During the Pannonian, the activity of the Sarmatian andesite volcanoes (about 10 Ma old, Slávik et al., 1976) as well as the activity of the most Vihorlat stratovolcanoes were ceasing. The youngest volcanics of the Vihorlat Mts. are about 9 Ma old (Slávik et al., 1976).

Pliocene (5.2–1.8 Ma)

The basin markedly diminished in the Pliocene. Lacustrine deposits from this stage comprise Čečehov Formation discordantly overlying Senné Formation. The transgressive character is suggested by the position of Čečehov Formation above the Hnojné Member of the Panonian age in the Sub-Vihorlat Depression. The formation is about 120–200 m thick.

Conclusion

The East-Slovakian Basin represents an autonomous, eastern part of Transcarpathian Basin. It occurred behind the accretionary wedge rising due to convergency of the European Platform and ALCAPA microplate. Since the Late Badenian, when subduction-related volcanic arc evolved (Lexa and Konečný, 1998), it may be classified as an interarc basin. Due to oblique subduction the basin had complex tectonic history represented by extensional (Karpatian), transtensional (Badenian, Sarmatian), transpressional and compressional regimes. The basin is mostly filled by Neogene, shallow-marine deposits containing caustobioliths and evaporites. Volcanics also comprise a significant portion of the basin fill. The spatial distribution of deposits, depositional palaeoenvironments and volcanism were strongly determined by subsidence history, sea level fluctuation and sediment input.

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The East Slovakian triple point junction area: collisional puzzle of the West Carpathian – Pannonian – East Carpathian units

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Abstract

The paper deals with alternatives for correlation of the units, which occur in the West Carpathian – Pannonian – East Carpathian junction. The Zemplín Unit appear to be a prolongation of the Tatro-Veporic Zone, comprising of the Middle Cretaceous formations and *Calpionella*- and *Globochaete*-limestones in the Ptrukša Zone. The Iňačovce-Kričevo Unit is considered to be a Penninic-like core complex, exhumed from below the Zemplín terrane during the back-arc extension. The Humenné-Užhorod Zone shows a strong slicing of the Centrocarpathian nappes in strike-slip zone between the Močarany-Topľa and Peri-Pieniny faults. Some regional aspects of Transylvanides, Outer Dacides in Marmaroš and Szolnok Zone in Northern Alföld are briefly discussed.

Key words: Eastern Slovakia, Transcarpathian units, Zemplinicum, interregional correlations

The Western and Eastern Carpathian junction is considered to be a node area of units of various regional-tectonic appurtenance (Mahel', 1995). In this area, the Western Carpathian units fade out in "en echelon" course and the Pannonian and Transcarpathian units appear. Changes in structural frame of the Western Carpthian units occur at the Hornád Fault. The boundary zone at the Hornád Fault is a system of normal faults (Grecula et al., 1977), syngenetic with marginal strike-slip faulting of the Western Carpathian segments along the Central Hun-garian lineament (i.e. the Zagreb-Zemplín Line and/or Darnó Line). Nevertheless, the Veporic unit of the Čierna hora Mts. continues behind the Hornád Fault to the Prešov Depression (Kecerovské Pekľany-1 and Rozhanovce-1 boreholes), taking a connection with crystalline complex of Zemplinicum (Vozárová and Vozár, 1997; Faryad and Vozárová, 1997; Finger and Faryad, 1999). Mesozoic formations of the Zemplinicum are known incompletely, preserved only as a Middle Triassic carbonates. The most complete data about a younger sediments of the Mesozoic formations have been obtained from the Ptrukša Zone. This Zemplinic subunit consists of dark pelitic formations (e.g. Ptrukša-55 borehole), which recently provide a foraminiferal evidences for the Middle Cretaceous age (*Whiteinella*-type associatian – Soták in press). Beside of these sediments, the Mesozoic rocks of the Ptrukša Zone are also reworked in the marginal delta-fan conglomerates of the Neogene formations (e.g. Ptrukša-55 borehole), where the carbonate pebbles consist of dolomites, *Calpionella*-limestones and *Globochaete*-limestones. Considering that, the Mesozoic formations of the Ptrukša Zone (Zemplinicum) are not different from those in the Central Carpathian units. Nevertheless, the Zemplín Unit is considered to be a marginal segment of the Tisia block wedged in structures of the Western Car-pathians along the Zagreb-Zemplín and Trebišov-Samoš Lines (Grecula et al., 1981).

Mesozoic units of the Central Western Carpathians beyond the Hornád Fault occur in the Humenské vrchy Mts. as well. They form an elevated area of the Humenné – Užhorod Zone. Structure of the Humenské vrchy Mts. reveals a strong slicing of Krížna, Tatric and perhaps also Choč nappes (Mahel', 1995; Jacko and Schmidt, 1994; Soták et al., 1997). The Humenné Unit joints with the basement units of the East Slovakian Basin (Iňačovce-Kričevo Unit) on the strike-slip system of the Močarany-Topľa Faults, indicating their possible tectonic juxtaposition. Eastward continuation of Mesozoic units along the inner side of the Klippen Belt is also traced by the Central Carpathian Paleogene sediments of the Kapušany-Humenné-Beňatina Zone, and than up to Transcarpathian area. The "Podhale Flysch" in the Transcarpathian area is developed as Šaflary Fm. and Zakopane Fm. (Sviridenko, 1973), that like as in the Šambron Zone, contain extremely abundat spinels (Kruglov, 1974).

The Gemericum does not continue beyond the Hornád Fault, where it sharply turns in N–S direction (Grecula et al., 1981). Nevertheless, there are also opinions, that the Gemeric-like complexes occur in the nappe structure of the Marmaroš massif (Delovec Nappe – Slavin et al., 1975). The Early Paleozoic formations of the Marmaroš massif are dated by the Ordovician graptoliths and conodonts (Drygant and Bojchevskaja, 1984). The Marmaroš massif shows a simmilarity to the Central Western Carpathians, which differ only in magnitude of horizontal displacement (Slavin et al., 1975). Another interpretations refuse this correlation, emphasizing the principal role of the Pieniny boundary fault (Vjalov, 1975; Sviridenko, 1976). However, the Marmaroš elements occur in the basement of the Transcarpathian Depression in Solotvino area as well (Petraškevič, 1968). This part of the Transcarpathian Depression is floored by the epicontinental Paleogene sediments (Bajlovo Fm.), which correspond to variegated facies of the Paleogene sediments in the Marmaroš massif (Petraškevič l.c.).

At the junction of the Inner Car-pathians with the Zemplín block probably disappear also units of the Silicicum – and Bükk-Meliata domain. Toward the east, the Meliata?-type sequence with radiolarites?, diabases and tuffites is constrained from boreholes near Beregovo and in Rusko-Komarov and Begač Zones (Sviridenko, 1976; Petrashkevič and Lozyniak, 1988). Based on these indications, Rakús et al. (1998) proposed a prolongation of Transylvanides to the basement structure of the Transcarpathian Depression.

The substratum of the Transcarpathian Depression is formed by the Iňačovce-Kričevo Unit, which consists of Late Paleozoic?, Mesozoic and Paleogene formations. Their stratigraphic classification is based on the occurrences of Jurassic and Lower Cretaceous fauna in the Kričevo Zone (*Posidonia sp., Vermicerae sp., Deshayesites borowae* UHLIG, calpionellids – Burov et al., 1975). In the basement of the East Slovakian Basin, the Iňačovce-Kričevo Unit consists of metasedimentary formations. Metamorphic lithology (Schwarzschiefer, Bündnerschiefer), MP to HP/LT metamorphism, Lower Miocene cooling age (≈ 20 Ma) and subductional-accretionary style enables to compare this unit with the Penninicum (Soták et al., 1993, 1994). Metasedimentary formations of the Iňačovce-Kričevo Unit are also completed by bodies of ultrabasics, recovered in deep boreholes and presumed in the area of large mag-netic anomalies near Nacinná Ves and Sečovce (Mořkovský and Čverčko, 1987; Gnojek et al., 1991). In the Eastern Carpathians, the Penninic-like units occur in the Ceahlau – Severin Zone, which westwardly links with the Porkurec Unit of the Ukraine Carpathians. The Porkurec Unit disappears in the system of Latorica faults, close to the Slovak-Ukraine border. According to some authors (e.g. Kovács, 1982; Chain et al., 1980), the Penninic-related units in the East Carpathian – Pannonian area are divided into two zones – Outer Dacide Zone ("Black Flysch" and Ceahlau Units) and Szolnok Zone. Vozár et al. (1993) proposed a direct connection of the Szolnok Zone with the Iňačovce-Kričevo Unit, developed as a post-Eocene subduction complex. The Szolnok Zone is formed by the Senonian and Paleogene sediments, which were detached from the Mecsek-type units (Balla, 1987). Pelagic marly facies of the Szolnok Zone (Púchov Marls) and the Mesozoic formations of the Mecsek Unit are not present in the Iňačovce-Kričevo Unit. Considering that, the Mesozoic formations of the Szolnok Zone likely correlate with those in the Pieniny Klippen Belt (Szentgyörgyi, 1989; Soták et al., 1995; Potfaj, 1998).

The units of the Western and Eastern Carpathian junction are covered by Neogene sediments of the Eastern Slovakian Basin, which in the deepest part attain thickness of up to 6–7 km (the so called Trebišov Depression sensu Rudinec, 1980). The subsidence of the basin during the Lower Miocene was taking place in depocentres formed by pull-apart mechanism (Vass et al., 1988), which also documents its foundation in the transtensional shear zone. During the Middle Miocene, the structural development of the basin tend to back-arc extension, mainly initiated by roll-back effect of the subducted plate (Kováč et al., 1995). Back-arc extension consequently led to mantle upheaval and intensive calc-alkaline volcanism. Andesite eruptive centres were mainly activated at crossing of significant tectonic lines in the system of volcanic apparatuses of the Slanské vrchy and Vihorlat – Gutin Mts. (Kaličiak and Pospíšil, 1990).

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Stripping the gravity field on the CDP profiles in the transcarpathians basin and interpretation of density-magnetic models

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Abstract

Area of present the environmental TIBREG project financed by Ministry of Environmental of Slovak Republic is situated in the eastern part of Carpathian basin in border zone of the Slovakia nad Hungary and in the border of the Western and Eastern Carpathian. The object of this article is the method of gravity stripping and following density – magnetic modelling.

Key words: Transcarpathians basin and its surrounding, stripping in gravimetry, density and magnetic models of a part of Earth's crust.

Introduction and short geological review

The main part of Transcarpathians basin, particularly East Slovakian Basin, is in the centre of interest from the hydrocarbons potencial point of view in not discovered yet perspective regions. In adition, the prospecting of base-metallic and precious stones deposits is removed from traditional areas in Slanske vrchy Mts. and Vihorlat Mts. to buried neovolcanic structures in own basin. The basin has a very high geothermal potential, up to now without known favourable hydrogeological structures (Franko et al., 1995).

Results of geophysical – geological interpretation

On the contrary of the former models for stripping (Pospíšil in Šefara et al., 1987) for density distribution of a sedimentary filling the results from twenty one boreholes have been studied. We divided them into main (with depth) and complementary (with time) dependence $\sigma_{(x,y,z)} = \sigma_{(d)} + \sigma_{(t)}$ (Fig. 1a). For quantitative analysis, a main distribution of density of Badenian and other units (Miocene – Pliocene, Sarmatian and Karpatian) and basement geometry by seismic section along profile 602/89 (Fig. 1b) were used for A model. For B model the dependence with time has been used (Fig. 2). To receive a stripped gravity effect $\Delta_{g\ strip}$, the body with differential density of 0.3 g.cm^{-3} had to be supposed under the Basin (gravity effect $V_{z\ strip}$). We included also modeling of magnetic measurement (ΔT), which corresponds with density model in the deepest part (to the curie temperature) and seismic results in the sedimentary cover were also utilized. This ideas will be applied in the future.

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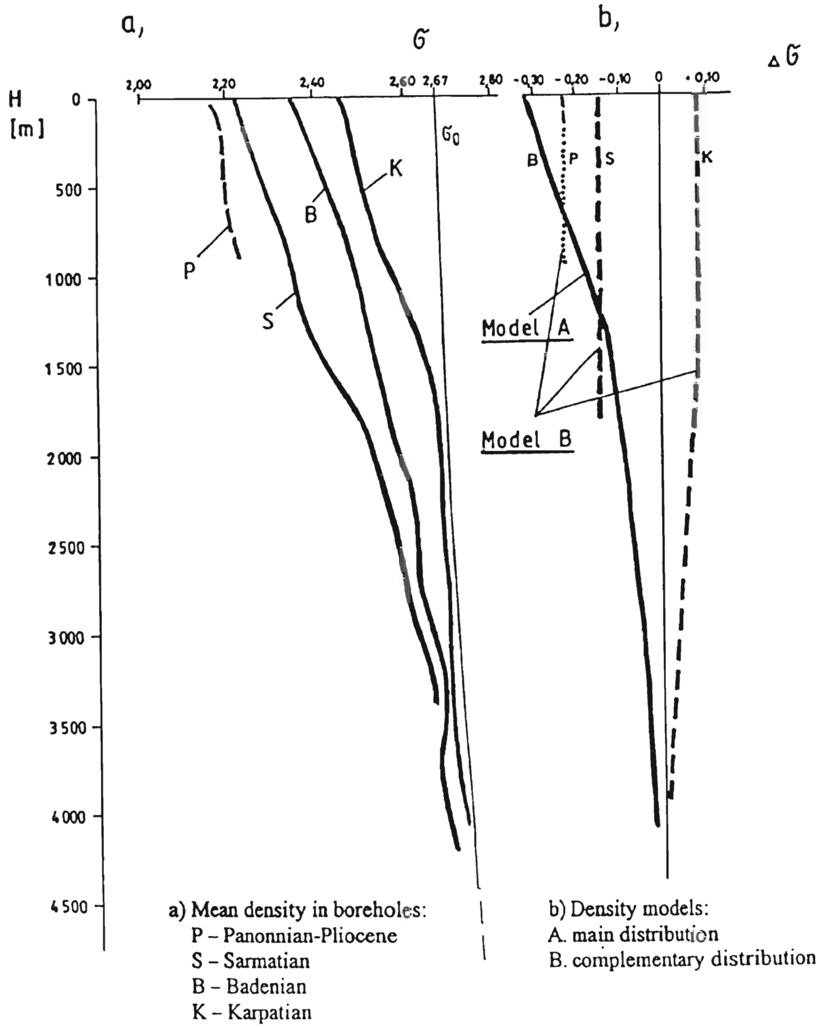
a)



b)

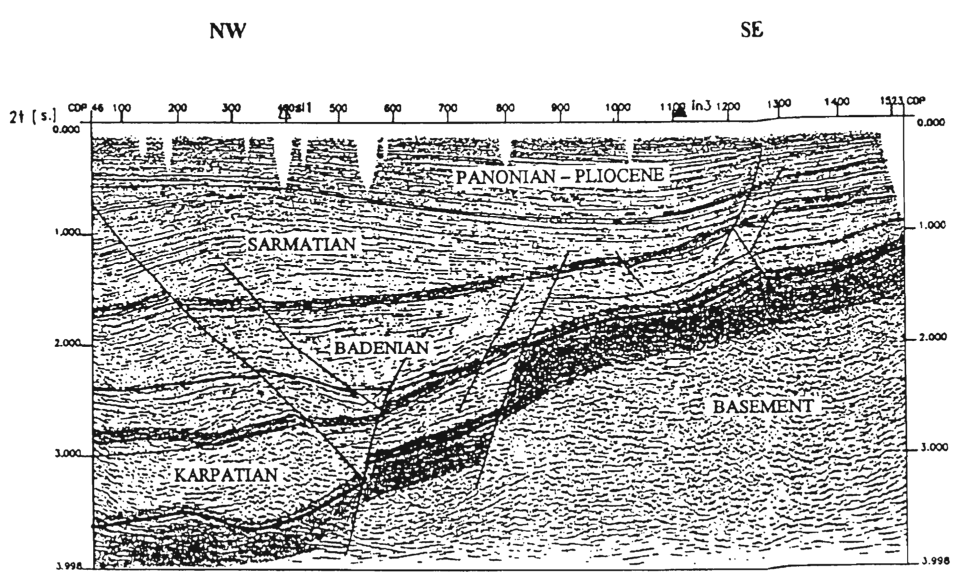


Fig. 1. a – Density analyses σ = *f* (d, t) (Šefara, J., 2000); b – Seismic section along CDP profile 602/89 (Rudinec, R. and Magyar, J., 1998).

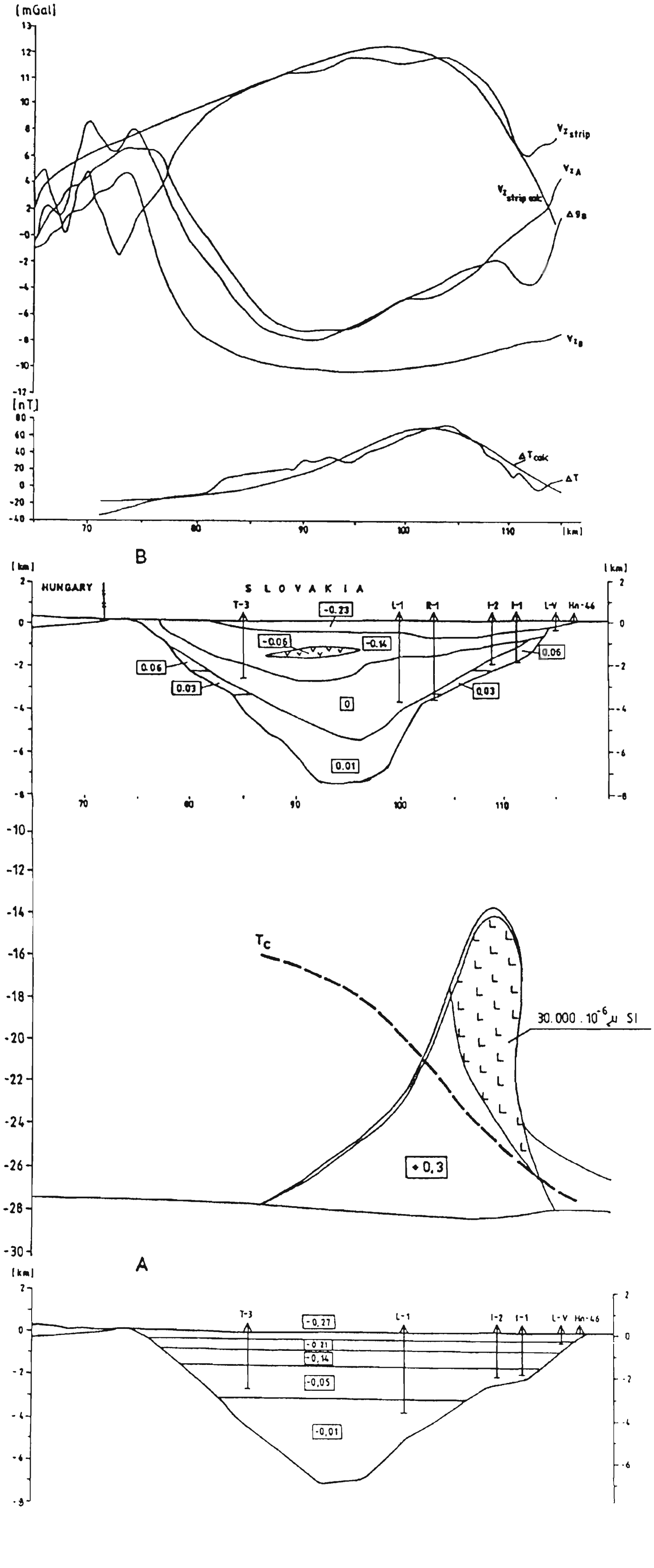


Fig. 2. Density – Magnetic model.

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Possible perspectives of hydrocarbon bussines in Eastern Slovakia

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Abstract

Eastern Slovakia and especially its Neogene basin presently belongs to the most perspective areas in natural gas exploitation. The highest potential is assumed in depth between 1000 and 2000 m. Geothermal resources connected with overheated groundwater and dry rocks play also important role as an additional energy source.

Key words: Hydrocarbon bussines, Neogene, flysch, Eastern Slovakia, Western Carpathians

Introduction

The Eastern Slovakia, comprising Košice and Prešov counties with areal extent 15 746 km^2, is a part of the Western Carpathians originated during the Alpine-Carpathian orogene. The area had a strong position in hydrocarbon exploration and exploitation in the past. Almost 50 years of systematic exploration activity resulted in knowledge on geologic evolution of the region and findings of potential mineral reservoirs hidden in its depth.

For the hydrocarbon enterprising in the territory two areas are most interesting: the East-Slovakian Neogene Basin separated by volcanics of the Slanské vrchy Mts. into East-Slovakian Lowland and Košice Depression. The second area is represented by the East-Slovakian flysch represented by the Central-Carpathian Paleogene, Klippen Belt, Magura Nappe and Dukla Unit (Fig. 1).

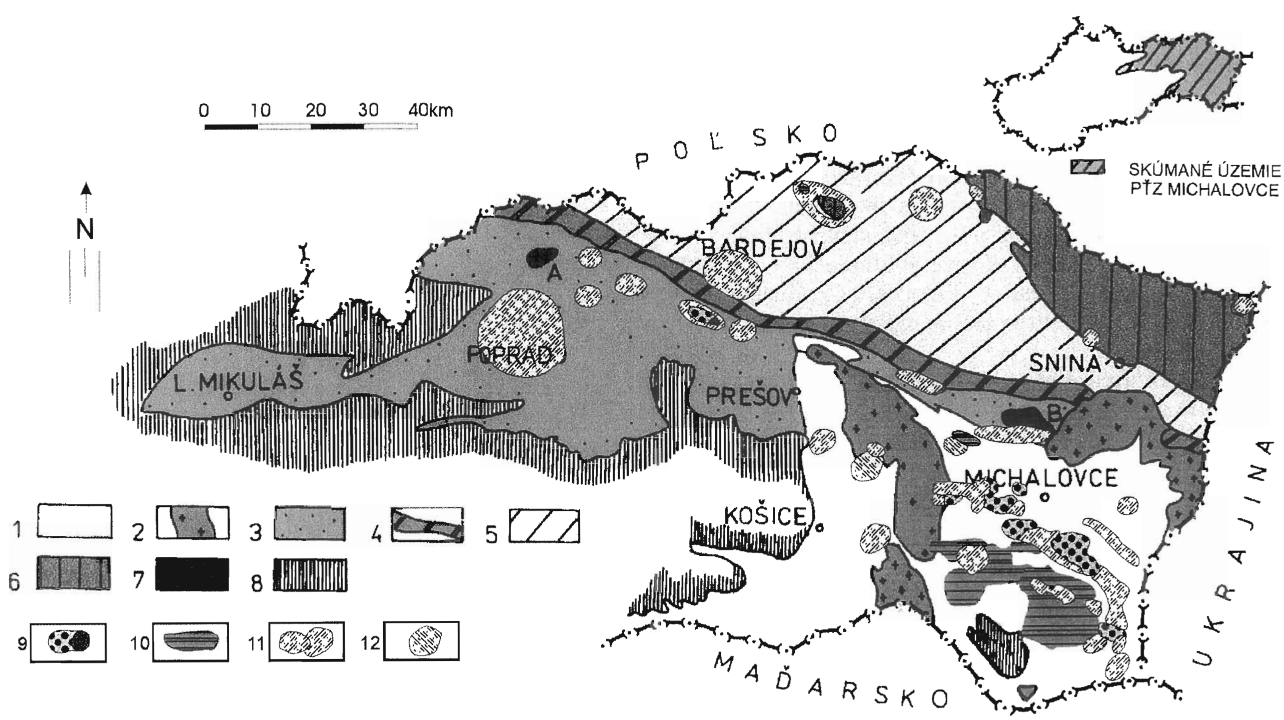

Fig. 1. Localization of the potential hydrocarbon reservoirs in the Eastern Slovakia.
Explanations: 1 – Neogene fill, 2 – Neovolcanics, 3 – Central Carpathian Paleogene, 4 – Klippen Belt, 5 – Magura Nappe, 6 – Dukla Unit, 7 – Mesozoics, 8 – Humenné Horst, 9 – hydrocarbon sites, 10 – low-capacity hydrocarbon reservoirs, 11 – perspective structures, 12 –reservoirs of CO_2.

Achieved results

According to the recent activities of the Nafta Gbely, a.s. the importance of the mentioned areas is expressed by the largest reservoirs of natural gas and by its exploitation in the relatively small Slovakia. The East-Slovakian Neogene Basin has a priority position. Its part, represented by the Neogene of the East-Slovakian Lowland, extends on 3981 km^2 large area and consists of continental and shallow-marine sedimentary-clastic, chemogenic and volcanoclastic fill more than 7000 m thick. Eight stratigraphic units were distinguished here during the geologic history – the Eggerian, Eggenburgian, Karpatian, Badenian, Sarmatian, Pannonian, Pliocene and Quaternary.

The Košice Depression extends on the 2615 km^2 large area. It is composed of Neogene deposits more than 2600 m thick. It has analogous character of rocks, however, some stratigraphic units are locally missing (Middle Badenian etc.). Potential of source rocks like generated gas (CO_2) and earth heat (water overheating) in the central and northern part are economically important (Fig. 2).

To the 1st March, 2000 4 mld. m^3 of natural gas had been exploited from the fields in the East-Slovakian Neogene Basin and 6220 thousand tons of gasoline and 41 thousand tons of propan-butan were producted.

The initial geologic perspective sources for the Neogene of the East-Slovakian Lowland are about 13 mil. tons of crude oil and 137 mld. m^3 of natural gas. The sources of the Košice Depression are assumed to 5 mil. tons of crude oil and 3 mld m^3 of natural gas (Janků et al., 1996).

In the East-Slovakian flysch area, the Klippen Belt as a regional phenomenon of the Western Carpathians, separates flysch areas into the Central-Carpathian Paleogene and Outer Flysch (Fig. 1).

Recent results in the Central-Carpathian Paleogene Basin are far more interesting. The Paleogene extends on 2500 km^2 area. The fill thickness varies. Maximum thickness of about 4 km it attains in depression parts along the Klippen Belt and transverse subtatric fault system. Its structure consists of several lithofacial units with stratigraphic span Eocene – Oligocene. Continental and shallow-marine fill units occur on mostly dissected mesozoic relief.

Natural occurrence of crude oil and natural gas are relatively rare and small. They suggest hydrocarbon generation and migration in sedimentary-clastic rocks till the recent. From the source potential pointview the geologic prognosis resources are composed of 5 mil. tons of crude oil and 15 mld. m^3 of natural gas.

The Outer Flysch represents relatively large area having about 3500 km^2. The exploration and exploitation activity has been conducted almost 150 years (Miková, Vyšný Komárnik). It represents 6000 m and more thick complex of flysch deposits (sandstone, variegated and monotonous claystone and siltstone) with complex fold-slice structure with age ranging from the Cretaceous to Paleocene and

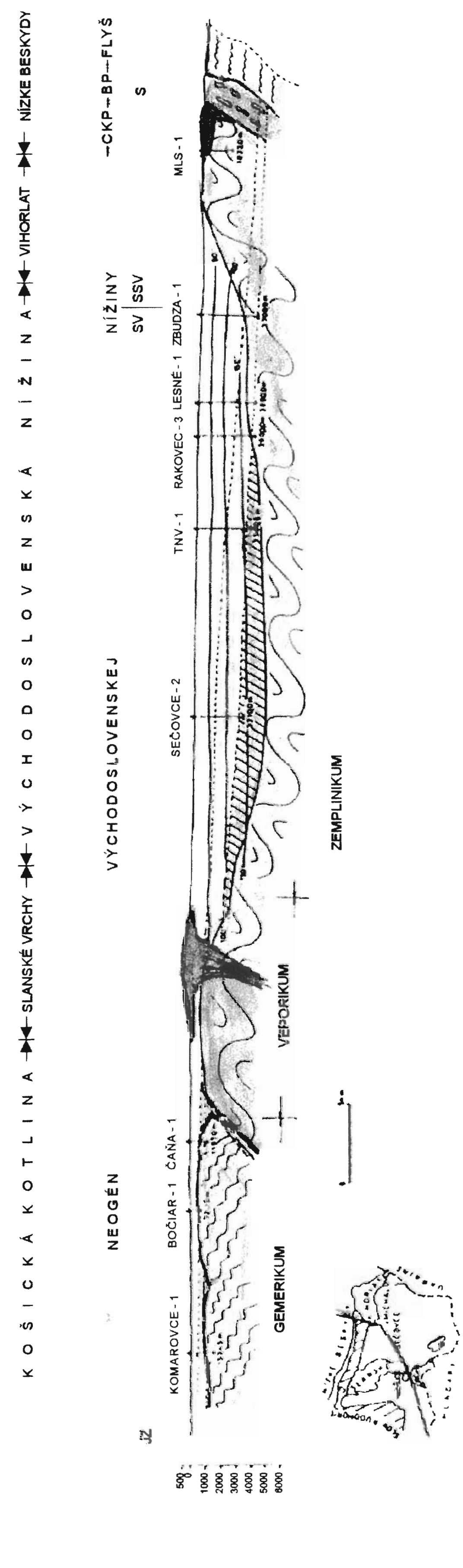

Fig. 2. Geologic profile across the East-Slovakian Neogene basin.

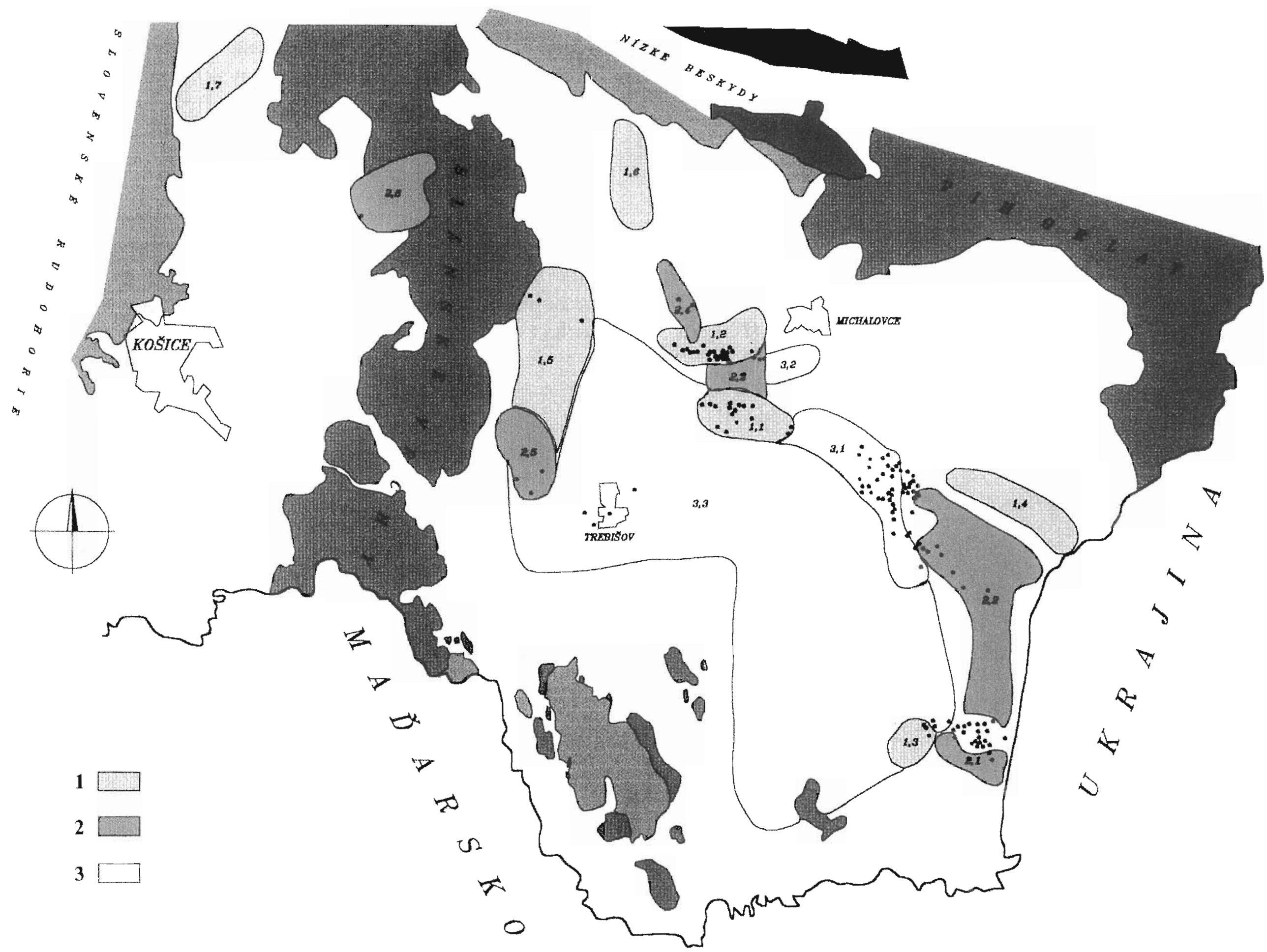

Fig. 3. Three intervals of possible hydrocarbon reservoirs. Prospekčné objekty: 1 – plytké (do 1000 m), 2 – strednohlboké (1000–2000 m), hlboké (2000–4000). Mierka 1:400 000.

Late Cretaceous – Early Oligocene. Besides well known oil deposit Miková the most noteworthy are low-capacity accumulations of combustible gas (Zboj, Smilno,Hanušovce n.T.). The initial geologic prognosis sources are assumed to 16 mil. tons of crude oil and 78 mld. m^3 of natural gas (Janků et al., 1996).

Current problems, perspectives and risks

Based on results from exploration, exploitation and knowledge gained during the last 50 years we can state that the above mentioned region belongs to the most perspective one in the Slovakia from the viewpoint of natural gas and crude oil occurrence. The most important area is represented by the East-Slovakian Neogene, mainly by its eastern part. In this area mainly natural gas and its higher homologues occur. Present knowledge clearly shows that the hydrocarbons are related to the structural-lithologic type of traps.

In accordance with the general trend it is necessary to realize 3-D seismic measuremens in order to minimalize expensive drilling works. These should be performed in striking gas-bearing belt Rakovec – Pozdišovce – Lastomír – Stretava – Ptrukša in the first etape. In following etapes the works should be also extended to the central and NW part (Horovce – Albínov near Sečovce – Klčovo Dlhé) and eventually to the Košice Depression.

Only detail results of 3-D seismics and their perfect analyses increase sucess of drilling works, thus the entire oil and gas bussines in our country. Unfortunately, it was mistakenly thought that positive results are "born". Only perfect and wide knowledge of geologic disciplines represents priority in this bussines. From the viewpoint of possible accumulations three depth intervals were divided (Fig. 3):

The first interval is up to 1 000 m. Prevailingly small amount of resources, mainly scattered gas deposits (Trhovište –west, Pozdišovce – middle block, Bánovce – Močarany, Ptrukša – Leles, Pinkovce, SE slopes of Podvihorlatská panva Depression, Kravany, Sečovce – south, Klčovo Dlhé – Vranov n. T., Drienov in the Košice Depression) occur in this interval.

The second interval is up to 2000 m. From the today's viewpoint it is the most interesting interval and it is unrivalled. The best gas deposits with favourable petrophysical properties are assumed here (Ptrukša –south, Maťovce, Stretava, Senné, Bánovce n.O., Trhovište, Rakovec n.O., Sečovce – south, Rankovce in the Košice Depression).

The third interval is up to 4 000 m and from the viewpoint of areal extent, thus also reservoirs, it is very interesting (Sečovce, Trebišov, Čičarovce, Križany, Stretava, Senné, Pozdišovce, Močarany). Big geologic gas reservoirs of 40–120 mld. m^3 are related to low-capacity deposits with complicated petrophysical parameters and p-t conditions. In order to successfuly meet these problems it is necessary to have both drilling and deposit technology which are only accessible from the foreign know-how. The risks might be compensated by high assumed reservoirs of natural gas and its higher homologues (Magyar, 1988; Janků et al., 1996).

The second perspective area in the Easter reprezented by Slovakia is the Central-Carpathian Paleogene Basin. Even if occurrence of crude oil and gas were detected here, the exploration is low so far. The best known area is a narrow belt neighbouring the Klippen Belt (Plavnica, Lipany). The most perspective is its central part (Levočské vrchy) and area along transverse subtatric fault (Fig. 1).

The verification of a large set of layers consisting of fissured quartzose sandstone underlying Paleogene and known flysch sequences in the Outer Flysch will be substantially more demanding. From the viewpoint of oil prospection it is interesting and new phenomenon extends from Zboj through Smilno to Oravská Polhora.

Additional energetic source of the mentioned areas occurs in the Neogene of the East-Slovakian Lowland and is represented by thermal water and heat from hot dry rocks.

Conclusion

Difficult geologic structure in the Slovakia provides conditions for findings of new hydrocarbon deposits adequate to the actual 50 years old history of exploration. We believe that also in these conditions it is possible to conduct oil bussines with profit.

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Structural research of the NE margin of the Central Carpathian Paleogene Basin: Kamenica railway section, Eastern Slovakia

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Abstract

The Šambrón – Kamenica zone occurs in the NE part of the Central-Carpathian Paleogene Basin. It consists of deposits stratigraphically ranging from the Middle Eocene to the Early Oligocene. The deposits are mainly composed of polymic conglomerate alternating with mudstone and sandstone. At the study location fold and fault structures are typical Fold axis orientations are prevailingly E–W and NNE–SSW. Variety of fault structures, discussed in the text, suggests several deformation etapes acting during the structural evolution of the studied area.

Key words: Central-Carpathian Paleogene Basin, fold description, faulting

Introduction

The Central-Carpathian Paleogene Basin is a part of the Western Carpathians. It is bounded to the Pieniny Klippen Belt to the north and to the pre-Tertiary Inner Western Carpathian Units to the south. The origin of the basin is related to the convergence of the North-European Platform and Western Carpathians where during the Early Tertiary back-arc extension of the Pannonian area occurred (e.g. Ratchbacher et al., 1991; Nemčok, 1993). The basin is genetically compared to the piggy back basin (e.g. Nemčok et al., 1996; Bezák et al., this vol., Janočko and Karoli, this vol.), or perisutural basin (Soták and Bebej, 1996). The basin fill is composed of several sedimentary sequences. The sequences, consisting of terrestrial, shallow-water and deep-water sediments, are thick up to 4000 m. The oldest deposits are of the Paleocene age and the youngest deposits indicate the Late Oligocene – Early Miocene age (Soták et al., 1996; Janočko et al., 1998). The basin was predominantly filled along its axis, however, smaller depositional systems entering the basin laterally played also an important role during the basin evolution (Janočko, 2000).

Our structural research was aimed at analysis of the NE margin of the Central-Carpathian Paleogene Basin, so called Šambrón-Kamenica structural zone. In this zone we studied sedimentary section at the railroad near the village Kamenica. The length of the section is about 2 km. In the section we studied mesoscopic structures, especially bedding, fold structures, fractures and shear zones. Geometric classification of folds has been based on the Hudleston (1973) principle of visual analysis of fold structures.

The studied profile consists of the Middle Eocene and Early Oligocene thin to thick (up to 10 m) bedded sandstone, polymic conglomerate with sandstone and mudstone intraclasts, alternating with mudstone layers.

The profile was analysed by Plašienka et al. (1998). He distinguished two fold generations F1 and F2 which differ by morphology, vergency and genetic features. The F1 folds reflect dextral transpression in the Klippen Belt and the F2 folds did not generated tectonic stress but they reflect dynamics related to the basin evolution.

It is not the aim of the paper to analyse deformation etapes neither to assign described structures to these etapes. We concentrated on synthesis of deformation etapes using structural data measured at the studied locality and at other sites of the Central-Carpathian Paleogene Basin. The objective is to separate the structures with local character and find the structures which are related to deformations typical for the entire periklippen belt.

Structural analysis

At the studied locality we recorded highly variable tectonic inventory showing active polyphase tectonic activity in this part of the Central-Carpathian Paleogene Baisn.

In the studied profile fold structure comprising two fold axes is characteristic. Similarly to Plašienka et al. (1998) we divided F1 and F2 folds. The F1 folds represent closed and isoclinal, penetrative folds of m order. They are often symetric, cylindric, vertical and less often sinusoidly repeating. The fold axes follow E–W and ENE–WSW direction with 5–25° dip of the fold axis toward east. According to the Hudlestone (1973) classification they correspond with several classes between 1C (only one fold) and D-E, 2-4. The F2 folds have minor occurrence in the profile and they are represented by close and isoclinal, non-penetrative, often symetric and cylindric folds. The fold axes follow NNE–SSW direction with 5–20°dip toward north. According to the Hudleston (1973) classification they belong to the 1D, 3D and 3E classes. Besides fold structures we can also observe fault structures in the studied profile. They are result of brittle deformations. Close relation between the F1 folds and overthrust structures are almost everywhere documented by duplexes parallel with fold limbs and overthrust vergency toward N, NNE and S, SSE. It suggests that the compression generating overthrusts and F1 folds is identical. The above mentioned duplexes are often developed in soft sediments at boundary between rocks with different competency.

The second striking fault group consists of strike-slips faults. According to their direction we divide them into three groups with NW–SE, NE–SSW and E–W fault directions. The NW–SE faults, parallel to the Klippen Belt, are characteristic by dextral displacement which is consistent with recent knowledge from the area. The importance of this fault system is emphasized by its identical direction with fault system responsible for the transpression of the Klippen Belt. The strike-slip faults of the E–W direction have both dextral and sinistral displacement suggesting relaxation fault structures. The last strike-slip faults have NNE–SSW direction. They are relatively young sinistral displacements parallel to the F2 fold axes, which segment the Central-Carpathian Paleogene rocks, Klippen Belt and continue into the flysch units of the Outer Carpathians.

The last group of fault structures are normal faults. They are parallel to the F1 fold axes (E–W and ENE–WSW), the dip of faults is toward N, NNE and S, SSW. We assign this type of fault structures to the youngest one. We relate their origin to the last deformation stages during the area evolution.

Conclusion

The studied area is composed of several fault and fold structures. The high variety of deformation structures reflects tectonic events related to the tectonic evolution of the Klippen Belt. It is possible to state that the activity connected with this kinematic active zone is recorded in the studied profile. It is suggested by the whole range of structures found at this section. The described succession suggests individual stages of this development. The evaluation of the structures will be object of our study in the future.

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Paleotemperatures in the Skole nappe (Outer Carpathians) inferred from diagenetic evolution of illite/smectite; the pilot results

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Abstract

A considerable difference in the degree of illite/smectite (I/S) diagenesis has been recorded in the surface samples of claystones from the Polish and Ukrainian part of the Skole nappe. While in Poland highly smectitic I/S has been found, in the Ukrainian part of the Skole nappe highly illitic, ordered interstratifications dominate. Assuming similar heat flow, these results imply little erosion of the Polish segment of the Skole nappe, and advanced erosion of the Ukrainian segment.

Key words: illite/smectite, diagenesis, Skole nappe, paleotemperatures

Introduction

Illite/smectite (I/S) is a mixed-layer clay mineral which abundantly occurs in soils and sedimentary rocks, accounting for about 30 % of the total mass of the Earth's sedimentary cover. Mixed-layer I/S is a product of progressive conversion of smectite to illite (a process referred to as smectite illitization), a diagenetic reaction which is induced by the increase of temperature most often related to deep burial of argillaceous sediments. These features make I/S a useful mineral indicator of diagenetic evolution of sedimentary basins. X-ray diffraction studies have shown that during diagenesis the percentage of smectite in mixed-layer crystals decreases at the expense of illite and the degree of structure ordering increases from random ($R = 0$) to progressively higher ordered ($R > 0$) interstratifications (R stands for Reichweite – an index of ordering). The degree of diagenesis is usually expressed as % smectite (% S) in mixed-layer crystallites and the type of ordering (R). Illitization of claystones seems to be controlled primarily by temperature. The data from the East Slovak Basin (Šucha et al., 1993) indicate that the measurable illitization of randomly interstratified ($R = 0$) clays composed of 70–90 %S, begins at about 80 °C. In the temperature range from 110 to 120 °C, with mixed-layer crystals containing about 35 %S, a transition from random to ordered interstratification ($R = 1$) takes place. $R > 1$ ordering appears at temperature of about 165 °C. Similar scenario is known also from other basins (e.g. Jennings and Thompson, 1986). The above scheme allows us to utilize I/S as a paleotermometer i.e. to establish the highest paleotemperatures which have affected the basin. One may also calculate the approximate thickness of the pile of sediments eroded after the time of maximum paleotemperatures, provided that the evolution of geothermal gradient in the basin is known (Środoń, 1995). This approach has been used to study the Skole nappe.

Geological setting

The Skole nappe extends from eastern Poland through Ukraine to the Romanian Carpathians in Moldova. In Poland, the Skole nappe is the outermost nappe of the Outer Carpathians which overthrusts the Stebnik and Zgłobice Units, and the unfolded Miocene strata of the Carpathian Foredeep (Fig. 1). The Polish part of the Skole nappe has been subdivided into inner and outer parts which differ in style of tectonic deformation (Książkiewicz, 1972). The rocks of the outer part are folded in tight, asymmetric folds and numerous slices. In the inner part, open folds are common. In Ukraine, the Skole nappe overthrusts the folds of Boryslav-Pokucie Unit which separates it from the Sambor Unit and the unfolded Miocene strata of the Carpathian Foredeep. In the Ukrainian part of the studied region the Skole nappe is composed of several slices (Fig. 1).

Materials and methods

The studies of I/S diagenesis were performed on 29 surface samples of claystones collected both in the Polish and Ukrainian parts of the Skole nappe. The samples were collected from the strata that range in age from the Miocene to late Cretaceous. The sample sites are shown

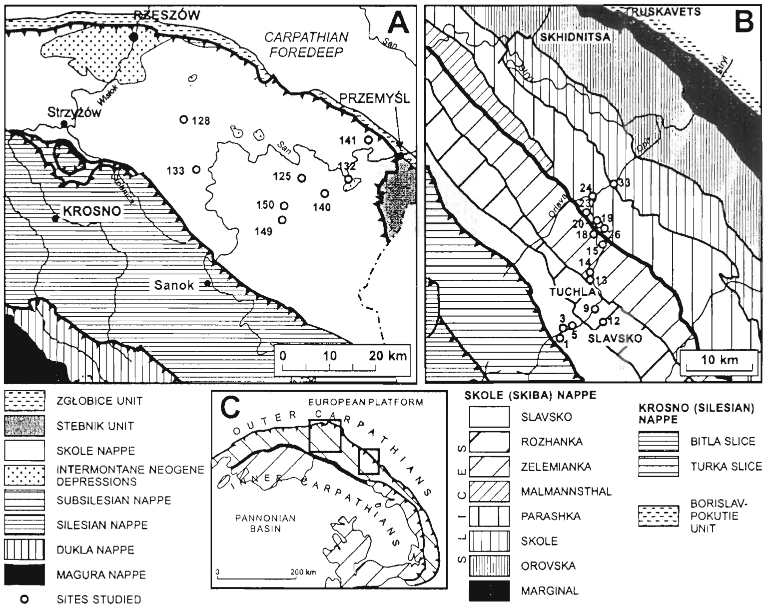

Fig. 1A and B Geological maps of the study areas with the location of the sample sites; A – Polish part of the Skole nappe (after Żytko et al., 1998); B – Ukrainian segment of the Skole (Skiba) nappe (after Zuchiewicz et al., 1997). Inset shows the location of the study areas (boxed) within the Carpathian arc.

in Fig. 1A and B. In Poland, the majority of the investigated samples come from the outer part of the Skole nappe. In Ukraine, samples were collected along the Opor river. The section is located perpendicular to thrusts and axes of the map-scale folds.

Illitization of smectite has been studied in the clay fraction (<0.2 Fm) of by X-ray diffraction. Sedimented preparations were analysed in air-dried and glycolated states by the Philips diffractometer equipped with Cu tube and graphite monochromator and scanned from 2 to 37 °2q with 0.02°2q step and counting time 5s/step at 45 mA and 60 kV. The percentage of smectite (%S) in mixed-layer crystals and degree of ordering were identified by XRD techniques of Środoń (1984).

Results and conclusions

In the Polish part of the Skole nappe, surface samples contain highly smectitic I/S (71–95 %S) characterised by random interstratification. This would imply that the rocks have never been subjected to elevated temperatures (probably less than 80 °C). The lack of measurable diagenesis of I/S in the Polish part of the Skole nappe corresponds to the low degree of diagenesis traced in the boreholes down to about 2000 m in the Miocene strata of the Polish segment of the Carpathian Foredeep (Dudek, 1999). In the Ukrainian part of the Skole nappe, the diagenesis of I/S in the surface samples is much more advanced. I/S in those samples contains 20 % smectite layers on average, and is characterised by R > 1 ordering. According to the scheme presented in the introduction, the high degree of diagenesis would suggest that the rocks were subjected to the elevated temperatures, probably exceeding 160 °C, which could be attained by deep burial.

In conclusion, the presented diversity in the degree of diagenesis between the two areas suggests no or little erosion in the Polish part of the Skole nappe, and extensive erosion in Ukraine, assuming that the two regions have been characterised by similar heat flow. Another explanation of this diversity may be the totally different heat flow in the two studied areas.

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Ultrabasites from the East Slovakian basin basement

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Abstract

In the basement of the East Slovakian basin there are ultrabasic rocks of different stages of alteration. In hapens only rarely that the rocks have preserved primary minerals (olivines, ortho- and clinopyroxenes, chromites). They are usually strongly serpentinized. On the basis of their chemical composition these rocks can be ranked with Alpine-type ultrabsites and from geotectonic point of view they correspond to metaperidotites which are part of ophiolite complexes.

Key words: ultrabasites, mineralogy, petrology, East Slovakia basin

Introduction

The basement of the East Slovakian basin is built up mostly by metasedimentary formations which are intercalated with ultramafic rocks, metabasalts and volcanoclastic horizons. These Penninic-like metamorphic rocks have been called Iňačovce – Krichevo unit (Soták et al., 1993) and they appear to be core complexes which were uncovered by exhumation of the lower plate. Within the basin area the ultrabasic rocks have been recorded in several deep boreholes (Zbudza-1, Pavlovce-1, Senné-2, Senné-8, Rebrín-1, Blatná Polianka-1). The presence of the ultrabasic rock bodies in the basin basement is also indicated by extended magnetic anomalies (Mořkovský and Čverčko 1987; Gnojek, 1987; Gnojek et al., 1991, etc.).

Geology and petrology

The ultrabasic rocks mostly make conform bodies in dark phyllites formations. They vary in thickness, from several metres to hundred of metres. They are usually strongly serpentinized, easy to crush and cleave. In the bodies of greater size also blocks of more compact fresh rocks have been preserved, they "float" in the serpentinized rocks. In the bedding structure the ultrabasic rocks act as the planes of detachment and shearing into slices as well as bigger horizontal overthrusts (shear duplexes). The ultrabasic rocks are tectonically superposed even on the Eocene formations of metapelites. Besides prevailing lizardite-chryzotile serpentinites there are not so frequent slightly serpentinized peridotites with preserved primary textures and structures. According to petrographic classification these types correspond to dunite, harzburgite through lherzolite. As for pyroxenes, there are orthopyroxenes prevailing. Dunite facies occur very rarely. Olivine (from Fo_{93} to Fo_{87}) is unzonal and slightly pressure deformed. Originally glomerophyric aggregates of short columns of orthopyroxene (from En_{93} to En_{86}) and sporadically clinopyroxene, are characteristic in places. Clinopyroxenes reach a size of 2–5 mm, and sporadically the lizardite pseudomorphoses after orthopyroxenes, attain a size of 7 mm. Within a part of the original glomerophyric orthopyroxene aggregates, indication of their preferred orientation can be observed. It is expressed in the whole preferred areal-parallel distribution of aggregates of orthopyroxene columns. Typical banded textures, characteristically for metamorphosed peridotites of ophiolite complexes, were observed only sporadically.

Mineralogy

Chemical composition of clinopyroxenes corresponds to diopside (Fig. 1). The diagram also shows that all silicate phases, i.e. olivines, orthopyroxenes as well as clinopyroxenes, have identical Mg/Mg+Fe ratio which is about 90. With their chemical compositions these minerals correspond to olivines, orthopyroxenes and clinopyroxenes from the metaperidotites of ophiolitic complexes. Olivines, ortho- and clinopyroxenes from the Mesozoic metaperidotites of the Inner Western Carpathians also have similar chemical composition. The course of serpentinization corresponds to the general scheme of alteration: Olivine – orthopyroxene – clinopyroxene. Lizardite and clinochrysolite are determining mineral phases of serpentinites of this type.

Another investigated primary mineral of considerable importance for petrological classification of these rocks is chromian spinel. We studied chromian spinels from rather fresh peridotites as well as from serpentinites. In metaperidotites chromian spinels are hardly altered at all and cor-

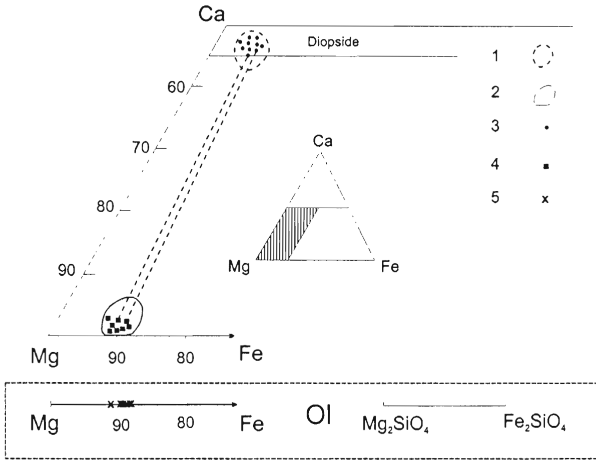

Fig. 1. Mg.Ca-Fe ternary diagram of pyroxenes. 1, 2 – composition of clino- and orthopyroxenes from metaperidotite of ophiolite complexes (Coleman, 1977), 3, 4, 5 – composition of clinopyroxenes, orthopyroxenes and olivines from ultrabasites from the East Slovakian basin basement.

respond to chromian spinels according to Stevens's (1944) classification. In lizardite-chrysolite serpentinites chromian spinels are the only relics of primary minerals. The original grains of chromian spinels underwent cataclasis and have been altered. The primary composition has been preserved only in cores. In the following stage of alteration (probably already after displacement of the serpentinite body to sedimentary sequences) the contents of hausmanite and jacobside end members increased (increased Mn contents). The final stage of alteration was the generation of Cr- magnetite in the form of veinlets, or idiomorphic grains. From geochemical point of view the contents of Al_2O_3, Cr_2O_3 and MgO were falling, or the contents of Fe tot. were rising the alteration. Mn contents were different in individual phases. The composition of chromian spinels from the metaultrabasites from the East Slovakian basin basement (in various discriminant diagrams, Jan and Windley, 1990 and others) is similar to Alpine type peridotites, harzburgites and oceanic tectonites. Such as geochemical classification of the rocks is also supported by the contents of main and trace elements.

As we have mentioned above, the prevailing rock types are lizardite – chrysotile serpentinites. These are further changed up to strongly altered talc – chlorite – tremolite – carbonate rocks. On the basis of the chemical composition and the character of the the alteration (minerals of lizardite- chrysotile group), these rocks can be compared to metaultramafites in the Mesozoics of the Inner Western Carpathians (Hovorka et al., 1985).

Conclusion

– The Iňačovce-Krichevo unit, forming a major part of the Transcarpathian Depression basement, is made up by complexes with some similarities of the Penninic zone; Its rock complexes were anchizonallyepizonally metamorphosed, considerably folded and stretched during post-Eocene tectonogenesis;

– From among primary minerals there have been preserved olivine (from Fo_{93} to Fo_{87}), orthopyroxene (from En93 to En86), clinopyroxenes (diopside) and chromian spinels.

– According to the characteristic of alteration (lizardite-chrysotile serpentinite) they are similar to metaultrafites from Mesozoic complex of the Inner Western Carpathians.

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Chloritoid schists from the Iňačovce–Kričevo Unit (Eastern Slovakia): implications for metamorphic conditions

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Abstract

Chloritoid schists found within metasedimentary formations of the Iňačovce-Kričevo Unit represent a low-temperature metamorphic equivalent of Al-rich pelitic rocks. Rosettes of chloritoid crystals occur embedded in a fine-grained matrix of Ms+Qtz±Pg±intermediate Na-K micas±Prl. Growth of porphyroblasts was post-kinematic with respect to main schistosity. Chloritoid is a Fe-rich variety with XMg between 0.09 and 0.15. The peak metamorphic paragenesis Cld + Prl suggests formation temperatures within the pyrophyllite stability field (~350°C). However, due to uncertainty in identification of the chloritoid-in reaction, the pressure conditions of metamorphism are not clear

Key words: Eastern Slovakia, Iňačovce-Kričevo Unit, LT-metamorphism, chloritoid schists

The East Slovak Basin is floored by the Penninic-like series of the Iňačovce-Kričevo Unit (IKU). This unit appears to be a metamorphic core complex exhumed jointly with back-arc extension of the East Slovakian Basin. Lithologically, it comprises mostly low-temperature metasedimentary rocks of oceanic origin (e.g. metapelites, metaarenites, marbles) with sporadic occurrence of metabasalts and metaultramafics. In this paper, it is our intention to describe mineralogy and petrology of particular type of lithology within IKU – chloritoid schists.

Chloritoid occurs in a metamorphosed high alumina (25–32 weight %) rocks within a metasedimentary complex of boreholes Iňačovce-3 and Senné-2. In these rocks, chloritoid porphyroblasts, constituting up to 30 % of the mode, are embedded in a fine-grained matrix of muscovite + quartz ± paragonite ± intermediate Na-K micas ± pyrophyllite ± pyrite ± rutile, zircon, and tourmaline. Chloritoid generally occurs as rosettes (up to 1 mm in diameter) of radiating crystals penetrating planes of metamorphic schistosity. The aggregates are often rotated with well-developed pressure shadows consisting of quartz and/or phyllosilicates. Single lath-shaped porphyroblasts oriented concordantly with planes s1 are less frequent. This suggests a post-kinematic growth with respect to the main schistosity. Chloritoid crystals or rosettes are also present in quartz-rich syn-folial segregations.

In thin sections, chloritoid usually shows clear pleochroism, greenish colour and polysynthetic (001) twinning developed in larger crystals. X-ray diffraction study reveals that only triclinic polytype occurs in studied rocks.

Average chemical compositions of chloritoid are presented in table 1. Structural formulae have been calculated on the basis of 12 oxygens (water-free). The Fe^{3+} content was obtained on a stoichiometric basis through the assumption $|4 - M^{3+}| = 2\ |2 - M^{2+}|$ (Chopin et al., 1992). Each of the resulting Si exceeds the ideal value of 2.0 p.f.u. Al_{tot} is generally lower than 4.0 p.f.u. and ranges from 3.90 to 3.96 p.f.u. Chloritoid is an iron-rich variety with X_{Mg} between 0.09 and 0.15. Other elements like Fe^{3+} and Mn are subordinate. Negligible contents of K, Na and Ca prove that crystals are not structurally intergrown with phyllosilicates (Banfield et al., 1989). Crystals do not show any chemical zonation. However, two chemically different groups of chloritoid crystals were observed in black phyllites of Iňačovce-3 borehole. Their compositions slightly differ in X_{Mg} by having values of 0.15 and 0.9, respectively (Tab. 1, analyses 2 and 2a). These compositionally different crystals may represent two different populations that crystallized under different (pressure?) metamorphic conditions. Their mutual textural relations are, however, not clear (e.g. they were found side by side within the same rosette).

The peak metamorphic assemblage of chloritoid schist is represented by the chloritoid + pyrophyllite paragenesis. This is indicative of metamorphic temperatures within the pyrophyllite stability field. Assuming that a_{H2O} = 1, this constrains the temperature range from 280–420 °C (Giorgetti et al., 1998). Definition of chloritoid-forming reaction is highly speculative. The reaction Chl + 4Prl = 5Cld + 14Qtz + 3W has been tentatively proposed by Biroň et al. (1993). However, it should be noted that except of sporadic vein occurrence chlorite was never observed in these rocks as a rock-forming mineral. Alternative possibility could be represented by the reaction Cph = Cld + Qtz + W. Despite of this uncertainty, both possible rea-

Tab. 1
EMP analyses of chloritoid from Al-metapelites of the Iňačovce-Kričevo Unit

Borehole / Sample	Iňačovce-3 1	2	2a	Senné-2 3
n[1]	6	10	4	12
SiO_2	24.19	24.62	24.84	24.07
TiO_2	0.03	0.00	0.00	0.16
Al_2O_3	39.78	40.32	40.59	39.34
Cr_2O_3	0.01	0.00	0.00	0.06
FeO[2]	26.21	25.26	2.41	25.92
MnO	0.15	0.29	23.73	0.28
MgO	1.35	1.45	0.47	1.87
CaO	0.01	0.003	0.003	0.01
Na_2O	0.02	0.00	0.00	0.02
K_2O	0.01	0.03	0.01	0.01
Total	91.76	91.98	92.04	91.74
Oxygen basis		12		
Si	2.03	2.05	2.05	2.02
Al	3.94	3.96	3.95	3.90
Ti	0.002	0.00	0.00	0.01
Cr	0.00	0.00	0.00	0.004
Fe^{3+}	0.04	0.00	0.00	0.08
Fe^{2+}	1.81	1.76	1.64	1.74
Mn	0.01	0.02	0.03	0.02
Mg	0.17	0.18	0.30	0.23
Total	5.97	5.92	5.92	5.98
Ca	0.001	0.00	0.00	0.001
Na	0.003	0.00	0.00	0.003
K	0.001	0.003	0.001	0.001
Total	0.005	0.003	0.002	0.005
$X_{Fe^{2+}}$	0.91	0.90	0.83	0.87
X_{Mg}	0.085	0.09	0.15	0.12
X_{Mn}	0.005	0.01	0.02	0.01

1 – Number of analyses, 2 – Fe_{tot} = FeO

ctions indicate that formation temperatures of Fe-rich chloritoid were close to ~350 °C (Vidal et al., 1992; Oberhänsli et al., 1995). On the other hand, there is significant difference in pressure conditions needed for occurrence of these reactions because former is typical for barrovian- and later for high-pressure metamorphism (e.g. Theye et al., 1992). Both higher (7~8 kbar) and low-pressure (<5 kbar) metamorphic events have been recognized in metabasalts of the IKU (Soták et al., 1999). Considering this, the question of chloritoid-in reaction in chloritoid schists remains still open.

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New knowledge on hydrogeology of Cenozoic rocks in the Eastern Slovakia

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Abstract

New results of the regional hydrogeological research in the Carpathian Flysch Zone and Central-Carpathian Paleogene have corrected the traditional conceptions of the hydraulic properties of the flysch rocks. The spatial distribution of the permeability is controlled here much more by decrease of permeability with depth than by lithology. Main continuous aquifer is the near-surface zone where different transmissivity categories related to the geomorphologic position are to be distinguished. Regional assessment of geohydraulic parameters in Neogene sediments, volcanics and Quaternary aquifers improved the conception of perspectivity in particular regions.

Key words: hydrogeology, permeability, aquifers, flysch rocks, Paleogene, Neogene, Quaternary

Introduction

The regional hydrogeological research made by the Geological Survey of Slovak Republic in the Eastern Slovakia in the last decennium contributed essentially to the recognition of real hydrogeological conditions in the Carpathian Flysch, Central-Carpathian Paleogene, in the sediments and volcanic rocks of the Neogene as well as in the Quaternary aquifers (Jetel, 1996, 1997, 1999; Bajo and Jetel, 1995; Jetel and Vranovská, 1997; Jetel et al., 1990, 1993, 1998).

Carpathian Flysch and Central-Carpathian Paleogene

The Carpathian Flysch has appeared up to now as a unit with rather simple hydrogeologic features. It has been treated as a region generally poor in groundwater and consisting mainly of alternating beds of permeable sandstones and practically impermeable shales. Stratiform bodies (beds) of sandstones and conglomerates have been considered generally as aquifers. Therefore, the groundwater studies in flysch rocks aimed to definition, geometry and permeability of individual stratiform aquifers assuming that the lithology is the main factor controlling the permeability of flysch rocks. New results of regional hydrogeological research and the systematic reinterpretation of hydrodynamic tests in the Carpathian Flysch Zone and Central-Carpathian Paleogene obtained by new methodological approaches (Jetel, 1995) have changed or corrected many traditional conceptions of the flysch hydrogeology.

The permeability of flysch rocks is distinctly controlled by actual depth position below ground surface (Jetel, 1985, 1999). Regular decrease of mean permeability in particular formations with depth can be described by exponential functions of depth. The mean permeability in depths of 0–100 m decreases on average to 26–59 % of the initial value per every 10 m of depth increase. At that, the rate of exponential permeability decrease within different depth intervals diminishes with depth: in the upper part of near-surface zone (0–30 m) the mean permeability drops even to 11–50 % of the initial value per 10 m of depth.

A striking dependence between the mean permeability of lithostratigraphic members in the Flysch Zone and the rock age has been observed (permeability decreases with age).Very ambiguous and varied is the relation between permeability and lithology. In some regions, the traditional conception of permeable sandstones and considerably less permeable claystones or siltstones cannot be substantiated; consequently, its validity cannot be treated as general. Somewhere even an inverse relation was found: increasing mean permeability with diminishing proportion of sandstones within the tested well intervals (cf. Jetel and Vranovská, 1997). Primary differences in permeability between sandstones and argillaceous rocks fade away as a result of diagenetic changes reducing integranular permeability. Fissure permeability is of decisive importance. The maximum permeabilities and transmissivities are found in tectonically predisposed joint zones without any unequivocal relation with lithology. Consequently, hydrogeological function of stratiform aquifers and intergranular permeability in the flysch complex is of rather little importance. The main aquifer is here the near-surface zone of increased permeability in first tens of meters below ground surface. Deeper circulation of groundwater occurs predominantly in subvertical joint zones.

The superposition of the exponentional decrease of permeability in the near-surface zone with the regular differences in water-table depth between relief depressions and elevations (the minimum depth of groundwater table below surface in valleys) results in regular spatial differentiation of mean transmissivity of the near-surface zone between valleys, slopes and mountain ridges even in quite identical rock environment. In regional assessment of transmissivity, in hydrogeological maps and at practical interpretation and predictions it is necessary to distinguish different categories of transmissivity related to the position in the relief morphology, especially the valley transmissivity (determined usually by aquifer test in wells) and the lower slope transmissivity (Jetel, 1990).

Neogene and Quaternary aquifers

Regional assessment of geohydraulic parameters in Neogene sediments, volcanics and Quaternary aquifers corrected the conception of perspectivity in particular regions. The factors of permeability distribution in Neogene volcanics (Jetel, 1993, 1997) are very similar to those in flysch rocks including the weak correlation between lithology and permeability. As opposed to the flysch and volcanic rocks, the mean permeability in the sediments of Neogene generally depends on lithology (Jetel, 1998; Jetel et al., 1998). Nevertheless, the maximum productivity (up to 80 $l.s^{-1}$ per well, mean transmissivity about 1.10^{-2} $m^2.s^{-1}$) is also here related to fractures in fault zones regardless of lithology. Prospects of groundwater exploitation in many places are limited by irregular lithofacial development of Neogene aquifers, hidden tectonic elevations and mineral water accumulations as well as by different functions of individual faults. Whilst some young fault zones of the N–S course provide important exploitable groundwater amounts even in mudstones, other faults convey sodium-chloride water from depth or represent no hydraulic communication at all. The quality of water from the Neogene sediments is most often deteriorated by high concentrations of ammonium ions.

The regional studies provided also a synthetic picture of the distribution of hydraulic parameters in Quaternary sediments. The most important aquifers are fluvial gravels in Quaternary tectonic depressions (Michalovce-Sliepkovce depression with very high mean transmissivity up to 3.10^{-2} $m^2.s^{-1}$, mean well discharge 14 $l.s^{-1}$ and with some wells discharging up to 70 $l.s^{-1}$) and in alluvial plains of some rivers (Laborec between Humenné and Michalovce, Latorica, Ondava, Hornád below Košice, Poprad near Stará Ľubovňa, upper Torysa) with mean transmissivities usually below 1.10^{-2} $m^2.s^{-1}$ and mean well discharges about 5–10 $l.s^{-1}$. The highest productivity of fluvial sands with mean transmissivities about 6.10^{-3} $m^2.s^{-1}$ has been observed in the fluvial plain of Latorica river and in the Quaternary depression of Strážne-Trakany depression between Bodrog and Tisa rivers.

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Geothermal energy utilisation – economic potential of Košice basin

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Abstract

Project of geothermal energy utilisation in town Kosice, based on 8 production and 8 reinjection wells with planned total heat output of 100–110 MWt is planned to be put in operation in near future. The four geothermal heat exchange centres will supply about 60 000 households in Kosice, payback time of project is calculated to 7 years. The first phase of work – drilling of 3 geothermal wells – confirmed the existence of geothermal reservoir in Durkov geothermal structure (15 km eastern of Kosice). Geothermal reservoir occur in depth 2100 in Mesozoic dolomites. Wellhead temperature of geothermal water range in 123–129 °C, dynamic wellheads pressure range in 0.9–2.2 MPa and free flow flowrate 56–65 kg/s. Chemical character of water is remarkable natrium chloride type with TDS 29–32 g/l. Model of calcium-carbonate equilibrium calculations as well as measurements in situ suggest scaling and corrosion properties of the water The wells results have significantly exceeded expected parameters that is promising for the realisation of the geothermal energy utilisation project in near future.

Key words: low enthalpy, geothermics, chemistry, water technologic properties, dolomitic reservoir, Kosice basin

1. Introduction

Geothermal heating project with heat output 100–110 MW_t supplied by 8 production and 8 reinjection wells will be completed in Kosice. Mesozoic dolomite aquifer, confirmed by 3 geothermal wells, occur in depth 2100 m. Heat flow of the area is very high (110 mW/m^2) due to neighbouring Slanské vrchy Mts, neovolcanic rocks. Geothermal water of 125–130 °C delivered from production wells will be reinjected back to the aquifer after heat exchange. The results of investigation has found that the structure is confined one, therefore can be utilised only by reinjection system. The heat will be delivered to TEKO Košice (Heat supply and distribution company) by pipeline from heat exchange sites in Bidovce, Ďurkov, Slanec and Ruskov with pump station in Olšovany. Geothermal heat will supply 60 000 households by hot water and heat in Košice by already existed network from TEKO Košice.

2. Geological Setting

Kosice basin is one of the most prospective geothermal areas in Slovakia that is situated in eastern Slovakia between Ore Mts. on western side and Slanské vrchy Mts. Basin is filled by Neogene sediments – Sarmatian clays (thickness 500–1000 m), Badenian calcareous sandy clays (thickness up to 1300 m), Karpatian calcareous claystones with conglomerates at base (thickness up to 400 m). The reservoir rocks of geothermal water are Mesozoic dolomites that form underlying layers of Neogene rocks, their thickness rises eastward from 300 to 2000 m (Pereszlenyi et al., 1998). From lithologic viewpoint there are dark grey fractured and massive dolomites with calcite veins, which are incorporated to Mesozoic mantle of Čierna Hora Mts. (Kullmanova, 1970). Dolomitic rocks that are reservoir rocks of geothermal water do not occur in the whole area of Košice basin in sufficient thickness. Košice basin is folded by 3 main fault zones – Karpatian direction (NW–SE), transversal direction (SW–NE) and Hornád direction (N–S). Faults cut basin into smaller structures, mainly Karpatian and transversal directions are important. Ďurkov geothermal structure is located in SE part of Košice basin. Slanské vrchy Mts. thermally influence the eastern side of Košice basin, heat flow of region is 110 mW/m^2.

3. Investigation Results

3.1. Drilling and testing

During 1998 and 1999 on base of previous seismic measurements and oil wells results, investigation wells GTD-1, 2 and 3 were set in Ďurkov geothermal structure (Fig. 1). That is depression of Neogene basement where Mesozoic dolomites occur in depth 2000 m and more and their thickness is at least 1000 m. The wells are drilled from one place, their orientation is in Tab. 1. The average thickness of production zone is about 300 m located in upper part of Mesozoic dolomites, low productive horizons occur deeper in tectonic dolomitic breccia. Short well tests were performed after completion of the wells, well test data are summarised in Fig. 2. During one step

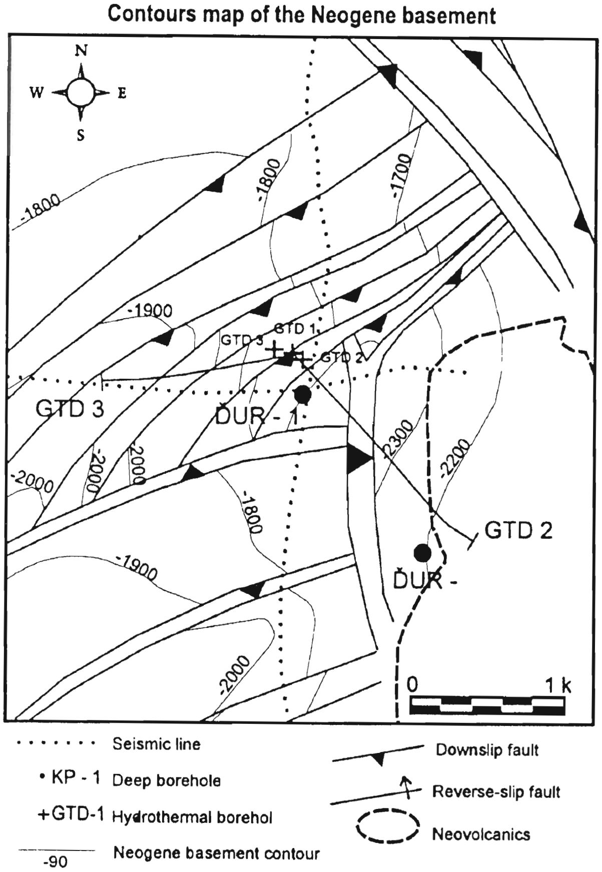

Fig. 1. Wells setting.

Tab. 1
Well orientation

WELL	GTD-1	GTD-2	GTD-3
Azimuth	0 (vertical)	140°	264°
Angle	0	38°	39°
TVD (m)	3210	3151	2252
TMD (m)	–	3730	2625

Tab. 2
Hydraulic parameters

WELL	T (m^2/s)
GTD-1	(2.1 ÷ 5.7) . 10^{-4}
GTD-2	1.6 10^{-4} – 8.2 . 10^{-5}
GTD-3	6.3 . 10^{-3} – 3.4 10^{-4}

well tests wells discharged water freely without submersible pump. On the base of well test data hydraulic parameters of reservoir rocks were calculated (Tab. 2, Jetel, 1999). In March 1999 one week well test proved pressure interference among wells. GTD-2 was used as production well, GTD-1 reinjection and GTD-3 monitoring one. Reinjection of 50 l/s 60 °C water was reinjected into GTD-1 without resistance of well. In geothermal water there is high gas/water ratio (up to 21 m^3/m^3) containing 98 % of

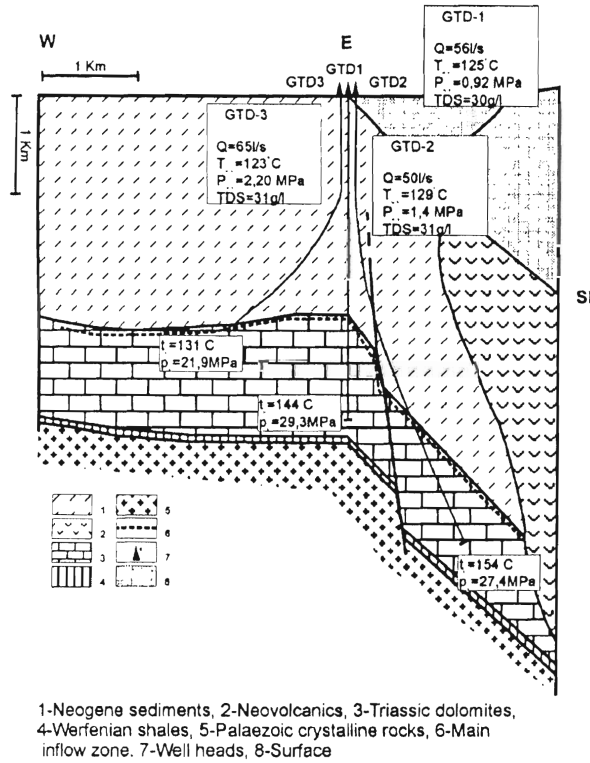

Fig. 2. Well test parameters.

CO_2. Degassing points of the wells are deep (750–1146 m), the utilisation of submersible pumps are concerned. Heat output of each well is about 15 MW.

3.2. Geochemical properties

From geochemical point of view the hydrogeothermal structure Ďurkov is complicated system – water-steam-solid phase. TDS value in both wells range in 29 g/l to 32 g/l. The chemical composition of water is remarkable sodium-chloride type with low content of $Na\text{-}HCO_3$. Compared with other geothermal sources in Slovakia, there is an interesting amount of arsenic (20 to 50 mg.l^{-1}), boron (about 1000 mg.l^{-1} as HBO_2), lithium, bromides (16.9–20 mg/l) and iodides (10–14 mg.l^{-1}) (Bodiš et al., 1998). From genetic point of view of geothermal water we suppose that it is petrogenic water, halogenic group. The calcium carbonate system is very sensitive to the changes of pressure (and consequent degassing) and temperature. The results of chemical equilibria model computations revealed that under partial degassing the water tends to form scaling. On the other hand, when the water would be kept under pressure high enough to maintain a sufficient amount of CO_2 dissolved, serious corrosion takes place. Required partial CO_2 pressure to maintain the calcium ions in solution reaches 2.1–2.2 MPa for GTD-2 and 3 wells (Drozd and Vika, 1998). With respect to these results the treatment of water by inhibitor protection against scaling and corrosion will be necessary for its long-term utilisation and careful handling of pressure.

4. Conclusions

The investigation done during 1998–1999 in Ďurkov geothermal structure showed existence of geothermal reservoir with heat potential at least 100 MWt that should supply about 60 000 flats in Košice. Ďurkov structure is depression of Neogene basement over 2100 m deep with the thickness of Mesozoic reservoir rocks more than 1000 m. The main inflow zones of geothermal water are in depth 2100–2600 m on upper part of Mesozoic dolomites with fractured permeability. The wells parameters – geothermal water temperature at wellhead 124–129 °C, free flow 56–65 l/s, dynamic pressure on wellhead 0,97–2,2 MPa , degassing point in depth 750–1146 m, hydraulic parameters: T range from $8.16.10^{-5}$ m^2/s to $3.41.10^{-4}$ m^2/s and k_f range from $9.44.10^{-8}$ m/s to $8.5.10^{-6}$ m/s. Geothermal water has high TDS content (25–32 g/l) with remarkable sodium-chloride type, scaling (carbonates) and corrosion will take place. During operation there is necessity of inhibitor dosage, pressure maintenance (2.2 MPa) and other precautions. Geothermal structure is confined one that can be used by reinjection. To avoid improper technology implementation the long term semi-operational test will be performed. The results of the wells provide good possibility for one heat exchange centre construction as the first step of the whole project implementation.

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Fresh-water limestones of the Hlavina Beds in the Rišňov furrow and Bánovce Depression

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Abstract

Fresh-water deposits of the Hlaviná Bed, stratigraphicaly assigned to the Late Pannonian (Zone H) mainly consist of carbonate deposits (lacustrine carbonates, fresh-water limestones, travertines; Fordinál and Nagy, 1997).They occur near the marginal faults of the Tríbeč and Považský Inovec Mts. They were studied at localities Malé Kršteňany (Bánovce Depression), Kližské Hradište and Sádok (Rišňovce Depression).

Structure, oxygene and carbon isotope composition (Repčok in Töröková, 1998) and content of trace elements (Cu, Zn, Sr, Mn, K, Na, Ti, V a B) were analyzed. Manometric analysis was also performed. At the locality Malé Kršteňany we also studied gastropods.

Key words: West Carpathians, Danube Basin, Panonian, fresh-water limestone, stratigraphy, lithogeochemistry, genesis, carbon and oxygene isotope

Characteristic of localities

In the Malé Kršteňany village and in the quarry localized NE of the village (Fig. 1) Hlavina Bed deposits consisting of fresh-water limestone crop out. A layer containing blocks of fresh-water limestones, floating in the unconsolidated calcareous matrix of lacustrine limestone type, occurs at the base of outcrops in the village (Fig. 2).

The limestones have micritic and biomicritic structure. Micrite consists of fine-grained calcite and it comprises main part of limestone matrix. The sparite cement, consisting of coarse-grained crystalline calcite, fills numerous pores, gaps and veins. Numerous sections of gastropod fragments filled by crystalline calcite occur in the limestone structure. Clastic grains are represented by quartz and occasional plagioclas. Dark spots of clay occur in the micrite. Fe coatings occur in pores and fissures of limestones. They also occur in the form of sphere bodies. In the quarry solid fresh-water limestones occur locally passin into loose rocks resembling lacustrine limestones ($CaCO_3$ content is as high as 92.34 %). Cores of terrestrial and fresh-water gastropods were found at the section. The following species were identified: Terrestrial gastropods: *Leucochroopsis kleini* (Klein), *Trpidomphalus (Mesodontopsis)* cf. *dederleini* (Brusina); Fresh-water gastropods: *Aplexa* cf. *subhypnorum Gottsch, Anisus* sp., *Viviparus* sp.

In the Malé Kršteňany – village fresh-water limestones crop out at three places. The limestone contains gastropods fauna in the core form: *Aegopinela orbicularis* (klein), *Fotuna clairi Schlickum-Strauch, Klikia* cf. *goniostoma* (Sandberger), *Cepaea* cf. *elelkae* (Halavats), *Cepaeaa* sp., *"Helix" richarzi* Schlosser, *Isognostoma* sp., *Claussilidae indet.* Monospecific assemblage consisting of tests of *Abida* species was found in a fragment.

In the quarry near Kližské Hradište light-brown, baige, solid and compact fresh-water limestone with occasional porous layers occur. Toward the overlying, about 20 cm thick bed, porous layers increase and the upper part is composed of weathered travertines containing red-coloured karst loams. The loams fill a few karst holes (Ivanička et al., 1998).

The limestone from the locality prevailingly has micrite structure which locally passes in to sparite structure. Numerous pores, holes and veins are filled by crystalline calcite. Onkoids, spheres of irregular form having concentric rims and central part filled by calcit, occur in the structure of the limestones. Partly irregular form of micritic rim of onkoids suggests increased wave activity. According to classification of Logan et al. (1964) they may be assigned to the structural type SS – C, concentricaly growing spheroids. The clastic grains of quartz also have accretionary microcrystalline calcite consisting of thin layers. They have form of pizoids.

Only fresh-water algae *Rivularia* cf. *harmatites* Shafer and Stapf and traces after their activity represent fossil remnants. They are are assigned to series Cyanophytae (blue-green alga) and family Rivulariaceae. The family is known from the pre-Cambrium.

The representants of the genus Rivularia prefer shallow lacustrine and fluvial environment with fresh-water. They also tolerate brackish water.

SE of the village Sádok travertine pile occurs (Fig. 3). The lower part of the pile consists of yellowish-brown

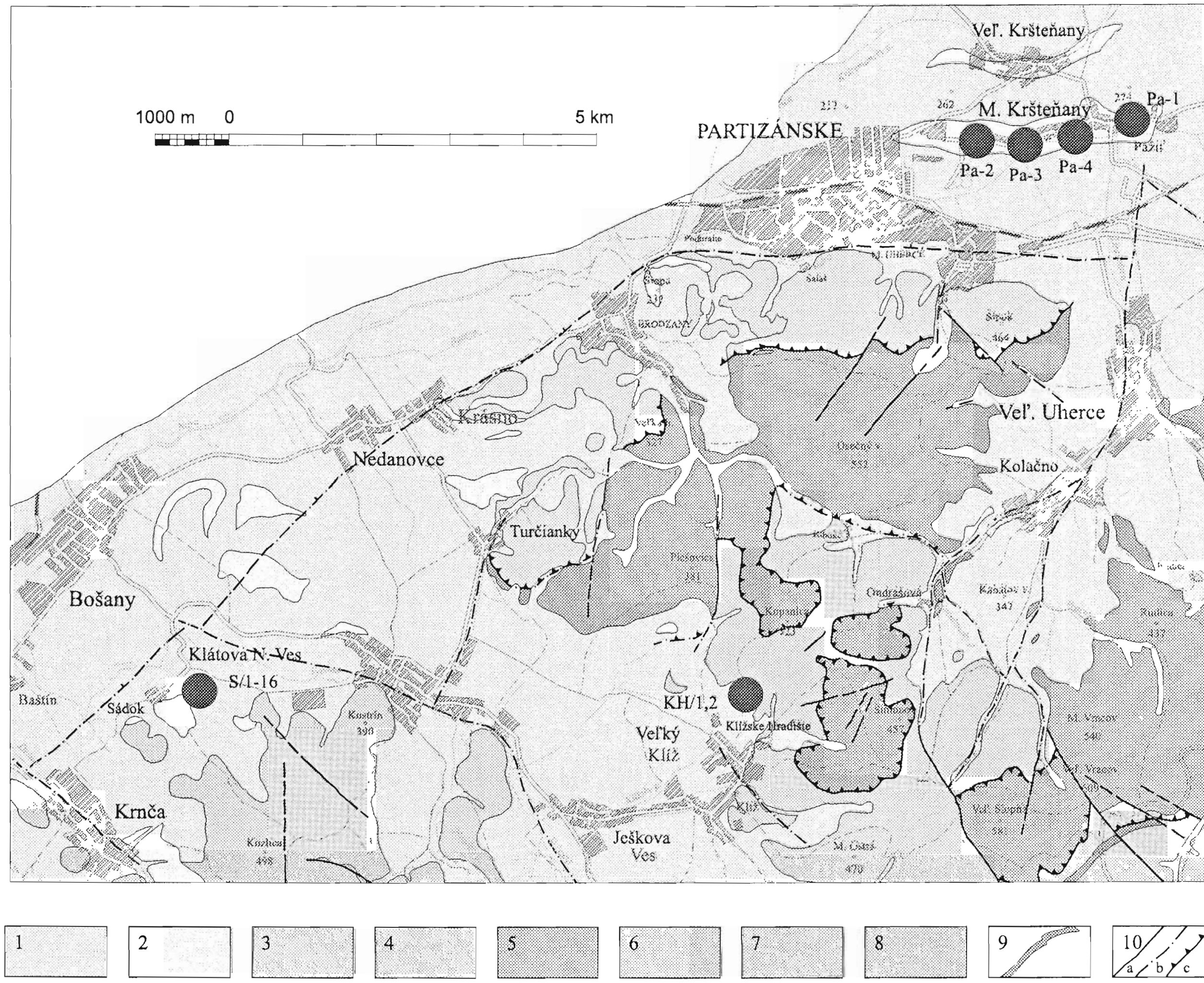

Fig. 1. Localization of the studied localities. 1 – Quaternary, 2 – Tertiary, 3 – Paleogene, 4 – Hronicum, 5 – Veporicum, 6 – crystalline rocks, 7 – Tatricum (envelop), 8 – crystalline rocks of Tatricum, 9 – metamorphic rocks, 10 – a) faults proved, b) faults assumed, c) nappe lines (After Ivanička et al. 1998, modified).

coloured solid and compact layers of travertines having occasional up to 0.6 m thick interlayers of porous travertines. This passes into porous travertine with observable accretionary layers. The upper part is composed of variegated clay having 5–10 cm thick bed of loose sharp-edged quartz clasts without matrix at the base. Other clasts are composed of crystalline rocks. They are 1–2 mm in diameter. They probably represent deposits of a rapid wash of already sorted sediment from coast. The clay contains ostracods *Candona (Typhlocypris) roaixensis* Carbonell and *Candona* sp. (Fordinal in Ivanička et al., 1998).

The carbonate structure consists of micrite passing into sparite. Numerous pores are filled by crystalline calcite. In the unfilled pores calcite forms druse crystals. Occasionally pores are rimed by limonite pigment. Some pores are rimed by coarse-grained calcite. They form geopetal structures in which the lower part is composed of microsparite having a gradual transition to sparite.

Similarly to Klížske Hradište also onkoids, algae *Rivularia* cf. *haematites* Schafer and Stapf and fragments of juvenile gastropode tests occur. Also quartz and plagioklas grains occur. A part of grains is of authigenic origin.

Lithogeochemistry of carbonates

Manometric analysis of studied limestones from the above mentioned localities showed that they contain 70–98 % of pure calcite. The part of them besides calcite also contains Fe dolomite (21–23 %). The insoluble rest, represented by clay minerals, clastic quartz and feldspat grains, limonite and authigenic quartz, varies in volume from 0.30 % to 6.25 %. The non-carbonate part contains an essential amount of insoluble rest which does not release carbonates. Its content in limestone varies from 1.69 to 7.29 %.

The CaO value varies from 45.59 to 54.06 % while the content of molar calcium is relatively high (81.4 % to 98 %). The MgO content is low (1.11 to 1.20 %). The molar amount of magnesium is also very low (2.7–3 %). The FeO value is relatively high considering fresh-water

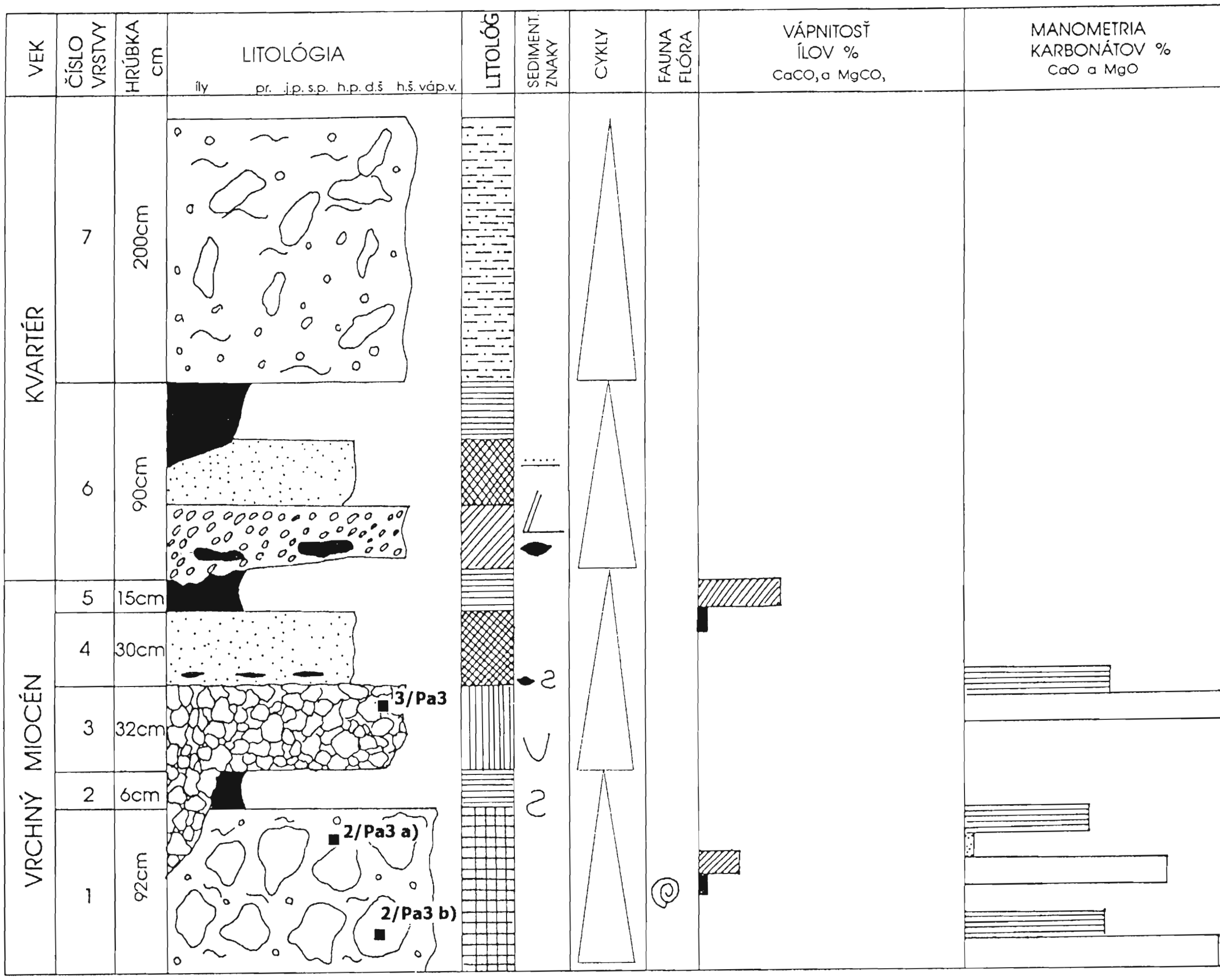

Fig. 2. Sedimentary log of the outcrop Malé Kršteňany, near village. 1 – oolitic limestone, 2 – massive beds of carbonates, 3 – porous carbonates and travertines, 4, 5 – carbonates with calcareous matrix, 6 – gray clay, 7 – lacustrine carbonates, 8- conglomerate, 9 – pebbles, 10 – gravelly loam, 11 – coarse-grained sandstone, 12 – medium-grained sandstone, 13 – fine-grained sandstone, 14- massive sandstone, 15 – duricrust, 16 – $CaCO_3$ content, 17 – $MgCO_3$ content, 18 – calcite content, 19 – CaO content, 20 – MgO content, 21 – horizontal lamination, 22 – cross lamination, 23 – ripple-cross lamination.

limestones (5.54–6.0 %). FeO was probably brought by warm springs circulating on the bottom of sedimentary basin. The carbon dioxide content varies from 40.59 to 43.06 %.

The mutual rate Sr/Ca shows high values up to 66.09. The reason may be high content of carboniferous part because Sr has tendency to bind to high-carboniferous components. The lowest value was observed in limestones from Klížske Hradište (5.34).

The rate Mg/Ca varies from 0.001 to 0.036 and the contents of individual samples does not show big differences. Mean value for marine carbonates is considerably higher (0.80–0.95) suggesting fresh-water origin of carbonates.

Content of trace elements in the studied limestones are considerably lower than referred by some authors for marine limestones. The low concentrations of individual elements in the limestones suggest their fresh-water origin.

Oxygen and carbon isotopes in limestones

Isotopic composition of oxygen (^{18}O) and carbon (^{13}C) was analyzed from four carbonate samples. Two samples were from the locality Sádok and two samples were from the locality Klížske Hradište. In the studied are limestones were also analyzed at localities Veľké Kostoľany, Bojnice, Sádok, Krásno, Záhrada nearby Veľké Tesáre, Veľký Kríž and Podhorany (Töröková, 1988).

Isotopic content of oxygen ^{18}O (Tab. 7, Fig. 16) from limestones sampled in Klížske Hradište has values $\delta^{18}O_{PDB}$ from 3.092 to +3.52 per mile. It suggest that the limestones are enriched in heavy oxygene isotope (^{18}O) and during their formation only small temperaturer fluctuation not exceeding 5°occurred. The limestones probably originated in cooler water having temperature 5–10 °C.

Isotope content of ^{13}C carbon in the studied limestone, which values is $\delta^{13}C_{PDB}$ from – 9.061 to – 9.165 per

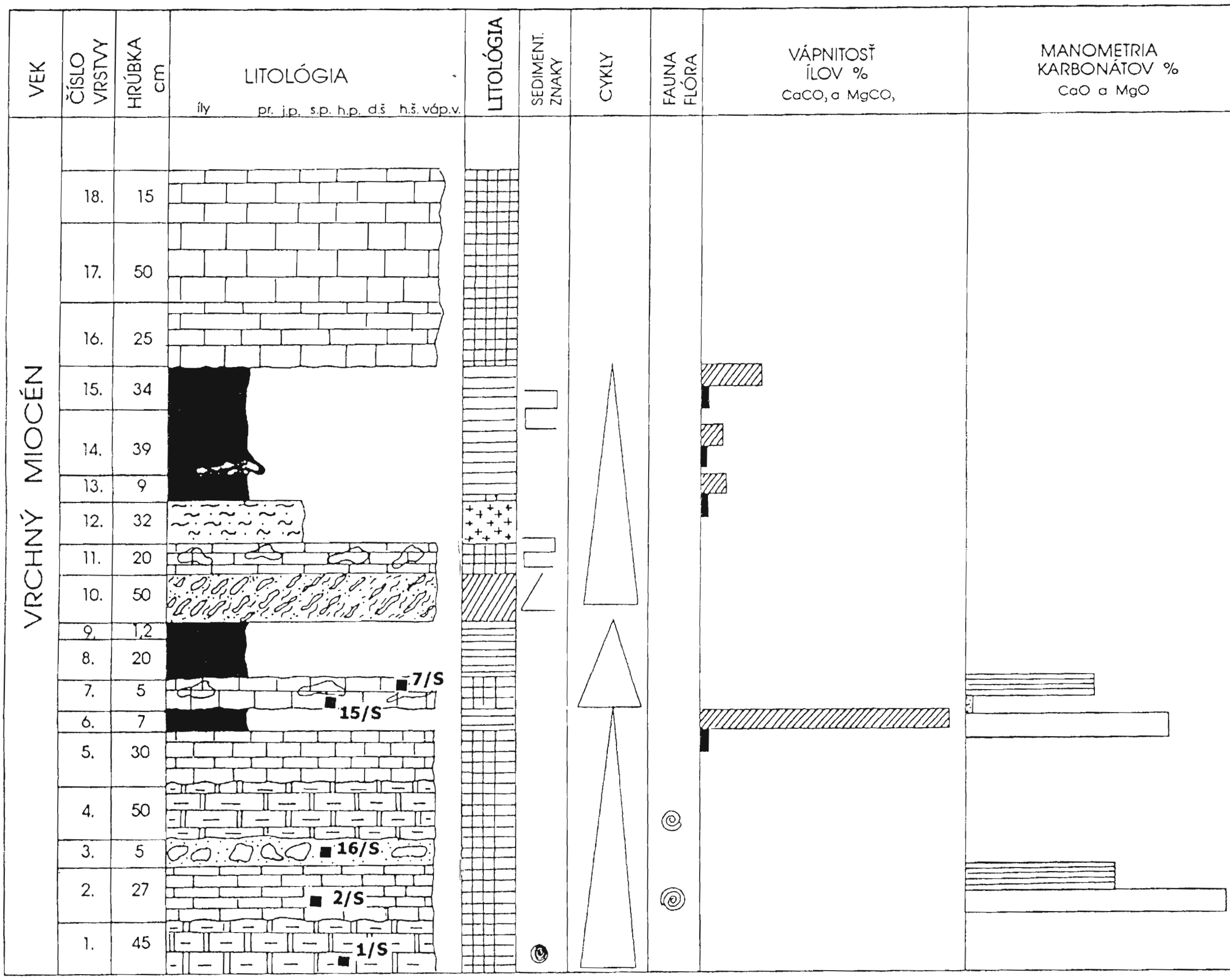

Fig. 3. Sedimentary log of the outcrop Malé Kršteňany, quarry.

mile, suggests enrichment in light carbon isotope ^{12}C which is of organic origin. It showes more intensive input of organic carbon also confirmed by macrofauna occurrence and abundant occurrence of algae identified by microscopic study of limestones.

The limestones from the locality Veľký Kríž, Záhrada, Podhorany have very homogenous oxygen and carbon isotope composition (Tab. 4) and they probably originated in very similar environment like limestones from Klížske Hradište. It is possible to consider them as coeval (Pannonian) and they probably had similar origin. (Fig. 16)

Oxygen isotope composition at the locality Sádok ($\delta^{18} O_{PDB}$ from 2.012 to +2.542 per mile) shows that the limestones are enriched in heavy oxygen isotope (^{18}O) and they also originated in cooler waters having temperature 5 to 10° similarly to limestones in Klížske Hradište.

Carbon ^{13}C and its isotope composition in the limestones at the studied locality is different ($\delta^{13} C_{PDB}$ form –7.891 to + 1.117 per mile). The values show big differences indicating possible change of the carbon source. The value ($\delta^{13} C_{PDB}$ + 1.117 per mile obtained from sample Sádok 16 shows that the limestone is enriched in heavy carbon isotope ^{13}C thus originally it is of organic origin. It is probable that it originates from warm springs. It is consisting with increased content of FeO in the limestones. The negative carbon value ($\delta^{13} C_{PDB}$ – 7.891 per mile obtained from sample S/15 (Sádok) shows the enrichment of the limestone in light carbon isotope ^{12} having organic origin. The organic carbon originates from found algae and fragments of gastropod tests.

Conclusion

Studied fresh-water limestones and travertines from localities Malé Kršteňany (Pa-3, Pa-4), Sádok and Klížske Hradište originated by different ways. Thick basal layers of boulder carbonates from Malé Kršteňany probably originated by their breaking and sliding. The occurrence of gastropode fauna in both limestone clasts and matrix proves synsedimentary origin of the boulder carbonates. Broken, chaotically arranged carbonate boulders may suggest a change of sedimentary conditions. The change might cause movement of carbonate beds and their subsequent breaking.

Beds of fresh-water limestones from localities Sádok and Klížske Hradište are prevailingly of organodetritic origin. However, a part of limestones has anorganic origin.

The organic origin of limestones is confirmed by occurrence of fresh-water algae of *Rivularia* genus and debris of gastropode shells. Layers of travertine limestone (Sádok and Kližske Hradište), having anorganic origin, occur between organogenic carbonates. They originated by precipitation of mineral springs and by hydrotherm effects at the bottom of sedimentary basin. Some percentage of Fe and limonite aggregates suggest their enrichment in Fe. Results of oxygene and carbon isotope analyses showed that except the limestones from Veľké Kostoľany and Bojnice, all the limestones probably originated in waters 5–10 °C warm. The first ones originated in 15–20 °C warm water. The water temperature could be influenced by warm mineral springs.

The depositional environment of limestones was influenced by increased wave activity. It is suggested by numerous bodies – onkoids with concentric structure. The cooler waters and climate is also evidenced by clay minerals in clays alternating with limestone layers. From clay minerals smectite prevails above illite and kaolinite. The content of trace elements in limestones proves their fresh-water origin.

Acknowledgement We sincerely thank isotopic laboratory of the Geological Survey of Slovak Republic which analysed oxygene and carbon isotops on limestones.

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Geophysical survey of the Quaternary sediments in Košická kotlina basin

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Abstract

In frame of the Slovak-Luxembourg project "Košice-biotic and abiotic components of the environment", the lithology and thickness of the Quaternary sediments have been studied. These sediments are the most important aquifers of the groundwater The vertical electrical sounding (VES) method was used. Besides VES results, the all available drilling data have been utilized for construction of the thickness map, resistivity maps for three depth levels as well as geological-geoelectric cross-sections.

Key words: Košická kotlina basin, Quaternary sediments, vertical electrical sounding, apparent and true resistivities, thickness, groundwater aquifers

Introduction

Among other sub-projects, the "Geophysical data on lithosphere-geoelectrics" one was a part of "Košice-biotic and abiotic components of environment" too. Whole project started in 1994 and terminated in 1999 year. The project was financed by Slovak and Luxembourg ministries of environment. The Project Manager was Jozef Hricko from Geocomplex a. s. Bratislava.

The major targets of above mentioned sub-project was determination of thickness and lithology of the Quaternary sediments and their spatial distribution in the area under study. The targets of the sub-project have been solved by vertical electrical sounding (VES) methods along selected profile lines.

Short geological review

The Quaternary sediments noncontinuously cover Tertiary and pre-Tertiary rocks. These sediments are characteristic by frequent lithological-facial changes in horizontal as well as vertical directions. The fluvial sediments of Hornád river are the most frequent ones. The Quaternary sediments also occur on foot-hills and slopes.

The Quaternary sediments can be divided into 4 basic groups:

– Fluvial sediments. They are dominant in geological setting of the Quaternary. This formation is typical by changing the sandy-gravely sediments and clayey-loamy beds. The sandy-gravely sediments are most frequent. Their resistivities vary in the interval of 100–700 ohm.m. Hydrogeologically, they have good permeability.

– Loamy-sandy gravels. They mainly form alluvial cones. The resistivity varies from 10 to 150 ohm.m. They are interbedded by clayey and occasionally by gravely layers.

– Deluvial sediments. They mainly occur on foot-hills and slopes. They create a hem in the part of Čierna hora Mts. and in the NW part of the studied area around Spišsko-Gemerské rudohorie Ore Mts. They consist of rock fragments from pre-Tertiary units and various loams. The resistivity interval: 100–1500 ohm.m.

– Surficial loams and clay rarely with thin layers of sand. They represent floody sediments. The resistivity: 9–100 ohm.m.

Results of the VES survey

The VES curves observed were used for compilation of apparent resistivity (ρ_a) maps for AB=40, 100 and 300 m, it means for depth level of 10, 25 and 75 m approx. They give review on spatial distribution of ρ_a values in pertinent depth as well as an imagination about lithology of the Quaternary sediments. The VES curves have been quantitatively interpreted. The true resistivities (ρ_t) and thicknesses of individual resistivity layers were utilized for construction of thickness map and geological-geoelectric cross-sections.

In this paper, we present resistivity map for AB=40 m (see Fig. 1), it means for depth penetration 10 m approx. We can see 4 areas with ρ_a above 100 ohm.m, which represent sandy-gravely Quaternary sediments and Pre-Tertiary rocks of Čierna hora Mts. and Volovské vrchy hills (in the n. part of the area under study). The areas with ρ_a

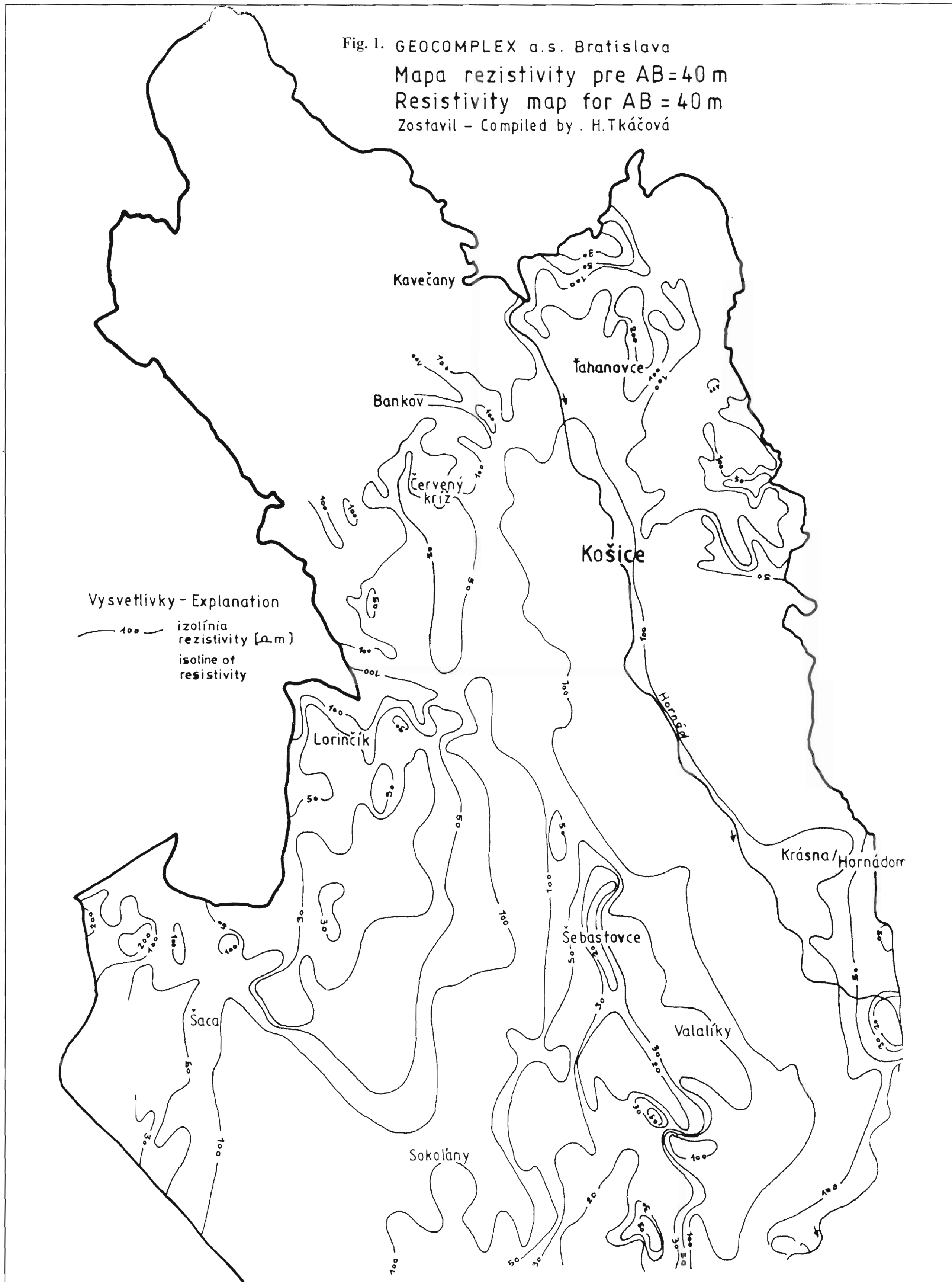
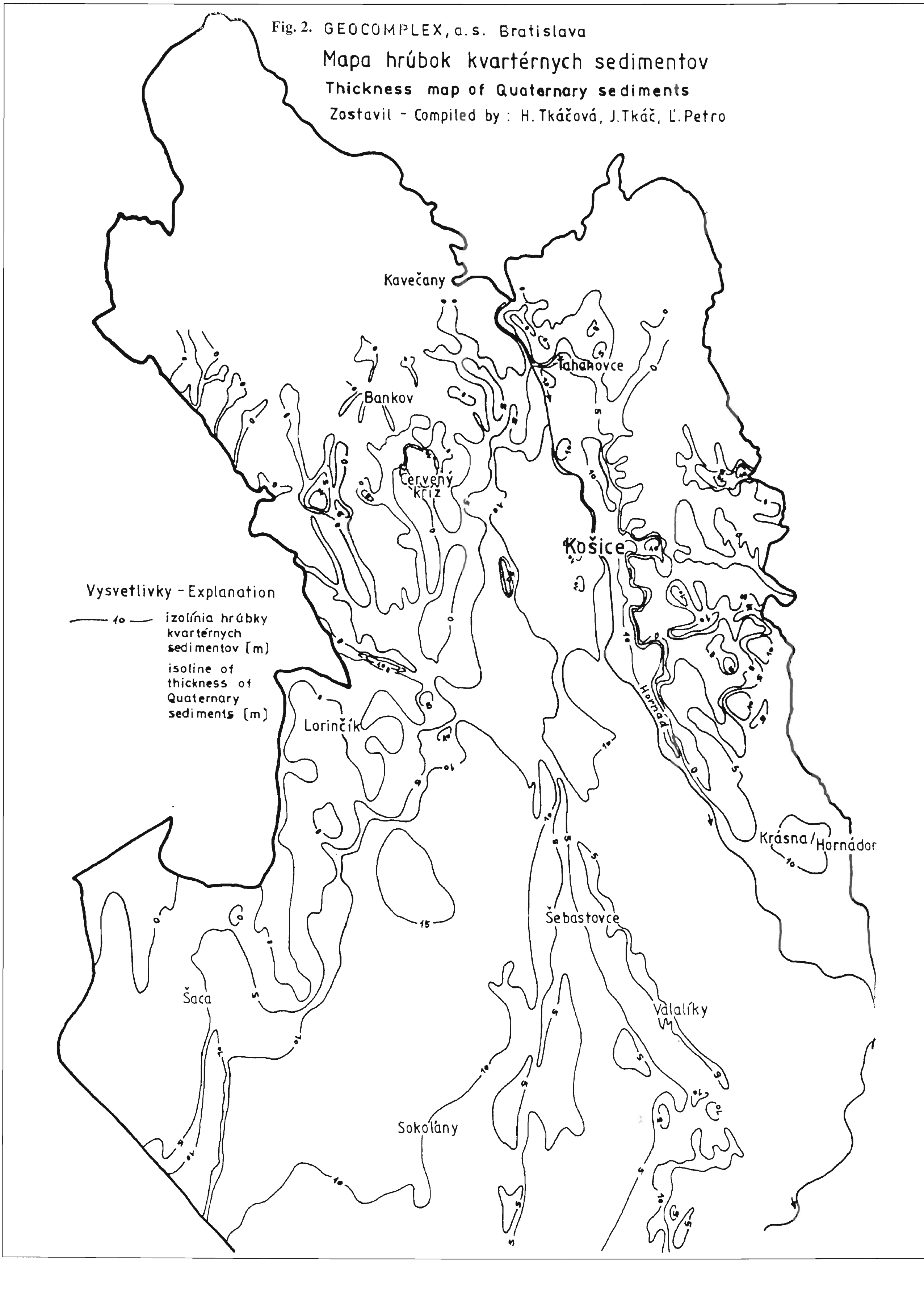


Fig. 1. GEOCOMPLEX a.s. Bratislava
Mapa rezistivity pre AB = 40 m
Resistivity map for AB = 40 m
Zostavil – Compiled by . H. Tkáčová

Fig. 2.


GEOCOMPLEX, a.s. Bratislava
Mapa hrúbok kvartérnych sedimentov
Thickness map of Quaternary sediments
Zostavil - Compiled by : H. Tkáčová, J. Tkáč, Ľ. Petro
Vysvetlivky - Explanation
10
izolínia hrúbky kvartérnych sedimentov [m]
isoline of thickness of Quaternary sediments [m]
Kavečany
Ťahanovce
Bankov
Červený kríž
Košice
Lorinčík
Hornád
Krásna/Hornádom
Šebastovce
Šaca
Valalíky
Sokoľany
15

under 30 ohm.m occur in the Pereš-Ľudvíkov Dvor and e. of Krásna nad Hornádom village sections. They represent loamy-clayey and clayey Quaternary and Neogene sediments.

The Quaternary sediments thickness map (see Fig. 2) gives picture on spatial distribution and thickness of these sediments in the studied area. The thinest sediments - less than 5 m-occur along contact of Čierna hora Mts. and Volovské vrchy hills with Košická kotlina basin. The biggest thicknesses of Quaternary deposits - more than 10 m-occur on the right side of Hornád river. In the Lorinčík potok creek and airport areas, the thickness reaches 15 m. The thickest Quaternary sediments-about 19 m-have been observed n. of Lorinčík potok creek.

The thicknesses above 10 m have been also detected on left side of Hornád river, in the area built by deluvial sediments with presence of landslides. The exception is isoline of 10 m thickness at Krásna nad Hornádom village, which is in connection with fluvial sediments of Hornád river.

Conclusion

By VES method, using all available drilling data, the lithology and thickness of the Quaternary sediments in Košická kotlina basin have been determined. These sediments represent the most important groundwater aquifers. For this reason, the data obtained are very valuable for location of the water wells and for water economical planning.

Analysis of depositional environment as a tool for hydrocarbon exploration: a case study from the Late Badenian deposits in the Trhovište–Pozdišovce area, East-Slovakian basin, Slovakia

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Abstract

Detail environmental analysis of deposits assigned to the Late Badenian Kolčovo Formation revealed high variability of facies, lithotypes and depositional environments. Based on the SP curves, we recognized three types of sandstone bodies sandwiched by relatively thick mudstone. The first type is represented by thin sandstone layers originating in front of delta by prevailing basinal processes (wave reworking). The second type is composed of thick, channelized sandstone bodies cut into mudstones. They represent deltaic distributary channels. The third type consists of thick, upward-coarsening sandstone bodies of deltaic front. Knowledge on depositional environment and associated geometry of sedimentary bodies is suggested as important tool for strategy of hydrocarbon exploration.

Key words: Late Badenian, deltaic deposits, sandstone geometry, SP curve, hydrocarbon exploration

Introduction

The East-Slovakian Neogene Basin belongs to the most perspective areas in Slovakia from the viewpoint of hydrocarbon exploration. Gas has been exploited since sixties and today it is exploited at Ptrukša, Stretava, Senné and Pozdišovce gas fields. Since 1966 about 3.9 milliard m^3 of gas has been exploited (Lačný and Danko, 1997). The largest hydrocarbon potential is assumed to occur in the Late Badenian and Early Sarmatian deposits. This is determined either by their tectono-sedimentary characteristics (occurrence of structural, structural-stratigraphic and stratigraphic traps, e.g. Rudinec, 1989a, Magyar, 1984, Čverčko et al., 1985) and depth of oil-generation window (1350–3800 m, Kráľ et al., 1991).

Hydrocarbon exploration, conducted by Nafta Michalovce company, has commenced in fifties in the East-Slovakian Neogene Basin. Several thousand meters of "counter-flash" boreholes drilled up to 600 m were performed during the first etape of exploration. Based on the boreholes, open-borehole geophysical logging and seismics the most perspective areas were chosen. One of the most known and most productive areas in the East-Slovakian Neogene Basin is Trhovište – Pozdišovce gas field. The exploitation in the field started in 1966 and has been continued up till now. The aim of this paper is to show in detail sedimentary characteristic of sediments, which are gas productive and to describe their sedimentary environment. This characteristics should serve as a guide for exploration of further potential hydrocarbon fields in sedimentary basins.

Geological setting

The area of gas field Trhovište – Pozdišovce occurs in the north-eastern part of the East Slovakian Basin (Fig. 1). The Neogene deposits, overlying Mesozoic rocks, are thick up to 3600 m. They consists of the Karpatian, Badenian and Sarmatian formations. The gas is exploited from the Late Badenian and the lowermost part of the Early Sarmatian Kolčovo Formation. The Late Badenian is time when major palaeogeographic changes in the basin occurred (e.g. Rudinec, 1989b, Vass et al., in press). The southern connection between the basin and Parathetys was definitely established, activitation of N–S faults governed new source areas for deposits and due to increased fresh-water flow into the basin the salinity of the water rapidly decreased. The deposits of Kolčovo Formation (Vass and Čverčko, 1985) fully reflect all these palaeogeographic changes. It consists of deposits originated in brackish environment and lithofacies suggest deposition in deltaic system entering the basin from the northwest and west (Janočko, 1990; Řeřicha, 1997). Toward the southeast it gradually passes into marine deposits represented by Lastomír Formation. The structure of deltaic deposits suggests a progradation of the whole body toward the southeast, which is conformable with the migration of the basin depocenter (Janočko, 1990, Vass et al., in press). The lower part of the formation mainly consists of coarse-clastic deposits (sandstone, conglomerate) alternating with claystones. The upper part is finer and mudstone prevails.

Řeřicha (1997) differs in the Kolčovo delta sediments of delta fronts, bars and prodelta. Janočko (1990) descri-

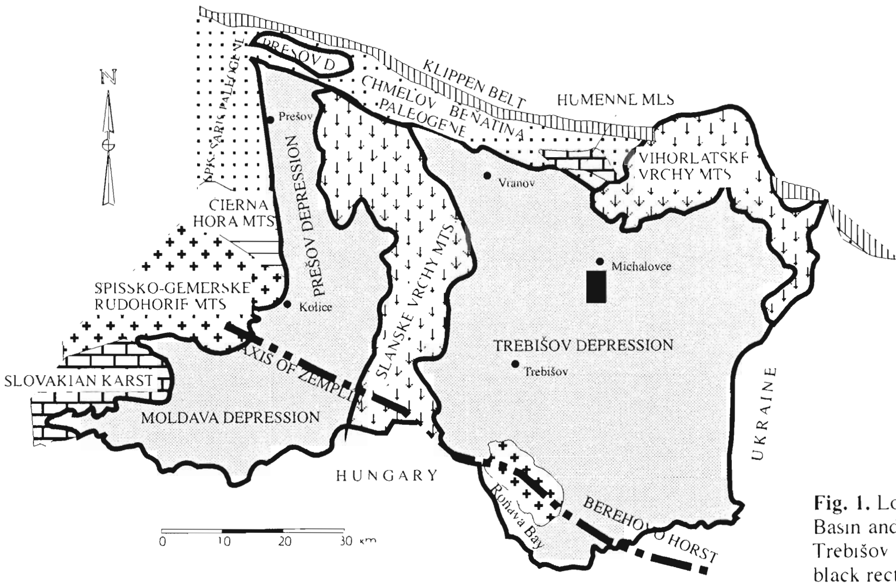

Fig. 1. Localization of the East-Slovakian Neogene Basin and its subdivision into Moldava, Prešov and Trebišov Depressions and Slanské vrchy Mts. The black rectangle marks the study area

bes Kolčovo deposits from the western part of the basin where he also recognized deposits of deltaic plain, front and prodeltaic deposits.

Characteristic of sediments in the Trhovište – Pozdišovce area

According to the SP and density curves the character of deposits differs from place to place in the studied area (Fig. 1). According to the SP response, we can divide three types of deposits there.

The first type is represented by alternation of straight base lines alternating with sharp-pointed curves (Fig. 2). The amplitude and shape of these curves suggest occurrence of thin sandstone bodies alternating with mudstones. According to the curves, the mean thickness of sandstone bodies is 1 m, the thickness of mudstone interval varies from 10 to 40 m.

The second type of SP response is represented by box-like shape of the SP curve alternating with straight SP base lines (Fig. 2). The box-like shape suggests thick sandstone bodies enveloped by fine mudstone deposits (straight line). The mean thickness of sandstone bodies is 5 m.

The third type of SP response is composed of sequence of peaks with upward increasing amplitude (belt-like shape, Fig. 2). This response suggests coarsening-upward trend of sandstone, possibly passing into conglomerates.

The three types of SP responses suggest variability in the facial development of Kolcovo delta depositional system. Lateral correlation of the SP logs from individual boreholes in the area (Trhovište and Pozdišovce boreholes) indicates both postsedimentary faulting and high facial variability. Based on the responses, we can distinguish three main depositional environments in the studied area. The first one is represented by responses of type I. Origin of alternating thin sandstone bodies and mudstone is interpreted in front of delta where basinal processes prevail (wave-reworked deltaic deposits). Thick sandstone bodies enveloped by mudstone (type II) suggests occurrence of channelized bodies (deltaic distributary channels?) cut

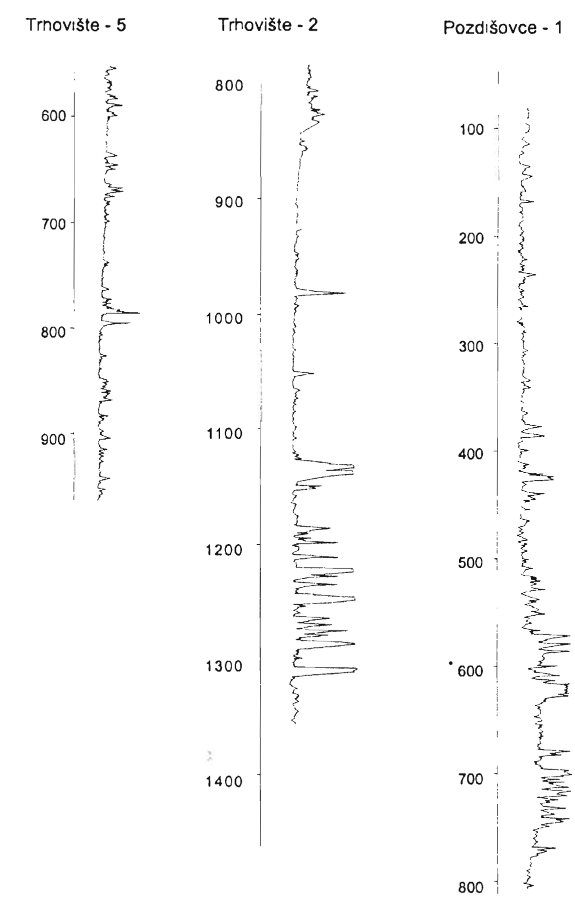

Fig. 2. Three types of the SP curves described in the text.

into basinal mudstone. Upward-coarsening sandstone bodies (type III) are thought to be deposits of prograding delta front.

Conclusion

The interpreted geometry of sandstone bodies may play an important role in strategy for hydrocarbon exploration. The strategy differs for exploration of linear (channelized), thick sheet-like (delta front) and thin sheet like (wave reworked) sandstone bodies as potential hydrocarbon traps. Careful investigation of lithofacies and understanding of sedimentary environments may play in this process one of decisive tasks.

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Quaternary fluvial and alluvial fan deposits of Torysa river in the Košice Basin, Slovakia: relationship and evolution

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Abstract

Four terrace steps overlain by deposits of alluvial fans are developed in the Torysa river valley south of Prešov. The study of relationship between the fluvial and alluvial fan deposits is facilitated by type of sediment composition. Polymic gravel comprises fluvial terraces and monomic, mostly andesitic gravel comprises alluvial fan sediments. The superposition of alluvial fans above the contemporaneous terrace steps suggests that the most active phase of alluvial fan development took place when fluvial sedimentation ceased.

Key words: fluvial sediments, alluvial fan sediments, erosion-accumulation cycle, Quaternary

Introduction

The Hornád river and its left-side tributary Torysa river are two main rivers draining the Neogene Košice Basin situated in the eastern Slovakia. During the Pleistocene evolution, they formed several terrace steps consisting of erosional plinths underlying fluvial deposits. The valley of the Torysa river is bordered by the Slanské vrchy Mts. from the east. Transition of a steep mountaine relief into low-energy relief in the valley caused development of several alluvial fan generations. The superposition of alluvial fan deposits and deposits of the axial river system suggests evolution of the valley during the Quaternary.

Geological setting

The Košice Basin is a part of the Neogene East-Slovakian Basin with prevailing mud and minor sand and gravel fill. It is separated from the main basinal area by a chain of volcanic Slanské vrchy Mts. Two positive morphostructures, laterally restricted by N–S faults, governed the development of three main N–S directed fluvial valleys in this region during the Quaternary. The Hornád river and its left side tributary, the Torysa river, representing axial river system in two N–S valleys, are medium sinuosity meandering rivers with prevailing gravelly and sandy load. Before entering the Košice Basin, they cross several geologically different areas rendering complex petrographical composition of transported load. In the Košice Basin, the rivers have built up several terrace steps during the Pleistocene. High energy relief of mountains surrounding Torysa valley governed existence of steep gradient perpendicular tributaries to the axial river, which resulted in deposition of alluvial fans during the Pleistocene and Holocene.

Fluvial deposits of the Torysa river

The Torysa river enters the Košice Basin through the gateway at the northern part of the basin, which separates two main river basins. The fluvial sediments are more widespread to the north of the gateway, in the Paleogene basin extending from Brezovica to Veľký Šariš, comparing to the souther Neogene Košice Basin. This sediment distribution shows prevailing deposition at the highland front in the middle river reach and more balanced equilibrium regime in the lower reach resembling a small-scale example of three-fold catchment basin model (Starkel, 1990). Four terrace steps and recent valley fill are preserved in the investigated area. Dissected terrace steps consisting of erosional plinths incised into the Miocene bedrock and overlain by fluvial accumulations are arranged into upper, middle and lower terrace systems according to their morphostratigraphy. The stratigraphy of terraces is not firmly established because of general lack of pollen and fauna in the fluvial deposits. The main stratigraphic criteria for dating were morphostratigraphy anf correlation with both overlying alluvial fan deposits dated on the base of fossil soils and terrace steps developed in the northern reach of the river (e.g. Harčár, 1972).

Alluvial fan deposits

A sharp transition between slightly undulating, low energy relief prevailing in the Torysa river valley and a high energy, sharply dissected relief of volcanic Slanské vrchy Mts. neighbouring the valley from the east side, rendered alluvial fan sedimentation recorded from the Middle Pleistocene. The petrography of alluvial fan sediments, which depended on the geology of its source material (mainly Neogene andesites) gave an unique possibility to study their relationship to the petrographicaly different, high variety fluvial sediments of the Torysa river. The development of alluvial fans has been depended on the development of local erosive base given by the incision of axial Torysa river system. This is reflected by a very consistent morphometric characteristic of terrace steps and alluvial fan toes. The most conspicuous are alluvial fans deposited by river Delňa, a left side Torysa river tributary. They have a telescopic structure with the head of younger, lower fan segment inserted into upper fan. The radial fan profiles, reflecting erosional and tectonic changes in its source area (Bull, 1964), are slightly concave. This type of fan structure indicates a relatively stable position between fan and source area (Bull, 1964). The fan consists of five segments (generations), that are according to the altitude of their toe divided into middle and low alluvial fan systems. The deposition of the lower alluvial fan system suppressed the Torysa river sedimentation and caused the bent of its channel westward.

Relationship between the fluvial and alluvial fan deposits

Different lithology of the alluvial fan and fluvial terrace deposits in the Torysa river valley as well as high number of mapping drillings (e.g. Modlitba et al., 1986; Petro et al., 1986) render a good correlation between the terraces and alluvial fans. Due to relatively stable tectonic conditions the relationship between alluvial fans and terrace steps in the Torysa river valley is mostly a result of climatic changes. Every segment of the alluvial fan system is superimposed to its fluvial terrace counterpart of the Torysa river. The preservation of this sediment succession in all stages of valley development suggests that the most active alluvial fan sedimentation took place at the end of fluvial accumulation phase in the erosion-accumulation cycle of valley development. This was followed by a period of river incision. The fluvial and alluvial fan sediments were partly destroyed during the next erosive – accumulation cycle, but the erosion has never expanded laterally as far to destroy all older sediments resulted in a new lower terrace step.

The terrace flight with alluvial fan veneer shows a cyclicity in the sedimentation of the fluvial – alluvial fan succession. Two periods of fluvial incision during the transition of warm – cold and cold – warm conditions with prevailed sedimentation during the glacial and interglacial time are generally accepted as an explanation for the cyclic river acitivity in the Pleistocene (Starkel, 1990; Vandenberghe, 1993). The development of alluvial fan sedimentation depends on many factors among which most important are morphology (relief), sufficient amount of detritus in rock drainage basin and suitable climatic conditions (hydrological regime favouring high rainfall amount). These factors form a "geomorphological treshold" that has to be exceeded in order to provide suitable conditions for alluvial fan sedimentation (e.g. Leeder, 1982). Assuming that the main fluvial aggradation phase took place during the glacial period, the main alluvial fan deposition occurred at the end of the glacial. This indicates that the conditions favouring the exceeding of geomorphological treshold were present particularly at that time. An intensive frost weathering during the glacial period revealed a high amount of loose detritus in the source area of alluvial fans. A sparce herbaceous vegetation at the end of the glacial has not been able to stabilise weathered material on steep slopes of mountains adjacent to the low relief basin and all "prepared" material was redeposited during the increased rainfall in the transitional period before the warm stage governing alluvial fan development at the foot of the mountains. The main trend of the axial river in the main valley, suppressed by the alluvial fan to the opposite side of the valley, was incision during a time of increase runoff and therefore it has already not switched back and recovered alluvial fan deposits. A new valley "storey" has been developed after the incision representing the beginning of a new erosion-accumulation cycle.

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Neotectonic character of Slovakia

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Abstract

Main aim of the article is to focus attention of the Slovak geological community on neotectonics. Proposal for definition of neotectonics is presented and discussed. Neotectonics for the territory of Slovakia and the Western Carpathians has been defined as tectonic events and processes that have occurred in the post Miocene and are continuing at the present day. Neotectonic character of Slovakia is estimated from following aspects · fault pattern ii) recent stress field iii) recent vertical movement tendencies related to crust thickness and heat flow iv) position and character of seizmotectonic zones (Klippen belt zone, Čertovica zone and Rába – Hurbanovo zone have been proposed and discussed) Slovak territory have been divided into neotectonic regions on the basis of aspects above.

Key words: neotectonics, Slovakia, fault pattern, recent stress field, recent vertical movement tendecies, seizmotectonic zones, neotectonic regions

Geology and tectonics of the NE part of the Komjatice depression

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Abstract

The Komjatice Depression is the northeasternmost branch of the Danube Basin. The geologic and tectonic evolution may be followed since the Middle Badenian. The sedimentary fill of the depression consists of the Neogene megacycle. Depositional environment passes from the marine to brackish, kaspibrackish, lacustrine and swamp during the Miocene. The overlying Pliocene cycle is characterized by lacustrine, deltaic and fluvial deposition.

The general NE-trend direction of the axial part of the depositional area was preserved during the entire evolution of the depression. The deposition was controlled by an NW–SE extension. The main controll for depocentres development were the NE-trending Mojmírovce and Šurany fault systems. Brittle faults are probably determined by extensional rejuvenization of the Veporicum thrust plane (Čertovica line).

Key words: Danube Basin, Komjatice Depression, Miocene and Pliocene sedimentation, Mojmírovce and Šurany faults, palaeostress orientation, Čertovica line

Geological and tectonic evolution of the Turiec depression in the Neogene (Central Slovakia)

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Abstract

The Neogene fill of the Turiec Depression represents a halfgraben filled above all in the Middle and Late Miocene. The material transport was from W toward E, the basin axis was situated in the NE–SW direction. The sediment distribution was determined by altered palaeostress field. During the Early Miocene a compressional component was oriented in the NW–SE direction and gradually it rotated into NE–SW direction in the Late Miocene. During the Pliocene a compressional component was again oriented in NW–SE direction. The paper contains lithostratigraphic division of Neogene deposits and we define a new lithostratigraphic unit – Turiec Formation.

Key words: strike-slipe neogene basin, paleostress orientation, miocene – pliocene sedimentation

Burial history of the Levoča Basin in the light of illite/smectite and vitrinite reflectance data

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Abstract

Illite/smectite (I/S) and vitrinite reflectance (VR) data have been applied to determine burial history of the Paleogene flysch formations of the Levoča Basin. With increasing stratigraphic age and burial temperature proportion of smectite layers in I/S decreases and progressive change of R0 to R3 ordering takes place. Smectite-rich I/S (≈ 85–40 %S) with random ordering was found in the youngest, Late Oligocene – Early Miocene rocks. The underlying Late to Early Oligocene formations are characterized by R1 I/S (≈ 40–20 %S), and R3 I/S (≤ 15 %S) was encountered mainly in oldest, Late Eocene strata. Correlation with VR data can be approximated as follows: R0 to R1 transition occurs at $R_m \approx 0.5$ %, and R1 to R3 transition at $R_m \approx 0.8$ %. Observed data indicate burial temperatures between <70 °C up to at least 165 °C. None of the flysch formations studied reached the anchimetamorphic temperature conditions (highest IC = 0.65°Δ2θ, $R_m = 1.5$ %). Presented diagenetic model, however, should be considered as generalized. A significant deviation was recorded in the central part of Levoča Basin (e.g. Tichý Potok area) where the youngest known Early Miocene sediments display more advanced illitization (R1 I/S with 25–35 %S) and higher VR values (Rm = 0.8 %) than rocks of similar age in the other parts of basin (R0 I/S, $R_m < 0.5$; e.g. Šambron Zone). Taking into account the range of possible paleothermal gradients 50–30 °C/km and normal heat flow, this observation implies, that ca. 2.8–4.6 km thick sequence of unknown sedimentary rocks has been removed in this area since the basin inversion. This suggests a continuation of sedimentation during the Early Miocene as well as diversity in subsidence history of the basin. It is proposed that during the Late Eocene-Early Oligocene the zone of maximum subsidence was located in the northern part of the basin (Šambron Zone), while during the Late Oligocene and Early Miocene it was shifted southward to the central part of the Levoča Basin.

Key words: Levoča Basin, burial history, illite/smectite/vitrinite reflecture data

Sarmatian deltaic processes beneath the Štiavnica stratovolcano (Danube Basin, Slovakia)

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Abstract

The studied area is situated at the eastern margin of the Danube Basin at the transition of the Komjatice and Želiezovce depressions.

The outcrop sedimentological study of Sarmatian (Middle Miocene) sea-shore deposits brought a possibility to reconstruct the relative sea-level changes, strongly influenced by volcaniclastic supply.

Due to the eustatic sea level changes the Badenian/Sarmatian boundary is widely transgressive. In the studied area the Sarmatian volcanic activity at the basin margin caused an enormous volcaniclastic supply, as well as periodical earthquake forced instability of both the subaerial and subaqueous slopes. This sediment supply is mirrored in normal regressive trends within the Lower Sarmatian sedimentary record.

During the Early Sarmatian the tectonic impulses trigerred the mobilization of coarse sandy gravity flows in the frontal part of the shoreface in the southern part of the studied area. The mass flows eroded the silty-clayey basinal sediments, thus forming mud-clasts rich sandy breccias, finger like reaching into the marly-sandy laminated basinal facies. At the gravity flows lower interfaces with the basinal facies frequent medium scale water escape flame structures can be find. Some soft sediment deformations, found in the gravity flow related bodies originated due to frictional freezing of mass flows. The relief instability is mirrored in slump folds. In the more flattly lying deposits the seismic activity caused the origin of complicated liquefaction disturbances.

The northern part of the studied area is characterized by very dynamic sedimentation of sandy and gravelly fan-deltaic system. The principal transport direction was measured from east and southeast, depending on particular fans geometry.

However, in places with decreased terrigenous sediment supply, normal eustatic transgressive trend is visible. Here the sedimentary record comprisses a deeepening upward setting of temperate-water carbonates, represented by bryozoan-algal-serpulid biostromes, going upwards into offshore clays.

With respect to the above mentioned effects, the paleogeography of the studied area shows prograding shorelines at the acting volcanic slopes and backstepping shorelines between the volcanic centres.

Key words: Danube Basin, deltaic sediments, sea-level change, soft deformation, palaeogeography

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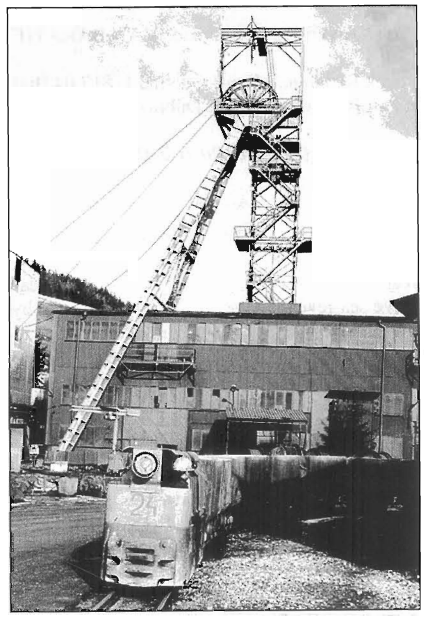

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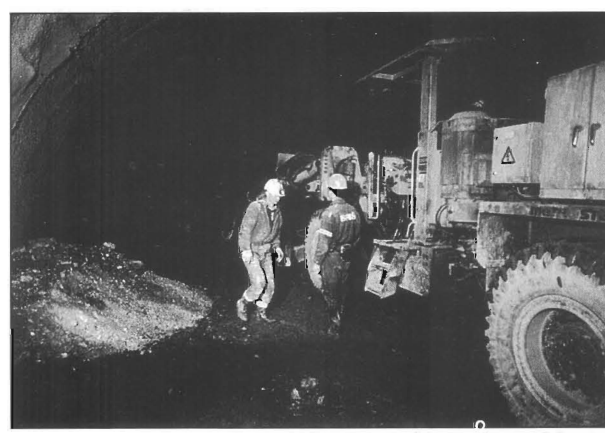

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   Radvanský, F., Slivka, B., Viktor, J. & Srnka, T., 1985: Žilné ložiská jedľoveckého príkrovu gemerika. Záverečná správa z úlohy SGR-geofyzika. Manuskript—archív GP Spišská Nová Ves, 28.
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