Characteristics of main research directions investigated at the institute and the achievements 2010−2014

Institute	

1.1 General characteristics

The **main focus of the Institute of Geonics CAS** can be generally characterized as investigation of processes in geological environment, especially processes associated with human utilization of the Earth crust. The aims involve solution to environmental problems, e.g. those related to the need of energy from classical and renewable resources, and research for other technologies, especially the use of high-speed water jet for various applications. The investigation of complex physical and chemical processes in the geological environment requires interdisciplinary approach and research in geosciences as well as in specific parts of physics, material science, material disintegration processes, chemistry, mathematics and computer science. Environmental and social geography are also related disciplines.

As concerns research on **technologies for the Earth crust utilization**, it was at first extraction of raw materials and the institute was founded in 1982 as Mining Institute of the Czechoslovak Academy of Sciences. But this focus was enlarged, as also expressed by change of the institute name, and nowadays increasingly more research is devoted also to other geo-technologies. For example, in the evaluated period, a lot of research was oriented to processes associated with geological deposition of the high level radioactive waste. In the future, we would also like to perform research oriented to further geo-technologies as enhanced geothermal systems, underground storage of energy, CO2 sequestration etc.

For the evaluation, the Institute of Geonics CAS (IGN) is divided into six **research teams**, namely

- Department of Laboratory Research on Geomaterials
  - in short Geomaterial team, commission Earth and Environmental Sciences
- Department of Geomechanics and Mining Research
  - in short Geomechanics team, commission Earth and Environmental Sciences
- Department of Applied Mathematics and Computer Science and IT4Innovations
  - in short Applied Math team, commission Mathematics
- Department of Material Disintegration
  - in short Material Disintegration team, commission Engineering and technology
- Physical Geography
  - in short P-Geography team, commission Earth and Environmental Sciences
- Human Geography
  - in short H-Geography team, commission Social sciences

These research teams are oriented on different scientific areas, but they are also capable to do complex collaborative research, what is one of strengths of the Institute.

The research of the institute is **funded** from more sources, about one half by the Czech Academy of Sciences and one half by research projects of other providers and contracted research. For the institute development, it was very important that within the evaluated period the institute participated as a partner in projects within EU Operational Programmes in the Czech Republic.

The **research equipment and measurement devices** of the institute were substantially up-graded and enriched in the evaluated period by new unique instruments for about 3.3 million EUR owing to partnership in the EU OP project (CZ.1.05/ 2.1.00/03.0082) Institute of Clean Technologies for Mining and Utilization of Raw Materials for Energy Use. The main new devices include tomography equipment with two X-ray CT systems Nicon XTH 450 and 225, rock mechanics laboratory with servo-hydraulic testing system MTS with triaxial chamber, new robotic and visualization systems for high speed water jet laboratory, new analytic equipment for FTIR and Raman spectroscopy and thermal analysis, equipment for in-situ rock mass investigation and others.

Long term interest in large scale mathematical modelling and high performance computing led to partnership in a **supercomputing project** Centre of Excellence IT4Innovations (CZ.1.05/1.1.00/02.0070), which provides space for research collaboration and access to massively parallel computing systems. The research is carried out by the Applied Math team, but also the Material Disintegration team was involved due to extensive simulations for nozzle optimization. The P-Geography team is interested in investigation of disaster management scenarios using geoinformation technologies.

Both the above mentioned projects and other EU OP projects were also important for **personal development** and collaboration within the institute and with VŠB-TU of Ostrava. Other EU OP projects as e.g. SPOMECH (CZ.1.07/2.3.00/20.0070) and ENGELA (CZ.1.07/2.3.00/20.0025) contributed to both quantitative and qualitative personal development including direct participation of the scientists from abroad.

International collaboration was supported not only from institutional budget and the above mentioned projects but also by EU projects within 7th Framework Programme as TIMBRE project oriented on brownfields, which was solved by the team of Human geography, and RATIOCOAL project on coal carbonization improvement solved by the Geomaterial research team in Coal and Steel programme. Smaller projects were COST Actions on renewable energy and landscape quality solved by the Human geography team and the Norway Fund project on computational mechanics and geothermal energy solved by team of Applied Math. In 2014, the Material disintegration team started participation in another Coal and Steel programme project and the HORIZON 2020 project was accepted with participation of the Human geography team. Further HORIZON 2020 projects were prepared and submitted in January 2015. Note also the solution of two phases of Decovalex project financed by a different model as described later.

Bilateral projects concerned collaboration with several partners. Let us mention collaboration supported by an official agreement with Kumamoto University (Japan). The topics of mutual interest concern X-ray tomography and rock stress measurement,

the collaboration include short and long term visits, special workshop, teaching intensive course on micromechanics in Kumamoto. Long term collaboration with IICT of Bulgarian Academy of Sciences (BAS) concerned parallel computing and its applications, joint project with NIGGG BAS dealt with human impact on vulnerable geosystems in protected areas. An agreement with Steklov Math Inst. of Russian Academy of Sciences focused on analysis of nonlinear mechanics problems, an agreement with Central Institute of Mining and Fuel Research, Dhanbad and Roorke (India) focused on stress state analysis in vicinity of underground structures by back analysis. Further bilateral projects were conducted with the Strata Mechanics Research Institute of the Polish Academy of Sciences, Cracow, Geographical Institute of Slovak and Romanian Academy of Sciences, etc.

A special role played the participation in two phases of the **Decovalex project** devoted to modelling of **coupled thermo-hydro-mechanical processes associated with nuclear waste deposition** and validation of the models against experiments. The Decovalex project is funded by organizations responsible for nuclear waste deposition in the participating countries. The phase of the project ending in 2011 was coordinated by SKB Sweden and the Applied Math team was involved in modelling thermo-mechanical processes and model validation against data from Pillar Stability Experiment conducted in Äspö, Sweden. The second phase ending in 2015 is at present coordinated from LBNL, Berkeley, USA and solved by the research teams from USA, Korea, Japan, China, France, Germany, Switzerland, UK and CZ. The Applied Math team is involved in modelling the hydro-mechanical processes in bentonite based sealing barriers and model validation against data from SEALEX experiment conducted in Tournemire, France.

Decovalex project motivated not only Applied Math but also other teams and increased competence of the institute in the field of research associated with geological deposition of nuclear waste. This competence led to participation of IGN in a national **consortium "Research support for the safety assessment of deep geological repository"** contracted by Radioactive Waste Repository Authority (RAWRA) of the Czech Republic and coordinated by Nuclear Research Institute in Rez near Prague. Within this consortium, the Geomechanics team started to participate in the Large Scale Monitoring Project with stress changes monitoring at Grimsel Underground Rock Laboratory (Switzerland) and Seismic stability projects. Another project aimed at transfer the experience to Bukov Underground Research Facility, which has recently been opened in the Czech Republic. Further projects within this consortium are under preparation.

The research in **mining** was oriented to safety and utilization of new mining technologies. It was supported by applied research projects like "Safety aspects of mining at depths of 800 m and larger" in Safety Research Programme of the Ministry of Interior and contracts from OKD and GEAM mining companies. The research was oriented on safety and contributed to binding guidelines and on assessment of new technologies like use of "room and pillar" mining method in OKD in the depths exceeding the existing worldwide experience. Another research was oriented on prolongation of technological life of mine corridors and their multiple uses; rock burst prevention; analysis of subsidence effects. The investigation at GEAM concerned registration of seismic response to blasting and assessment of possible rock burst risk.

The international cooperation and industrial applications are highly visible in activities of the Material disintegration team. This team performs long term research oriented to intensification of **high-speed water jets** and their use for various applications ranging from geo and civil engineering, through automotive industry to medical surgery applications. The main result of the team, generation of ultrasound pressure pulsations in high-speed water jet system, was protected by patents in US, Canada, Australia, EU including CR and Japanese utility model. All these patents are utilized by an exclusive licence agreement with a renowned German manufacturer Hammelmann GmbH. The research results attract also interest and establish cooperation with further foreign partners, let us mention TU Dresden and Fraunhofer IVV Dresden or ANT Applied New Technologies AG (Germany) and DeuroS Sarl (France). The cooperation with Hammelmann GmbH is involving collaborative research oriented to specific high-speed water jet applications, e.g. reducing the energy consumption in applications in the automotive industry. Medicine applications started in collaboration with J. A. Raiman hospital in Prešov (Slovakia) and continue in an international consortium supported by START Danube Region Project Fund for preparation of a Horizon 2020 project.

Many **safety and environmental problems** are included in the described research areas. They are visible in safe nuclear waste management; minimization of subsidence effects; rock burst prevention in deep mines. High pressure water jet applications can also contribute to environmentally sound treatment of surfaces like coatings or roadways. There is also specific research from the P-Geography team devoted to interplay of nature conditions and human activities in the cases of floods, sliding of slopes, dry periods and possible future scenarios. Specific research of H-Geography team concerns social consequences of brownfields and abandoned areas, their revitalization, landscape changes and society reactions in connection with use of wind and solar energy or bioenergy, development of urban and rural spaces.

The institute is also involved in **observatory activities** (seismicity) by operating a seismic net in North Moravia region. This net is a part of national seismic net and obtained support via project CzechGeo/EPOS in programme of large national and European geophysical infrastructures.

From the **editorial activities**, let us mention that the institute, through its Department of Environmental Geography, publishes an international peer-reviewed journal **Moravian Geographical Reports** (MGR, de Gruyter), which is indexed in both SCOPUS and Web of Science databases. The emphasis at MGR is on the role of 'regions' and 'localities' in a globalized society and MGR addresses problems of regional economies and society; society in an urban or rural context; regional perspectives on the influence of human activities on landscapes and environments; environmental impacts of technical processes on bio-physical landscapes; and physical-geographic processes in landscape evolution, including the evaluation of hazards. Theoretical questions in geography are also addressed, especially the relations between physical and human geography in their regional dimensions.

Researchers from the institute are also involved in journal **editorial boards and reviewing** activities, as described in special documents. The activities of the institute in organizing conferences lead to publishing of proceedings and special issues. At present two special issues are prepared, which is the special issue of Mathematics and Computers in Simulation (Elsevier) devoted to the conference MODELLING 2014 and

the special issue of Canadian Geotechnical Journal devoted to the Colloquium on Geomechanics and Geophysics and Geo3M day held in 2014.

To summarize, the **general research directions** are investigation of processes important for development of technologies for the Earth crust utilization and other new technologies as well as research devoted to the solution to environmental problems. The research results of the individual institute teams can be incorporated into these general directions like mining safety and efficiency, design of geologic high-level radioactive waste repositories, development of high-speed water jet tools for different applications, investigation of the impact of new technologies into landscape and social life.

The particular research results are realized within the research teams, which are briefly described with pointing out their main research outputs in the following paragraphs. More detailed description can be found in separate documents for each team.

1.2 Research teams and their main research results

The team "**Department of Laboratory Research on Geomaterials**" represents one unit in the organization structure of the IGN. This team investigates properties of geomaterials and selected construction materials in relation with the physical and chemical processes associated with different technologies of Earth crust utilization. The team has excellent laboratory equipment and investigates:

- composition, chemistry and structure of geomaterials and selected construction materials (using infrared and Raman spectroscopy, thermal analysis, optical, confocal and infrared microscopy and image analysis methods),
- corrosion and alteration processes in geomaterials and construction materials,
- rock behaviour under uniaxial and triaxial loading with elastic or inelastic response as well as response behind the failure limit of the material,
- permeability of porous materials to gas and liquids, physical interactions between rocks and water solutions, and coupled hydro-mechanical and thermal processes,
- further geomaterial properties as thermal properties, ultrasound waves propagation, pore space and microfracturing characteristics,
- geology and biostratigraphy of coal basins and geological problems associated with important geotechnical constructions.

The **main research results** of the team have been achieved in the areas such as: characterization of geomaterials and construction materials using spectroscopic and microscopic analytical methods combined with thermal analysis; interactions between rocks and fluids under different states of stress; thermal behaviour of geomaterials; improvement of rock and soil properties by polymer grouting; biostratigraphic studies; and analysis of specific problems related to carbon dioxide in the rock mass.
The team **"Department of Geomechanics and Mining Research"**

The team is again identical with the organization unit of the institute. Besides the newly established X-ray CT laboratory, it mainly investigates natural and technological impacts on geomechanical and geophysical processes in the Earth crust. More precisely, it investigates

- **stress in the rock mass** by measurements using hydrofracturing and overcoring with conical probe as well as by modelling with finite element software,
- **deformation changes** in the rock mass using tensometric rock bolts and flat tensometric probes as well as by convergence measurements. The convergence measurements (change of distances among selected points) are evaluated with the use of back analysis in collaboration with the Applied Math team,
- **rock mass quality** using various borehole inspection tools as well as by testing rock samples in collaboration with Geomaterial team,
- **seismic activity** in North Moravia by operation a local seismic net as well as by monitoring mining induced seismicity,
- **stability of underground constructions and mining openings** by FEM simulations utilizing information on stress, deformation, material properties, rock mass structure as well as its seismic response,
- safety and efficiency of **mining technologies**,
- use of **X-ray tomography** for understanding the rock structure and processes in the small scale.

The **main research results of the team** concern: development and verification of different variants of conical probe for measuring the complete stress tensor; measurement of the stress state in both sedimentary and granitic rock mass; rock stress evaluation in connection with rock burst prevention in OKD mines, intended construction of underground gas storage Milasín – Bukov, and stability investigation in Grimsel, Switzerland (project LASMO); preparation of safety directives for mining works at great depths; analysis of subsidence due to mining in geological situation including rock faults; analysis of seismic records including rotational component of wave signals and wavelet analysis of seismograms; establishment of a new X-ray CT laboratory for analysis of geomaterials.

The team **"Department of Applied Mathematics and Computer Science and IT4Innovations"**

The team is composed of two organization units of the institute, namely Department of Applied Mathematics and Computer Science and Department IT4Innovations. The second unit was established in 2011 due to participating in the supercomputing project Centre of Excellence IT4Innovations, which started that time and required independent organizational anchoring. Due to partly common history and strong interconnections, both units were joined for the evaluation. The Applied Math team as a whole had a broad scope of research interests which can be divided into three particular aims:

- mathematical modelling of problems arising in geoengineering and geosciences,
- analysis of models and development of suitable numerical methods,
- computer implementation of numerical modelling tools and performing the simulations.

Following the above general aims, **the main research results** of the team involve

- development of mathematical models and numerical simulations for the solution to problems associated with geological **deposition of high-level radioactive waste**.

In the framework of participation in the international Decovalex project, the team developed its own way for modelling of crystalline rock damage and analysis of hydro-mechanical processes in bentonite based sealing. Further, the thermal analysis of different high-level radioactive waste repository concepts was done in research contracted by RAWRA CR,

- **analysis and development** of various types of iterative solution methods and preconditioners applicable to porous media flow problems in rigid and deformable porous matrix; analysis of Newton type solvers for nonlinear problems; investigation of higher order time discretization methods; analysis of numerical methods for solving plasticity problems and procedures for determination of limit load in ideal plasticity. The results were also obtained in application of inverse problems on material parameter identification and rock stress determination. Further, models of suspension bridges and geotubes were developed and analysed,
- **implementation of numerical algorithms** mainly into in-house academic software. A stress was given to implementation of parallel solvers, which were tested and compared with solvers from well-known Trilinos library. The tests were performed at the solution to large scale problems, as e.g. finite element analysis of elasticity problems up to 200 million of degrees of freedom arising in micromechanics. The parallel performance was tested up to 512 cores of ANSELM computer in IT4Innovations centre in Ostrava.

The team "Department of Material Disintegration"

The team (identical with a unit in the institute structure) deals mainly with development and intensification of the high-speed water jet tools for various applications ranging from geotechnics and civil engineering to biomechanics and medicine applications. Main research topics of the team were as follows:

- intensification of high-speed water jet effects,
- abrasive materials for abrasive water jets,
- study of the flow using combination of numerical simulation with the use of computational fluid dynamics methods and direct measurement of the flow by methods of particle image velocimetry, shadowgraphy and laser induced fluorescence,
- study of topography and quality of surfaces created by high-speed water jets.

Main results of the research of the team were achieved in areas of further development and application of high-speed pulsating water jets (such as influencing physical-mechanical properties of surface layers of materials by pulsating water jets, development of hydrodynamic nozzle as a tool for surfaces treatment and material disintegration), development of a new abrasive water jet cutting head by means of the numerical simulation of the three-phase flow of water, abrasive particles and air, determination of effects of water jets on thermally loaded concrete, and preparation of mineral and ceramic particles of micron to sub-micron sizes with desired morphology and intact internal structure using high-speed water jets.

The team "Physical Geography"

The team, which has been defined with respect to the structure of Commissions in the professionally oriented evaluation of research activities in the period 2010 – 2014, is a part of the Department of Environmental Geography. Complex physical-geographical research is conducted by the team, particularly for the issues related to landscape. The team focuses on the following key issues:

- the evaluation of natural processes (especially geomorphological) and natural extremes with regard to their impacts on the landscape; including the historical impact of climatic and hydrological extremes, and solutions in crisis management scenarios with using geoinformation technologies;
- research on environmental impacts of human activities on the landscape and its components, including historical context. The research is supported by available instrumentation (terrestrial laser scanner, electrical resistivity tomography);
- complex research on the current cultural landscapes, directed towards understanding the structure and dynamics of natural and historical development of contemporary cultural landscape, including the introduction of innovative biogeographical approaches.

The **main research results** of the team involve:

- documentation and assessment of neotectonic aspects of landscape evolution based on geomorphological analysis of relief in the south and southwest Moravia. Significant neotectonic features of relief were gathered by team members on the basis of direct and indirect geomorphological and geological data.
- methodological approaches to relief assessment and extension of the concept of environmental geomorphology. The concept of environmental geomorphology was first mentioned in Czech geomorphology and extended by team on methodological approaches to the assessment of geomorphosites in selected areas in eastern part of the Czech Republic.
- utilization of modern technologies for collecting, processing and GIS analysis of landforms geo-data in physical geography. Implementation of field research (unique pseudokarst and karst landforms) by means of terrestrial laser scanning technology, elaborating data with special software Cyclon 7.4. and presenting results as 3D models in GIS.
- mapping, typology, cartographic presentation of post-industrial landscapes. For the first time in the Czech Republic, members of the team developed a specific original methodology for identification of the post-industrial landscapes. Determination of the Czech post-industrial landscapes based on above methodology was performed and results were depicted with using GIS.

The team "Human Geography"

The team, which is one of two teams together forming the Department of Environmental Geography, focuses on the human-geographical aspects (including social, economic and cultural issues) of interactions between human individuals or societies and their natural environments. The research activities have been

concentrated around four key themes related to the transformation of urban spaces and changing nature of rural spaces:

- Re-urbanization, urban renewal and brownfields redevelopment
- Spatial models of behaviour in changing urban environment
- Renewable energy development and rural land-use conflicts
- Restructuring and diversification of agriculture

The **main research results** of the team concern: (i) analysis of existing spatial patterns, drivers and barriers of post-socialist urban redevelopment; (ii) analysis of urban spatial mobility, shopping behaviour and accessibility to services for socially-excluded population groups; (iii) explanation models of local community acceptance of renewable energy developments in the conditions of the Czech Republic; (iv) novel conceptualization of the energy–tourism nexus and the first empirical evidence of potential impacts of on-shore wind farms on tourism in the European context; (v) analysis of market adaptations and diversification trends of Czech farmers under the CAP reforms.

Interconnection and collaboration of the research teams

The described research teams work in their own areas but also complement each other and provide the institute possibility for complex solving problems arising from development of technologies for the Earth crust utilization and solution of environmental problems. Team collaboration can be illustrated by the following examples

- development of methods for numerical upscaling - testing of heterogeneous materials with geometry of microstructure provided by CT scans and local material properties given by lab experiments and/or inverse analysis were done. The research was supported by GACR project “Multiscale modeling and X-ray tomography in geotechnics”. The work is continuing, see e.g. recently published paper by authors from all teams “Digital image based numerical micromechanics of geocomposites with application to chemical grouting, Int. J. Rock Mechanics and Mining Sci. 77(2015)”. (Applied Math + Geomechanics + Geomaterial teams);
- analysis of the pore space of geomaterials by using a combination of mercury porosimetry, X-ray computed tomography, and image processing as well as investigation of interactions between rocks and liquids in relation to the rock internal structure is in progress within a TACR project. (Geomaterial + Geomechanics teams);
- research into the structure and properties of polymer grouted geomaterials (Geomaterial + Geomechanics + Applied Math teams);
- evaluation of the impacts of high-speed water jets on materials subjected to disintegration and surface treatment; modification of properties of abrasive materials for improvement of efficiency of abrasive water jet technology for material disintegration (Geomaterial + Material Disintegration teams);
- providing reliable input data for mathematical modelling of heat transport, thermal dilatation and mechanical behaviour of rocks, including rock failure under various loading regimes (Geomaterial + Geomechanics + Applied Math teams).

1.3 Short comparison of the present and past evaluation periods

To characterize the institute activity in the presently evaluated period 2010-2014 and compare it with the previous one 2005-2009, it is possible to point out several topics:

- Success in large projects of the EU Operational programmes provided the institute new excellent research equipment, partnership in supercomputing project Centre of Excellence IT4Innovations and possibility of hiring some foreign scientists. All these factors are influencing not only the evaluated period but also future development of the institute.
- Concerning publication activities of the institute, let us mention the number of papers in journals indexed in Web of Science database as a widely used characteristic. This number in the evaluated period increased more than three times in comparison with the period 2005-2009.
- The international visibility of the institute increased due to its publication activity, participation in international projects, organizing international conferences and schools, publishing MGR as an internationally recognized journal etc.

The activities of the institute were also appreciated by the International Society of Rock Mechanics, which entrusted the institute with the organization of the EUROCK 2017 conference.

Research Report of the team in the period 2010–2014

Institute	Institute of Geonics of the CAS, v. v. i.

Scientific team	Department of material disintegration

Research activities of the team were mainly defined by the content of projects solved by the team. In particular, they were aimed at the high-speed water jet disintegration of materials and geomaterials. Main research topics were as follows: intensification of high-speed water jet effects, abrasive materials for abrasive water jets, numerical simulation of flow, study of topography and quality of surfaces, and new areas of high-speed water jet utilisation.
The RDIOP project “Institute of clean technologies for mining and utilization of raw materials for energy use”, in which the team has participated considerably since 2011, has represented a significant stimulus for the development of research activities of the team. The project has also provided the team with the up-to-date equipment for high-pressure waterjet generation (two high pressure pumps delivering up to 67 l/min at maximum pressure of 160 MPa and up to 7.5 l/min at maximum pressure of 420 MPa), for manipulation with waterjet cutting tools (6-axes robot) and for the measurement and visualisation of high speed water jets (high-speed camera, 2 cameras for PIV, double-pulse laser). Thanks to that, the water-jetting laboratory of the team became top-level facility in the field, at least in Europe.

1) Intensification of high-speed water jet effects

The research was oriented at the study of basic characteristics of high-speed water jets (HSWJ), processes of generation of HSWJ and effects of HSWJ on materials to be disintegrated. The objective was to enhance effectiveness of the HSWJ use in broad spectrum of applications, from cutting through removal of surface layers to volume removal.

a) Further development and application of high-speed pulsating water jets

The team has primarily oriented the research in the area of intensification of effects of high-speed water jets to the solution of problems of generation of pulsating water jets (PWJ). It is well known that the collision of a high-velocity liquid mass with a solid material generates short high-pressure transients which can cause serious damage to the surface and interior structure of the target material. Therefore, the research activities were focused on the study of possibilities for influencing the flow upstream the nozzle exit in a way that a water jet exploiting the above mentioned physical phenomenon is generated.
A proprietary method of generation of pressure pulsations in high-pressure system to generate PWJs using an acoustic generator (proposed, designed and verified in the previous period) was further developed. PWJs generated by the method demonstrated significant increase in disintegration effects on various types of materials in comparison to continuous ones. In 2013, the patent protection of the acoustic generator of PWJs

was completed by granting the Canadian patent and Japanese utility model – in addition to US patent, Australian patent, and European patent validated in 20 countries.
Numerical methods of flow simulation and experimental verification of results provided by numerical models were used to study fundamentals of processes of excitation and propagation of acoustic waves (and/or high-frequency pressure pulsations) in pressure liquid in a high-pressure system, and their effects on formation and properties of pulsating liquid jets. Problems connected with generation and propagation of pressure pulsations at frequencies in the range of tens of kHz in the liquid under pressure of tens of MPa and subsequent discharge of the liquid in the air environment were solved. Subsequently, acoustic generators of pressure pulsations for operating pressures up to 150 MPa and excitation frequencies of 20 and 40 kHz were developed, designed and manufactured. Internal profiles of the generators were optimised with respect to the maximum amplification of pressure pulsations in the pressure liquid upstream from the nozzle exit using CFD and FEM methods. In addition, a new shape of the ultrasonic sonotrode flange was designed to reduce undesirable transmission of ultrasonic vibrations into the generator body.
Based on results obtained, an exclusive license agreement on commercial application of PWJs was signed with a renowned German manufacturer of high-pressure equipment,XXX. The cooperation with the industrial partner under the license agreement provided new stimuli for the research.
Study of branched hydraulic circuits in relation to transmission of pressure pulsations using numerical modeling of various configurations of multi-nozzle cutting tools and subsequent experimental verification of results led to the cooperation with an industrial partner XXX (Germany). XXX.

Influencing physical-mechanical properties of surface layers of materials by PWJs
First experiments aimed at comparing the effects of continuous and pulsating water jets with classical methods of surface hardening of metals were carried out. The effects were compared by the Almen strip method, commonly used in industry to determine the level of residual stress in the process of surface hardening. The application of pulsating water jets demonstrated effects comparable to those of conventional methods. Therefore, experiments to investigate whether it is possible to favorably affect the fatique life of a material by applying pulsating water jets were realised in cooperation with the Institute of Physics of Materials of the CAS in Brno (IPM).
Specimens made from 316L austenitic stainless steel with carefully polished surfaces were subjected to impacts of PWJ of various water pressures in a way that every place of the specimen was hit by approximately one hundred water droplets. The results showed the PWJ process as a new possibility of surface cold-working treatment. The hardened surface layer was thinner than in the case of shot peening; however, the beneficial effect on fatigue life was comparable. (Surface treatment was performed by the team; fatique tests, SEM microscopy and microhardness measurement were realised at the IPM).

Hydrodynamic nozzle as a tool for surfaces treatment and material disintegration
Based on a detailed study of the phenomenon occuring in the fluidic nozzle, a new nozzle was designed using the numerical flow modelling. The nozzle enables to generate pressure and velocity/flow pulsations of the liquid which are significant enough to break up effectively the outgoing continuous liquid jet into bunches of liquid. Sufficiently high amplitudes of pressure and flow oscillations can be achieved at

frequencies form units up to hundred thousands of Hertz, depending on the value of supply pressure, i.e. the fluid flow rate and type of the nozzle. Vital part of this solution is the shape of the hydrodynamic nozzle located in the tool which has been designed in a way to avoid the generation of cavitation, particularly in the areas of inlet and oscillation chamber, and to eliminate undesirable pulsation damping of hydraulic quantities. This type of nozzle is then called the hydrodynamic nozzle.
The usability of the above-described principle of self-excited oscillations was confirmed first theoretically (by numerical modeling of the flow). The calculations clearly showed that the principle of the pulsating water jet generation could be effectively used in the field of high pressure cleaning and cutting. Based on the results of numerical calculations, a tool with the hydrodynamic nozzle was designed. Laboratory tests showed the functionality of the device over a very wide range of input pressures (0.5 to 70 MPa). The proposed tool also demonstrated its ability to cut materials and clean surfaces under more favourable energetic conditions, compared to continuous jet. Due to the design of the hydrodynamic nozzle, the above-mentioned physical principle of self-excited oscillations can be exploited in the areas of high pressure waterjet cutting and cleaning of materials. This further enhances development of very small, lightweight and effective tools for cutting and cleaning with high-pressure fluids. The described technical solution of the hydrodynamic nozzle was protected by a patent application.
Projects: ED2.1.00/03.0082, RFSR-CT-2014-00010, 01673/2010/RRC
Outputs: patents and patent application, utility models, papers in WOS and Scopus journals, conference papers

b) Development of a new cutting head by means of the numerical simulation of the three-phase flow of water, abrasive particles and air

The optimisation of the process of abrasive water jet generation by means of the numerical simulation of the three-phase flow of water, abrasive particles and air was solved within the project No. FR-TI3/733 (see Appendix 3.1). The objective was to find the most suitable internal geometry of the cutting head with respect to the maximum efficiency of the abrasive water jet (AWJ).
The realised CFD simulation, analyses and measurements served as the basis for the development of a stable stationary 2-D rotationally symmetric CFD model of the flow of water, air and abrasive particles inside the cutting tool used for the abrasive water jet cutting. The model consists of real geometries of the water nozzle, abrasive nozzle and mixing chamber with a modified inlet for air and abrasive to fulfil the condition of the rotational symmetry. The model was designed in such a way that each parameter of geometry can be easily changed. Within the model realisation, a special methodology for computing control, which enables significantly faster convergence of computing, was also developed. Thus, results can be obtained in significantly shorter time than ever before. Computational time of a particular geometric configuration varies from 8 to 36 hours. The indicated times enable to realise the so-called parametric optimisations.
In the next phase of the problem solution, the numerical model was verified with laboratory tests. For this purpose, a modular assembly of the cutting head was constructed and consequently used for experiments aiming at measuring parameters of a flow field, i.e. measurements of pressure at different places on the cutting head, measurements of the focusing tube wear and measurements of the rate of abrasive particles at the inlet into the cutting head. Experimental results were used for determination of boundary conditions used in the numerical modeling of the flow of

water and abrasive particles in the cutting head. Furthermore, in order to verify the numerical model and optimise the design of the cutting head for generation of abrasive water jets, a method for measurement of the velocity of abrasive particles at the nozzle exit by means of the fluorescence particle image velocimetry (FPIV) was proposed. The proposed method allowed detecting abrasive particles inside the high speed flow of the water-air mixture (hundreds of m/s) and determining their velocity. Measurements of the abrasive particles velocity at the exit from the abrasive nozzle showed good conformity with the results of numerical simulation. Thus, the numerical model was considered as reliable and the results obtained by means of the numerical simulation as corresponding to the reality.
The developed 2-D model was further used for determination of the optimal shape of the cutting head. During optimisation, unique information related to individual phases of the flow was provided. The output parameter was the velocity of an abrasive particle at the exit from the geometry. The optimal internal shape of the cutting head geometry was determined by the maximum velocity of the particle. Based on the parametric analysis of the flow, modified internal geometries of a new cutting head and a new head for micro-cutting were proposed. Subsequently, new cutting heads were designed by the project partner, the company PTV (Czech producer of complete systems for high pressure water jet cutting).
Cutting capabilities of the new cutting head were then compared with cutting capabilities of selected commercially-available cutting heads.There was no one cutting head which could be considered the best; however, the newly developed cutting head consistently achieved very good results.
The comparison of cutting efficiencies of the new cutting head with selected commercially-available cutting heads showed that the numerical simulation could significantly contribute to optimisation of the new cutting head design. Therefore, it is necessary to continue with the efforts to adjust the model on the one hand and to develop and ensure a suitable way for production of the optimised cutting head on the other hand.
Based on available information, it can be stated that the optimisation of cutting head design by means of numerical modeling of the flow of the mixture of water, air and abrasive in the cutting head and the subsequent verification of the results obtained by direct measurement of the velocity of abrasive particles in abrasive water jet at the nozzle exit with the FPIV method are unique not only in Europe but also globally. According to provided information, the process of development of cutting heads by the leading companies in the area of high-speed water jet technology is mostly based on the method of "trial and error".
Project: FR-TI3/733
Outputs: patent application, utility model, conference papers

2) Abrasive materials for abrasive water jets

Within the project No. FR-TI3/733, the problems related to determination of suitable types of abrasive materials for the technology of high speed abrasive water jet cutting and machining which will increase the efficiency of the turning process and the quality of cutting surfaces while preserving the existing economic parameters and price ratios of the technological process were solved. First, a new methodology for determination of cutting capabilities of abrasives was elaborated in order to enable an objective assessment of the suitability of particular abrasive material for the AWJ technology, or, if appropriate, a comparison of various types of abrasives. In the early stages of the project solution, the original methodology used at the IGN was applied. The

methodology was significantly simplified and precised with the use of new and more accurate measurement and evaluation techniques. The methodology consists of specification of the tested material, specification of the abrasive material, reference test procedure, and evaluation and interpretation of results.
Another part of the project solution was a detailed study of selected properties of abrasives, which was motivated by the need of understanding the behaviour of a particular abrasive during the process of cutting and machining with AWJ. The obtained data were further used in a database processed for all studied abrasives. In addition, the acquired scientific knowledge and experiences were used for an intentional treatment of properties of abrasive materials.
Based on previous research, tests and analyses, several groups of abrasives were selected for laboratory and field tests:

- standard product of Barton's 80 HPX garnet - this abrasive was used as standard abrasive for tests of cutting efficiency of the AWJ technology on individual materials,
- commonly used garnet products from worldwide producers (Australian garnet, Indian garnet),
- unconventional products which have only recently entered the Czech market (Ukrainian garnet, zircon),
- completely new garnet products which have not entered the Czech market yet (Tanzanian garnet, Mongolian garnet)
- recycled abrasives (recycled Australian garnet, recyclates from the company PTV),
- abrasives of grain size of 120 MESH (Czech garnet, Australian garnet, Mongolian and Tanzanian garnet),
- heat-treated abrasives – the most commonly used abrasive product (Australian garnet) was heat-treated at various temperatures,
- abrasives with plastic coating – the most commonly used abrasive product (Australian garnet) was coated with various types of coating materials.

Cutting abilities of all tested abrasives were compared with the Barton's 80 HPX garnet concentrate; the results were processed in a form of graphs. For each tested abrasive type, a protocol with all available information about the particular type of abrasive was elaborated (including its physical properties, particle shape, cutting ability in relation to the reference abrasive of Barton's 80 HPX garnet, grain size curves before cutting, hardness and elastic modulus of abrasive grains, etc.)
The research focused on the preparation of various types of abrasive materials, which were expected to increase their cutting efficiency when used for technology of cutting and machining with high-speed abrasive water jet, provided a wide range of new scientific experiences. In some cases, cutting ability was significantly increased; for example, when using abrasive particles coated with a layer of plastic. Exceptionally, it was increased up to tens of percent in comparison to the Barton's 80 HPX garnet, the standard and long-term best commercially-available abrasive; for example, when cutting ceramic material with the Tanzanian garnet. However, some expectations remained unfulfilled; for example, those related to the use of zircon or heat-treated abrasives. Finally, it was considered appropriate to use a particular type of abrasive for a particular type of material to be cut. Abrasive material suitable for one type of material to be cut was often ineffective for another material. Conscious of this, the cutting ability of a particular type of abrasive can be significantly increased.
Similarly extensive and detailed research on abrasive materials used for the AWJ technology has not been realised yet. In the future, the acquired knowledge will be

intensively exploited for the preparation and selection of abrasives suitable for specific applications of AWJ and materials to be machined.
The research team cooperated with the team of researchers from the Department of Laboratory Research on Geomaterials, which mainly solved the issues of mineralogy and properties of abrasive grains.
Project: FR-TI3/733
Outputs: in preparation

3) Study of topography and quality of surfaces

This study aimed at experimental determination of parameters of the abrasive water jet cutting process which significantly affect the quality of the cutting surface. This problem was solved in two interrelated ways. Firstly, a database of materials for precise cutting with AWJ was elaborated. In this case, the effects of cutting depth, traverse speed, abrasive feed rate and size of abrasive grains on the topography of the cutting surface were examined. Secondly, the research was focused on precise determination of basic characteristics of the cutting surface and elaboration of tables which would set out the quality of cutting surfaces.
As part of the problem solution, a uniform methodology for realisation of the experiment and evaluation and analysis of measured data was developed. All measured data including determination of the impact of the cutting depth (material thickness), traverse speed, mass flow rate and abrasive grain size on the topography of cutting walls were clearly recorded in the form of tables. The tables were elaborated in such a way that any other types of materials and combinations of operational parameters of the AWJ cutting could be, if necessary, added to the acquired database of materials. Furthermore, all data measured with an optical profilometer were archived for the purpose of their further processing or use for other applications.
According to available information, the research results may be considered unique not only in Europe but also globally. Such a complex analysis and precise determination of the quality of cutting surfaces of a wide range of materials in relation to parameters of the AWJ cutting process has not been realised so far.
Project: FR-TI3/733
Outputs: paper in WOS journal

4) New areas of high-speed water jet utilisation

a) Effects of water jets on thermally loaded concrete

It is well known that concrete structures exposed to high temperatures lose their load-bearing capacity, especially in the most stressed surface layers. Defects may be so serious that the complete construction gets destroyed. The temperature of the fire damaging a concrete structure, for example in a road tunnel, reaches values up to 1200 °C. At this temperature, the entire structure of the cement stone is affected by degradation and the load-bearing capacity decreases rapidly. The rate and character of concrete degradation and destruction of the entire construction depend on the type of fire, rate of increase in temperature and fire duration.
The above-described problem may be partially solved by the use of suitable components of concrete (cement matrix, aggregates, fibres) which, when mixed, may eliminate undesired effects of thermal loads and/or fire. The research team is trying to find a solution based on exploitation of basic raw materials commonly available in the

Czech Republic in order to ensure cheaper production of concretes resistant to high temperatures.
Experiments with removal of concrete surface layers damaged at high temperature aimed at studying the behaviour of tested concretes after thermal load in water jets applications, in case of future application of this technology for removal of thermally damaged layers during repair works. Several concrete mixtures were prepared. They differed by the type of used aggregate, cement and types of fibres. The mixtures were further used for preparation of cubic testing samples. After curing, the samples were loaded at various temperatures. The damaged surface layers were subsequently removed by means of the water jet and the efficiency of the process in relation to the composition of concrete, temperature of heating and parameters of jets was studied.
The obtained results show that larger quantities of concrete are removed at higher working pressure of water and slower movement of the nozzle over the surface being treated; whether the concrete is affected by high temperature or not. The higher is the thermal load of the concrete, the better is the disintegration of damaged surface layers with the water jet. As the concrete structure is damaged and its strength is lower, the jet penetrates into greater depths. The concrete with basalt aggregate is more resistant to effects of the water jet than the conventional concrete with granite aggregate. The addition of polypropylene fibres has a positive effect especially on strength of concretes; however, the difference in resistance against the penetration by the water jet is rather negligible. The resistance of concretes against the penetration by the water jet is mainly influenced by the type of used aggregate and cement.
The efficiency of water jets in the process of removal of concrete layers damaged at high temperature can be significantly increased by high-frequency pulsations inserted in the jet. The pulsating water jet penetrates to greater depths and removes larger amounts of concrete under appropriate setting of parameters.
During the realisation of the research on damages of concretes at high temperatures, the team cooperated with the team of the Department of Geomechanics and Mining Research. Due to the industrial X-ray tomography, the same sample of concrete before and after the exposure to the thermal load could be compared and analysed. The acquired knowledge was further used when analysing the penetration of water jets into damaged surface layers.
Project: GAP104/12/1988
Outputs: papers in WOS and Scopus journals, conference papers

a) Preparation of mineral and ceramic particles of micron to sub-micron sizes with desired morphology and intact internal structure

Disintegration of mineral and ceramic grains using the high-speed water jet is widely known since the grains have been used as abrasives in the process of cutting and material disintegration by the abrasive water jet (AWJ). Destruction of abrasive grains during their interaction with the water jet, walls of the mixing chamber and walls of the focusing tube is considered a negative phenomenon occurring in the high-speed abrasive water jet technology. However, this disadvantage may be an advantage, if it is desired to preserve destructive capabilities of the device for the disintegration of mineral and ceramic grains (garnet, zircon, glass, ceramics). Main part of the process of destruction of abrasive grains happens during the interaction of abrasive grains with the water jet and walls of the mixing chamber. The grains are further destroyed in the interaction with walls of the focusing tube and the material being cut.

Based on theoretical presumptions and practical experiences, a special water mill exploiting the phenomenon of the destruction of abrasive grains inside the abrasive cutting head was developed. Experiments were aimed at preparing precursors and carriers of nanoparticles based on disintegration of mineral and ceramic particles. The effect of working parameters of the jet, pressure in particular, on the level of material disintegration was studied. Muscovite, vermiculite and kaolin samples were used as test materials. Prepared samples were then delivered to the Palacký University Olomouc where the possible use of these materials for the preparation of precursors and carriers of nanoparticles was verified. To increase the efficiency of the comminution process, a numerical model of the milling chamber was designed. Consequently, the existing water mill was modified based on numerical simulations and the accuracy of numerical calculations was verified with experiments. The model of the multiphase flow in the milling chamber enables to examine the shape of the flow field, including the movement of solid particles of the comminuted material (proper destruction of solid particles of the comminuted material through mutual particle-particle contact and contact with surrounding walls is not reflected in the model). The efficiency of the comminution process is evaluated in relation to the frequency of contacts between solid particles of the material with the surrounding walls.
Experiments with comminution in the water mill showed that while other technologies of mechanical comminution cause defects in the structures of comminuted materials, the abrasive water jet technology enables to preserve the original structure and cleavage of the comminuted material. At higher water pressure, the final product is finer; however, only to a certain limit which is for each comminuted material and comminution pressure different. Repeated comminution of an already comminuted product also ensures a finer product; here again, only to a specific limit. Further comminution is then inefficient. Comminuted particles are of micron to sub-micron sizes and due to the specific properties of the comminution technology based on the water jet, the particles are suitable for further use as precursors and carriers of nanoparticles. This technology ensures continuous production of microparticles in industrial amounts with consistent quality.
Project: ED2.1.00/03.0082
Outputs: utility model, paper in WOS journal, conference papers

b) Milling and turning with AWJ

Milling
During the project solution, a series of experiments with AWJ milling was planned and realised in order to design a predictive model suitable for the use of the AWJ technology for milling applications based on experimental results. In the experiments, the influence of main technological factors on geometric characteristics of a milled surface was studied. The average milling depth was a primarily evaluated parameter. In the first phase of the research, the effects of the distance between the cuts, number of passes, abrasive mass flow rate and traverse speed of the abrasive cutting head on the profile and the depth of milled cuts were investigated. For the determination of the optimal distance between the cuts, it was found important to get the difference between the maximal and minimal depths of kerfs as small as possible while avoiding the „sliding“ of the jet into already formed kerfs. Other important parameter in optimising the AWJ milling was the maximal usable traverse speed of the cutting head or dynamic characteristics during start of the movement and direction changes. Great attention

was paid to the selection of an appropriate milling strategy. The best results were achieved when using the zigzag milling strategy with the crossing at 90 °.
Based on the experiments, measurements and analyses, a set of recommendations for the AWJ milling applications was elaborated. Milling of materials with the AWJ has been studied worldwide only marginally. The results acquired so far focused on one particular material exclusively. Generalisation and use of these results in industrial practice were impossible. It can be stated that significant progress in this area of research has been achieved by the team. Accurate milling procedures for various materials ensuring the creation of impassable kerfs with an accuracy up to ± 0.2 mm have been elaborated.

Turning
Experiments with turning of rock materials, metallic materials, wood and graphite using the AWJ were planned and realised. The objective was to determine the optimal technological factors for turning of various materials using the AWJ. In addition, the impact of major technological factors on geometric characteristics of a turned surface was analysed. Based on the realised experiments, measurements and analyses, a collection of acquired knowledge and recommendations for turning using the AWJ technology has been elaborated.
Classical turning by means of the AWJ is not commonly used in the world. The AWJ is usually applied for cutting holes in thin-walled pipes and profiles, where rotational axes are used. The research team has developed unique technologies which enable classical turning of technical materials with an accuracy of ± 0.1 mm. The technology of turning with the AWJ can be used for rough turning of difficult-to-machine materials and for turning of non-rotational semi-finished products, where the cutting is interrupted.
Project: FR-TI3/733
Outputs: papers in WOS journals, conference papers

c) Pulsating water jets used for medical applications

As a part of the research realisation, a pulsating waterjet based surgical dissector was developed and tested. The achieved results confirmed a high potential of the pulsating water jets for special medical applications. In relation to this area of research, experiments with disintegration of bone cement samples prepared under realistic clinical conditions at the orthopaedic department of the University Hospital of J.A. Raiman in Presov were carried out. Mechanical properties of cements were determined by means of the nanoindentation at the Institute of Materials Research of the Slovak Academy of Sciences in Kosice. As a part of the research on the minimal technological parameters of the water jet, great potential of the pulsating water jet for orthopaedic applications in the area of the extraction of cemented knee and hip replacements was revealed. Preliminary results of disintegration of bone cements have motivated the creation of an international research team of professionals covering all aspects of the development of a new technology for reimplantation of joint replacements. The objective is to receive the support through Horizon 2020.
Projects: ED2.1.00/03.0082, 02574/2014/RRC
Outputs: papers in WOS journals, conference papers

Results achieved by the research team in the last period **stimulated the interest of foreign partners**, both from **academic** and **research** institutions (e.g. ETH Zurich, TU

Dresden, Fraunhofer Institute Dresden, University of Salerno), and **industrial** partners XXX, in scientific and research cooperation.

Research Report of the team in the period 2010–2014

Institute	Institute of Geonics of the CAS, v. v. i.

Scientific team	Physical geography

The Physical Geography team (PG team), working in the Department of Environmental Geography, was defined especially for the purposes of the current evaluation of research and professional activities of the Department for the period 2010 – 2014. This formal definition reflects the fact that there are independent evaluation panels for Physical Geography and for Human Geography. Hence, the Human Geography (HG) team of the Department was also defined. The division into two teams reflects current general trends in basic scientific research, which are represented by the partial specialization of researchers with aims to deal with these sub-issues at a detailed scale. Complex physical-geographical research is conducted by the PG team, particularly for the issues related to landscape. Such landscape research is also a common platform for interdisciplinary collaboration between the PG team and the Human Geography team. In the future research period, based on team-specific research findings, collaboration between the two teams will be strengthened, within the overall objective of an environmental geographical synthesis.
In the evaluation period 2010 – 2014, the PG team was composed of seven research scientists (with an aggregated average workload of approximately four full-time researchers) and four other workers (with an aggregated workload of these Ph.D. students and research assistants of approximately 1.6 full-time workers). The PG team worked on various different scientific issues, and the most important results were achieved not only from the institutional support of CAS (in 2010 no. AVOZ 30860518, in 2011-14 no. RVO 68145535) but also with the support of international and national grants, and applied research (contractual research). The results were obtained by means of the various methods of the physical-geographical sub-disciplines, with emphases also placed on interdisciplinary geo-sciences approaches, as well as cooperation with archaeologists and historians. Research activities were mainly focused in the territories of the Czech Republic, to a lesser extent in Austria (Niederösterreich), in the Danube regions in Slovakia and Hungary, and in the border regions with Silesia and Klodzsko in Poland. Members of the PG team also collaborated in research at these study sites with colleagues, primarily geographers, at the following institutions: University of Vienna; the Geographical Institute and Research Centre of Astronomy and Earth Sciences of the Hungarian Academy of Sciences, Budapest; Comenius University in Bratislava, Slovakia; and the University of Wroclaw, Poland.

The research results achieved, related to the concepts of environmental geography, focused primarily on the following key issues:

A. the evaluation of natural processes (especially geomorphological) and natural extremes with regard to their impacts on the landscape, including the historical impact of climatic and hydrological extremes, and solutions to natural extremes in crisis management scenarios, using geo-information technologies with available databases;

B. the environmental impacts of anthropogenic activities on the landscape and its components, including historical contexts, knowledge of unique geomorphological landscapes and geomorphological assessment of geomorphosites, using the instrumentation of the Department (terrestrial laser scanner Leica ScanStation C10, Electrical resistivity tomography (ERT) - ARES 850W, GF Instruments s.r.o.); and

C. the dynamics of current cultural landscapes, directed towards understanding the complex structure and dynamics of the natural and historical development of contemporary cultural landscapes, including the introduction of innovative bio-geographical approaches and the use of GIS technology.

The concrete task reports that were published within these three key issue areas are as follows.

Key Issue A: The evaluation of natural processes and natural extremes.

A.1. Extreme meteorological and hydrological phenomena of the Czech Republic and neighbouring countries of Central Europe (PL, SK, A and D) in the past and at present, their impacts and the lessons learned:

The disastrous atmospheric precipitation and floods in the Czech Republic and Central Europe occurring in July 1997, in August 2002, and in the following years, took society by surprise and found it unprepared, because historical "flood memory" had been lost during the 20th century. These floods showed the importance of learning from the history of such natural extremes. The research was focused on the analysis of meteorological and hydrological extremes reaching as far as possible into the past (results of measurements and observations in the national meteorological networks, as well as results from the pre-instrumental era – from historical sources). New information obtained by members (Munzar and Ondráček) of PG team was collected and critically evaluated, with respect to the temporal and spatial incidence of the above-mentioned extreme phenomena, their quantification and magnitude, their course, manifestations and impacts – but also some lessons learned, i.e., the responses of society (adopted and implemented flood-control measures, etc.). In this way, the mosaic of findings from the history of floods in the Czech Lands and in Central Europe, as well as from the history of extreme hydro-meteorological phenomena, has been complemented and knowledge broadened.
Support: Institutional projects - AVOZ 30860518, RVO 68145535
List of selected outputs (member(s) of the PG team are underlined, continued below):

- Munzar, J. & Ondráček S. (2013). A note on extreme European rainfall events. *Weather, 68* (8), 199 - 200.
- Munzar, J. & Ondráček S. (2010). Precipitation extremes and disastrous floods in Central Europe in July 1897. In Przybylak, R. et al. (Eds.), *The Polish climate in the European context: an historical overview* (pp. 389 – 396). Dordrecht, Heidelberg, London, New York, NY: Springer.

A.2. ***Documentation and assessment of neotectonic aspects of landscape evolution:***
Multi-faceted investigation of natural phenomena, related both directly and indirectly to neotectonic activity, enables the researcher to evaluate the older stages of landscape development as well as recent environmental processes conditioned by those neotectonic events, which could also result in significant impacts on socio-economic processes and the location of industrial activities. A comprehensive geodynamic assessment was carried out of significant old fault zones in the Bohemian Massif of the Czech Republic and north-eastern

Austria, reaching south to the Alpine-Carpathian area from where the movements in the neotectonic period were repeatedly reactivated. The spatial arrangement of horst and graben structures, slopes, topographic lineaments and fluvial systems, including extensive alluvial and terrace levels, were primarily defined and completed by an investigation of direct and indirect (slope, fluvial) neo-tectonic-related sedimentary records. Collected above mentioned geomorphological data (by team member Roštínský) from south-western Moravia were used in a complex regional geomorphological study, which served as one of the background materials for the possible seismic hazard assessment of the Dukovany Nuclear Power Plant enterprise in regulatory procedures, both of the renewal of the present-day production license for the plant and for its planned structural expansion (new production unit).
Support: 7AMB13AT023 MOBILITY - Neotectonics in the foreland of the Alpine-Carpathian Junction (2013-2014), International Visegrad Fund no. 11410020 Multidisciplinary research of fluvial terrace systems in Slovak-Hungarian border region (2014).

- Roštínský, P., Pospíšil, L., & Švábenský, O. (2013). Recent geodynamic and geomorphological analyses of the Diendorf–Čebín Tectonic Zone, Czech Republic. *Tectonophysics*, 599, 45 - 66.
- Švábenský, O., Pospíšil, L., Weigel, J., Roštínský, P., & Witiska, M. (2014). Results of repeated measurements at the Železné hory–Tišnov Fault System surroundings. *Acta Geodynamica et Geomaterialia, 11* (3), 211 - 223.
- Pospíšil, L., Roštínský, P., Švábenský, O., Weigel, J., & Witiska, M. (2012). Active tectonics in the eastern margin of the Bohemian Massif – based on the geophysical, geomorphological and GPS data. *Acta Geodynamica et Geomaterialia, 9* (3), 315 - 329.

A.3. ***The evolution of slope processes in relation to disturbance of vegetation cover at high altitude mountain locations:***

The total clearance of non-indigenous dwarf pine covers was proposed in high-altitude summits of the Hrubý Jeseník Mts. Such a sudden strong human impact, however, could induce a significant activation of slope processes with irreversible changes in this Landscape Protected Area – especially debris flows and related phenomena. Based on geomorphological surveys, Roštínský - member of the PG team - defined primary topographic categories and evaluated their general vulnerability to ineligible slope processes, information that was summarized in a certified procedure manual and atlas maps.
Support: Grant agency of Forest of the Czech Republic (Grantová služba Lesy ČR), project no.39: Geobiocenosis of upper part timber line and influence of dwarf pine stands in mountain landscape of Hrubý Jeseník Mts. (Geobiocenózy horní hranice lesa a vliv porostů borovice kleče na horskou krajinu v Hrubém Jeseníku (2008-2011).

- Šenfeldr, M., Maděra, P., Buček, A., Roštínský, P., Špinlerová, Z., Culek, M., Friedl, M., Vavříček, D., & Tippner, A. (2012). Atlas rozšíření a kategorizace klečových porostů nad horní hranicí lesa v Hrubém Jeseníku. 150 map, měřítko 1:7500. Prague: Ministry of Agriculture of the Czech Republic (certified atlas maps).
- Roštínský, P., Šenfeldr, M., & Maděra, P. (2013). Effects of dwarf pine stands on slope deformation processes, as a basis for their management in the Hrubý Jeseník Mts. *Journal of Landscape Ecology, 6* (1), 63 - 83.

A.4. ***Risk assessment of hazardous natural processes to support disaster management using available databases:***

Disaster management is a system needing constant improvements. Solutions to disasters with negative impacts on human life and health, both tangible and intangible values, the landscape and nature in general, comprise such management systems. It is therefore essential to create and improve technologies, techniques, processes and procedures, as well as their applications in

practice, to develop effective disaster management systems. The outputs of such research are represented by the completion and testing of model scenarios of geo-information support for solutions to selected types of emergencies that occur in the Czech Republic. The research of PG team concentrated especially on the development of selected scenarios (e.g., flash floods, landslides). The other researchers of project have applied an operational meteorological data in scenarios and prepared models for the effective management of such emergency situations.
Support: Programme of safety research - Ministry of Interior of C.R. VG3VS/114 Disaster management support scenarios using geoinformation technologies (2013-2015).

- Rapant, P., **Kolejka, J**., Inspektor T., **Batelková K., Zapletalová, J., & Kirchner, K**. (2014). Early warning of flash floods based on the weather radar. International Carpathian Control Conference, *Szilvásvárad, Hungary, Conference Proceedings* (under review).

Key Issue B: The environmental impacts of anthropogenic activities on the landscape.

B.1. ***Anthropogenic transformation of relief in selected areas:***
The influence of human activities is increasingly manifested in the transformation of relief and in influencing current geodynamic processes, which hve negative impacts on the landscape. Geomorphological knowledge of anthropogenic forms (obtained by Kirchner and Roštínský with using field survey) is therefore an essential part of the research on current relief. In selected anthropogenically-influenced study territories (e.g., the Slavkovský les Forest), the typical genetic categories of anthropogenic landforms were analysed and the main development phases and specifics of the territories were defined.
Support: Grant Agency of C.R.105/09/0089 Prognosis of spatiotemporal changes in stability of mining area of the technical cultural monument Důl Jeroným in Čistá (2009-2013).

- Kirchner, K., & Roštínský, P. (2013). Vývoj antropogenních transformací reliéfu v oblasti historického Dolu Jeroným ve Slavkovském lese (Development of anthropogenic relief transformations in the historical Jeroným Mine area in the Slavkovský les Mts.). *Zprávy o geologických výzkumech v roce 2012,* 132 - 136. Prague: Česká geologická služba.
- Raška, P., & Kirchner, K. (2011). Assessing landscape changes in a region affected by military activity and uranium mining (Prameny municipality area, Western Bohemia, Czech Republic): a multi-scale approach. *Moravian Geographical Reports 19* (4), 29 - 37.
- Kirchner K., & Roštínský P. (2011). Antropogenní transformace reliéfu v oblasti dolu Jeroným (Anthropogenic relief transformations in the Jeroným mine area). *International Journal of Exploration Geophysics, Remote Sensing and Environment*, *18* (1), 92 - 98. Prague: Czech Association of Geophysicists.

B.2. ***Methodological approaches to relief assessment and environmental geomorphology:***
With the increasing effects of economic activities on relief, the role of geomorphological research has developed in terms of recognising and understanding the range, dynamics and interactions between relief systems and environmental influences. Following developments in current British-American geomorphology, the sub-discipline of environmental geomorphology has been defined, with the objectives to research such problems comprehensively. The concept of environmental geomorphology was first mentioned in Czech geomorphology (by team member Kirchner), in this research which was primarily focused on methodological approaches to the assessment of geomorphosites in selected areas in Moravia (eastern CR). Team member Kirchner prepared and collected data dealing with landforms and relief types from the Outer Western Carpathians. In the Czech Republic, this research also comprised the first relief assessment that was processed using the areal representation of genetic categories of surface landforms; hence, the geomorphodiversity of the entire state was represented.

Support: Institutional projects - AVOZ 30860518, RVO 68145535

- Kirchner, K., & Kubalíková, L. (2013). Relief assessment methodology with respect to geoheritage based on example of the Deblínská vrchovina Highland. In Fialová, J., & Kubíčková, H. (Eds.). *Public recreation and landscape protection – with man and hand in hand* (pp. 131 – 141). Brno: Universita Mendeliana Brunensis. ISBN 978-80-7375-746-5. Proceedings Paper WOS: 000321223700024.
- Demek, J., Kirchner, K., Mackovčin, P., & Slavík, P. (2011). Geomorphodiversity derived by a GIS-based geomorphological map: Case study the Czech Republic. *Zeitschrift für Geomorphologie, 4*, 415 - 436. ISSN 0372-8854. DOI: 10.1127/0372-8854/2011/0058.

B.3. ***Specific geomorphological landscapes and landforms, their geomorphological development and importance in current landscapes:***

In the Czech Republic, there are unique landscapes with specific types of relief, which form the bases of geodiversity. Geomorphological research was focused on the characteristics of these specific geomorphological landscapes, indicating some basic information about the uniqueness of the relief of these areas of interest and their importance for the country. The research activities of the PG team (members Kirchner and Roštínský) included the following studies: a very detailed case study of the canyon-like valley of the Dyje/Thaya River on the south-eastern margin of the Czech Highlands; the analysis of polygenetic relief with rock formations in the central part of the Žďárské vrchy Highland (planation surface type etchplain in the dome structure), which is unique within the Hercynian Central European Mountains; more specific landforms such as the debris accumulations in the volcanic relief of the České středohoří Mts., and on the relations between the topography and microclimate of the sites; and, processes studies in the flysch Outer Western Carpathians in Moravia and Silesia, where member of the PG team (Kirchner) focused on hillslope processes and landforms and their recent development. The latter research enabled the inclusion of the study area into understandings of the overall development of the Carpathian-Balkan-Dinaric region. In addition, PG team members (Kirchner and Roštínský) contributed to geomorphological knowledge of the historical development of cultural landscapes, which requires the interdisciplinary cooperation of the geosciences and social sciences. In collaboration with archaeologists and historians, the geomorphological characteristics of selected areas and sites (e.g., case study areas of Velká Bíteš, the surroundings of Brno, the Krumlovský les Forest) were analysed (data collected by Kirchner and Roštínský). The mentioned findings helped to explain the origin and development of the archaeological and historical sites of interest.

Support: ESF OPVK CZ.1.07 Education for competitiveness CZ.1.07/2.4.00/31.0032 - Platform for landscape formation (2012 - 2014). Institutional project - RVO 68145535.

- Kovář, J. J., Roštínský P., & Kos, P. (2014). Průzkum stavebních materiálů a geomorfologie hradu Vildenberk u Pozořic, okr. Brno-venkov (Survey of building materials and geomorphology of the Vildenberk castle at Pozořice, Brno-venkov district). *Vlastivědný věstník moravský, LXVI* (2), 60 – 76. (Muzejní a vlastivědná společnost v Brně)
- Burešová, M., Kirchner, K., Unger, J., Roštínský, P., Šedo, O., & Velek, J. (2013). Zaniklé Otěchleby u Velké Bíteše (okr. Žďár nad Sázavou). [The defunct village Otěchleby near Velká Bíteš town (Žďár nad Sázavou Region)]. *Vlastivědný věstník moravský, 65* (3), 301 - 305.
- Kirchner, K. (2014). The Dyje canyon-like valley: geomorphological landscape of deep valley at the eastern part of marginal slope of the Bohemian Massif. In Pánek, T., & Hradecký, J. (Eds.). *Landscapes and Landforms of the Czech Republic*. Dordrecht: Springer (under review).
- Bajer, A., Hlaváč, V., Kirchner, K., & Kubalíková, L. (2014). *Za skalními útvary CHKO Žďárské vrchy (Isolated rock formations in the Žďárské vrchy Protected Landscape Area).* Brno: Mendelova univerzita v Brně. ISBN 978-80-7375-959-9.

B.4. ***Utilization of modern technologies for collecting, processing and GIS analysis of landforms geo-data in physical geography:***

Laser scanning technology is important for the collection of highly precise geo-data of the landscape and changes over time. It this sense, this technology provides an exceptional opportunity to study selected landscape forms in high resolution. By means of terrestrial laser scanning technology (scanner Leica ScanStation C10 combined with GNSS Leica GS08, software Cyclon 7.4.), very precise data were collected that captured pseudo-karst and karst relief forms, as well as relief forms created by fluvial processes (field data obtained and elaborated with using GIS by team members Kuda and Divíšek). These data enable the creation of new knowledge bases of the spatial distribution of landscape forms and their development.

Support: ESF OPVK CZ.1.07 Education for competitiveness CZ.1.07/2.4.00/31.0032 - Platform for landscape formation (2012 - 2014). Institutional project - RVO 68145535. Contractual research.

- Kuda, F., Kajzar, V., Divíšek, J., & Kukutsch, R. (2014). Aplikace pozemního laserového skenování v geovědních disciplínách. (Application of the terrestrial laser scanning in geoscience research). Brno: Ústav geoniky AV ČR. ISBN 978-80-86407-50-0.
- Kuda, F. (2013). Revize speleologické dokumentace pseudokrasových jeskyní "Ledové sluje" z archívu Správy Národního parku Podyjí a její implementace do GIS. (Implementation of speleological survey from locality Ledove sluje (Ice Caves) to GIS, Podyji National Park, Czech Republic). *Thayensia, 10* (10), 17 - 25.
- Kuda, F., Divíšek, J., & Kirchner, K. (2013). Terrestrial Laser Scanning: A Dataframe for multiply Research in a Pseudokarst Area, Case Study of the Locality Ledove Sluje (Ice Caves) in the Podyji National Park, Czech Republic. In *Protected Karst Territories – Monitoring and Management Proceedings*, 118 - 121. Sofia: Bulgarian Academy of Sciences, National Institute of Geophysics, Geodesy and Geography. ISBN 978-954-9531-18-3.

Key Issue C: The dynamics of current cultural landscapes.

C.1. ***Post-industrial landscapes of the Czech Republic - mapping, typology, cartographic presentation:***

Post-industrial landscapes are a heritage from the previous industrial era that lasted over two centuries in the industrialized countries of the world. This industrial heritage, whether objects and areas directly shaped by industry or related areas of former residential, transportation, agricultural, military and other functions, is rooted in current cultural landscapes, usually without its original function. The concentration of such vestiges is significant for a particular character of such landscapes, which could then be labelled post-industrial landscapes, which had not been systematically analysed and mapped in the Czech Republic. The PG team members (Kolejka, Hrádek, Kirchner, Ondráček) defined the physicogeographical characteristics of post-industrial landscapes and developed a specific original methodology (team member Kolejka) for their identification. Mapping the occurrence of post-industrial landscapes in the Czech Republic was carried out on the basis of available geo-data on selected components of the natural environment altered by humans, and on other additional characteristics of industrial heritage. The natural, economic and historical parameters of the identified post-industrial landscapes were determined. An internal zonation of the selected post-industrial landscapes was also prepared by means of testing various geostatistical methods, and a screening of various forms for the cartographic presentation of test results was carried out.

Support: Grant Agency of C.A.S IAA300860903: Destiny of Czech post-industrial landscape (2009-2011).

- Kolejka, J., & Klimánek, M. (2014). The process of transition from industrial to post-industrial society identified in land use and land cover data: Case of the Czech Republic. In Bičík, I., Himiyama, Y., Feranec, J., & Kupková, L. (Eds.). *Land Use/Cover Changes in Selected Regions in the World* (pp. 95-104). Volume IX, (1). Asahikawa: International Geographical Union Commission on Land Use/Cover Change.
- Kolejka, J., Hrádek, M., Kirchner, K., Klimánek, M., Klusáček, P., Krejčí, T., Lněnička, L., Martinát, S., Nováková, E., Ondráček, S., Plšek, V., Ruda, A., Svatoňová, H., & Svobodová H. (2012). Postindustriální krajina Česka (Post-industrial landscape of the Czech Republic). Ostrava: Ústav geoniky AV ČR, v.v.i.
- Kolejka, J., & Klimánek, M. (2012). Vymezení a typologie postindustriální krajiny Česka (Survey and typology of post-industrial landscape in Czechia). *Geografie, 117* (3), 289 - 307.
- Kolejka, J. (2010). Post-industrial landscape - its identification and classification as contemporary challenges faced by geographic research. *Geographia Technica*, *14* (2), 67 - 78.

C.2. *Permeability assessment of the Czech-Polish border after joining the Schengen area:*
After the Czech Republic and Poland joined the Schengen area (21 December, 2007), it was possible to cross the border at any place except those areas with a special status, such as National Parks, Landscape Protected Areas, and bird sanctuaries. This research project was focused on verification of the current state of permeability of the Czech-Polish border. The research was conducted by a joint Czech-Polish research team. The PG team (members Kolejka, Kirchner, Batelková) selected and evaluated a set of Czech-Polish border permeability classification criteria. The state border itself was divided into regular length segments, which were described according to their natural and socio-economic features (methodological approach after Kolejka). The permeability of border segments was tested using statistical analyses, and the results obtained were also presented in maps that are important for public administration purposes.
Support: Ministry of Foreign Affairs of C.R. "Permeability of Czech-Polish border after entry to Schengen area": 96313_2013_OVD Czech-Polish forum (2013)

- Kolejka, J., Żyszkowska,W., Batelková, K., Ciokl, S., Dolzbasz, S., Kirchner, K., Krejčí, T., Raczyk, A., Spallek, W., & Zapletalová, J. (2014). Permeability of Czech-Polish border using by selected criteria. *Geographia Technica*, (under review).

C.3. *Biogeographical research in environmentally impacted areas:*
The mining and processing of uranium ores and their subsequent remediation have had significant impacts on the current landscape of the Českomoravská vrchovina Highland (Rožná deposit), including its flora and fauna. Since 1998, members of the PG team (Lacina and Halas) have conducted research activities focused on the state of habitats in ecologically important landscape segments, with respect to the possible environmental impacts of the economic activities of the uranium industry. Biogeographical researchers have monitored 28 plots, including the Bukovský potok Brook basin with its municipal solid waste landfill. As final outputs, proposals were made recommending the preservation of species and the promotion of species diversity. In another major research initiative, members of the PG team (Lacina and Halas) paid particular attention to the problems of alluvial meadows in South Moravia, as such meadows in broad valleys are among the most endangered habitats in the Czech Republic. During the 20th century, they were the most ploughed areas, or flooded by dam construction. The aim of this research project is to determine the relationship of the species diversity of the alluvial meadows with current and historical use of the surrounding landscape. During the evaluation period, data from 140 phytocenological sites were processed by researchers Lacina and Halas, and then analysed in conjunction with the outputs of GIS analyses of old and contemporary maps of land use. In particular, woody debris has a significant effect on river

flows, increases geodiversity and the diversity of river organisms, especially animals, and contributes to the varied mosaic of habitats along the river. Water managers require information and possible measures to stabilize woody debris or its removal. Researchers from the PG team (Roštínský, Lacina and Halas) measured some of the parameters of woody debris and conducted detailed phytocenological and geomorphological investigations to determine the potential of woody debris in river habitats of the model sections of Czech and Moravian rivers.
Support: Contractual research. Institutional project - RVO 68145535. Project - GA205/08/0926 - Environmental significance of the woody debris in river ecosystems (2008-2011)

- Havlíček, M., Halas. P., Lacina, J., & Mlejnková, H. (2014). Změny využití krajiny u jihomoravských vodních nádrží. *Acta Pruhoniciana, 108*, 25 - 35.
- Halas, P. (2012). Environmental factors influencing the species composition of acidophilous grassland patches in agricultural landscapes. *Moravian Geographical Reports, 20* (1), 16 – 27.
- Lacina, J., Halas, P., & Švec, P. (2012). Biogeographical relationships between landscapes pattern, chosen local abiotic factors and vegetation in forest edges. *Moravian Geographical Reports, 21* (4), 2 - 12.
- Máčka, Z., Krejčí L., Gryc, V., Halas, P., Kolář, P., Kolářová, N., Koňasová E., Lacina, J., Loučková, B., Peterková, L., Roštínský, P., Rybníček, M., Smetana, M., Vašátko, J., & Vavrčík, H. (2011). *Říční dřevo ve vodních tocích ČR. (River wood in streams of the Czech Republic).* Brno: Masarykova univerzita. ISBN 978-80-210-5624-4.

C.4. ***Contributions to the knowledge base of biogeography in the Czech Republic:***
Species distributions and their underlying determinant factors traditionally have been the focus of research by ecologists and biogeographers. The data which would enable comparisons of the distribution and diversity patterns of more distinct species groups have not been fully analysed at present. In the Czech Republic, there are currently available unique data sets describing the spatial distributions of all groups of vertebrates, some groups of invertebrates, plant communities, and even individual plant species. These data sources thus provide an exceptional opportunity to carry out research on the distribution and diversity patterns of distinct species groups in the Czech Republic. Environmental factors influencing patterns in the composition of assemblages of five distinct animal groups (non-volant mammals, birds, reptiles, amphibians, butterflies) were examined. At the same time, the first statistical classification of Czech landscapes based on the distribution of natural habitats was produced. This classification was subsequently compared with former expert-based classifications. Member of the PG team (Divíšek) contributed to the methodology in this project, and processed and analysed the available data.
Support: Institutional project - RVO 68145535

- Divíšek, J., Zelený, D., Culek, M. & Šťastný, K. (2014). Natural habitats matter: Determinants of spatial pattern in the composition of animal assemblages of the Czech Republic. *Acta Oecologica, 59*, 7 - 17.
- Divíšek, J., Chytrý, M., Grulich, V., & Poláková, L. (2014). Landscape classification of the Czech Republic based on the distribution of natural habitats. *Preslia, 86* (3), 209 - 231.

Research Report of the team in the period 2010–2014

Institute	Institute of Geonics of the CAS, v. v. i.

Scientific team	Department of laboratory research on geomaterials

The Department of Laboratory Research on Geomaterials conducts a comprehensive material research on a wide range of geomaterials and selected construction materials. Mineralogy and petrography belong to the main research areas, where new methodologies of the identification and characterization of materials are being developed especially based on infrared spectroscopy, thermal analysis, optical and infrared microscopy and image processing and analysis. Other important research fields include: mechanical properties of geomaterials in different states of stress; interaction of materials with fluids; and thermal properties of geomaterials. The geology and biostratigraphy of coal basins and geological problems associated with important geotechnical constructions also form a part of the research.

The following are the most significant results achieved by the team in the evaluated period:

1) Effect of the stress-strain and thermal state of rocks and coal on their gas permeability

Motivation: In the area of extraction and storage of energy raw materials, reliable data on the filtration properties of rocks and the rock massif as well as an understanding of the major influencing factors are of critical importance. Quality information on the permeability of rocks and coal constitutes a fundamental prerequisite to an effective extraction of coal bed methane, shale gas, for the design of underground gas and spent nuclear fuel storage facilities, for CO_2 geosequestration, or for tapping geothermal energy from deep underground sources. The gas permeability of coal significantly influences the threat of methane and gas and coal outbursts in coal mines. This is why, for successful coal seam degassing operations performed to enhance the safety of coal mining, it is necessary to reliably evaluate the filtration behaviour of coal under the conditions of stress to which the rock massif is exposed.
Rock permeability is significantly influenced by the character of the pore space and fracturing present in the rocks on either the microscopic or the macroscopic scale. Changes in morphology of the pore system and, thus, changes in permeability may be provoked by mechanical or thermal stressing of the rock, by the presence of liquids within the rock, by physico-chemical interactions of the rock with the filtration medium, or by combinations thereof.
Result: A comprehensive experimental study has been undertaken, focused on the effects of the stress-strain state and the temperature conditions of rocks and coal on their gas permeability. It has been confirmed by extensive measurements of permeability in a triaxial loading cell, conducted using a series of 100 rock and coal specimens subjected to a special loading program, that an increased hydrostatic stress may bring about a significant, even a multiple reduction in permeability of the rock. A

drop in permeability amounting to as much as several orders of magnitude was noted for the coal samples tested.
Measurements of the changes in total and effective porosity of the test samples being exposed to loading and gradual disintegration have shown that permeability is a highly sensitive parameter reflecting the changes occurring within the pore space as well as the intensity of fracturing.
Special attention was paid to the gas permeability of coal. In addition to nitrogen, which is the standard reference gas, another gas employed in the experiments involving coal was CO_2. With this latter gas, it has been ascertained that permeability will drop significantly due to CO_2 sorption on the coal matter. The measurements conducted on coal samples previously affected by coal and gas outbursts showed differences in permeability compared with unaffected samples from the identical seam.
The study into the effect of thermal stressing on permeability was conducted using genetically different types of rocks. The measurements of permeability on rocks exposed to thermal loading under various heating conditions confirmed that an important effect of temperature on permeability existed especially at temperatures above 700 °C, mainly in the case of low-porosity rocks having a compact structure. The changes in pore system morphology provoked by thermal loading were less marked in the case of porous rocks.
The project findings were the result of collaboration of the team members. Only in the case of the study focused on coal affected by coal and gas outbursts, the team members benefited from cooperation with M. Wierzbicki from the Strata Mechanics Research Institute of the Polish Academy of Sciences in Cracow.

Cooperation: The Strata Mechanics Research Institute of the PAS in Cracow.

Outputs: 3 × Jimp, 1 × J,
KONEČNÝ, P. , KOŽUŠNÍKOVÁ, A. Influence of stress on the permeability of coal and sedimentary rocks of the Upper Silesian Basin. *International Journal of Rock Mechanics and Mining Sciences*, 2011. Vol. 48, No. 2, pp. 347-352.
KOŽUŠNÍKOVÁ, A., KONEČNÝ, P. Influence of Temperature on the Permeability of Rocks. *Geotechnique*, 2011. Vol. 61, No. 12, pp. 1081-1085.
WIERZBICKI, M., **KONEČNÝ, P., KOŽUŠNÍKOVÁ, A.** Permeability changes of coal cores and briquettes under tri-axial stress conditions. *Archives of Mining Sciences*, 2014. Vol. 59, No. 4, pp. 1129-1138.
KONEČNÝ, P., KOŽUŠNÍKOVÁ, A. Study into permeability of rocks in triaxial stress state for the purpose of designing for underground structures. *Tunel*, 2012. Vol. 21, No. 2, pp. 11-15.

2) Characterization and differentiation of kaolinites using infrared spectroscopy and differential thermal analysis

Motivation: Kaolinites are materials ranking among clay minerals that presently find the widest range of industrial applications. They are of truly extraordinary importance to a host of industries (such as, the production of ceramics; construction materials; foundry products; pharmaceuticals; or cosmetics). They are used as sorbents, filters, catalysts, insulation materials, etc. Inasmuch as kaolinite is a natural, environment-friendly material consisting of particles having less than 2 μm in size, it also offers a wide application potential in the area of nanotechnologies, in the preparation of nanoparticles and nanocomposites.
Modified by organic or inorganic substances, these layered-structure silicates yield materials that exhibit novel service properties. Kaolinite used in the production of

polymer/clay nanocomposites with interesting optical and mechanical properties, active substance carriers in nanomedical applications, or the development of new types of paints, varnishes and vitreous enamels capable of absorbing noxious substances from the atmosphere can serve as examples. Inasmuch as the specific properties of kaolinites are significantly influenced by their structural ordering, it is indispensable that further efforts be made to acquire an even wider, in-depth understanding of the structural features of these layered minerals.

Result: A new methodology has been developed for the purpose of assessing the degree of ordering of the kaolinite structures, relying on a combination of two advanced analytical techniques—infrared spectroscopy and thermal analysis. An analytical study has been undertaken on a set of kaolinite samples that differed in the degree of their ordering and their geological provenience. For the purpose of evaluating the structural parameters of kaolinites from the infrared spectra, an empirical and numeric classification has been designed that makes use of characteristic absorption bands of OH groups in the structure. The degree of ordering is determined based on coefficients computed from the intensities of the pertinent absorption bands. In case of thermal analysis, the degree of ordering of kaolinites is rated based on the dehydroxylation temperatures and transformations derived from the DTA curves. Thanks to the results obtained by combining the two analytical techniques, the kaolinites tested can be assigned to different classes depending on their degree of structural order. The results achieved were confronted with published data obtained by X-ray diffraction, attesting to the correctness of the approach adopted. This analytical approach has also been successfully applied to the structural characterization of mechanically and chemically activated kaolinites.

The main part of analytical measurements (infrared spectroscopy and thermal analysis) was performed by team members L. Vaculikova and E. Plevova in the Institute of Geonics laboratories. Verification analyses were performed by co-authors from VSB -Technical University. In case of treated kaolinites, the milling and acid activation together with X-ray diffraction measurements were performed by authors from VSB-Technical University.

Cooperation: VSB-Technical University of Ostrava

Outputs: 2 x Jimp

VACULÍKOVÁ, L., PLEVOVÁ, E., VALLOVÁ, S., KOUTNÍK, I. Characterization and Differentiation of Kaolins from selected Czech Deposites using infrared spectroscopy and differential thermal analysis. *Acta geodynamica et geomaterialia*, 2011. Vol. 8, No. 1, pp. 59-67.

VALÁŠKOVÁ, M., BARABASZOVÁ, K., HUNDÁKOVÁ, M., RITZ, M., **PLEVOVÁ, E**. Effects of brief milling and acid treatment on two ordered and disordered kaolinite structures. *Applied Clay Science*, 2011, Vol. 54, No. 1, pp. 70-76.

3) Structure and properties of polymer grouted geomaterials

Motivation: New specific composite materials are formed in the field of grouting technologies by grouting of polymer grouts into soils, disturbed rock mass or into damaged building structures. The high structural and textural variability of these composites complicates significantly the determination of their physical and mechanical properties because it is often impossible to prepare representative test specimens for laboratory tests from the samples taken after grouting in situ. The aim of the research was to define the basic relations between structure of grouted geo-materials and their physical-mechanical parameters, and to assess how this knowledge can be used for the prediction of properties of geotechnical structures created in both underground and civil engineering.
Result: A new classification system for description of structures and textures of geomaterial-polymer composites according to various criteria has been developed. An extensive experimental study on structural and physical-mechanical properties has been performed on a set of model composites prepared by laboratory grouting of polymer grouts into different types of rock and building materials. The advanced methods of digital imaging and image analysis were used for quantification of structural parameters at both microscopic and macroscopic scales. Laboratory testing methods used in rock mechanics has been adapted to specific deformation behaviour of geomaterial-polymer composites and used for the determination of their mechanical properties. The statistical methods of cluster analysis and regression analysis were applied to assess relations between the determined parameters.
In addition to the above-mentioned experiments, selected types of real in-situ grouted sand and gravel type composites have been evaluated in terms of an impact of structural parameters and anomalies on the water permeability and stress-strain behaviour of the materials.
The results achieved showed that an analysis of structures and textures of geomaterial-polymer composites represents a possible indirect way to estimate their physical and mechanical properties. The architecture of composite materials originating from geotechnical practice can be compared with structures of similar composites, whose physical and mechanical properties are already known.

Cooperation: Department of Geomechanics and Mining Research, Institute of Geonics of the CAS; GME s.r.o.; VSB-Technical University of Ostrava

Outputs: 1 × Jimp, 1 × eng M, 2 × J

SCUCKA, J., **MARTINEC, P.**, SOUCEK, K. Polyurethane grouted gravel type geomaterials – a model study on relations between material structure and physical-mechanical properties, *Geotechnical testing journal,* 2015*.* Vol. 38, No. 2, pp. 229-242.
BÓDI, J., BÓDI, Z., **ŠČUČKA, J.**, **MARTINEC, P.** Polyurethane grouting technologies. In: Polyurethane. Rijeka: InTech Open Access Publisher, 2012 - (Zafar, F.; Sharmin, E. Eds.), pp. 307-336. ISBN 978-953-51-0726-2
SOUČEK, K., STAŠ, L., **ŠČUČKA, J.**, **VAVRO, L.**
Laboratory research into permeability of cohesionless soils grouted by chemical grouts, *Tunel,* 2010*.* Vol. 19, No. 2, pp. 60-68. ISSN 1211-0728
ŠČUČKA, J., HRUBEŠOVÁ, E., **MARTINEC, P.**, PETŘÍK, T. Polyurethane-grouted sand - analysis of stress-strain state of a geocomposite material with anomalous structure. Transactions of the VŠB – Technical university of Ostrava, 2012. Vol. 12, No. 2, pp. 1-9. ISSN 1213-1962 (in Czech)

4) Origin and properties of building materials used in cultural monuments

Motivation: In 2010, an unique set of 76 Gothic sandstone architectural elements discovered during repair works on the wall surrounding the church and cemetery in the village of **Staříč** (North Moravia) was acquired by the VSB – Technical University of Ostrava. The finding not only provoked discussions focused on art history but also elicited questions regarding the material properties and the origin of the stone from which the blocks were hewn and of the original mortars, paints, and pigments of which the residues were found stuck to the blocks discovered. The team members P. Martinec and J. Scucka were invited to solve the material properties and provenance issues.

In the same period, an extensive interdisciplinary archaeological research on the St. Martin's church in the village of **Bohušov** (North Moravia) has been performed under the coordination of the National Heritage Institute. The above named team members participated in this research in the field of material characterisation and provenance determination of rocks in building stones and gravestones.

Result: An approximate dating of **the Staříč elements** was made based on a form analysis and on the developmental relationships of the church. A computer 3D visualisation of selected elements has been undertaken with the possibility of inserting the models into the “wire” model of the vault structure to which the elements most probably belonged. Using advanced microscopic and spectroscopic methods, a detailed material analysis of the stone and residues of mortars and coats was performed, focused on material composition and properties and locating the probable sources of initial raw materials used.

The results were published in the form of Czech-English monograph. P. Martinec and J. Scucka created the essential part of the book. They performed descriptions and analyses of the stone, mortars, paints, and pigments in terms of their composition and properties. They specified the surface layers stratigraphy and degree of material preservation. They also discussed the origin of materials and prepared the final manuscript for publication. The other authors performed dating of elements and put the finding into a historical context. They also ensured the 3D visualisation of elements.

An important discovery originating from a Gothic sacral object built right at the north-eastern boundary of the Moravian medieval cultural sphere were multidisciplinary analysed in detail. Collections of this nature are not numerous on Czech Republic’s territory, and none of these has been subjected to an interdisciplinary analysis as thorough as that of the Staříč. Based on the analytical results probable sources of building materials and raw materials were determined. The research resulted in a number of new findings, such as the application of “hot” mortars employing an unusual kind of aggregate, the application of painted ornaments right on the stone ribs that so far has only been documented on several more recent examples, or the explanation of why the building stone exhibits a high corrosion stability. Also the analysis of system of pores in the sandstone and of its interaction with water yielded an important information in terms of conservation agents and methods possibly chosen for the treatment of building stones of similar type in historical building structures or objects of art.

The research on the **St. Martin's church in Bohušov** resulted in an extensive Czech monograph with 525 pages. P. Martinec and J. Scucka prepared two chapters on rocks in building stones and Renaissance grave stones used in different historical phases of the construction development. The authors performed detailed petrographic analyses

of rocks, specified the geology of the region and identified probable sources (deposits and quarries) of rocks used as the building stone.

Cooperation: VSB-Technical University of Ostrava

Outputs: 1 × eng/cze B, 2 × cze M
AUGUSTINKOVÁ, L., **MARTINEC, P.** , **ŠČUČKA, J.**, PEŘINKOVÁ, M. The Gothic Fragments of Staříč. Ostrava: Šmíra Print, 2012. 118 p. ISBN 978-80-87427-44-6. 1
MARTINEC, P., **ŠČUČKA, J.** St. Martin's church - building materials and their provenance. In: St. Martin's church in Bohusov (Kozak, P., Prix, D., Zezula, M. Eds.), Ostrava: National Heritage Institute, 2011, pp. 325-334. ISBN 978-80-85034-59-2 (in Czech)
MARTINEC, P. Excursus. Petrography of rocks in tombstones. In: St. Martin's church in Bohusov (Kozak, P., Prix, D., Zezula, M. Eds.), Ostrava: National Heritage Institute, 2011, pp. 411-419. ISBN 978-80-85034-59-2 (in Czech)

5) Ammonite fauna contributing to the new knowledge of geology and stratigraphy of selected Mesozoic localities

Motivation: In sediments of the Mesozoic period, ammonite fossils represent the group which is most important for stratigraphy. They allow to pinpoint the dating of marine sediments down to an accuracy of tens of thousands of years and to correlate the corresponding stratified successions and events on a broad international scale. During the evaluated period, unique collections of Lower Cretaceous and Upper Jurassic ammonites from two prime localities were studied: **Boljetin** (eastern Serbia) and **Štramberk** (Czech Republic).
Result: Specific section in pelitic pelagic Lower Cretaceous sediments of Late Barremian age with a rich association of fossil ammonites was outcropped in the locality of **Boljetin**. The association is considerably different compared to other Late Barremian sections in Europe. The study on ammonites was performed in cooperation with the University of Belgrade. 24 species of ammonites were determined and described in this locality; 6 of them are new species. Considering that the ammonite association lacks the zone species the study was combined with the microanalysis of non-calcareous dinoflagellate cysts. Combination of results enabled to define the age of the section on the level of international ammonite zonation. Dinoflagellate association indicate warm-water neritic milieu with an influx of terrestrial material. The results were published in 2 parts in the Cretaceous Research journal. The team member professor Z. Vasicek is the main author of the study. He visited the locality of Boljetin in Serbia and collected micropalaeontological samples and also a part of macrofossil samples. He specified the lithological documentation. He prepared the collection of ammonites, performed measurements of shell-parameters, drawing of suture-lines, and photo-documentation. He determined the ammonites on a level of species, and performed also the stratigraphic evaluation and correlation with similar sections in Europe.
Until recently, the fossil faunas of worldwide fame from the **Štramberk** area limestones were regarded as Upper Jurassic. In 2012 at Kotouč Quarry, the zone ammonite *Pseudosubplanites grandis* was found which identifies these limestones as belonging to Lower Cretaceous. Subsequent surveying revealed a faunistic position within the quarry wall, at the exit from level 3 to level 4, where more than a hundred ammonites were collected. Professor Vasicek has examined and identified a total of 8 species of ammonites. Some of these were zone ammonites, constituting evidence of the Cretaceous age of the limestones (Lower Berriasian). Eventually, in addition to Lower

Cretaceous ammonites, several positions with Upper Jurassic ammonites (Tithonian) were discovered, too. An analysis of the new collection of ammonite fauna has demonstrated that the sedimentation of Štramberk limestones progressed from Upper Jurassic as long as until the base of Lower Cretaceous. It has also documented that the body of Štramberk limestones at the Kotouč Quarry is of a highly complicated geological structure. This has made it possible to put to rights the hitherto distorted notions of the structure of the limestone body at the quarry that failed to correspond with reality. In addition to his own field sampling, professor Vasicek has also undertaken a taxonomic processing of the collection of ammonites, to an extent similar to that of the aforementioned Boljetin collection.

Cooperation: University of Belgrade; VSB-Technical University of Ostrava

Outputs: 5 × Jimp

VAŠÍČEK, Z., RABRENOVIČ, D., RADULOVIČ, V.J., RADULOVIČ, B.V., MOJSIĆ, I. Ammonoids (Desmoceratoidea and Silesitoidea) from the Late Barremian of Boljetin, eastern Serbia. *Cretaceous Research*, 2013. Vol. 41, No. 3, pp. 39-54.

VAŠÍČEK, Z., RABRENOVIČ, D., SKUPIEN, P., RADULOVIČ, V.J., RADULOVIČ, B.V., MOJSIĆ, I. Ammonites (Phylloceratina, Lytoceratina and Ancyloceratina) and organic-walled dinoflagellate cysts from the Late Barremian in Boljetin, eastern Serbia. *Cretaceous Research*, 2014. Vol. 47, No. 1, pp. 140-159.

VAŠÍČEK, Z., SKUPIEN, P. Recent discoveries of Tithonian ammonites in the Štramberk Limestone (Kotouč Quarry, Outer Western Carpathians). *Annales Societatis Geologorum Poloniae,* 2014*.* Vol. 84, No. 2, pp. 131-141.

VAŠÍČEK, Z., SKUPIEN, P. Early Berriasian Ammonites from the Štramberk Limestone in the Kotouč Quarry (Outer Western Carpathians, Czech Republic). *Annales Societatis Geologorum Poloniae,* 2013. Vol. 83, No. 4, pp. 329-342.

VAŠÍČEK, Z., SKUPIEN, P., JIRÁSEK, J. The northermost occurrence of the Lower Cretaceous ammonite Pseudosubplanites grandis (Štramberk Limestone, Outer Western Carpathians, Czech Republic). *Geologica Carpathica,* 2013. Vol. 64, No. 6, pp. 461-466.

6) Application of chemometric methods in infrared spectroscopy of minerals contained in sedimentary rocks

Motivation: The research project was aimed at verifying the possibility of identification and quantification of minerals contained in sedimentary rocks using the method of infrared spectroscopy (FTIR) in combination with multivariate statistical methods. At the present, quantitative phase analysis is conducted mainly using the Rietveld refinement, i.e., the Rietveld technique of X-Ray diffraction analysis (XRD). Compared to this method, the chemometric analysis of infrared (IR) spectra is substantially simpler in processing the data readings. Except for the design and elaboration of the chemometric models, this method also is less time-consuming. Moreover, thanks to the relatively low acquisition and operating costs of the FTIR spectrometers, there is a growing number of laboratories that have availed themselves of this technology.

Result: A user library has been established comprising the IR spectra of 90 mineral standards including their attendant admixtures, and of 138 sedimentary rock samples. The IR spectra were measured in the middle infrared range using the KBr pellet and the diffuse reflection techniques.

Discriminant analysis (DA) of the IR spectra of the mineral standards was employed to identify the various mineral components present. Several calibration models were designed to ensure a reliable identification.

The contents of the minerals present in the sedimentary rocks were predicted based on chemometric models composed of the experimental IR spectra using the principal component analysis (PCA) and the partial least squares method (PLS). Subsequently, the results obtained were compared with the results of an XRD analysis. The experimental data have shown that FTIR spectroscopy combined with chemometric methods yields results that, statistically, are abreast of those obtained by the Rietveld method of XRD analysis.
The presented deliverable was the result of a successful Czech Science Foundation project no. 105/08/1398, of which L. Vaculiková, a team member, was the Scientist-in-Charge, and M. Ritz from VSB - Technical University of Ostrava was the project partner. The major analyses (FTIR spectroscopy and thermal analysis) were performed at the Institute of Geonics of the CAS. The FTIR analyses of minerals and rocks as well as the establishment of the user library of spectra and the processing of some of the spectral data readings using TQ Analyst software were the responsibility of L. Vaculiková. Supplementary measurements of TG/DTA curves using thermal analysis were carried out by team member E. Plevová. M. Ritz from VSB - Technical University who collaborated on the project was responsible for processing the spectral data using Unscrambler software. Other co-workers from VSB-TU were instrumental in the provision of the base of rock samples (J. Malis) and in performing a quantitative analysis of the rock samples by the XRD method (D. Matysek).

Cooperation: VSB-Technical University of Ostrava

Outputs: 3 × Jimp
RITZ,M., **VACULÍKOVÁ, L., PLEVOVÁ E.**, MATÝSEK, D.,MALIŠ, J. Determination of chlorite, muscovite,albite and quartz in claystones and clay shales by infrared spectroscopy and partial least-squares regression. *Acta geodynamica et geomaterialia*, 2012, Vol. 9, No. 4 (168), pp. 511–520.
RITZ, M., **VACULÍKOVÁ, L., PLEVOVÁ E.**, MATÝSEK, D., MALIŠ, J. Determination of predominant minerals in sedimentary rocks by chemometric analysis of infrared spectra. *Clays and Clay Minerals*, 2012, Vol. 60, No. 6, pp. 511–520.
RITZ, M., **VACULÍKOVÁ, L., PLEVOVÁ, E.** Identification of Clay Minerals by Infrared Spectroscopy and Discriminant Analysis, *Applied Spectroscopy*, 2010, Vol. 64, No. 12, pp. 1379-1387.

7) Thermal behaviour of rocks under non-isothermal conditions

Motivation: Changes of the rock structure and its phase transformations brought about by non-isothermal heating are factors important to the comprehensive assessment of the behaviour of the rocks and the rock massif. Qualitative and quantitative percentages of the rock-forming minerals present, as well as their size and arrangement within the rock, are absolutely essential for the impact of temperature changes, i.e., for the extent and intensity of the temperature effects at play. This is true not only of progressive heating but also of cooling. Within the body of methods used to study the effects of temperature on rocks, the thermoanalytic methods hold an irreplaceable position. The greatest merit of these methods is that they make it possible to examine the temperature dependences of one or more physico-chemical properties of the rocks during the course of a pre-defined temperature program.
Result: A comprehensive study into the effects of temperature on the thermal behaviour of three genetically different types of rocks (sandstones, marbles, and

granites) has been undertaken. The effects of heating and cooling on the physical and chemical changes of the rocks were studied.
A methodology has been proposed of measuring the thermal dilation with regard to the measuring conditions, sample pretreatment, and anisotropy of the rock structure. For selected rock types, the regression relationships describing thermal dilation as a function of temperature were determined. Predictions were made of the thermal behaviour of rocks depending on their composition, structure and the character of their system of pores bearing in mind the changes in permeability due to various temperature effects.
The results of the study have confirmed that the method of simultaneous thermogravimetry and differential thermal analysis, combined with the method of thermomechanical analysis, represents an analytical tool well adapted to effective studies of the thermomechanical properties of rocks.
The research findings were the result of collaboration of the team members: E. Plevova, L. Vaculikova, A. Kozusnikova, P. Martinec, J. Scucka, and P. Konecny. The measurements employing the methods of simultaneous thermogravimetry, differential thermal analysis, and thermomechanical analysis, together with predictions of the thermal behaviour of rocks, were performed by E. Plevova. The FTIR spectroscopy of the rocks was taken care of by L. Vaculikova. A. Kozusnikova and P. Martinec were responsible mainly for optical microscopy and mineralogical analysis. J. Scucka undertook the image processing and analysis, and P. Konecny performed the rock permeability measurements. Our colleagues from VSB – Technical University and Palacky University have contributed the analyses using X-ray diffraction and Moesbauer spectroscopy as well as a statistical processing of the data.

Cooperation: VSB-Technical University of Ostrava, Palacky University Olomouc

Outputs: 4 × Jimp
PLEVOVÁ, **E.**, **KOŽUŠNÍKOVÁ**, **A.**, **VACULÍKOVÁ**, **L.**, SIMHA MARTYNKOVÁ, G. Thermal behavior of selected Czech marble samples. *Journal of Thermal analysis and Calorimetry*, 2010. Vol. 101, No. 2, pp. 657-664.
MARTINEC, P., VAVRO, M., **SCUCKA, J.**, MASLAN, M. Properties and durability assessment of glauconitic sandstone: A case study on Zamel sandstone from Bohemian Cretaceous Basin (Czech Republic). *Engineering Geology*, 2010. Vol. 115, No. 3/4, pp. 175-181.
PLEVOVÁ, E., VACULÍKOVÁ, L., KOŽUŠNÍKOVÁ, A., DANĚK, T., PLEVA, M., RITZ, M., SIMHA MARTYNKOVÁ, G. Thermal study of sandstones from different Czech localities. *Journal of Thermal Analysis and Calorimetry*, 2011. Vol. 103, No. 3, pp. 835-843.
KOŽUŠNÍKOVÁ, A., KONEČNÝ, P. Influence of Temperature on the Permeability of Rocks. *Géotechnique*, 2011, 61, 12, pp. 1081-1085.

8) Carbon dioxide and the rock massif

Motivation: CO2 within rock massif is a topic of worldwide importance, widely discussed today especially in relation to CO2 underground storage. Deposition of CO2 for storage in suitable natural or artificial collectors situated underground represents one of the innovative technologies aiming at the conservation of carbon dioxide generated by combustion of fossil fuels or by other greenhouse gas producing processes.
Mining activities conducted in the Upper Silesian, Lower Silesian, and Central Bohemian coal basins during the second half of the 20th century were accompanied by coal, rock and gas outbursts, including the outbursts of CO2 liberating large volumes

of this gas. These events have contributed unique information on the collector properties, on the ways of CO2 becoming accumulated within the rock massif, and on the distribution thereof in geological formations. Today, the experience acquired in coping with these problems assumes a new level of importance thanks to its relations with the issues of underground storage of CO2.
Result: The monograph “Carbon dioxide and the rock massif” is concerned with the natural occurrences and the accumulation conditions of CO2 in natural collectors and with the ways in which the mine workings respond to the CO2-containing rock massif. The book summarizes and analyses unique information gathered thanks to mining activities in coal basins in the Czech Republic and in Polish part of Lower Silesian basin during recent decades. A sizeable volume of very valuable knowledge and data about CO2 and methane accumulations, collector properties, rock and gas outbursts, and other problems has been collected and processed. This body of information is irreplaceable when interpreting the genesis and distribution of gases within the massif based on geological surveying by means of boreholes as well as when assessing the suitability of the massif for underground gas sequestration.
Professor P. Martinec, a team member, is the main author of the output. The monograph builds on his earlier publications complemented by analytical results in the field of gas sorption/desorption on coal (B. Taraba; University of Ostrava) and modelling of CO2 behaviour in rocks (P. Kolar; Mitsubishi Chemical). Co-author V. Martinec (Veolia CZ) prepared the chapter on impact of CO2 on corrosion of concrete in mines and underground constructions. The team member B. Schejbalova ensured the editorial work.

Cooperation: University of Ostrava, Mitsubishi Chemical, Veolia CZ

Outputs: 1 × eng B, 1 × cze B
MARTINEC, P., KOLÁŘ, P., MARTINEC, V., **SCHEJBALOVÁ, B.**, TARABA, B.
Carbon dioxide and the rock massif. Ostrava: Institute of Geonics of the CAS, 2012. 153 p. ISBN 978-80-86407-28-9. 1
MARTINEC, P., KOLÁŘ, P., MARTINEC, V., **SCHEJBALOVÁ, B.**, TARABA, B. *Oxid uhličitý a horninový masiv. [Carbon dioxide and the rock massif]*. Ostrava: Institute of Geonics of the CAS, 2011. 138 p. ISBN 978-80-86407-14-2.1 (in Czech)

Multidisciplinary research on urinary calculi

In addition to the above-mentioned research topics and scientific results, the team members investigated also specific interdisciplinary problems related to **public health protection**. The mineralogical and chemical **structure of urinary calculi** in the human body has been studied, considering the patients in Ostrava urban agglomeration. The aim of the research, which is still in process, is to find out the development of mineral occurrence of urinary tract stones in patients from the Ostrava region in the years 1978–2011, in relation to sex, age, and location of stones. Furthermore, the aim is to find the relationships between the character of urinary calculi and significant socioeconomic changes in the Czech Republic. This research is conducted in cooperation with Hospital Frydek-Mistek, Brno University of Technology, Masaryk University Brno, Sincrotrone Trieste S.C.p.A., Italy, and Calculi - Laboratory Specializing in Urinary Stones Analyses, Brno.

Outputs: 1 × Jimp, 1 × J, 3 × eng A

KUTA, J., MACHÁT, J., BENOVÁ, D., ČERVENKA, R., ZEMAN, J., MARTINEC, P. Association of minor and trace elements with mineralogical constituents of urinary stones: A hard nut to crack in existing studies of urolithiasis. *Environmental Geochemistry and Health,* 2013. Vol. 35, No. 4, pp. 511-522.
KAISER, J., HOLÁ, M., GALIOVÁ, M., NOVOTNÝ, K., KANICKÝ, V., MARTINEC, P., ŠČUČKA, J., BRUN, F., SODINI, N., TROMBA, G., MANCINI, L., KOŘISTKOVÁ, T. Investigation of the microstructure and mineralogical composition of urinary calculi fragments by synchrotron radiation X-ray microtomography: a feasibility study. *Urological Research*, 2011. Vol. 39, No. 4, pp. 259-267.

Research Report of the team in the period 2010–2014

Institute	Institute of Geonics of the CAS, v. v. i.

Scientific team	Human geography

I. Introduction

The scientific Team of **Human Geography** (in short HG Team) within the **Department of Environmental Geography, Institute of Geonics CAS,** has been defined for the purposes of the current scientific evaluation for the period 2010-2014. The second team within the Department has been defined as the Physical Geography Team. This formal division reflects the option of inclusion in the evaluation criteria (i.e. evaluation panels) and rules.

The formal division of the Department into two broad research teams reflects two principal aspects of geographical research: (i) the physical-geographical aspect (including climatological, geomorphological, hydrological and biogeographical issues); and (ii) the human-geographical aspect (including social, economic and cultural issues, approached primarily from a spatio-temporal perspective). This division reflects not only current trends within the discipline of Geography, but also general trends in scientific research today. On the one hand, especially from the perspective of basic research, it is important to develop scientific specialisation to tackle sub-issues at a detailed scale. On the other hand, especially from the perspective of applied research, increasing importance is placed on interdisciplinary cooperation, the implementation of holistic and synergistic approaches. The landscape (in the broadest sense of the term) represents a common platform for the long-term collaboration of Physical Geography and Human Geography Team members. The aim of cooperation of both Teams' members within the Department is to epitomise particular research findings and to achieve an environmental geographic synthesis, which is a desirable result within the research on complex and environmentally and socially significant phenomena and problems, such as natural biophysical extreme events and hazards, landscape changes and land-use conflicts, and resource management problems such as sustainable energy issues.

In the evaluation period 2010-2014, the HG Team was created from **11 researchers** (with an aggregated average workload of approximately five full-time researchers) and **7 other workers** (aggregated workload of these Ph.D. students was approximately 4 full-time workers). The Team brings together experts from several sub-disciplines of Human Geography, including urban geography, economic geography, rural studies, behavioural and cultural geographies, cartography and GIS, etc.

II. Research Focus Areas

The research activities of the HG Team have been concentrated around two wider areas of research and development, which have involved partial sub-themes (see the description below) being tied to specific international and national grant projects, international bilateral and multilateral scientific cooperation agreements, and expert studies. Most of the partial themes are interconnected and interdependent phenomena. For example, the decline and restructuring of the post-socialist

agricultural sector caused the extinction of many enterprises, the emergence of abandoned sites (rural brownfields), and problems with finding alternative forms of post-productive business models (e.g., cultivation of energy crops and development of biogas stations).

The two broad areas of research encompassing work by the HG Team are:

1. The transformation of urban spaces:

1.1 Re-urbanization, urban renewal and brownfields redevelopment
1.2 Spatial models of behaviours in changing urban environments

2. The changing nature of rural spaces:

2.1 Renewable energy development and rural land-use conflicts
2.2 Restructuring and diversification of agriculture

These specific research foci of the HG Team reflect current global environmental challenges, as well as regional, socially relevant issues. Significant progress has been made in addressing major environmental research topics that have so far been neglected in the discipline of Geography, especially in its social science research aspects, in the Czech Republic (e.g., brownfields regeneration, or land-use conflicts in the context of renewable energy development). In the above-mentioned fields of research, the Team members already play a leading role -- not only within the scope of Czech geographical research, but also with respect to the broader East-Central European context.

The scope and focus of the Team's research activities have been significantly shaped by long-term cooperation with key foreign partner institutions (e.g., the Helmholtz Centre for Environmental Research – UFZ Leipzig (Germany), School of Geosciences, University of Edinburgh (UK), Department of Environmental Sciences, Informatics and Statistics, Universita Ca' Foscari Venezia (Italy), or the School of Geographical Sciences and Urban Planning at Arizona State University (USA)). Such cooperative relationships have been reflected in the common preparation and successful implementation of several international projects (EU's 7th Framework programme, COST programme, Horizon 2020, etc.). These trends are positively reflected as well in the growth of high-quality publications with international co-authorships.

The multidisciplinary nature of the HG Team has also allowed us to respond to more applied demands based on the needs of policy and practice (e.g., decision makers in the spheres of landscape and urban planning, nature and landscape protection authorities, investors and developers in the field of renewable energy development and urban regeneration, educators, etc.).

III. Description of the Major Research Results of the HG Team

The description of the partial research themes identified above, relevant projects and key publications, are summarized in the following text. Only research projects in which the Principal Investigator (project leader) was a member of the HG Team are included. Team members are marked by underlined type in the list of publications.

1. The transformation of urban spaces:

1.1 Re-urbanization, urban renewal and brownfields redevelopment

In large cities – specifically those developing from transitional economies – the processes of de-industrialization, residential and commercial suburbanization, and re-urbanization, have resulted in significant migration flows, the expansion of cities into the surrounding countryside, changing social structures within the inner parts of cities, and the appearance of abandoned or underused sites, so-called brownfields. The HG Team research – as one of the few extant studies, world-wide and particularly those with a regional basis – applied a rigorous spatial (geographical) approach to the analysis and assessment of urban renewal and brownfields regeneration processes. We have defined and elaborated an 'area-wide approach' to the study of brownfields regeneration, which takes into account the wider community or geographic area of brownfields, and which can be regarded as an alternative to the more common 'site-based approach' (as in the technical sciences and environmental management). Besides providing original empirical evidence on existing spatial patterns, drivers and barriers of post-socialist urban redevelopment, we have also presented novel interpretations of micro-perspectives on 'framings' and the roles of actors in the regeneration processes. The results, which were achieved in collaboration with researchers from other European countries and experts from practice, can be considered examples of "applied geography", representing both a significant contribution to theoretical understanding of urban transformation processes, and their implications for urban planning and practice.

Relevant research projects:

- New methods for improving brownfields regeneration to optimize decision-making processes (2014-2015, Czech Technology Agency, No. TD020259)
- Tailored improvement of brownfield regeneration in Europe - TIMBRE (2011-2014, EU's 7th Framework Programme, No. ENV.2010.3.1.5-2)
- The development of population and housing in Czech and Austrian city regions: A comparative study of Prague, Vienna, Brno, Graz, Linz and Pilsen (2009-2010, KONTAKT, MEB 060907)

Key publications:

- Kunc, J., Martinát, S., Tonev, P., Frantál, B. (2014). Destiny of urban brownfields: Spatial patterns and perceived consequences of post-socialistic deindustrialization. *Transylvanian Review of Administrative Sciences*, *41E*, 109-128. IF: 0.532 – WOS. Times Cited: 2.
- Alexandrescu, F., Martinát, S., Klusáček, P., Bartke, S. (2014). The Path From Passivity Toward Entrepreneurship: Public Sector Actors in Brownfield Regeneration Processes in Central and Eastern Europe. *Organization & Environment, 27* (2): 181-201. IF: 1.386 – WOS. Times Cited: 5.
- Frantál, B., Kunc, J., Nováková, E., Klusáček, P., Martinát, S., Osman, R. (2013). Location Matters! Exploring Brownfields Regeneration in a Spatial Context (Case Study of the South Moravian Region, Czech Republic). *Moravian Geographical Reports*, *21*(2), 5-19. IF: 0.341 – WOS. Times cited: 5.
- Frantál, B., Martinát, S. (2013). Brownfields: A Geographical Perspective. *Moravian Geographical Reports, 21*(2), 1-5. IF: 0.341 – WOS. Times cited: 2.
- Haase A., Bierzynski A., Grabowska M., Klusáček P., Martinát S., Uherek Z., Maas A. (2011). Old-new Diversity: Processes and Structures of Socio-Demographic Change in the Inner City. In: Haase A., et al. (eds.): *Residential Change and Demographic Challenge The Inner City of East Central Europe in the 21st Century* (pp. 143-183), Ashgate, England. WOS Times Cited: 11.
- Steinführer, A., Bierzyński, A., Großmann, K, Haase, A., Kabisch, S., Klusáček. P. (2010). Population Decline in Polish and Czech Cities During Post-socialism? Looking

Behind the Official Statistics. *Urban Studies*, *47* (11): 2325 - 2346. IF: 1.510 – WOS. Times cited: 10.

1.2 Spatial models of behaviours in changing urban environments

Political and economic changes that occurred in the Czech Republic during the last 20 years have been reflected both in the spatial organisation of society and in the everyday activities of individuals. The most influenced fields, apart from labour markets, are the retail and service sectors and leisure time. The urban environment represents an ideal space for research on spatial behaviours. Cities compress the lives of a large number of people into a relatively small space, which reduces the amount of time for the realisation of interpersonal activities and, together with modern means of transport and communication technologies, relativize time-space, shape and materialize the daily rhythm of human activities. In the HG Team research on spatial behaviours, we were inspired by the original concepts of time geography but we applied and developed some new research tools and data modelling methods (e.g., combination of travel diaries, GPS records and participant observation, methodological innovations to Reilly's retail gravitation models, 3-D data visualizations in GIS). Empirical comparative research (involving cities of different scale) focused on aspects of mobility in space and time, shopping behaviours, and the socio-spatial isolation and accessibility to services for some socially-excluded population groups (single mothers, seniors or handicapped people). The extensive data and their interpretations, which are quite unique in the Czech context, represent not only a significant contribution to inter-disciplinary research in the social sciences – especially in bringing together geographical and sociological perspectives on research into human behaviours – but they also provide information applicable in the field of municipal planning (e.g., accessibility issues).

Relevant research projects:

- Spatial models of behaviour in transforming urban environment: time geographical approach (2009-2011, Czech Science Foundation, No.403/09/0885)
- Quantitative methods and synthesizing graphic methods in approximation, projection and modelling of geographical phenomena (2009-2011, Czech Academy of Sciences, No.KJB300860901)

Key publications:

- Frantál, B., Klapka, P., Siwek, T. (2012). Human Behaviour in Space and Time: Theoretical-Methodological Foundations [in Czech]. *Sociologický časopis/Czech Sociological Review, 48*(5), 833-857. IF: 0.652 – WOS. Times Cited: 0.
- Kunc, J., Tonev, P., Frantál, B., Szczyrba, Z. (2012). Retail Gravity Models, Shopping Habits and Shopping Centres: The Case of the Brno Agglomeration [in Czech]. *Sociologický časopis/Czech Sociological Review*, *48*(5), 879-910. IF: 0.652 – WOS. Times Cited: 1.
- Kunc, J., Frantál, B., Tonev, P., Szczyrba, Z. (2012). Spatial patterns of daily and non-daily commuting for retail shopping: Case of the Brno city, Czech Republic. *Moravian Geographical Reports*, *20*(4), 39-54. IF: 0.341 – WOS. Times Cited: 2.
- Frantál, B., Maryáš, J., Jaňura, J., Klapka, P., Kunc, J., Nováková, E., Osman, R., Siwek, T., Szczyrba, Z., Tonev, P., Toušek, V. (2012). *Spatial behaviour: Activity patterns, mobility and everyday life in a city* [in Czech]. Brno, Masarykova univerzita.

- Halás, M., Klapka, P. (2010). Regional division of Czechia on the basis of spatial interaction modelling [in Czech]. *Geografie*, *115*(2), 144-160. IF: 0.787 – WOS. Times Cited: 3.

2. The changing nature of rural spaces:

2.1 Renewable energy development and rural land-use conflicts

Environmental and security concerns have led during the last decade to a rapid and far-flung development of renewable energies. The exploitation of renewable energy sources has become a global ambition, which raises considerable social controversy at both regional and local levels, with impacts on landscape, human well-being and local tourism as the main opposition arguments. Renewable sources are spatially dispersed, requiring substantial land resources in comparison to traditional sources, and they have been mostly undertaken in rural areas hitherto unaffected by large-scale industrial development. The problem of balancing the pros and cons of projects often provokes social conflicts arising from differing concerns and conceptions of land use. The HG Team research developed a theoretical understanding of the socio-spatial dynamics of renewable energy developments in the Czech Republic and their regional divergences, and classified barriers that impede effective utilization of the realizable potential of under-used energy resources. Inter alia, a novel trans-disciplinary perspective on the energy–tourism nexus was presented and the first empirical evidence of potential impacts of on-shore wind farms on tourism in the European context was published (in a highly respected social science journal (IF=3.259), *Annals of Tourism Research*). Analytical results from our studies were synthesised into a proposal for adaptive governance strategies that enable the stakeholders and communities involved to mitigate social conflicts during the expected future expansion of renewable energy developments. Our publications on the social acceptance of wind energy gained a positive feedback within the international scientific community, and contributed to establishing productive cooperation with some of the leading experts in the field of renewable energy development (Dr. Van der Horst (UK), Prof. Pasqualetti (USA), Prof. Roth (Germany), etc.).

Relevant research projects:

- Renewable Energy and Landscape Quality - RELY (2014-2018, COST Action TU1401, Horizon 2020)
- Energy landscapes: innovation, development and internationalization of research - ENGELA (2011-2014, ESF CZ.1.07/2.3.00/20.0025)
- The use of wind energy: evaluation of spatial relations, environmental aspects and social context by the means of GIS (2008-2010, Czech Academy of Sciences, No. KJB700860801)

Key publications:

- Frantál, B. (2014). Have local government and public expectations of wind energy project benefits been met? Implications for repowering schemes. *Journal of Environmental Policy & Planning*. DOI:10.1080/1523908X.2014.936583. IF: 1.279 - WOS. Times Cited: 2.
- Frantál, B., Pasqualetti, M., Van der Horst, D. (2014). New trends and challenges for energy geographies. *Moravian Geographical Reports*, *22*(2), 2-6. IF: 0.341 – WOS. Times Cited: 1.

- Frantál, B., Urbánková, R. (2014). Energy tourism: An emerging field of study. *Current Issues in Tourism*, DOI:10.1080/13683500.2014.987734. IF: 0.958 – WOS. Times Cited: 0.
- Van der Horst, D. (2014). Landscapes of lost energy: Counterfactual geographical imaginary for a more sustainable society. *Moravian Geographical Reports*, *22*(2), 66-72. IF: 0.341 – WOS. Times Cited: 0.
- Frantál, B., Kunc, J. (2011). Wind turbines in tourism landscapes: Czech experience. *Annals of Tourism Research*, *38*(2): 499 - 519. IF: 3.259 - WOS. Times Cited: 16.
- Frantál, B., Kunc, J. (2010). Factors of the uneven regional development of wind energy projects (a case of the Czech Republic). *Geografický Časopis/Geographical Journal*, *62*(3), 183-201.

2.2 Restructuring and diversification of agriculture

In its traditional productive form, agriculture is no longer a governing element of the economic system in rural areas. There is an evident shift from the previous key paradigm of food production to post-productive approaches, which emphasize the necessity of rural economic diversification based on market-oriented, multifunctional, effective and environmentally-friendly farming and landscape stewardship. Our research has focused both on the macro- and meso-scales of these issues (assessment of structural and functional changes of post-socialist agriculture and regional divergences in the ongoing trends), and on the micro-scales of the issues (study of market adaptations, competitiveness and diversification trends of Czech farmers and their motivations to develop new business models, including for example renewable energy production or farm tourism). The Team results have provided original data about how the political narratives concerning the role of farmers, as competitive entrepreneurs willing to diversify their activities towards multifunctional agriculture, are in accord with the perspectives of post-socialist farmers themselves, and about the main divergences in the Czech agricultural sector in comparison to the rest of Europe.

Relevant research projects:

- Farming in mountain conditions, its spatio-temporal changes and importance for development of mountain areas (2009-2010, Czech Academy of Sciences, No. KJB300860902
- Working out an experimental model for complex monitoring of protected karst territories aiming at their sustainable management and development (2009-2012, Bulgarian National Science Fund, No. ДО 260.02/18.12.2008)

Key publications:

- Frantál, B., Martinát, S., Halfacree, K., Walker, G., Wolsink, M., Van der Horst, D., Maye, D., Dax, T., Hall, C. M., Clark, G., Kunc, J., Petr, O., Šauer, M., Tonev, P., Vystoupil, J. (2013). *New Rural Spaces: Towards Renewable Energies, Multifunctional Farming, and Sustainable Tourism*. Brno, Institute of Geonics.
- Klusáček, P., Krejčí, T., Martinát, S., Kunc, J., Osman, R., Frantál, B. (2013). Regeneration of agricultural brownfields in the Czech Republic: Case study of the South Moravian Region. *Acta Universitatis Agriculturae Et Silviculturae Mendelianae Brunensis, 61*(2), 547-561.
- Martinát, S., Dvořák, P., Frantál, B., Klusáček, P., Kunc, J., Kulla, M., Mintálová, T., Navrátil, J., Van der Horst, D. (2013). Spatial consequences of biogas production and agricultural changes in the Czech Republic after EU accession: mutual symbiosis, coexistence or parasitism? *Acta Universitatis Palackianae Olomucensis Facultas Rerum Naturalium, Geographica, 44*(2), 75-92.

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Apart from the basic research foci and results noted above, Team members have focused attention also on applied research, the practical utilization of results in the field of public administration, landscape planning and regional development, and for innovations in teaching within the geographic study subjects (active participation of students from co-operating universities in Team field research activities, project-based learning, new subjects informing the current trends of international geographical research, supervision of students theses, etc.). The pedagogical and popularization activities of Team members are summarized and described in detail in the part 3.10.

Research Report of the team in the period 2010–2014

Institute	Institute of Geonics of the CAS, v. v. i.

Scientific team	Department of geomechanics and mining research

The activity of the team includes all types of research, regarding to the research direction – from basic research (especially in the fields of distribution of stress and seismicity in the rock mass, laboratory tomographic research and development of measuring instruments) to the targeted and applied research for the solution of various geomechanical tasks which result in proposed measures, working methods and legislative outcomes.
Involvement in the project Institute of clean technologies for Mining and Utilisation of Raw Materials for Energy Use of extraction and use of energy resources project has brought a significant support for the instrumental equipment and allowed the development of a new research direction in the field of X-ray tomography.
The research activities of the team currently include a wide range of topics. The main topic areas include:

- Stress measurements in rock mass
- Technical, induced and natural seismicity research
- Solving problems in the field of mining geomechanics (stability and reinforcement of underground workings, dynamic manifestations of rock mass pressures, impact of mining on the surface)
- Laboratory tomographic research methods of structures and disintegration of geomaterials

The used methods therefore include field and laboratory research and they are characterized particularly by a large amount of demanding in situ measurements. The research in several different fields within one team allows close cooperation and working on the topics on the field boundaries as it is evident from the composition of authors in the list of publications.
International team cooperation with The University of Kumamoto and … in Japan includes a long involvement in developing the methods for stress measurements in the rock mass and X-ray tomography. There is an ongoing long-term cooperation with CRMFI Dhanbad (India) and University of Wollongong (Australia) on solving of mining geomechanics tasks supported by common projects. The team workers cooperate with scientists from Russia (institute) and Italy (institute) in the field of geophysical methods development. There is also a traditional long-term cooperation with neighboring countries (GIG Katowice, Technical University of Košice, GFC Potsdam).
The main results of the department achieved in the reporting period can be characterized as follows:

Completion of the development and verification of several variants of conical probe for complete stress tensor measurements and acquiring new knowledge on stress state of the rock mass and its changes due to anthropogenic activities.

The research team represents the only workplace systematically dealing with measuring the stress in the rock mass in the Czech Republic.
A unique method of measuring the stress tensor and its changes in the rock mass based on strain gauge measurements of deformation of the borehole bottom surface in the shape of a cone has been tested and developed. This shape allows obtaining enough information for subsequent numerical calculation of the complete stress tensor and its changes. The method has been successfully applied to measuring and monitoring the primary stress and changes in the stress field during changing geomechanical situation (e.g. progress in mining works, heat source). Several developmental modifications of the device have been invented (CCBM probes – Compact Conical Borehole Monitoring for stress changes and CCBO – Compact Conical Overcoring for measuring the initial stress) at the Institute of Geonics.
The device uses measurements of deformation development on determined oriented strain gauges of conical bottoms of boreholes, depending on the changes in ambient stress field (either on the principle of long-term monitoring of observed deformation dependence or relieving the drill core). The device allows to work in multiple observation modes, from single triggered measurements to continuous resp. semi-continuous autonomous measurements enabling bidirectional remote data transmission, e.g. Ethernet. The probe is alternatively equipped with heating units allowing faster completion of installation in areas with relatively low temperature.
The method configuration CCBO has been used by Japanese colleagues from the University of Kumamoto for the first time. It is currently used only by specialists in Japan with whom we cooperate in this field for a long time.
References (1)
The detailed research and understanding of the deformation behavior of the rock mass is limited not only to the knowledge of local geomechanical conditions but also to the knowledge of stress field distribution in a broader context, including the regional and global dependences of the stress state on the rock formation and related processes in rocks. The wide deployment of conical probes and other devices (hydrofac) enabled solving research problems in the fields of structural geology and tectonics.
For the verification of the hypothesis of tectonic development and consequently on the stress strain development in the Carpathian and Bohemian Massif, structural analysis was supplemented by stress data measured in the Carpathian and Carboniferous rock mass. The analyses demonstrate good correlation between the structural framework in Variscan and Brunovistulian structures. The knowledge of stress fields in Carboniferous rock mass is of main importance in underground mining in this region.
Similarly, a detailed structural and stress analysis in uranium deposits Rožná-Olší of the Strážek Moldanubicum area has been performed. It is important for the potential use of the area for underground storages and nuclear waste repository.
References (2,3)
Entirely new knowledge about stress-strain states of the rock mass in relation to anthropogenic interventions has been acquired which significantly contributes to the formulation of fundamental principles for the safe extraction and the development of preventive methods for the stability of mine workings with a high possibility of rockbursts. The destructive effects of rockbursts are the greatest danger in the mining work. In this context, the efficiency of security measures in areas of destress blasting in the system of rockburst prevention has been studied. The main objective of this work is to reduce the possibility of dangerous stress accumulation in susceptible areas or eventually to release already accumulated dangerous energy of the rock mass under controllable conditions. We are currently implementing an extensive experiment within

the international project Large Scale Monitoring (LASM) in granite environment at the Swiss underground laboratory GTS NAGRA involving all mentioned research fields using the stress monitoring and its changes.
References (4,5)

1.1 *New insight in induced, technical and natural seismicity research*

Research on induced seismicity was focused mainly on the seismic manifestation of the mining activities in the Upper Silesian Coal Basin. Also the issue of vibration effects from blasting has been studied. The research contributed to the compilation of precise measuring methods for short distances from the source. The analysis of the measured vibration amplitudes was performed by using the attenuation law of the waves and showed the possibility of using this empirical relationship for creating a “sufficiently homogeneous” environment even on short distances from the blasting source. This technique allows to predict the maximum amplitude of induced vibration and therefore the proper dimensioning of temporary and final tunnel walling, and also to determine the seismic load of the buildings on the surface.
References (6,7,8)
The aim of the research was the study of rotational vibration components of mining induced seismic events. An adjusted seismometer S-5-S was used as sensor station of rotation component of the seismic vibrations in the frequency range of 0.2-25Hz. The parameters of the new sensor are determined by measurement on a vibrating table. The research and the experimental field measurements of rotational vibration component took place in Karviná area in which the intense mining induced seismicity is detected. The measurements took place at an outcrop where Carboniferous rocks reach the surface (Orlová) and also in an area with the Carboniferous rocks being covered by about 300m of sedimentary rocks (Doubrava). Measured values for rotational movements around the vertical axis did not exceed 1mrad.s-1, whereas the seismic energy of these phenomena has been about 105J and the hypocentral distance about 2km.
References (9,10,11)
In cooperation with Dr. Telesca (Italy) and Prof. Lyubushin (Russia), research using advanced numerical methods for processing digital data series has been performed. A fractal analysis was used for hourly reading of changes in overburden of the mine Jeroným’s chamber, which is a national cultural heritage of the Czech Republic. The properties of the data set have been analysed with the help of various methods: power spectrum method, detrended fluctuation analysis, Higuchi analysis and analysis of the mean distance spanned within time. The values of scaling exponents obtained from these methods show that the temporal changes in back height do not have purely random character (ie. white noise) but instead show long-term correlation. A new method of seismic record resolution of earthquakes and blasting based on the properties of multifractal singularity spectra has been proposed. The efficiency of this method is supported by the analysis of seismic records from the Aswan Dam in Egypt.
References (12,13)
Another research area was focused on the evaluation of secondary properties of microseisms, seismic sources and the propagation of waves on the surface and inside of the Earth. Based on observation data measured at several global seismic stations, three key sources of microseisms have been identified: 1. The effect of changes in atmospheric pressure, 2. The effect of thermoelastic waves, 3. The effect of deformation waves induced by strong earthquakes. The individual sources differ in

their spectral oscillations inside of so called “knobs”. These sources have been described in articles for the first time.
References (14,15)

1.2 *The use of new in situ geoinformation technologies for describing and predicting of mining effects of mineral deposits*

Within the ICT and SPOMECH projects, new methods for the monitoring and evaluation of subsidence in undermined areas with complicated geomechanical conditions have been developed. Primarily, the research is aimed at determining the consequences of undermining. A pair of observational networks used for geodetic surveying of the changing surface due to recent deep mining has been built at selected areas of the Czech part of the Upper Silesian Coal Basin. The survey methods based on GNSS were primarily used to monitor the movement and deformation of the surface while mathematical statistics, geostatistics and interpolation functions were used to analyse spatial data.
The results of measurements and subsequent analyses of the surface deformation within the observational network were confronted and complemented with results obtained by other methods, e.g. precise levelling, aerial photogrammetry and radar interferometry, and also with results from in situ geomechanical research. The unique results of long-term monitoring and evaluation of changes show that the combination of measurement methods and evaluation methods of obtained spatial data greatly expands the possibilities of understanding the exploitation induced deformation processes in the rock mass and on the surface.
References (16,17, 28, 29)

1.3 *Safety aspects of the conduct of mining works at great depths*

This area represents targeted and applied research with results being used in the mining industry. The research was supported by the grant project “Security aspects of mining works management of mining works at depths of 800m and more”. The work focused on stability of the mining roadways and included obtaining information complemented with experimental measurements in laboratory and in situ. Based on analyses of this information, a mathematic model of the support has been created and used in later stages of the project. In another stage, the development of parameters of a coal mine during the last decades has been analysed and the analytical prediction of endpoint parameters of support reinforcement has been performed. The mathematical modelling using existing software has been mainly used for finding the solution. Experimental research in order to assess input parameters (material constants, etc.) for numerical models has been done.
Further, the models developed in the experimental section have been inversely analysed and verified. In other part of the research, experimental sections for the validation of new stabilization methods in underground works were proposed. The new projects have been prepared and the monitoring and subsequent evaluations of result have been done. The methods to ensure the stability of mining workings at great depths were developed by using the information from experiments and camera observations. These methods were implemented into binding corporate rules of mining organizations after approval by the Czech Mining Authority.
References (18, 19, 20, 21)

1.4 *Development of methods for the X-ray tomography research on geomaterials*

An important progress was made in processing the certified methods of 3D visualization of buildings and geomaterial structures using industrial X-ray computed tomography and principles for acquiring good quality of X-ray tomographic data. The method has been developed for the preparation of geomaterial test samples in the laboratory and for the visualization of their inner 3D structures by X-ray tomography. These methods have been proposed and tested for the detection and identification of individual component properties of geocomposites (grouted rocks) scanned in 3D and 2D images. On the basis of parameters, the ideal setting of X-ray source, detector and CT scanning modes were studied. The study was performed by means of uniformly scaled 2D tomographic projections and the introduction of standard materials in the process of progressively scanned tomographic slices. Finally, methods and procedures for the testing of representative elastic parameters of geomaterials for the evaluation of the results of mathematical modeling have been proposed.
The use of X-ray CT enabled the development of methods in micro (geo)-mechanics and their use for the study of geocomposites. Within the project, GA "Multiscale modelling and X-ray tomography in geotechnics" mathematical tools to assess the influence of microstructures on the macro-properties of composite geomaterials, especially geocomposites consisting of carbon polyurethane grouting, were developed. A digital model of the specimen was developed on the basis of the microstructure determined by X-ray tomography, local material properties and the implementation of test algorithms (homogenization) with different boundary conditions (uniform deformation, uniform tension, uniaxial and triaxial tests). Also the sensitivity to changes in the local material properties and to the fineness of scanning rasters was tested. Finally, inflexible behavior of geocomposites was tested.
Further use of X-ray CT has been focused on the determination of pyrite in roofing slates. The study deals with both traditional methods of mineralogical-petrographic analysis as well as completely new methods (X-ray CT) rendering fast and reliable determination of qualitative parameters and potential slate durability in building constructions. A mutual combination of the methods represents a rapid, effective and modern alternative to lengthy laboratory tests to determine physical-mechanical properties of newly used roofing, especially in historical buildings.

The method of the X-ray Computed Tomography was also used for monitoring changes in inner structure of concrete samples of different composition before and after their exposure to various thermal loads. Damages and character of changes in the inner structure caused by high temperatures were influenced by the character of cement and aggregate we used.

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Research Report of the team in the period 2010–2014

Institute	Institute of Geonics of the CAS, v. v. i.

Scientific team	Department of applied mathematics and computer science and IT4Innovations

The evaluated team Department of applied mathematics and computer science and IT4Innovations, or for short **Applied Math team,** is composed of researchers from two organizational units of the Institute of Geonics of the CAS (IGN). It is the Department of Applied Mathematics and Computer Science and a newly established Department IT4Innovations. The second unit was established in 2011 due to participating in a supercomputing project Centre of Excellence IT4Innovations, which started that time and required independent organizational anchoring.

In general, our research attempts to encourage interactions between mathematical and engineering communities and we would like to use benefit from fact that engineering experience motivates development or extension of many mathematical theories and, conversely, an advanced mathematical background can substantially improve engineering computations. Further, our research is inspired and/or oriented on geo-applications.
Therefore the Applied Math team as a whole had a broad scope of research interests which can be divided into three particular aims:

- mathematical modelling of problems arising in geoengineering and geosciences,
- analysis of models and development of suitable numerical methods,
- computer implementation of numerical modelling tools and performing the simulations.

Fulfilling these aims in the evaluated period 2010-2014 can be briefly illustrated as follows (the more detailed description will follow later).

- The team solved geotechnical problems mainly arising from the research related to underground deposition of high-level radioactive waste. In this respect, the team participated in two periods of the international Decovalex project and performed research contracted by RAWRA Czech Republic (the national agency responsible for nuclear waste deposition). The solved problems include modelling of crystalline rock damage, thermal analysis of different repository concepts, and an analysis of hydro-mechanical processes in bentonite based sealing.
- The team performed analysis and development of various types of iterative solution methods and preconditioners applicable to porous media flow problems in rigid or deformable porous matrix, analysis of Newton type solvers for nonlinear problems, investigation of higher order time discretization methods, analysis of numerical methods for solving plasticity problems and procedures for determination of limit load in perfect plasticity. It also examined application of inverse problems on material parameter identification and developed models of suspension bridge and geotube behaviour and performed their analysis.

- A long term interest of the team in developing the codes and use of parallel high performance computing was increased by entering the supercomputing project IT4Innovations and installing the ANSELM computer with more than 3200 computing cores in Ostrava. The own parallel solvers as well as solvers from Trilinos library were tested on the solution of large elasticity problems arising in micromechanics and discretized up to 200 MDOF's. The parallel performance was tested up to 512 cores of the ANSELM computer.

In the evaluated period, the team not only continued within the research in the fields already considered in the period before 2010, but drove its attention to several research fields which were not investigated by the team members earlier. In this respect, we can mention the flow in fully or variably saturated porous media, poromechanics, continuum damage mechanics, plasticity and procedures for limit load computation, micromechanics as analysis of global response of heterogeneous materials and role of its components, solution of inverse problems for determination of initial rock stress and identification of material parameters. These topics are covered by publications, conference lectures and papers, even some invited lectures on these topics were presented at international conferences e.g. Interpore 2013, Preconditioning of Iterative Methods (PIM 2013), Numerical Methods for Scientific Computations and Advanced Application 2014, Modelling 2014.

The research followed plan and general scientific progress, required applications and participation in funded research projects. The main funded research projects in the evaluated period were the following ones,

- already mentioned Decovalex, particularly its two periods Decovalex2011 and Decovalex2015, where we solve problems of damage of granitic rocks and developed hydro-mechanical model for bentonite based sealing, respectively,
- two projects of the National Grant Agency on continuum damage mechanics and on multilevel analysis of geomaterials (micromechanics),
- three projects supported from European operational funds - the supercomputing project Centre of Excellence IT4Innovations (CZ.1.05/1.1.00/02.0070), project Institute of Clean Technologies for Mining and Utilization of Raw Materials for Energy Use (CZ.1.05/ 2.1.00/03.0082), project on Reliable Nonlinear Mechanics (CZ.1.07/2.3.00/20.0070),
- participation in one project oriented to geomechanical stability and funded by Ministry of Industry and Trade CR.

Within the Decovalex project (acronym for DEvelopment of COupled models and their VALidation against Experiments) we had intensive international collaboration with teams from Sweden, Finland, France, Germany, UK, Japan, Korea, China, USA and Switzerland. This project is funded by national authorities responsible for the nuclear waste management, in CR namely by a state organisation RAWRA (Radioactive Waste Repository Authority). The collaboration in mathematical topics was supported by bilateral projects with Steklov Math. Institute RAS, St. Petersburg and Institute of Information and Communication Technologies BAS, Sofia. Less formal research collaboration was with Uppsala University (M. Neytcheva), RICAM and University Duisburg-Essen (J. Kraus), ELTE University Budapest (J. Karatson), KAU Jeddah SA (B. Ahmad), ETH Zurich (P. Arbenz, E. Turan).

The involvement of the team in teaching, organization of regular winter schools, organization of seminars and conferences, participation at professional societies, editorial boards etc. is described in a separate document.

Further we provide **annotation of selected main results,** their list is as follows

- Preconditioners for saddle point systems; numerical methods for porous media flow and poroelasticity
- Robust and efficient numerical methods for solving evolution problems
- Efficient nonlinear solvers in computational plasticity
- Development of tools for thermo-mechanical stress analysis and modelling of damage of quasi brittle rocks
- Inverse problems
- Stability analysis of suspension bridges in lateral wind
- Mathematical modelling of geosynthetic tubes
- Development of hydro-mechanical model for bentonite based sealing elements.
- Thermal analysis of reference design of repository for spent nuclear fuel
- Micromechanics, multiscale problems
- Parallel algorithms and software

Preconditioners for saddle point systems; numerical methods for porous media flow and poroelasticity

In the evaluation period, we investigated block oriented preconditioners for solving saddle point systems as e.g. indefinite systems arising from mixed FEM discretization of porous media flow problems and from space/time discretization of poroelasticity problems. The focus was given on construction of block preconditioners and several block diagonal and block triangular variants mainly using augumentation of the main block (Schur complement to a suitable regularization block) were introduced and their performance was analysed. These preconditioners can be considered as a first step requiring involving suitable inner solvers as a second step. As concerned this second step, we introduced and investigated two types of preconditioners for the inner augumented system (a) Schwarz type domain decomposition, (b) preconditioning using projection property in the case of discrete Laplacian type regularization.

Selected outputs: [1] O. Axelsson, R. Blaheta, Preconditioning of matrices partitioned in 2 x 2 block form: Eigenvalue estimates and Schwarz DD for mixed FEM. Numerical Linear Algebra with Applications. 17(2010), pp. 787-810. **[2]** O. Axelsson, J. Karátson, Condition number analysis for various forms of block matrix preconditioners. Electronic Transactions on Numerical Analysis. 36(2010), pp. 168-194. **[3]** Axelsson, O. Preconditioners for regularized saddle point matrices. Journal of Numerical Mathematics. 19(2011), pp. 91-112. **[4]** O.Axelsson, R. Blaheta, P. Byczanski, Stable discretization of poroelasticity problems and efficient preconditioners for arising saddle point type matrices. Computing and Visualization in Science. 15(2012), pp.. 191-207. **[5]** O. Axelsson, A general approach to analyse preconditioners two-by-two block matrices. Numerical Linear Algebra with Applications. 19(2012), pp. 1-20 **[6]** O. Axelsson, R. Blaheta, P. Byczanski, J. Karátson and B. Ahmad. Preconditioners for regularized saddle point operators with an application for heterogeneous

Darcy flow and transport problems. Journal of Computational and Applied Mathematics DOI:10.1016/j.cam.2014.11.044

Robust and efficient numerical methods for solving evolution problems

The result concerns the solution of evolution problems appearing in many applications. The heat conduction, flow and transport in porous media and poroelasticity are particular evolution problems we dealt with. For solving these problems one frequently uses the implicit Euler method, which is stable and leads to efficiently solvable systems. But in terms of approximation, the Euler method is only first order which may demand to use a large number of small time steps. It turns our attention to higher order discretization methods that allow the use of longer time steps, but there was a question how to solve more complex linear systems arising in each time step. We focused on iterative solution methods and our new result consists in constructing very efficient preconditioning. The linear system to solve in each time step can be expressed as a matrix polynomial, the preconditioner is constructed by approximation this polynomial by a factorizable one. Then for example, when solving the systems arising from discretization by a third order method using Radau integration, the cost for application of preconditioning is equal to the cost of the solution of two time steps of Euler method and the overall efficiency of the new technique is significant.

Selected outputs: [1] O. Axelsson, R. Blaheta , S. Sysala, B. Ahmad, On the solution of high order stable time integration methods. Boundary Value Problems, Springer Verlag, 2013: 108 doi:10.1186/1687-2770-2013-108 **[2]** O. Axelsson, R. Blaheta, P. Byczanski, Stable discretization of poroelasticity problems and efficient preconditioners for arising saddle point type matrices. Comput Visual Sci. DOI 10.1007/s00791-013-0209-0 **[3]** O. Axelsson, Preconditioners for algebraic systems arising in implicit Runge-Kutta time integration methods for parabolic and hyperbolic problems. Invited lecture at the conference Preconditioned Iterative Methods, Prague 2013 **[4]** O. Axelsson, R. Blaheta, R. Kohut: Preconditioned methods for high order strongly stable time integration methods with an application for a DAE problem, Submitted to Numerical Linear Algebra with Applications, special issue Preconditioned Iterative Methods.

Efficient nonlinear solvers in computational plasticity

Computational plasticity has been studied at the Institute of Geonics for longer time, see e.g. the book „R. Blaheta: Numerical methods in elasto-plasticity, PERES Publishers, Prague, 1999“. On the other hand, the research performed in 2010-2014 started a new period of research which has been oriented mainly to efficient nonlinear solvers. In particular, the Newton method and its variants have been used and analysed for time-discretized elastoplastic problems. Within the evaluated period, the research was gradually extended as follows.

First of all, it was necessary to use a nonsmooth variant of the Newton method with respect to expected properties of elastoplastic operators. Similarly as other researchers, we chose the **semismooth Newton method** which has a local quadratic convergence subject to a certain assumption. The assumption means that the elastoplastic operators are represented by strongly semismooth functions. This was shown for some models but not in general since the operators are mostly given in implicit forms. To prove the strong semi smoothness in associative plasticity, we suggested a new approach - represent the elastoplastic operator by the so-called generalized projection on a convex set of admissible generalized stresses. This approach based on a convex analysis was successfully used for a wide class of models

with internal hardening variables. At the end of the period, we have started to investigate the strong semi smoothness for non-associative plasticity.

Further, we used the fact that a time-discretized problem in associative plasticity can be equivalently formulated as a minimization problem with a convex and smooth functional. It is well-known that Newton directions are descent for the functional and the semismooth Newton method can be interpreted as a descent direction method if a suitably chosen damping is included into the Newton step. We proposed a simple line search method to find damping parameters. Then we proved that the **damped semismooth Newton method** is globally convergent and even the local quadratic convergence is preserved. We also derived dependence of the convergence on the discretization parameter of a finite element mesh. We have observed that the damping is important mainly in perfect plasticity. Note that within this period, we originally introduced the damped methods for another application – beam on a unilateral subsoil.

It is well-known that Newton-like methods can be used even for smooth optimization problems with constraints. This leads to solving problems of quadratic programming in each Newton step. Using this idea, we extended the damped and undamped semismooth Newton methods and their convergence analysis on: a) simple **contact problems of elastoplastic** bodies; b) **FETI-based domain decomposition** methods enabling a parallel implementation of the elastoplastic problems.

Besides the damping, we have used another modification of the semismooth Newton method – **regularized tangential stiffness matrices**. The regularization was done by a convex linear combination of the elastic and tangential stiffness matrices. Such an approach is useful if the tangential stiffness matrices are ill-posed. This happens, e.g., in perfect plastic or plastic-damage models.

Finally, we have focused on a computation of a **limit load parameter** in the deformation theory of perfect plasticity. The limit or safety parameter for a prescribed load is important in practice since a structure collapses if the limit value is exceeded. We suggested a new load incremental method enabling to control the loading process in a stable manner up to the limit load. The idea is based on finding a suitable control parameter and its relation with the load parameter. For each value of the control parameter, the stored energy functional is minimized subject to an equilibrium load constraint. This optimization problem is also solved with the semismooth Newton method described above.

Support: The research in this field has been supported by the following projects: GA CR grants reg. no. 105/09/1830 and 13-18652S, IT4Innovations Centre of Excellence project CZ.1.05./1.1.00/ 02.0070, bilateral cooperation between the Czech and Russian academies of sciences – Institute of Geonics and St. Petersburg Department of Steklov Institute of Mathematics, and the SPOMECH project reg. no. CZ.1.07/2.3.00/20.0070. Within this topic, we also cooperate with CTU Prague and VSB-TU Ostrava.

Selected outputs: [1] S. Sysala, Application of a modified semismooth Newton method to some elasto-plastic problems. Mathematics and Computers in Simulation. Vol. 82, no. 10 (2012), pp. 2004-2021. **[2]** S. Sysala: Properties and simplifications of constitutive time-discretized elastoplastic operators. Z. Angew. Math. Mech. 94, No. 3, 233-255 (2014). **[3]** M. Čermák, T. Kozubek, S. Sysala, J. Valdman: A TFETI Domain Decomposition Solver for Elastoplastic problems. Applied Mathematics and Computation 231 (2014) 634-653. **[4]** M. Cermak, S. Sysala: Total-FETI method for solving contact elasto-plastic problems, Lecture Notes in Computational Science and Engineering 98, 955-965, 2014. DOI 10.1007/978-3-319-05789-7_93 **[5]** S. Sysala, J. Haslinger, I. Hlaváček, M. Cermak: Discretization and numerical realization of contact problems for elastic-perfectly plastic bodies. PART I - discretization, limit analysis. Z. Angew. Math. Mech., Volume 95, Issue 4, pp. 333–353, 2015 **[6]** M. Cermak, J.

Haslinger, T. Kozubek, S. Sysala: Discretization and numerical realization of contact problems for elastic-perfectly plastic bodies. PART II – numerical realization, limit analysis. Z. Angew. Math. Mech., published online: 21 JAN 2015, DOI: 10.1002/zamm.201400069. **[7]** O. Axelsson, S. Sysala: Continuation Newton methods. Submitted to Computers and Mathematics with Applications, 2014.

Development of tools for thermo-mechanical stress analysis and modelling of damage of quasi brittle rocks

The result was oriented to analysis of thermo-mechanical (TM) processes appearing during the Äspö Pillar Stability Experiment (APSE). This analysis is based on finite elements with elasticity, plasticity and continuum damage mechanics models of rock behaviour and some least squares calibration techniques. The main aim was to examine capability of continuous mechanics models to predict brittle damage behaviour of granite rocks. The performed simulations used an in-house finite element software GEM and self-developed experimental continuum damage MATLAB code. The main contribution was building and application a hierarchical set of models to estimate the pillar damage zones, i.e. elastic model with Drucker–Prager strength criterion, elasto-plastic model with the same yield limit and a combination of elasto-plasticity with continuum damage mechanics. The damage mechanics model was also used to simulate uniaxial and triaxial compressive strength tests on the Äspö granite. The research was mainly supported by the Decovalex 2011 project and continues under GA CR project 13-18652S Numerical modelling of damage and transport processes in quasi-brittle materials.

Selected outputs: The results are described in the final report of the international Decovalex 2011 project and in journal paper R. Blaheta, P. Byczanski, M. Čermák, R. Hrtus, R. Kohut, A. Kolcun, J. Malík, S. Sysala: Analysis of Äspö Pillar Stability Experiment: Continuous thermo-mechanical model development and calibration, Journal of Rock Mechanics and Geotechnical Engineering, Vol. 5(2013), pp. 124-135

Inverse problems

The AMR team met first the identification problems within analysis of Äspö Pillar Stability Experiment (APSE) in the framework of Decovalex 2011 project. Inverse analysis was required there (1) for verification of measurement of an initial stress in the rock mass by back analysis of convergence measurement during construction of the access tunnel and (2) identification of heat transfer properties of the rock mass by inverse method based on the knowledge of heat sources and temperature measurements. The inverse analyse were implemented as linear and nonlinear least squares problems, respectively. Consequently, other applications for identification of local material properties were found. It motivates testing of different optimization methods for solving nonlinear least squares problems gradient Gauss-Newton type methods, Nelder-Mead simplex method, genetic methods with numerical parameter vector representation. These methods were compared in terms of computational costs in sequential and parallel computers. Further research concerns specification of classes of material parameter identification problems with fixed or parametrizable material interfaces and showing existence of optimal solution in these cases. The research continues with considering various objective functionals and corresponding optimization methods.

Selected outputs: [1] R. Blaheta et al. : Analysis of Äspö Pillar Stability Experiment: Continuous thermo-mechanical model development and calibration, Journal of Rock

Mechanics and Geotechnical Engineering, Vol. 5(2013), pp. 124-135, **[2]** R. Blaheta, R. Hrtus, R. Kohut, O. Axelsson, O. Jakl, Material Parameter Identification with Parallel Processing and Geo-applications. In Wyrzykowski, R.; Dongarra, J.; Karczewski, K. (ed.). Lecture Notes in Computer Science. Berlin, Heidelberg: Springer-Verlag, 2012, pp. 366-375, **[3]** R. Blaheta, R. Hrtus, R. Kohut, O. Jakl. Optimization Methods for Calibration of Heat Conduction Models. In Large Scale Scientific Computing, I. Lirkov, S. Margenov, and J. Wasniewski (Eds.), Lecture Notes in Computer Science. Berlin, Heidelberg: Springer-Verlag, 2012, pp. 541-548 **[4]** R. Hrtus, J. Haslinger, R. Blaheta, Identification problems with a priori given material interfaces. WOFEX 2013. Journal paper is in preparation.

Stability analysis of suspension bridges in lateral wind

The original Tacoma suspension bridge was opened on 1 July 1940 and was relatively stable till 7 November 1940, when torsion vibrations appeared on the central span at 10 a.m. These vibrations lasted about one hour and the amplitude was more than 5 meter. This led to the destruction, which is not fully explained even now. The goal of this research is to provide an explanation of the collapse and study stability of suspension bridges in lateral wind. A continuous model of central span was developed. This model describe vertical and torsion oscillation of the centre span, the main cable behaviour, the reaction of cable stays connected the main cables and centre span and the impact of diagonal ties put on the central cable bands. Equation of three basic dynamic problems corresponding with the way the central cable bands are fixed were formulated an analysed. The equation describe the following situations: First, the both central cable bands are loosened. Second, the both bands are fixed. Third, one band is loosen and the other is fixed. The third situation corresponds with the event when large oscillations appeared and the centre span collapsed. Three eigenvalue problems corresponding with the three dynamic problems were formulated and analysed for the parameters of the original Tacoma suspension bridge, which leads to a surprising result. The sudden asymmetry brought about by loosening of just one cable band results in a special shape of the first eigenvector which contains torsion oscillation. This does not happen for the other two problems whose first eigenvectors contain only vertical oscillation. In the end the asymmetry led to the collapse whose causes are as follows: First, just one cable band loosened. Second, the loosened cable band was on the windward edge of the deck. Third, the aerodynamic properties of the deck generated forces which led to huge oscillation. The equations describe all types of suspension bridges. They were analysed and the existence, uniqueness and continuous dependence on wind induced forces were proved. Moreover, the analysis shows that stability first of all depends on aerodynamic properties of the deck and the way the main cable bands are fixed. It is surprising that vertical and torsion stiffness of the deck does not have a big impact on the stability of suspension bridges in lateral wind. On the other hand weight of the deck influences stability positively. The analysis shows how to affect stability and increase economic efficiency of suspension bridge constructions.

Output: Josef Malík: Sudden lateral asymmetry and torsional oscillations in the original Tacoma suspension bridge, Journal of Sound and Vibration, 322, 2013, 3772-3799.

Mathematical modeling of geosynthetic tubes
Geosynthetic tubes are frequently used technology which finds its applications in many branches of the civil engineering. The tubes are used, for instance, as river bank reinforcements and flood fighting devices. They are usually filled with water or slurry. The material from which the tubes are made is a special synthetic fabric that is inextensible, perfectly flexible, and leak-proof. Equilibrium equations of the tube sitting on a rigid horizontal foundation is formulated and analysed as a two dimensional object which corresponds to the cross section of the tube. The equations describe the tube filled several separated layers of liquids with different densities. This problem is connected with the modelling of consolidation processes in the tube filled with slurry. After some time the consolidation of slurry takes place and heavier parts of the slurry sink to the bottom of the tube. The equilibrium equations describing the layered state are solved by Newton's method. The values like the pressure on the top and bottom of the tube, the tension in the synthetic fabric, the length of the contact zone between the tube and the rigid foundation can be obtained with respect to the given perimeter, the volumes, and densities of the liquids. The numerical implementations make it possible to compare two tubes. The first one is filled with several liquids with different densities and the second one is filled with one liquid with the average density. The calculations reveal the following results: First, the contact zone for the consolidate case is longer. Second, the height of the tube increases if the consolidation takes place. Third, the pressure on the top and bottom of the tube reduces for the consolidated state. Fourth, the consolidation results in the reduction of tension forces in the fabric. Especially the last result is of a great importance for the designer. This result guarantees that the fabric is not damaged after the consolidation takes place.

Output: J. Malík, S. Sysala, Analysis of geosynthetic tubes filled with several liquids with different densities. *Geotextiles and Geomembranes*. Vol. 29, n. 3 (2011), pp. 249-256.

Development of hydro-mechanical model for bentonite based sealing elements.
The construction of the deep geological repository for spent nuclear fuel uses sealing elements based on bentonite and it is important to be able to assess the effectiveness of sealing through simulation of hydro-mechanical (HM) processes in bentonite sand mixture sealing and the surrounding host rock. The result consists in construction and COMSOL implementation of an HM model based on Richards variably saturated flow model and nonlinear elasticity. Our contribution is in use of water retention function depending also on porosity and constructed under assumption that the change of porosity concerns only the bigger pores; incorporating swelling process reflecting possible mechanical deformation; introducing of special technique for modelling the closure of technological void between the sealing and host rock. The result was obtained within Task A of Decovalex project and the simulations are verified by modelling SEALEX experiments (Tournemire, France) and comparisons with results of other research teams in Decovalex.

Outputs: The results have been so far described mainly in progress reports and presentations at Decovalex workshop which is held twice per year. The project is planning to write the final report and journal papers in 2015. A comparison of the results concerning the modelling of laboratory experiments can be found in a paper A Millard, R. Blaheta et al, Modelling benchmark of a laboratory test on hydro-mechanical behavior of bentonite. In Unsaturated Soils: Research & Applications, eds. N . Khalili , A . R . Russell , and A . Khoshghalb, CRC Press 2014, pp 489–495. Another conference paper by IGN authors was submitted to EUROCK 2015.

Thermal analysis of reference design of repository for spent nuclear fuel

For reliable assessment of spent nuclear fuel repository, it is necessary to analyse thermo-hydro-mechanical processes including the thermal field generated by the containers with the spent nuclear fuel. The thermal analysis performed by the team concerned evaluation and comparison of different repository concepts with three types of storage – in one and two-levels of horizontal deposition tunnels and storage in inclined tunnels. The analysis was performed for various input parameters (thickness of bentonite layer around containers, thermal conductivity of bentonite, initial thermal power of containers, distance of storage tunnels) aiming to ensure the condition of temperature on the surface of the stored containers not exceeding 90°C. The analysis mainly concerns the time evolution of temperature at critical points (the points on the surface of the container with a maximum temperature) and sensitivity to parameter changes.

The overall analysis was carried out for model repository designs including 3456 containers with spent nuclear fuel. Consequently, it used a superposition of numerically computed thermal field around monitored borehole and contribution from surrounding boreholes expressed analytically (the containers were replaced by point sources). The accuracy of superposition method was tested and also found to be in a good agreement with another way of modelling, when a smaller area of interest is separated by suitable boundary conditions and modelled by FEM.

Output: Results were described in R. Blaheta, P. Byczanski, J. Malik, R. Kohut, A. Kolcun J. Starý, Thermal analysis of spent nuclear fuel repository reference designs. Technical report RAWRA, Prague 2012. The research was contracted by RAWRA.

Micromechanics, multiscale problems

Computational upscaling/homogenization technique was examined for assessment of the influence of microstructure on the macro-properties of composite geomaterials and determination of upscaled material properties. The upscaling is based on averaging and applied to general heterogeneous materials with non-periodic microstructure. Finite element software were developed which exploits voxel grids and information on microstructure geometry from X-ray tomography. In this respect, the research was done jointly with Geomechanics team, X-ray tomography lab group. The local material properties were taken from tests on individual constituents, but also inverse modelling for determination of local material properties were tested. The upscaling was computed with application of different boundary conditions, which allows to obtain estimates for homogenized (elasticity, heat conduction etc.) tensor representing the material behaviour. A particular application was analysis of grouted coal samples with investigation of sensitivity to changes in the local material properties and on the scanning resolution. The research was mainly supported by GA CR project "Multiscale modeling and X-ray tomography in geotechnics".

Selected outputs: Main outputs are two conference papers **[1]** R. Blaheta, R. Kohut, A. Kolcun, K. Souček, L. Staš: Micromechanics of geocomposites: CT images and FEM simulations. In: Rock Mechanics for Resources, Energy and Environment, M. Kwasniewski, D. Lydzba eds., Taylor & Francis Group, London 2013, pp. 399–404, **[2]** R . Blaheta , R . Kohut , J . Starý , and S . Sysala, Computational and reliability aspects of micro-geomechanics. In Computer Methods and Recent Advances in Geomechanics, Edited by Fusao Oka, Akira

Murakami, Ryosuke Uzuoka, and Sayuri Kimoto. CRC Press 2014. Pages 205–210, and a journal paper **[3]** R. Blaheta, R. Kohut, A. Kolcun, K. Souček, L. Staš, L. Vavro: Digital image based numerical micromechanics of geocomposites with application to chemical grouting. Int. J. Rock Mech. Min. Sci., Volume 77, 2015, pp. 77–88.

Parallel algorithms and software

Solvers exploiting our own research results in Schwarz type domain decomposition methods with coarse grid created algebraically by aggregation, with inexact solution of subproblems, were implemented in an in-house software GEM. These solvers were tested on the solution of large symmetric positive definite systems arising from micromechanics (FEM on voxel grid for elasticity problems) with dimension up to 200 million. These parallel solvers were compared with corresponding solvers from Trilinos library with a better performance of GEM solvers tuned for the particular applications. Estimates of homogenized tensors (elasticity, heat flow etc.) required to solve also large scale singular systems, which was done by suggestion and implementation of a stabilized conjugate gradient method.

Selected outputs: [1] R. Blaheta, O. Jakl, R. Kohut, J. Starý, GEM - A Platform for Advanced Mathematical Geosimulations. In Wyrzykowski, R.; Dongarra, J.; Karczewski, K.; Wasniewski, J. (ed.). Parallel Processing and Applied Mathematics. Vol. Part 1.. Berlin, Heidelberg, New York : Springer - Verlag, 2010, s. 266-275; **[2]** R. Blaheta, O. Jakl, J. Stary, E. Turan: Parallel Solvers for Numerical Upscaling. Proceedings of the Workshop of the State-Of-The-Art in Scientific and Parallel Computing (PARA 2012, Helsinki, 10.-13.6.2012), LNCS, Springer, 2013 **[3]** R. Blaheta, O. Jakl, J. Stary: Iterative solution of singular systems with applications. Parallel Processing and Applied Mathematics (R. Wyrzykowski et al eds), Springer-Verlag 2014, Lecture Notes in Computer Science. 8384. Part 1, pp. 114-123