THE CZECH ACADEMY OF SCIENCES

INSTITUTE OF GEOPHYSICS

REPORT 2012—2015

INDEX

A.1.1 INSTITUTE OF GEOPHYSICS OF THE CZECH ACADEMY OF SCIENCES

The Institute of Geophysics of the Czech Academy of Sciences is a public research institution. The Institute conducts fundamental research in physics of the solid Earth and its immediate space environment, with the mission to increase the level of general scientific knowledge as well as to contribute to practical application of the results of scientific research.

Our research includes studies of the lithosphere and sub-lithosphere structure, geodynamics of the seismoactive regions, climatic changes, solar-terrestrial relationships, environmental geomagnetism and many others. Theoretical modelling and numerical simulations of geophysical fields are an integral parts of the research programme of the Institute. The activities of the Geophysical Institute comprise regular observatory monitoring of Earth's physical fields as well as a broad collaboration with world-wide network services and data centres. The European cooperation was strengthened by establishment of large research infrastructure EPOS (European Plate Observing System). The Institute of Geophysics is a coordinator of the national consortium CzechGeo/EPOS. A significant part of the Institute's activity is focused on higher education: many researchers lead and co-lead university courses and supervise research students, especially at the doctoral level, at universities both in the Czech Republic and abroad. The Institute organizes scientific meetings and seminars on both national and international levels and publishes a scientific journal Studia Geophysica et Geodaetica.

The Institute as well as its individual researchers are regularly involved in various public outreach activities. In addition to the participation on Science and Technology Weeks coordinated by the Academy of Sciences, the Institute organizes annual Earth Day celebration and other public lectures, meetings, exhibitions aimed at elevating the public awareness about the Earth Sciences. Our researchers make tens of media appearances annually, typically on occasions such as large earthquakes or volcano eruptions. The Institute employs approximately 70 researchers organized in four research departments: seismology, geothermics, geomagnetism, and tectonics and geodynamics. The research activities are supported by five technicians at the research departments and about 30 staff members of the operating division (IT centre, library, administrative and technical services). In 2012-14, fifteen of the research staff members were PhD students.

A direct successor to the State Institute of Geophysics founded in 1920, the Institute of Geophysics was incorporated into the Czechoslovak Academy of Sciences in 1953. Currently it is one of 53 public research institutes of the Academy of Sciences of the Czech Republic. (Detailed information about the structure of the ASCR and other institutes can be found at: www.avcr.cz).

In 2015, the Institute of Geophysics is the main scientific partner of the Czech National Committee of Geodesy and Geophysics in the organization of the 26th General Assembly of the International Union of Geodesy and Geophysics (IUGG). We look forward to welcoming our colleagues from the Earth Science community worldwide and believe that together we will make this event a great success. .

A.1.2 INSTITUTE OF GEOPHYSICS OF THE CZECH ACADEMY OF SCIENCES

INSTITUTE
OF GEOPHYSICS
ASCR

Dynamic Earth: Since 2013, the Institute of Geophysics has a new visual identity, including a new logo (above). The colour version of the logo, inspired by the layered Earth in constant motion, shows dynamic motion and integrity at the same time. The logo was created by the graphic design studio Carton Clan.

The sculpture at the top of the Institute's building dates back to late 1950s. Its author, unfortunately, remains unknown. Although commissioned for a public institution during the Communist era, it is remarkable as a piece of abstract art, free of political content that was so typical of art in public space at that time.

A.2 MANAGEMENT OF THE INSTITUTE

MANAGEMENT OF THE INSTITUTE, 2015

Director: RNDr. Pavel Hejda, CSc.
Deputy director: RNDr. Bohuslav Růžek, CSc.
Head of the Economy Department: RNDr. Marta Tučková
Scientific secretary: RNDr. Josef Pek, CSc.

BOARD OF THE INSTITUTE

Chair: RNDr. Jan Šafanda, CSc. (until April 2013 - became vice-president of the Czech Academy of Sciences)
RNDr. Eduard Petrovský, CSc. (from May 2013)

Internal members: RNDr. Pavel Hejda, CSc.
Ing. Josef Horálek, CSc.
RNDr. Eduard Petrovský, CSc. (Vice-chair until April 2013)
RNDr. Jaroslava Plomerová, DrSc.
RNDr. Jan Šafanda, CSc.
RNDr. Aleš Špičák, CSc.
RNDr. David Uličný, CSc.

External members: Doc. RNDr. Hana Čížková, CSc.
(Vice-chair from May 2013; Faculty of Mathematics and Physics, Charles University)
RNDr. Jan Laštovička, DrSc. (Institute of Atmospheric Physics, Academy of Sciences)
Prof. RNDr. Jiří Zahradník, DrSc. (Faculty of Mathematics and Physics, Charles University)
RNDr. Jiří Málek, CSc. (Institute of Rock Structure and Mechanics, Academy of Sciences)
Secretary: RNDr. Josef Pek, CSc. (Institute of Geophysics)

SUPERVISORY BOARD:

Chair: prof. RNDr. Jan Palouš, DrSc. (Astronomical Institute, Academy of Sciences)
Vice-chair: Ing. Marcela Švamberková (Institute of Geophysics)
Members: Ing. Dalia Burešová, CSc. (Institute of Atmospheric Physics, Academy of Sciences)
Prof. Ing. Pavel Novák, PhD. (Faculty of Applied Sciences, University of West Bohemia, Plzeň)
Ing. Jan Vondrák, DrSc. (Astronomical Institute, Academy of Sciences)
Secretary: PhDr. Hana Krejzlíková (Institute of Geophysics)

A.3.1 RESEARCH STAFF, 2015

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Boušková Alena	Mgr.	381	ab
Brož Milan	Ing. CSc.	381	milan
Brož Petr	Mgr.	313	petr.broz
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Červ Václav	RNDr. CSc.	354	vcv
Dědeček Petr	Mgr.	054	pd
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Horálek Josef	Ing. CSc.	076	jhr
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Klicpera Jakub	Ing.	019	jk
Kolář Petr	RNDr. CSc.	012	kolar
Kovačíková Světlana	Ing. Ph.D.	319	svk
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A.3.2 RESEARCH STAFF, 2015

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Kyselica Juraj	PhD.	331	kyselica
Lávička Vojtěch	Mgr.	365	lavicka
Laurin Jiří	Ph.D.	071	laurin
Machek Matěj	Ph.D.	017	mates
Mrlina Jan	RNDr. Ph.D.	314	jan
Munzarová Helena	Mgr.	021	helena
Nejedlá Jaroslava	Ing.	335	jn
Novotný Miroslav	RNDr. CSc.	386	mn
Pek Josef	RNDr. CSc.	320	jpk
Petrovský Eduard	RNDr. CSc.	333	edp
Plomerová Jaroslava	RNDr. DrSc.	391	jpl
Polák Václav	Ing.		v.polak
Pšenčík Ivan	RNDr. CSc.	383	ip
Pýcha Josef	RNDr. CSc.	340	jpy
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Staněk Martin	Mgr.	313	stanekm
Střeštík Jaroslav	RNDr. CSc.	321	jstr
Šafanda Jan	RNDr. CSc.	384, 350	jsa
Šimkanin Jan	RNDr. Ph.D.	351	jano
Šílený Jan	RNDr. CSc.	016	jsi
Šmejkal Emanuel	Ing.	388	es
Špičák Aleš	RNDr. CSc.	345	als
Špičáková Lenka	RNDr. Ph.D.	343	spicka
Telecký Josef	Ing.	316	jot
Uličný David	RNDr. CSc.	326	ulicny
Vaněk Jiří	RNDr. DrSc.	346	
Vavryčuk Václav	RNDr. DrSc.	020	vv
Vecsey Luděk	RNDr. Ph.D.	021	vecsey
Vlk Michal	Ing.		vlk
Závada Prokop	Ph.D.	313	zavada
Zedník Jan	RNDr.	015	jzd

RESEARCH DEPARTMENTS

DEPARTMENT OF GEOMAGNETISM

Head: **RNDr. Eduard Petrovský, CSc.**

— observations of the Earth's magnetic field
— field measurements of secular variations of geomagnetic field
— geodynamo modelling
— space weather studies
— research in effects of solar and geomagnetic activities on climatic changes
— research in rock and environmental magnetism
— investigations of the crustal and upper mantle electrical conductivity
— theoretical and methodological research of electromagnetic fields and their numerical modelling
— study of external geoelectromagnetic fields investigations of solar-terrestrial relationships

DEPARTMENT OF GEOTHERMICS

Head: **RNDr. Jan Šafanda, CSc.**

— experimental and theoretical investigations of the temperature field of the Earth's crust and upper mantle
— temperature logging in boreholes experimental studies of the thermo-physical properties of crustal rocks, thermal conductivity and diffusivity and radiogenic heat production
— instruments for geothermal research, portable thermometers for borehole logging and systems for a long-term temperature monitoring
— reconstruction of climatic changes from temperature-depth profiles in deep boreholes study of the air, ground and bedrock temperature coupling and of the thermal regime within the soil and the underlying bedrock.

DEPARTMENT OF SEISMOLOGY

Head: **RNDr. Jan Šílený, CSc.**

— operating a regional network of broadband seismological stations, compilation of earthquake catalogs and bulletins, data exchange with European and world data centers
— collecting macroseismic data related to seismicity on the territory of Czech Republic
— monitoring and interpreting the seismicity and gas emanation in the geodynamically active region of West Bohemia
— study of deep geological structures down to the mantle litosphere by active and passive seismological experiments
— theoretical research on seismic waves generation and propagation in complex structures
— theoretical modeling of fracturing the rock massif – investigation of foci of earthquakes and events induced by industrial activities

DEPARTMENT OF TECTONICS AND GEODYNAMICS

Head: **RNDr. Aleš Špičák, CSc.**

— study of processes at convergent plate margins, focused on tectonic interpretation of earthquake distribution and mechanisms
— study of orogenic processes and rheology of Earth's crust and mantle in ancient orogens study of volcanic processes on Earth and other planets, experimental and field study of magma ascent and diapirism
— research on evolution of sedimentary basin fills as sensitive records of the interaction between tectonic processes, sea-level fluctuations and climate changes
— study of recent crustal movements in tectonically active regions using gravity and geodetic methods
— monitoring and analysis of Earth tides, slope stability monitoring based on tilmeter and groundwater observations
— studies of oriented microporosity of rocks and its relation to elastic properties and permeability, e.g. for planning of radioactive waste repositories
— microgravity measurements in engineering geology and archaeology

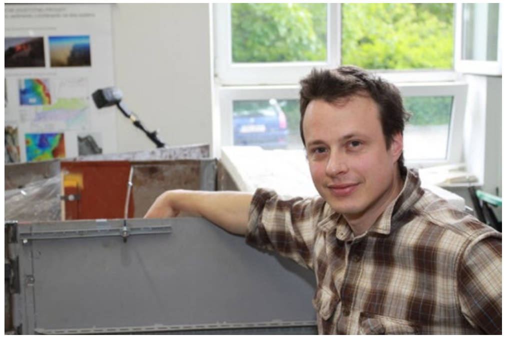
PROFESSIONAL AWARDS TO OUR RESEARCHERS

L'ORÉAL FOR WOMEN IN SCIENCE, CZECH AWARD 2012: ZUZANA KRATINOVÁ (ROXEROVÁ SINCE 2013)

In partnership with UNESCO, the L'Oréal-UNESCO For Women in Science program provides support for women researchers on all continents and at different points in their careers. Zuzana's professional background includes classsical field-based structural geology as well as a broad range of analytical methods, petrology, and physical modelling of geological processes. One of her primary research interests is the study of processes of magma flow and its record in finite rock and AMS (anisotropy of magnetic susceptibility) fabric. She has worked in the Department of Tectonics and Geodynamics of the IG since 2007, when, together with Prokop Závada, she started building an analogue-modelling laboratory at the Institute of Geophysics.

OTTO WICHTERLE AWARD, 2014: PROKOP ZÁVADA

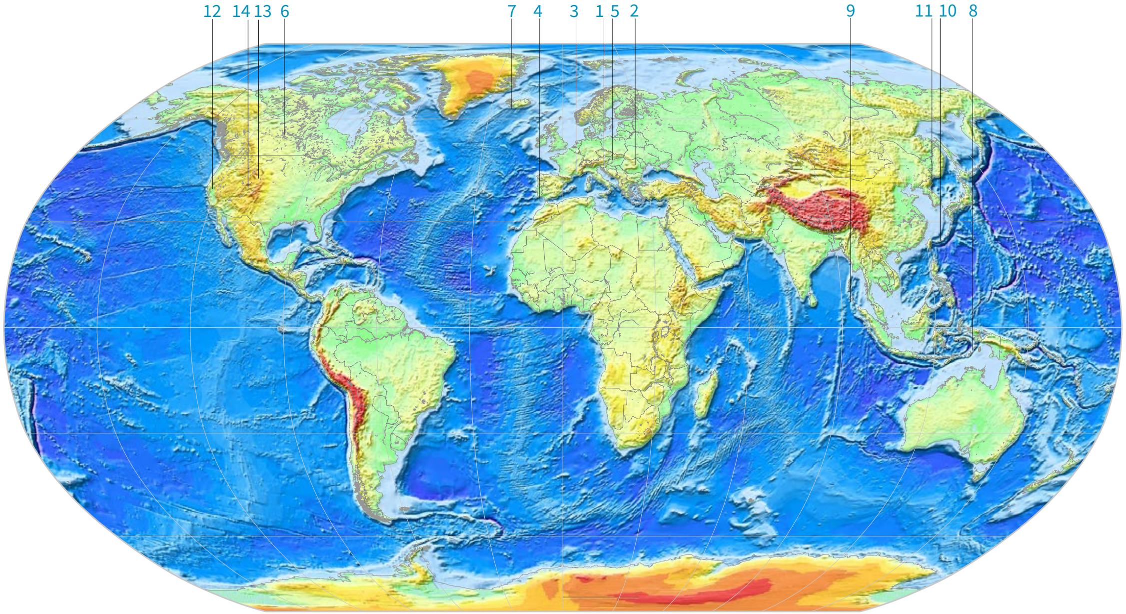
The award is given annually by the Czech Academy of Sciences to young researchers (under 35 years of age) who have shown an outstanding contribution in their branches of science. In 2014, the award went to 26 recipients, two of them from Earth Science institutes. Prokop Závada, a researcher at the Department of Tectonics and Geodynamics since 2007, has devoted his research to the study of microstructures and deformation of rock materials, including salt diapirs and volcanics. Since his graduate work at Charles University he has applied analogue-modelling approaches gain insight into tectonic and volcanic processes. For a number of years he has led research of a group of Czech and U.S.scientists devoted to the origin of the iconic Devils Tower in Wyoming, which gained international publicity in early 2015. His current interests include the study of melt migration and coupled rock deformation in orogenic lower crust.



AWARD OF THE PRESIDENT OF THE CZECH ACADEMY OF SCIENCES FOR PROMOTION AND DISSEMINATION OF SCIENTIFIC KNOWLEDGE: ALEŠ ŠPIČÁK

Each year, the President of the Czech Academy of Sciences, based on recommendations from the Academy's institutes, recognizes the contribution of up to three prominent researchers to popularizing and promoting science among the general public. Aleš Špičák, a former director of the Institute (1998-2007) and currently the Head of the Department of Tectonics and Geodynamics, has worked at the Institute since 1980. He founded the Department of Tectonics and Geodynamics in 2004, and over the years has launched many professional and outreach initiatives: membership of the Czech Republic in the ICDP (International Continental Drilling Programme), seismic experiments CELEBRATION 2000 and SUDETES 2003, building of the Geopark Spořilov, public outreach series Earth Days with the Academy of Sciences, more recently a seminar series „Spořilov Expeditions", among others. His long-term commitment to bringing the results of scientific work closer to the public was recognized in 2014 by the Academy's president Jiří Drahoš.

MAIN RESEARCH TOPICS



The global focus of research undertaken at the Institute of Geophysics is illustrated by the map above.

World map constructed using the GMT software: Wessel, P. and Smith, W.H.F. (1998): New, improved version of the Generic Mapping Tools released. EOS Trans., AGU, 79, 579.

1 Depth-temperature profiles in boreholes, Slovenia
2 Magnetic properties of soils, Bulgaria (Belogradchik)
3 Magnetic properties of soils, France (Boree)
4 Microstructural study of the Loulé Diapir, Portugal
5 Effects of postglacial warming in borehole temperature logs, Alberta, Canada
6 Anisotropy analysis of magnetotelluric data, W Slovakia
7 REYKJANET seismic network, study of swarm seismicity in SW Iceland
8 Seismicity and magmatism of the Banda Arc region, SE Asia
9 Seismicity and magmatism of Andaman-Nicobar region
10 Seismicity and magmatism of southern Ryukyu Arc
11 Study of seismic data related to the 2013 nuclear explosion, North Korea
12 Study of pre- and post-collisional plutons penetrating the Klamath Mts. accretionary complex, California / Oregon, USA
13 Structural and geophysical study of volcanics emplacement in the Devils Tower National Monument, Wyoming, USA
14 Sea-level and carbon-isotope records across the Cenomanian-Turonian boundary (Cretaceous), SW Utah

The core of the yearbook is devoted to short communications summarizing the principal results achieved in various lines of research at the Institute between the years 2012 and 2015.

The topics studied and methods applied cover a very broad range, our researchers are commonly involved in multi-disciplinary teams and collaborate with colleagues from many institutions worldwide. Therefore the organization of the text does not follow the administrative structure of the Institute's departments. The topics are arranged in several more or less loosely tied groups, following a direction from regional – scale studies of lithosphere structure in Europe, through studies of volcanic and magmatic processes in various localities on Earth and Mars, climate change records in deep and recent geological past as well as current relationships between short-term climate change proxies and solar/geomagnetic processes. This section is followed by several modelling studies devoted to the Earth's magnetic field and space weather, modelling approaches to seismic ray-theory, and development of geophysical methods, leading finally to applications of geophysical approaches in various fields including nuclear explosion detection, energy industry, or environmental hazards.

DEEP LITHOSPHERE STRUCTURE IN CENTRAL EUROPE

Several passive seismic experiments executed during the past two decades provided high-quality teleseismic data from dense temporary arrays of stations for studying velocity structure of the upper mantle beneath the Bohemian Massif and its surroundings. The deep structure is typically characterized by P-velocity perturbations in isotropic tomography images. However, due to the systematic, large-scale, preferred orientation of olivine, a major constituent of the mantle lithosphere, seismic anisotropy of the upper mantle can be investigated and inferences drawn on mantle lithosphere tectonics.

High-resolution tomography (Karousová et al., 2012; 2013) images the Bohemian Massif as a part of a large-scale, low-velocity region in the upper mantle beneath central Europe, with a central high-velocity heterogeneity beneath the Moldanubian unit (Fig. 1). This heterogeneity reflects thickening of the lithosphere southward, towards the Alps (Plomerová and Babuška, 2010). The SW–NE elongation of the eastern part of the heterogeneity parallels the mantle contact of the Brunovistulian and Moldanubian lithosphere domains (Babuška and Plomerová, 2013). We interpret this high-velocity heterogeneity as a lithosphere thickening due to an under-thrusting of the Brunovistulian beneath the Moldanubian as a consequence of the Brunovistulian microplate collision with the eastern rim of the Bohemian Massif during the Variscan orogeny. Besides the Variscan central Europe, we have investigated the mantle structure beneath the Northern Apennines (Munzarová et al., 2013) and also in the Precambrian of northern Europe. Seismic tomography and anisotropy of body-wave velocities permitted recognition of domains characterized by consistent fabrics in the mantle lithosphere that differ from structure of the sub-lithospheric mantle.

Three-dimensional fabrics of the mantle lithosphere retrieved from the large-scale seismic anisotropy were modelled by a joint inversion of travel-time deviations, expressed in P-residual spheres showing directionally dependent terms of relative residuals and shear-wave splitting parameters (Plomerová et al., 2012). Five major domains (micro-plates) with their own anisotropy and symmetry axes oriented generally in 3D (i.e. inclined from horizontal) have been recognized. Boundaries of the domains are delimited by changes of seismic anisotropy in the mantle lithosphere (Fig. 2). The mantle domains approximately correspond to major crustal units, although in detail the crustal and mantle boundaries are often shifted with respect to each other. Each of the domains bears a consistent fossil olivine fabric formed before their Variscan assembly. The collisional mantle boundaries, blurred by tectonometamorphic processes in easily deformed overlying crust, served as major channels for rocks exhumed from the mantle (Babuška and Plomerová, 2013).

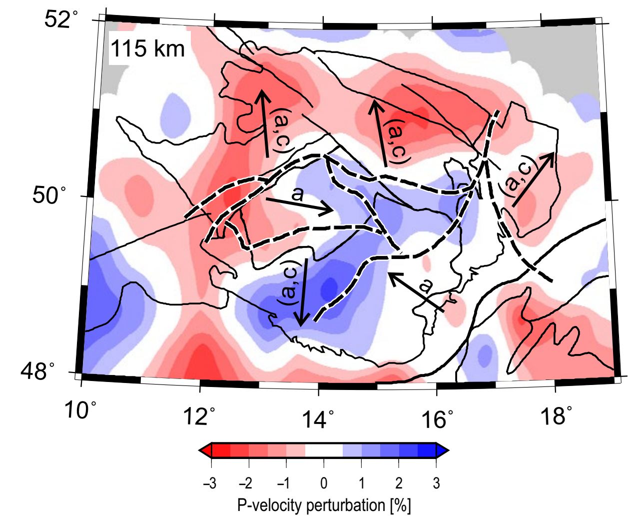


Fig. 1: Isotropic P-velocity perturbations at depth of 115 km in the high-resolution tomography of the upper mantle based on teleseimic data recorded during the BOHEMA III experiment along with boundaries (dashed) of mantle lithosphere domains characterized by anisotropy with inclined symmetry axes (Plomerová et al., 2012; Babuška and Plomerová, 2013). Directions of fast axes (lineation) a or dip directions of foliations (a,c) of individual anisotropic models (see Fig. 2) are indicated by arrows in each domain.

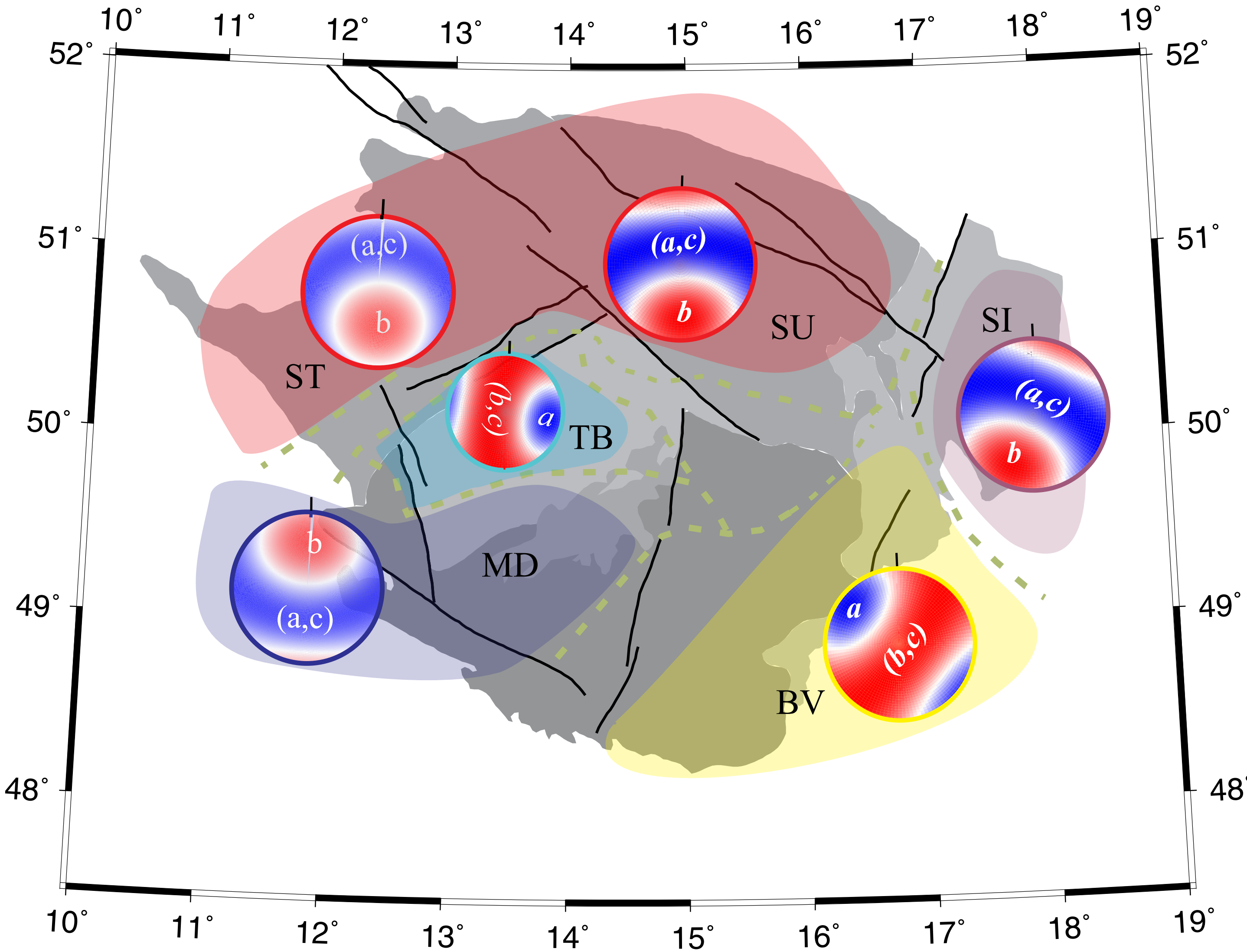


Fig. 2: Self-consistent, three-dimensional anisotropic models of the Bohemian Massif mantle lithosphere with inclined symmetry axes retrieved by joint inversion of body-wave anisotropic parameters. The models characterize mantle domains that correspond to crustal tectonic units: Saxothuringian (ST), Sudetes (SU), Teplá-Barrandian (TB), Moldanubian (MD), Brunovistulian (BV) and Silesian (SI). Minimum extent of each domain modelled by a similar fabric is coloured. Green dashed curves delimit the domain boundaries according to the P-sphere patterns (Babuška and Plomerová, 2013). Smaller lateral extent of the models results from a lower density of distribution of the broad-band stations relative to the short-period stations, as well as from ~40 km wavelength of shear waves.

B.1.3 DEEP LITHOSPHERE STRUCTURE IN CENTRAL EUROPE

Analysis of shear-wave splitting (SKS phases) recorded during the PASSEQ passive experiment (Vecsey et al., 2014) focused on the upper mantle structure across the Trans-European Suture Zone (TESZ). A distinct regionalization of the mantle lithosphere is observed in the Bohemian Massif, characterized by domains with consistent orientation of seismic anisotropy and relatively sharp boundaries. On the contrary, the anisotropic signal north of the Bohemian Massif, across the TESZ and further towards the East European Craton, seems to be weaker and its changes are less evident. A significant change of the mantle lithosphere structure appears at the northern edge of the Bohemian Massif (Fig. 3). Based on geographical variations of shear-wave splitting, a south-westward continuation of the Precambrian mantle lithosphere beneath the TESZ and probably even further southwest, is suggested.

I.G. research staff involved:

J. Plomerová, V. Babuška, L. Vecsey, H. Munzarová, H. Karousová

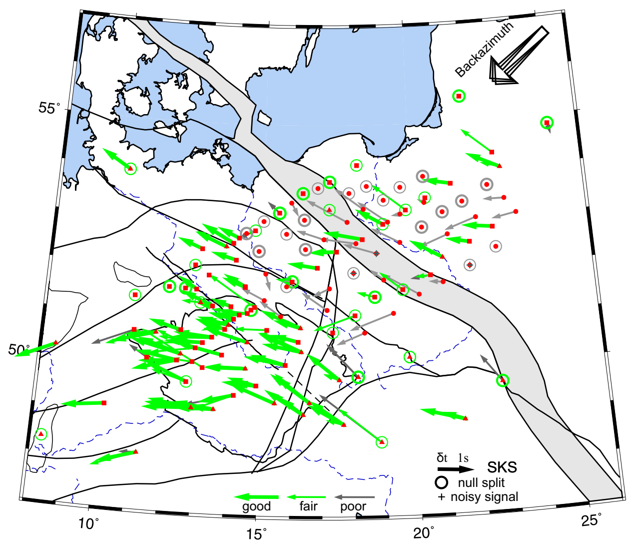


Fig. 3: Azimuths φ of the fast polarizations and the split-delay times δt of SKS waves recorded during the PASSEQ experiment, which were evaluated for three events from the NE back azimuths (Vecsey et al., 2014). Anisotropic signals dominate in the BM, while null splits or small provinces with coherent polarizations prevail in the west and north of the massif. Complementary measurements at stations equipped with 2–3 s seismometers are shown in light-grey colour.

References:

Babuška V. and Plomerová J., 2013. Boundaries of mantle–lithosphere domains in the Bohemian Massif as extinct exhumation channels for high pressure rocks, Gondwana Res., 23, 973–987, doi:10.1016/j.gr.2012.07.005.

Karousová, H., Plomerová J. and Vecsey L., 2012. Seismic tomography of the upper mantle velocity structure beneath the north-eastern Bohemian Massif (central Europe). Tectonophysics 564-565, 1-11, doi: 10.1016/j.tecto.2012.06.031.

Karousová H., Plomerová J. and Babuška V., 2013. Upper-mantle structure beneath the southern Bohemian Massif and its surroundings imaged by high-resolution tomography, Geophys. J. Inter., 194, 1203–1215, doi:10.1093/gji/ggt159.

Munzarová, H., Plomerová, J., Babuška, V. and Vecsey, L., 2013. Upper-mantle fabrics beneath the Northern Apennines revealed by seismic anisotropy. Geochem. Geophys. Geosyst. (G3), 14, 1156-1181, doi:10.1002/ggge.20092.

Plomerová J., Vecsey L. and Babuška V., 2012. Mapping seismic anisotropy of the lithospheric mantle beneath the northern and eastern Bohemian Massif (central Europe), Tectonophysics 564–565, 38–53, doi:10.1016/j.tecto.2011.08.011.

Vecsey L., Plomerová J., Babuška V. and PASSEQ Working Group, 2014. Mantle lithosphere transition from the East European Craton to the Variscan Bohemian Massif imaged by shear-wave splitting, Solid Earth 5, 779-792, doi:10.5194/se-5-779-2014.

B.2.1 MAGNETOTELLURIC INVERSION FOR 2D CONDUCTIVITY DISTRIBUTION WITH ARBITRARY ANISOTROPY

Electrical macro-anisotropy in the Earth's crust is an indicator of a large-scale, quasi-uniform, arrangement of conductive fractions within the geological structures and represents thus a strong link between the distribution of crustal conductivity and tectonics. Although forward simulations of electromagnetic fields in structures with arbitrary anisotropy have been in routine use for some time both in two-dimensional (2D) and three-dimensional (3D) settings, magnetotelluric inverse procedures for anisotropic conductivities are available for 1D layered structures structures only, or for 2D structures with principal anisotropy axes strictly aligned with the axis of homogeneity of the model.

Pek et al. (2012) have recently developed a non-linear conjugate gradient (NLCG) version of the magnetotelluric inverse algorithm for a 2D conductivity distribution with arbitrary electrical anisotropy. The algorithm is based on Occam inverse strategy. As a direct solver in the algorithm, we employ our earlier 2D finite volume forward modeling code for structures with arbitrary anisotropy, which is also further used to effectively evaluate parametric sensitivities by employing the reciprocity principle. Standard Polak-Ribiere NLCG algorithm is then applied to minimize the inversion target function which consists of a data misfit term and of regularization penalties imposed both on the structure complexity and on the anisotropy throughout the model. The algorithm operates either on physical anisotropy parameters based on the conductivity tensor diagonalization and Euler angles decomposition, or on a stable and regular parametrization via a logaritmic conductivity tensor. The inverse procedure shows good performance in both synthetic tests and in tests with practical data. Contrary to simple 1D inversions, the 2D approach often reduces the spurious electrical anisotropy considerably because it properly accounts for the effects of lateral inhomogeneities.

Even in case of isotropic 2D modeling, the inversion with anisotropy included may provide valuable information. In particular, it verifies that secondary impedances for the suggested model are not completely discrepant from those experimentally observed. Moreover, large-scale weakly anisotropic domains may indicate and, to some degree, accomodate deviations of the true regional strike from that adopted for the 2D model.

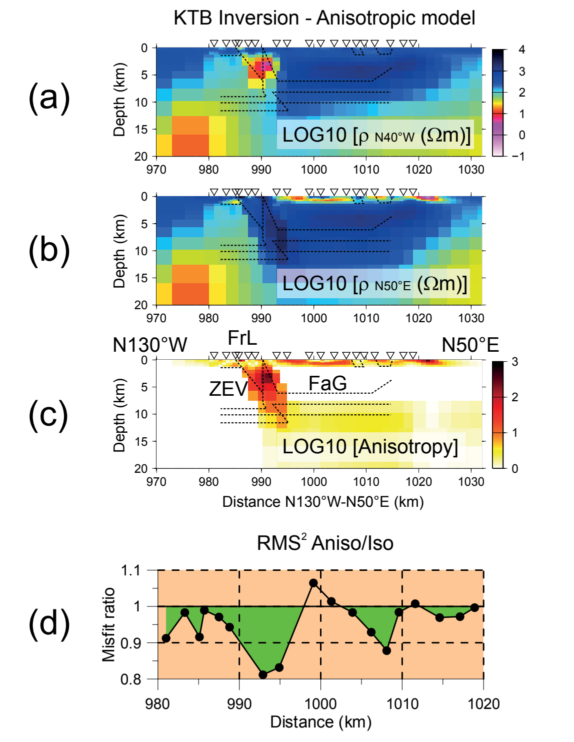


Fig. 1: Anisotropic 2D inversion of magnetotelluric data from the area of the KTB deep borehole, NE Bavaria, Germany. Result of a 2D anisotropic inversion for electrical resistivities along the N40°W (along the Franconian Line, a) and N50°E (b) directions are shown. The suggested structural anisotropy (c) shows the highest conductivity in the N50°W direction and is concentrated mainly in the Zone of Erbendorf-Vohenstrauss (ZEV). Bottom panel (e) indicates an improvement in the impedance data fit of the anisotropic model with respect to a 2D isotropic inverse model from the same data, in terms of the ratio of the RMS squared. Symbols used: FL – Franconian Line, FaG – Falkenberg Granite. Triangles on the surface indicate positions of magnetotelluric sites.

B.2.2 MAGNETOTELLURIC INVERSION FOR 2D CONDUCTIVITY DISTRIBUTION WITH ARBITRARY ANISOTROPY

We carried out an extended anisotropy analysis for magnetotelluric data from the profile MT-15 in western Slovakia (Bezák et al., 2014; Fig. 2), where no specific conditions exist which would speak in favour of large-scale crustal macro-anisotropy. The inversion with an anisotropic model improves the overall fit to the experimental data slightly and a relatively weak anisotropy appears mainly on conductive fault zones, which may be due to smearing of the conducting paths filled with fluids or solid conductive accessories along the tectonic disturbances. Weak anisotropy over a large domain of the deeper crust and uppermost mantle is likely an artifact produced by the effect of a spatially varying regional strike at large depths beneath the profile.

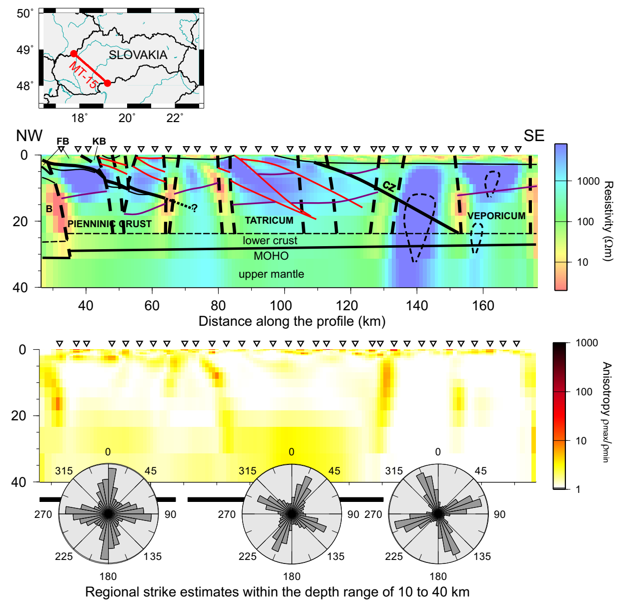


Fig. 2: Interpretation of a magnetotelluric model along the profile MT-15 in western Slovakia (Bezák et al., 2014). Top panel: Isotropic 2D resistivity model correlated with tectonic features along the profile (thick dashed lines – known fault zones and Neogene shear zones; full lines – thrust faults, B – Brunia; FB – Flysch Belt; KB – Pieniny Klippen Belt). Bottom panel: Electrical anisotropy, as a ratio of the maximum to minimum principle resistivities obtained from the 2D anisotropic inversion. Rose diagrams at the bottom show histograms of estimates of the regional strike beneath three sections of the profile for penetration depths of the magnetotelluric field in the range of 10 to 40 km.

I.G. research staff involved:

J. Pek

References:

Pek, J., Santos, F. A. M. and Li, Y., 2012: Non-Linear Conjugate Gradient Magnetotelluric Inversion for 2D Anisotropic Conductivities, in Proc. 24th Schmucker-Weidelt Colloquium on Electromagnetic Depth Investigations, Neustadt a. d. Weinstr., Sept. 19 – 23, 2011, Börner, R.-U. and Schwalenberg, K. (Eds.), Potsdam, Deutsche Geophysikalische Gesellschaft e. V., 187-206.

Bezák, V., Pek, J., Vozár, J., Bielik, M. and Vozár, J., 2014: Geoelectrical and geological structure of the crust in Western Slovakia, Stud. Geophys. Geod., 58, 473-488, DOI: 10.1007/s11200-013-0491-9

B.3.1 THREE-DIMENSIONAL SEISMIC VELOCITY MODEL OF THE WEST BOHEMIA/VOGTLAND SEISMOACTIVE REGION

The West Bohemia/Vogtland earthquake-swarm region has been a subject of permanent research interest for seismologists. The goal of this work was to calculate a three-dimensional (3D) velocity model for this region where only 1D velocity models have been available so far. An accurate 3D model is a decisive factor for better performance of many seismological methods (e.g., hypocenter location, determination of focal mechanisms, etc.).

A new smooth 3D seismic model, WB2012, was derived by means of seismic tomography. Inverted data were represented by a set of 2920 Pwave traveltimes from controlled shots fired in a framework of different experiments and a set of 11339 P and Swave arrival-times from 661 local earthquakes between December, 1991 and March, 2010. A standard tomographic approach was used for independent calculation of P- and S-wave velocity fields in a rectangular grid whose size was 1 km in all co-ordinates. The travel-times and rays were calculated by a numerical solution of the eiconal equation. While locating seismic events, our new WB2012 model yielded arrival-time residuals on average by 13% lower and hypocenter depths by 0.95 km shallower compared to the locations of the foci in the standard 1D vertically inhomogeneous isotropic velocity model of the West Bohemia swarm region. Further, we converted the P and Swave velocities (α and β, resp.) to the bulk modulus K and the Poisson's ratio (the bulk modulus is a measure of rock resistance to being compressed and is defined as volumetric stress over volumetric strain; the Poisson's ratio is the ratio of transverse contraction strain to longitudinal extension strain in the direction of the applied load, thus in some sense a measure of liquidity). The bulk modulus is calculated for the density ρ = 2700 kgm^{-3}. It was found that the bulk modulus (~40 – 70 GPa) correlates acceptably with the tectonic and geological structure of the area. The anomalously low values of the Poisson's ratio (~0.15) are typical for the most active focal zones of Nový Kostel and Lazy in West Bohemia. The lower values of ν can coincide with the increased ability of rock to a brittle failure (the higher the value of ν the closer the medium is to a fluid material which cannot generate seismic events). It may imply that abrupt changes of the bulk modulus are linked to tectonic lines and the low Poisson's ratio is a characteristic feature of the seismogenic volume.

I.G. research staff involved

B. Růžek, J. Horálek

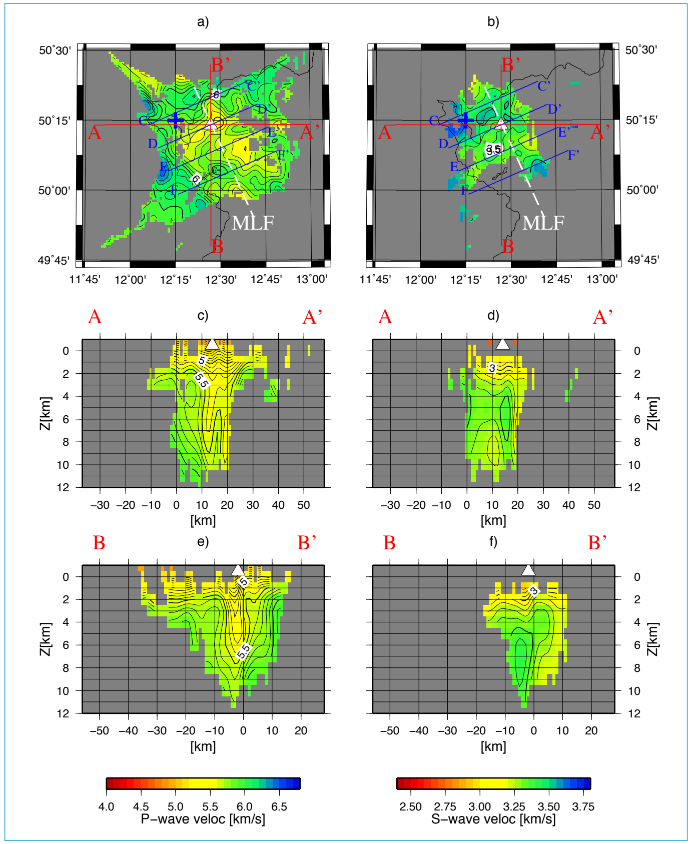


Fig. 1: (a, b) horizontal cross-sections of the P-wave (a) and S-wave (b) velocity fields at a depth of 3 km. (c-f) vertical cross-sections along profiles A-A' (c,d) and B-B' (e,f). The profiles intersect at the station NKC (indicated by a white triangle). Approximate course of the Mariánské Lázně fault (MLF) is shown by a dashed white line.

References:

Růžek, B. and Horálek, J., 2013. Three-dimensional seismic velocity model of the West Bohemia/Vogtland seismoactive region. Geophysical Journal International, 195, (2), 1251-1266. ISSN 0956-540XR&D, http://hdl.handle.net/11104/0224782.

B.4.1 HIGH-RESOLUTION FAULT IMAGE OF THE FOCAL ZONE IN WEST BOHEMIA,CZECH REPUBLIC

In the seismically active region of West Bohemia, Czech Republic, earthquake swarms occur within a system of faults the spatial structure of which has not been known in detail so far. In order to screen the detailed structure of the focal zone situated at depths between 7 and 11 km, we have analyzed 463 micro-earthquakes in the magnitude range from 0.5 to 3.8 that occurred during the 2008 earthquake swarm in West Bohemia, Czech Republic (Fig. 1). A double-difference location method was applied to records of 22 local seismic stations with an epicentral distance of less than 25 km in order to retrieve the locations of hypocenters with a high accuracy of less than 20 m. The hypocenters are well clustered and distinctly map the system of activated faults. The fault system has a complex geometry composed of several fault segments with different orientations. Some of the segments intersect each other. The orientations of the segments coincide well with the focal mechanisms (Fig. 2). We have introduced and evaluated the so-called fault instability of the individual fault segments. The fault instability ranges from 0 (most stable faults) to 1 (most unstable faults) and measures the susceptibility of the fault to be activated under specified stress. In the West Bohemia focal zone, two fault segments are optimally oriented with respect to the tectonic stress characterized by an instability value higher than 0.9. Tractions on these fault segments are concentrated in the Mohr's diagram in the area of validity of the Mohr-Coulomb failure criterion and the associated micro-earthquakes are mainly shear. The other fault segments are slightly misoriented, with instability values between 0.7 and 0.9 and the shear traction is significantly lower. These earthquakes are probably more tensile and activated most likely by the local redistribution of Coulomb stress during the swarm activity.

IG research staff involved:
V. Vavryčuk, F. Bouchaala, T. Fischer

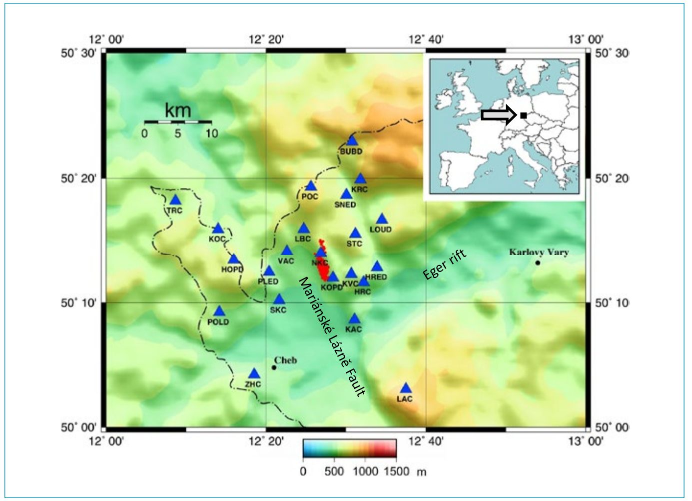


Fig. 1: Topographic map of the West Bohemia/Vogtland region. The epicenters of the 2008 swarm earthquakes are marked by red dots. The WEBNET stations are marked by blue triangles. The dashed-dotted line shows the border between the Czech Republic and Germany.

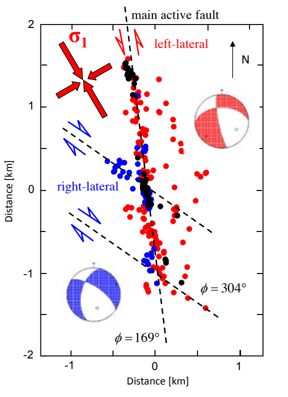


Fig. 2: Tectonic sketch of the focal zone, with colour-coded epicentres according to their focal mechanisms. The dashed lines show the active principal fault segments. Full red arrows show the orientation of the maximum and minimum compressive stress axes. The beach balls show the focal mechanisms associated with the principal faults: left-lateral (in red) and right-lateral (in blue) strike-slips.

References:

Bouchaala, F., Vavryčuk and V., Fischer, T., 2013. Accuracy of the master-event and double-difference locations: Synthetic tests and application to seismicity in West Bohemia, Czech Republic, J. Seismology, 17, No. 3, 841-859, doi: 10.1007/s10950-013-9357-4.

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Vavryčuk, V., Bouchaala, F. and Fischer, T., 2013. High-resolution fault image from accurate locations and focal mechanisms of the 2008 swarm earthquakes in West Bohemia, Czech Republic, Tectonophysics, 590, 189-195, doi: 10.1016/j.tecto.2013.01.025.

B.5.1 MAGMA ASCENT AND MIGRATION BENEATH SUBMARINE VOLCANIC ARCS REVEALED BY EARTHQUAKE SWARM ANALYSIS

Large portions of volcanic arcs at convergent plate margins are submarine, hidden to direct observations. Their volcanic and magmatic activity as well as the eruptive history are thus poorly documented and understood. A detailed analysis of teleseismic earthquake occurrence has proven as a useful tool to contribute to better understanding the behaviour of magma beneath the Earth's surface and to delimitation of domains of current submarine magma unrest. Teleseismic earthquakes are those that were detected, processed and localised by global seismological networks such as Earthquake Seismological Center (ISC) (www.isc.ac.uk/) or the National Earthquake Information Center (NEIC) of the US Geological Survey (www.earthquake.usgs.gov/earthquakes/search/) or programs such as Global Centroid Moment Tensor Solution (GCMTS) Project at the Lamont-Doherty Earth Observatory of Columbia University offering earthquake focal mechanisms from the period 1976-present (www.ldeo.columbia.edu/~gcmt/GCMT_Website_Additions/www.globalcmt.org.ghost.html). Our recent studies were based mainly on hypocentral determinations derived from ISC observations by the procedure of Engdahl, van der Hilst and Buland (1998) covering the time interval 1960 – 2008.

A specific seismicity pattern has been observed beneath submarine portions of several volcanic arcs at convergent plate margins (Banda Arc, Nicobar-Andaman Arc, southern Ryukyu Arc). The following features allow such a seismicity pattern to be interpreted as a magma-driven process: (1) clustering of medium-size earthquakes (M>4) in space and time in shallow earthquake swarms beneath the volcanic arcs; (2) a gap in earthquake occurrence in the Wadati-Benoff zone of the subducting slab beneath the swarms; (3) lateral migration of earthquakes during the swarms; (4) correlation of epicentral zones of the swarms with distinct seamounts and submarine ridges.

1 – Earthquake swarms have been considered an important indicator of magmatic/volcanic activity in general as they often result from brittle failure driven by an active intrusion of magma and/or magmatic fluids and melts. As earthquake swarm occurrence itself need not be sufficient evidence of current magmatic activity, we seek specific features of swarm development, accompanying phenomena and surface morphology. Epicenters of the earthquake swarms are situated almost exclusively along the volcanic arcs of the studied regions (Fig. 1).

2 – A closer look at vertical sections cutting the convergent plate margins (Fig. 2) reveals that a part of the Wadati-Benioff zone with a specific, contrasting seismicity pattern, is situated at depths between 70 and 90 km below the swarm epicentres. There, a gap in earthquake occurrence is observed. The loss of ability of such a domain of the subducted slab to generate earthquakes – at least the stronger, teleseismically recorded ones - probably reflects a significant change in rheological properties due to fluid release from the slab.

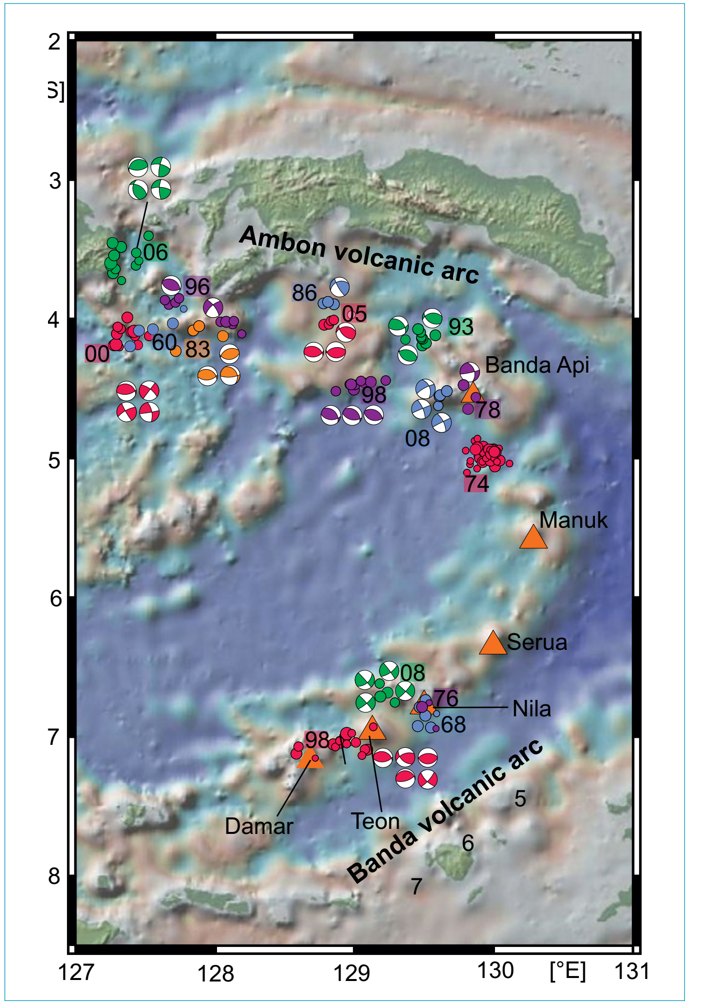

Fig. 1: Epicentral map of earthquakes (circles) occurring in swarms beneath the Banda and Ambon volcanic arc domains. Each sequence is denoted by a different color and year of occurrence. Volcanoes are denoted by orange triangles. Beach balls represent fault plane solutions of available earthquake focal mechanisms of the Global Centroid-Moment-Tensor Project. The morphological map was created using GeoMapApp (Ryan et al. 2009).

B.5.2 MAGMA ASCENT AND MIGRATION BENEATH SUBMARINE VOLCANIC ARCS REVEALED BY EARTHQUAKE SWARM ANALYSIS

3 – A detailed analysis of the space-time progression of earthquake swarms beneath the studied volcanic arcs revealed their non-random evolution. Comparison of epicentral maps of individual stages of the swarm development showed consistently that earthquake epicenters migrate laterally, at a rate of several hundred metres 1 km per hour (Fig. 3). Because of the position of the swarms beneath the volcanic arc and above the gap in seismicity of the Wadati-Benioff zone, we interpret the lateral migration of earthquakes during the swarms as a consequence of transport of magma (or magmatic fluids and melts) related to the process of subduction. The magma probably migrates along pre-existing faults and fractures, changing the state of stress as well as frictional properties along these structures and induces series of earthquakes.

4 – Epicentral zones of the swarms usually coincide with distinct elevations at the seafloor – the rim of the Manipa Basin in the Banda Arc, Cratered and Southern Seamounts in the Andaman-Nicobar region and the Cross-Backarc Volcanic Trail and other seamounts in the southern Okinawa Trough. As many earthquakes of the analysed swarms are very shallow (≤ 5 km), extrusions of magma at the seafloor during the swarms cannot be excluded.

Our studies document high accuracy of hypocentral parameter determinations published by data centers such as ISC and NEIC USGS and the usefulness of the EHB relocation procedure.

Utilisation of teleseismically recorded and rapidly processed data (USGS/NEIC, Global CMT Project) enables to observe magmatic activity in almost real time even in remote areas where regional seismic networks are not available. Utilization of teleseismic data can reveal activation of plumbing systems of submarine volcanoes and highlight areas with the potential of near-future volcanic events. The studied submarine regions deserve attention of volcano seismologists through the almost continuous activity and represent attractive areas for on-site geophysical monitoring and direct seafloor observations.

I.G. research staff involed:

A. Špičák, J. Vaněk, R. Matějková, V. Kuna

References:

Špičák, A., R. Matějková and J. Vaněk, 2013. Seismic response to recent tectonic processes in the Banda Arc region, Journal of Asian Earth Sciences, 64, 1-13, doi. org/10.1016/j.jseaes.2012.11.014.

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Špičák, A., V. Kuna and J. Vaněk, 2013. Earthquake occurrence reveals magma ascent beneath volcanoes and seamounts in the Banda region, Bulletin of Volcanology, 75(12), Art. No. 777, DOI: 10.1007/s00445-013-0777-3.

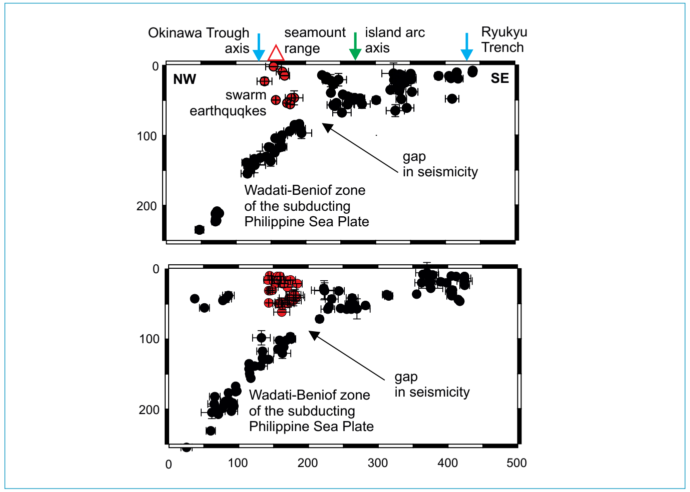

Fig. 2: Vertical sections across the convergent plate margin in the southern Ryukyu area. The sections were constructed along swaths 50 km wide oriented perpendicular to the plate boundary in the azimuth of 135°. Earthquakes denoted by circles, accompanied by standard error bars where the standard errors were available (EHB data). Earthquakes belonging to earthquake swarms are denoted by red circles.

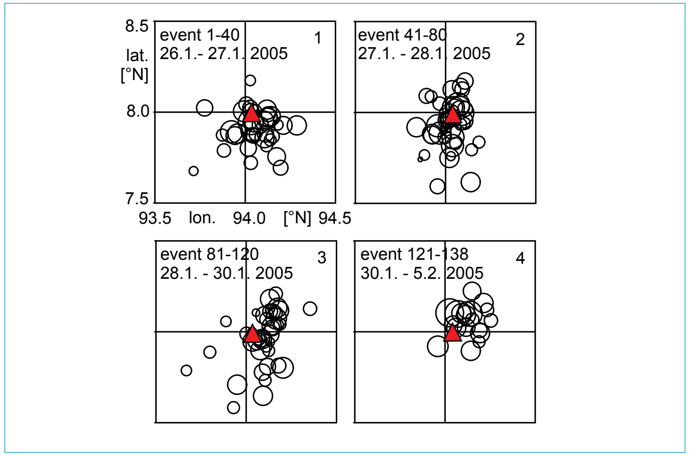

Fig. 3: Four episodes of the January 2005 Nicobar earthquake swarm demonstrate migration of earthquake epicenters (circles) by about 30 km in 5 days, i.e. at a rate of 250 m per hour. Red triangle denotes position of the Cratered Seamount.

B.6.1 GEOLOGICAL ORIGIN OF THE DEVILS TOWER PHONOLITE MONOLITH (WYOMING, USA)

The Devils Tower phonolite represents the world's finest example of columnar jointing and possibly the longest columns developed in a volcanic rock (Fig. 1). A number of hypotheses were earlier put forward for this 49-million-year-old volcanic structure, but most of them considered subterranean explanation; a magmatic stock, a laccolith, or a volcanic conduit, with the latter interpretation being presented in many Earth science textbooks.

A new hypothesis for the geological origin of Devils Tower was inspired by a survey of a similar, butte called Bořeň in Czech Republic (Závada et al., 2011). Bořeň and Devils Tower show similar composition, display two tiers of columns and outward flaring columns at their base. Earlier research at Bořeň suggested that it may represent a remnant of a lava dome emplaced into the maar of a phreatomagmatic volcano. Phreatomagmatic volcanoes form when rising magma encounters groundwater and resulting explosions of expanding steam disintegrate both the magma and host rocks (Fig. 2). Several such explosions leave behind a diatreme filled with chaotic debris and a maar on the surface that typically displays a succession of alternating lacustrine sediments and tuff surges. At last, the magma can intrude the diatreme, when magma-water interaction processes.

The similarities of both landmarks inspired a new survey at Devils Tower that documented phreatomagmatic deposits in the area. Two primary structural features of Devils Tower were then examined to pinpoint its original shape and emplacement level: the shape of the distinctive columns and the alignment of magnetic minerals within them. Although near the base of the tower the minerals are aligned vertically, closer to the top of the formation the minerals become horizontal and imply horizontal stretching at late stages of magma/lava flow. These informations were then evaluated in light of the models, both physical and digital (Finite Element numerical models). The physical model involved squeezing of soft plaster upward through an inverted cone filled with sediment until it formed a mound on the surface. This setup mimicked intrusion of magma into a maar-diatreme volcano. Hardened plaster models were then cut vertically and examined for internal flow fabrics from admixed magnetite particles. The digital models simulated cooling of the igneous mass and allowed direct comparison of the columnar jointing of Devils Tower with thermal structure of the models. Since volcanic columns form perpendicular to the cooling surfaces during progressive cooling, their shapes reflect the margins of the original volcanic/magmatic body. Iterated physical and corresponding digital modeling finally revealed that the tower's columnar jointing pattern is best reproduced by cooling of a low lava dome or a coulée of lava just above its feeding conduit (Fig. 2).

I.G. research staff involved: **P. Závada, P. Dědeček**

References:

Závada, P., Dědeček, P., Lexa, J., and Keller, G. R., 2015. Devils Tower (Wyoming, USA): A lava coulée emplaced into a maar-diatreme volcano? Geosphere, 11 (2), 354-375, doi:10.1130/GES01116.1.

Závada, P., Dědeček, P., Mach, K., Lexa, O. and Potužák, M., 2011. Emplacement dynamics of phonolite magma into maar-diatreme structures - correlation of field, thermal modeling and AMS analogue modeling data. Journal of volcanology and geothermal research, 201(1-4), 210–226. DOI:10.1016/j.jvolgeores.2010.07.012.

Fig. 1: Devils Tower phonolite monolith, a spectacular 230 m high volcanic structure with distinct roughly hexagonal columns decorating its walls.

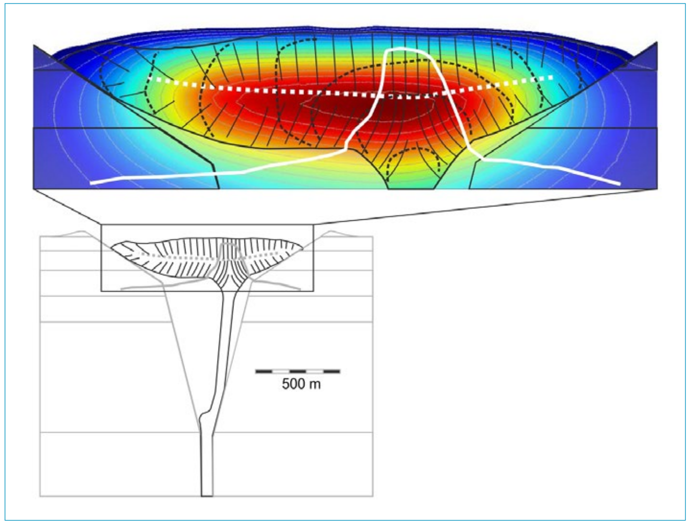

Fig. 2: Digital model of cooling of a lava body shaped like one of the plaster models. Thin black black lines indicate the columns that would form. Thick white line shows the overlain shape of Devils Tower.

B.7.1 SMALL-SCALE VOLCANISM ON MARS

Volcanoes differ in sizes as does the amount of magma which ascends on the planetary surface. On Earth, the size of volcanoes is anti-correlated with their frequency, i.e. small volcanoes are much more numerous than large ones. Therefore, the most common terrestrial volcanoes are small-scale (<few km in diameter) scoria cones followed by tuff cones/tuff rings. As Mars was also volcanically active in the past, a similar distribution of volcano size might be expected. Martian small-scale volcanoes were not intensely studied for a long time due to a lack of high-resolution data enabling their proper identification; however their existence and basic characteristics were predicted on theoretical grounds. Streams of new high-resolution images now enable discovering and studying kilometer-size volcanoes with various shapes in unprecedented detail.

The shape of volcanoes depends on the formation mechanism (e.g., eruption processes and environmental conditions). Scoria cones are formed by particles that are ejected due to magma fragmentation caused by "dry" degassing, whereas tuff rings are formed when magma interacts with water. Therefore, the presence of scoria cones provides a record of the presence of volatiles dissolved in magma and tuff rings indicate the paleo-presence of water. In our work we focused on these processes in the attempt to better understand and clarify some aspects of Martian volcanic history.

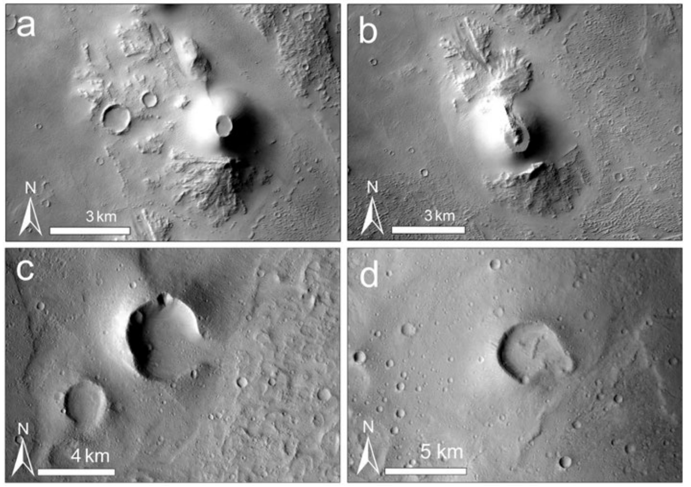

Fig. 1: Examples of investigated small-scale volcanoes: scoria cones in volcanic field Ulysses Colles (a, b) and tuff cones/rings in Nephentes/Amenthes region (c, d) Based on CTX images.

SCORIA CONES AS INDICATORS OF MAGMA DEGASSING

Based on theoretical grounds, explosive basaltic volcanism should be common on Mars, yet the available morphological evidence is sparse. We test this hypothesis by investigating a volcanic field Ulysses Colles north of the shield volcanoes Biblis Patera on Mars, where we observe several small conical edifices and associated lava flows. Twenty-nine volcanic cones are identified and the morphometry of many of these edifices is determined using established morphometric parameters such as basal width, crater width, height, slope and their respective ratios. Their morphology, morphometry and a comparison to terrestrial analogues suggest that they are martian equivalents of terrestrial scoria cones, the most common volcanoes on Earth. According to absolute model age determinations, they formed in the Amazonian period. Our results indicate that these scoria cones were formed by explosive activity. The cone field is superposed on an old, elevated window of fractured crust which survived flooding by younger lava flows. It seems possible that a more explosive eruption style was common in the past and that wide-spread effusive plain-style volcanism in the Late Amazonian has buried much of its morphological evidence in Tharsis (Brož and Hauber, 2012).

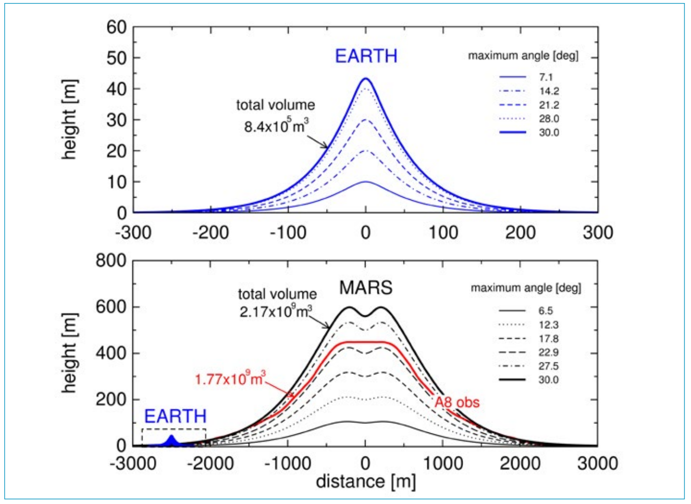

Fig. 2: Evolution of scoria cones on Earth (top) and Mars (bottom) until the angle of repose (30°) is reached. Dashed lines illustrate the gradual growth of the cone. The maximum angle attained for each profile is given in the legend. The red profile shows the average topography of one scoria cone in Ulysses Colles based on CTX DEM.

DISCREPANCY IN SHAPES BETWEEN MARTIAN AND TERRESTRIAL SCORIA CONES

Morphological observations of scoria cones on Mars show that their cross-sectional shapes are different from those on Earth. Due to lower gravity and atmospheric pressure on Mars, particles are spread over a larger area than on Earth. Hence, erupted volumes are typically not large enough for the flank slopes to attain the angle of repose, in contrast to Earth where this is common. The distribution of ejected material forming scoria cones on Mars, therefore, is ruled mainly by ballistic distribution and not by redistribution of flank material by avalanching after the static angle of repose is reached.

As a consequence, the flank slopes of the Martian scoria cones do not reach the critical angle of repose in spite of a large volume of ejected material. Therefore, the topography of scoria cones on Mars is governed mainly by ballistic distribution of ejected particles and is not influenced by redistribution of flank material by avalanching. The growth of a scoria cone can be studied numerically by tracking the ballistic trajectories and tracing the cumulative deposition of repeatedly ejected particles. We apply this approach to cones in Ulysses Colles and compare our numerical results with observations. We demonstrate that the topography of these scoria cones can be rather well (with accuracy of ~10 m) reproduced provided that the ejection velocities are a factor of ~2 larger and the ejected particles are about ten times finer than typical on Earth, corresponding to a mean particle velocity of ~92 m/s and a real particle size of about 4 mm. This finding is in agreement with previous theoretical works that argued for larger magma fragmentation and higher ejection velocities on Mars than on Earth due to lower gravity and different environmental conditions (Brož et al., 2014).

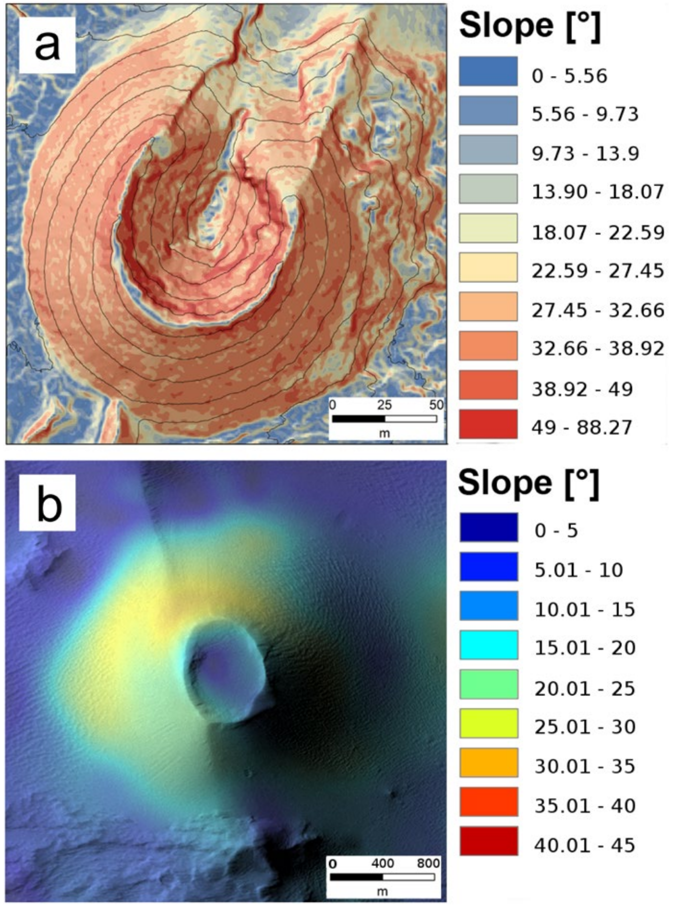

Fig. 3: (a) Slope map of Puu Kapanaha, a scoria cone at the eastern flank of Mauna Loa, Hawai`i (19.5474°N, 155.4557°W). Slopes were calculated on the basis of an airborne LIDAR-based Digital Elevation Model (DEM) (Hawaii Big Island Lidar Survey, doi: 10.5069/G9DZ067X). A best linear fit to the flank slopes yields 33°. Slopes increase to >40° very close to the summit, probably caused by spatter material that stabilizes the loose scoria particles. The black lines represent the counter lines with interval to be 5 m. (b) Cone A2 in the Ulysses Colles volcanic field. Slopes are derived from HRSC DEM. Background image is part of CTX image P22_009554_1858 (5.70°N, 237.04°E). As visible, angles do not reach values of 30°.

HYDROVOLCANIC TUFF RINGS AND CONES AS INDICATORS FOR PHREATOMAGMATISM

Hydrovolcanism is a common natural phenomenon on Earth and should be common on Mars, too, since its surface shows widespread evidence for volcanism and near-surface water. We investigate fields of pitted cones in the Nephentes/Amenthes region at the southern margin of the ancient impact basin, Utopia, which were previously interpreted as mud volcanoes. The cone fields contain pitted and breached cones with associated outgoing flow-like landforms. Based on stratigraphic relations, we determined a Hesperian or younger model age. We test the hypothesis of a (hydro)volcanic origin. Based on a detailed morphological and morphometrical analysis and an analysis of the regional context, an igneous volcanic origin of these cones as hydrovolcanic edifices produced by phreatomagmatic eruptions is plausible. Several lines of evidence suggest the existence of subsurface water ice.

The pitted cones display well-developed wide central craters with floor elevations below the preeruptive surface. Their morphometry and the overall appearance are analogous to terrestrial tuff cones and tuff rings. Mounds that are also observed in the same region resemble terrestrial lava domes. The hydrovolcanic interaction between ascending magma and subsurface water and/or water ice may explain the formation of the pitted cones, although other scenarios such as mud volcanism cannot be ruled out. Together with the mounds, the cones might represent effusive and explosive edifices of a monogenetic volcanic field composed of lava domes, tuff rings, tuff cones and possibly maars (Brož and Hauber, 2013).

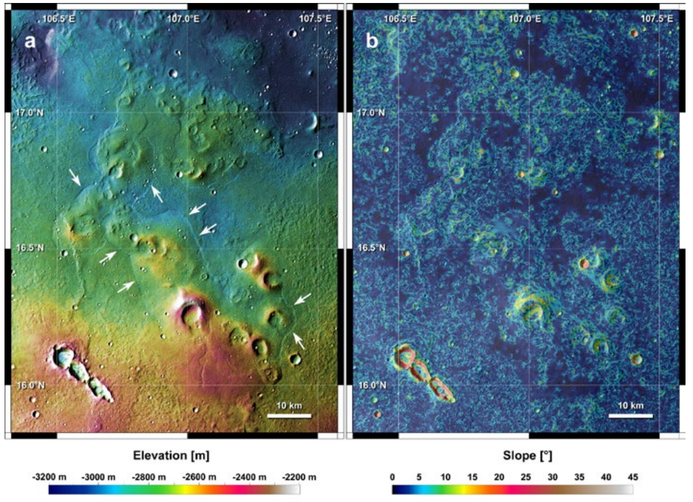

Fig. 4: Topographic image map based on HRSC image (left) and slope map derived from HRSC DEM (right) of tuff rings and cones in Nephentes/Amenthes region.

I.G. research staff involved:

P. Brož

References:

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Brož, P. and Hauber, E., 2013. Hydrovolcanic tuff rings and cones as indicators for phreatomagmatic explosive eruptions on Mars, J. Geophys. Res., 118, 1656-1675, doi: 10.1002/jgre.20120.

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B.8.1 INTRUSION OF LAMPROPHYRE DYKE AND RELATED DEFORMATION EFFECTS IN THE HOST ROCK SALT: A CASE STUDY FROM THE LOULÉ DIAPIR, PORTUGAL

A sub-vertical contact zone between a rock salt and a lamprophyre dyke was investigated for its petrographic, mechanic and physical properties by means of anisotropy of magnetic susceptibility (AMS) and rock magnetic properties, coupled with quantitative microstructural analysis and thermal mathematical modeling. The AMS and magnetic studies provided trends of fabric in both igneous and salt rocks. The AMS fabric across the lamprohyre dyke, together with the magmatic texture without any sub-solidus deformation overprint, suggests that the primary emplacement-related fabric was not affected by later deformation. In the salt, there is a change in the fabric orientation, from regionally recorded NW-SE trending steep foliation to NE-SW subvertical dyke parallel foliation closer to the dyke (Fig. 1). The quantitative microstructural analysis confirmed that AMS in this case correctly describes the orientation of the rock fabric in the salt. However, to decipher the processes that led to the formation of the dyke-parallel planar fabric, more detailed study of rock salt microstructure and texture were necessary. They revealed that, with decreasing distance from the dyke, unusual microstructural changes occurred in the salt (Fig. 1), characterized by high temperature, high fluid activity, random CPO but also high stress. However, the thermal modeling surprisingly showed that the salt should not melt even at the salt/dyke contact. Paleomagnetic results evidenced that dyke has rotated from its original position and thus additional deformation affected the dyke/salt system.

The dyke-parallel planar fabric at the NW side is due to its unusual microstructure assumed to be related to the dyke intrusion keeping the dyke emplacement- or ascent-related fabric. However, the asymmetrical fabric patterns on the opposite sides of the dyke, together with the apparent rotation of angular lamprophyre fragments, indicate a tectonic reworking of the dyke-parallel planar fabric at the SE side of the dyke. However, we can not exclude the possibility that angular fragments in the rock salt originated as peperite breccia during the first contact of lamprophyre magma with cold and wet salt and not during deformation after dyke emplacement. Therefore it is possible that the structure on both sides of the dyke originated due to dyke emplacement.

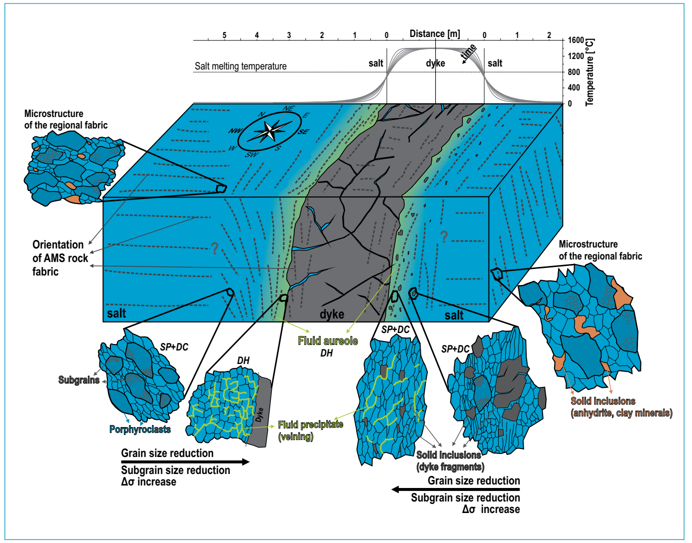

Fig. 1: Block diagram ilustrating the most important findings and interpretations of AMS, microstructural analysis and thermal modelling. Operating deformation mechanisms: SP+DC - solution precipitation + dislocation creep, DH - Fluid overpressure driven dilation hardening. Δσ - differential stress. The geographic orientation of the block diagram is marked by the compass rose.

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M. Machek, Z. Roxerová, P. Závada, P. Dědeček, E. Petrovský

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B.9.1 SEA-LEVEL CHANGES, PALAEOCLIMATE AND THE GLOBAL CARBON CYCLE AT THE PEAK OF THE CRETACEOUS GREENHOUSE REGIME: INSIGHTS FROM THE TURONIAN OF BOHEMIA

The mid-Cretaceous thermal maximum represents an interval of extreme greenhouse climate attributed to high partial pressure of atmospheric carbon dioxide (pCO_2 800-1500 parts per million by volume, p.p.m.v.; Berner, 2006) and other greenhouse gases. The peak warmth was probably reached in the Turonian (93,9 to c. 89,7 Ma; Laurin et al. 2014). This stage includes a global long-term sea-level maximum near the Cenomanian-Turonian boundary (93.9 Ma) as well as a long-term sea-level low in the Middle Turonian (e.g. Miller et al., 2005). Therefore, the Turonian is one of key intervals in the Phanerozoic within which to study the links between sea-level change, greenhouse climate, oceanographic conditions and the carbon cycle .

New research core Bch-1 in Běchary, Czech Republic, was drilled as part of a project aimed at obtaining a high-resolution, multi-proxy stratigraphic record of the Turonian stage. The drilling recovered a thick (> 400 m) succession of offshore strata of latest Cenomanian through middle Coniacian age. Primary data generated during the course of the project include a set of geophysical well logs, carbon stable-isotope data in a 50 cm resolution, quantitative palynological data, major and minor elemental proxies, organic carbon and carbonate contents, micropetrography, magnetic susceptibility, core photographs used for image analysis, macrofossil record, calcareous nannofossils and standard macroscopic description of lithofacies. The results of the project were expected to bring significant progress to the understanding of the links between the global carbon cycle, orbitally-driven climate cyclicity and sea-level change and to provide a new high-resolution reference section for correlations of chemostratigraphic data between basins in Europe and other continents.

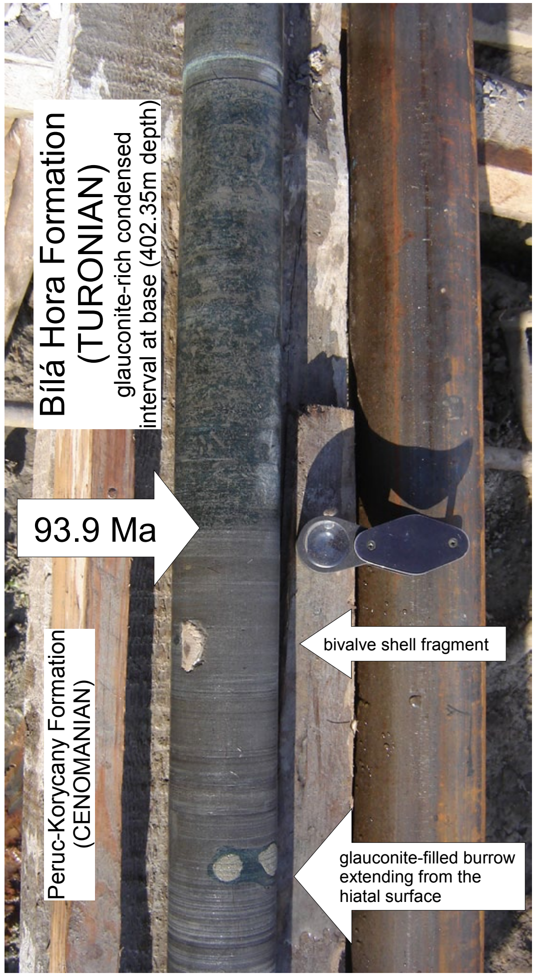

Fig. 1: The base of the Turonian stage is marked by a zone of condensed deposition in the Bohemian Cretaceous Basin. In the Bch-1 core the slowed deposition rate is expressed by approx. 30 cm of green-grey, strongly bioturbated, glauconite-rich marlstone at 402.35 m depth. The basal surface, penetrated by burrows reaching 25 cm deep, formed during a hiatus which, based on combined biostratigraphic and C-isotope data, represents over 300 thousand years (kyr) of the latest Cenomanian.

SEA-LEVEL VS. CARBON-ISOTOPE RECORDS

Causal links between carbon isotope fluctuations and eustatic sea-level variation have been suggested, with a positive correlation between sea level and $\delta^{13}C$ initially being proposed based on low-resolution studies focusing on the long-term maximum flooding near the Cenomanian/Turonian boundary. An underlying assumption was that an increase in organic C production and deposition will result in an increase in $\delta^{13}C$ value of the remaining dissolved C in the oceanic reservoir (Scholle and Arthur 1980). Later work, utilizing progressively higher-resolution datasets, resulted in interpretations of the covariance between global sea level and carbon isotope events (CIEs) on a Myr timescale (Jarvis et al., 2006, among others). Other authors have suggested, however, that some positive CIEs in the Cretaceous correlate to relative sea-level falls , including those of the Middle and Late Turonian (e.g., Bornemann et al. (2008).

The Bch-1 dataset yielded so far the highest-resolution C-isotope curve for the Turonian stage and was correlated to the highest-resolution published $\delta^{13}C$ data available worldwide (Fig. 2). Geophysical well-log - based correlations between the Bch-1 site and two separate depocentres of the Bohemian Cretaceous Basin made it possible, for the first time, to achieve direct, biostratigraphically calibrated, basinal-scale correlation of interpreted sea-level records in proximal strata and carbon-isotope record in distal strata. This correlation (Uličný et al., 2014) showed that no systematic relationship between C-isotope and sea-level change can be inferred. Most of the statements in previous literature of a positive or negative co-variance of C-isotope curves with sea level change, were affected by insufficient temporal resolution of data.

On the other hand, the high-resolution correlations allowed the frequency of interpreted relative sea-level changes to be estimated. A number of short-term, basin-wide regressions in the Bohemian Cretaceous Basin, likely to reflect eustatic falls, show a recurrence interval of 100 kyr or less. This is an order of magnitude shorter than the timing of sea-level falls inferred from the New Jersey margin and the Apulian platform, interpreted to be driven by glacioeustacy. The 2.4 Myr period suggested by others to generate 3rd-order cycles, is too long to be the principal cycle generating unconformities in tectonically active basins, where the rate of eustatic fall must exceed the subsidence rate. Unconformities in low-accommodation settings such as passive margins most likely represent amalgamated records of multiple cycles of sea-level fluctuations of 100 kyr scale, recognizable only in high-resolution datasets from expanded basinal sections.

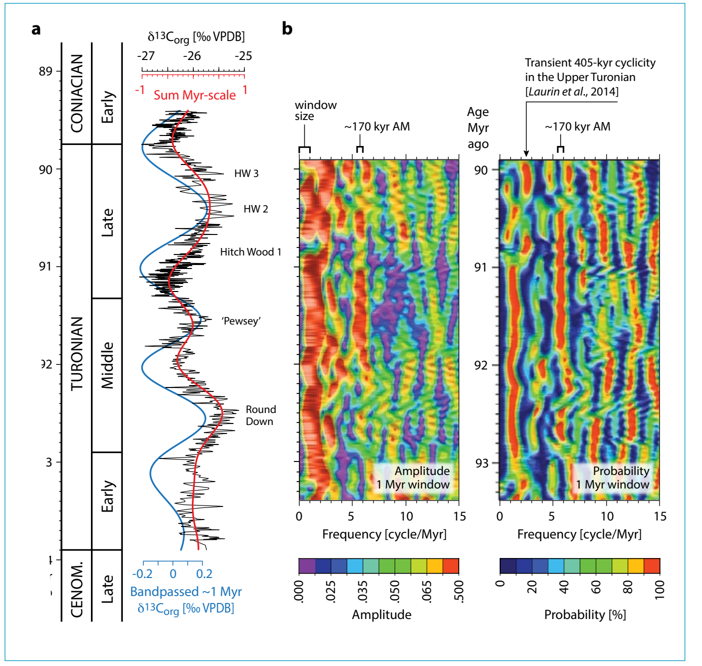

Fig. 2a, b: Data – model comparison of the C-isotope cyclicity of the Turonian stage. (a) Age-calibrated δ^{13}_{Corg}, Bch-1 borehole. Major C-isotope events indicated (HW2 and HW3 refer to Hitch Wood 2 and Hitch Wood 3 of Uličný et al., 2014). Bandpassed ~1 Myr signal (Gaussian filter 0.9 ± 0.3 cycle/Myr) in blue and a sum of Myr-scale components (piecewise linear filter 0.7 ± 0.7 cycle/Myr) in red. (b) Evolutive Harmonic analysis (EHA) spectral estimate for the calibrated Bch-1 curve. Note that the 405 kyr eccentricity signature interpreted earlier (Laurin et al., 2014) forms only a transient feature in the study interval.

REVISED TIME SCALE OF THE TURONIAN AND MULTI-PROXY INTER-BASINAL CORRELATION

Additional C-isotope profiles acquired during the course of the project and correlated to Bch-1, combined with spectral analysis of geophysical well logs, were used to construct a new, astrochronologically tuned time scale for the Upper Turonian substage (Laurin et al., 2014). This time scale was further used to develop time-domain C- isotope records (Laurin et al., 2015). The palynological study of Bch-1 core yielded the highest-resolution and fully stratigraphically constrained, Turonian dinocyst dataset published to date (Olde et al., 2015). A succession of 22 dinocyst datum levels from Bch-1 was combined with 10 C-isotope events and compared to British sections to provide a a revised dinocyst zonation scheme, applicable at least in Northern and Central Europe. A broader applicability of this stratigraphic scheme is likely and awaits testing.

ORBITAL CONTROLS ON GREENHOUSE CARBON CYCLE

Uličný et al. (2014) suggested that the long-term 'background' cycle in Bch-1 carbon isotope data shows a duration close to the 2.4 Myr long-eccentricity cycle; Laurin et al. (2014) noted that the main C-isotope excursions in the Upper Turonian are coherent with 405-kyr eccentricity variations. Subsequent spectral analysis and carbon mass-balance modelling using the most recent age model for the Late Cretaceous, found, however, that the million-year scale variations in the Late Cretaceous carbon budget was controlled by amplitude modulation of axial obliquity. The nonlinear transfer of variance in $\delta^{13}C$ from the much shorter primary obliquity signal to longer amplitude-modulation periods is explained by recycling of carbon on astronomical time scales by episodic formation and decay of reservoirs of organic matter and/or methane (e.g., terrestrial peat, soil and lakes, permafrost and marginal parts of marine euxinic settings). The obliquity signature suggests that these reservoirs responded to high-latitude insolation or middle- to high-latitude insolation gradients. The quasi-stable character of this type of reservoirs dictates their low preservation potential. They are probably underrepresented in the geological record, but their role in controlling the Myr-scale variability in the greenhouse climate might have been prominent.

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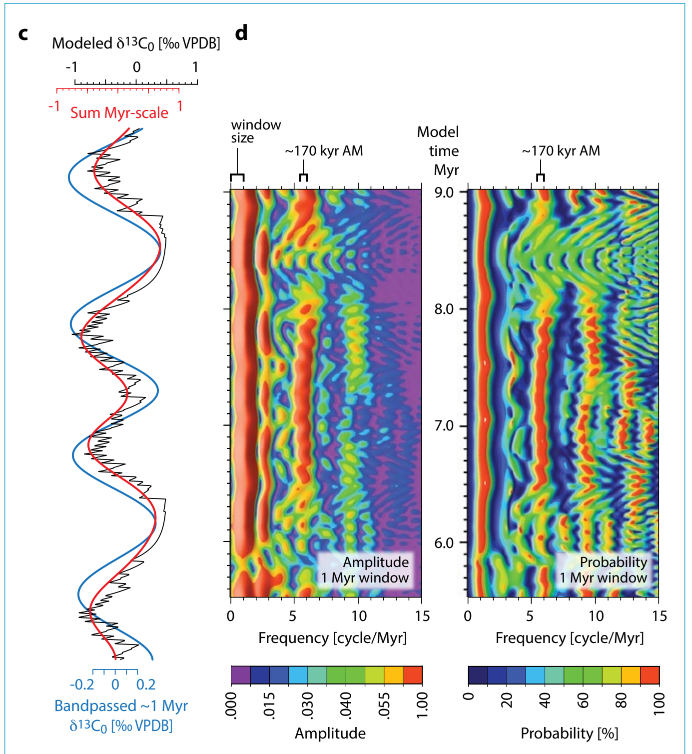

Fig. 2 c,d: Data – model comparison of the C-isotope cyclicity of the Turonian stage. (a) Age-calibrated $\delta^{13}C_{org}$, Bch-1 borehole. Major C-isotope events indicated (HW2 and HW3 refer to Hitch Wood 2 and Hitch Wood 3 of Uličný et al., 2014). Bandpassed ~1 Myr signal (Gaussian filter 0.9 ± 0.3 cycle/Myr) in blue and a sum of Myr-scale components (piecewise linear filter 0.7 ± 0.7 cycle/Myr) in red. (b) Evolutive Harmonic analysis (EHA) spectral estimate for the calibrated Bch-1 curve. Note that the 405 kyr eccentricity signature interpreted earlier (Laurin et al., 2014) forms only a transient feature in the study interval.

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B.10.1 PRECISE TEMPERATURE MEASUREMENTS IN DEEP BOREHOLES

Temperature vs depth measurements in boreholes present an important geophysical method. In addition to the temperature logs combined with the laboratory determination of the thermal properties of the drilled rocks used for assessments of the terrestrial heat flow and in the extrapolation of the subsurface temperature data into greater depth, the principal task of geothermics, the knowledge of the precise temperature-depth distribution can be used in many other geophysical studies, namely in the paleoclimate reconstructions of so called borehole climatology. Here we present three examples of our present studies, which may well illustrate the present research activities of the Geothermal Department of the Geophysical Institute.

ANTHROPOGENIC AND REGIONAL CLIMATIC TRANSIENT SIGNALS IN TEMPERATURE LOGS FROM CZECHIA AND SLOVENIA

Geothermal research based primarily on the temperature-depth logs measured in several hundred meters to several kilometres deep boreholes provides information on the energetic balance of the Earth. However, the information stored in the transient component of the temperature-depth profiles, which is considered as a noise in the terrestrial heat flow determinations, can be used as a valuable archive of the past climatic changes. The steady-state part of the subsurface temperature corresponds to the long-term annual mean of the ground surface temperature. The seasonal and inter-annual surface temperature variations propagate downward and disappear at the depth of 15–25 m. In case of a climatic change, however, the long-term annual mean of the surface temperature changes and this transient signal propagates much deeper—to hundreds of meters for the centennial and millennial climatic changes and to first kilometres for the glacial—interglacial cycles. By solving the inverse problem, the history of the ground surface temperature (GST) variations can be reconstructed from this transient component obtained by a precise temperature logging and by removing the steady-state part of the temperature-depth profile. Beside the natural causes, the activities of people have been involving more and more in forming the Earth's surface. Human impact is either passive, when human activity changes the albedo or isolation of the Earth's surface, thereby altering the surface air temperature (SAT) – GST relation, or active, e.g. when heat is supplied into or extracted from the ground with the use of geothermal (ground source) heat pumps. Another substantial change has been brought by urbanization. Urban agglomerations, apart from extensive paved surfaces with a low albedo (asphalt, concrete) that absorb sunshine, bring also an active energy exchange due to heated or cooled buildings. As a contribution to better understanding of this complex problem we investigated the simultaneous impact of local anthropogenic structures and regional climatic changes on the subsurface temperature field at two sites in the Central Europe, in Czechia and Slovenia.

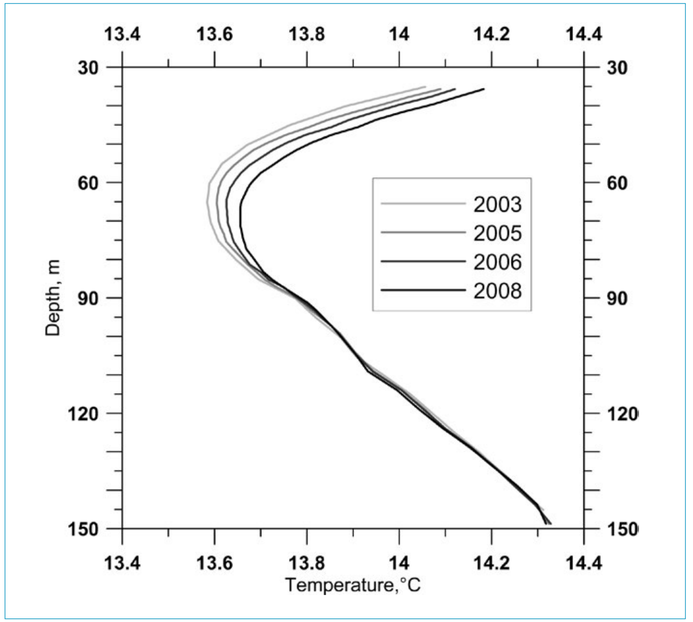

Figure 1: Temperature logs in the borehole Še-1, Slovenia, measured in the years 2003,2005, 2006 and 2008 (from left to right) at the depth section 40 m–150 m.

B.10.2 PRECISE TEMPERATURE MEASUREMENTS IN DEEP BOREHOLES

The analyzed temperature records were obtained by temperature monitoring in a borehole in Prague-Spořilov (Czechia) and by repeated logging of a borehole in Šempeter (Slovenia). The observed data were compared with temperatures yielded by mathematical 3D time-variable geothermal models of the boreholes' sites with the aim to decompose the observed transient component of the subsurface temperature into the part affected by construction of new buildings and other anthropogenic structures in surroundings of the boreholes and into the part affected by the ground surface temperature warming due to the surface air temperature rise. A direct human impact on the subsurface temperature warming was proved and contributions of individual anthropogenic structures to this change were evaluated. In the case of Spořilov, where the mean annual warming rate reached 0.034°C per year at the depth of 38.3 m during the period 1993 – 2008, it turned out that about half of the observed warming can be attributed to the air (ground) surface temperature change and half to the human activity on the surface in the immediate vicinity of the borehole. The situation is similar in Šempeter, where the effect of the recently built surface anthropogenic structures is detectable down to the depth of 80 m and the share of the anthropogenic signal on the non-stationary component of the observed subsurface temperature amounts to 30% at the depth of 50 m.

GROUND-AIR TEMPERATURE TRACKING AND MULTI-YEAR CYCLES IN THE SUBSURFACE TEMPERATURE TIME SERIES

Long-term observations of air, near-surface (soil) and ground temperatures, collected between 1994 and 2011, monitored in the Geothermal Climate Change Observatory at Spořilov, Prague were analyzed to better understand the relationship between these quantities and to describe the mechanism of heat transport at the land-atmosphere boundary layer. The 17 years long monitoring series provided a surprisingly small mean ground-air temperature offset of only 0.31 K with no clear annual course and with the offset value changing irregularly even on a daily scale. Such value is substantially lower than similar values (1-2 K and more) found elsewhere, but it may be well characteristic for a mild temperate zones, when all so far available information referred rather to more southern locations. As many other observed geophysical data, temperature time series consist of a systematic pattern (usually a set of identifiable components) contaminated by random noise, which makes the identification of the proper pattern difficult. To identify the existing systematic patterns (cycles) of the temperature-time series at several depth levels in the investigated depth interval 0 - 40 m, the observed data were processed with the help of the Fast Fourier Transform and Recurrence Quantification Interval analysis. The latter represents recently developed powerful technique to uncover hidden periodicities in a noisy time environment. At low frequency band the Re-

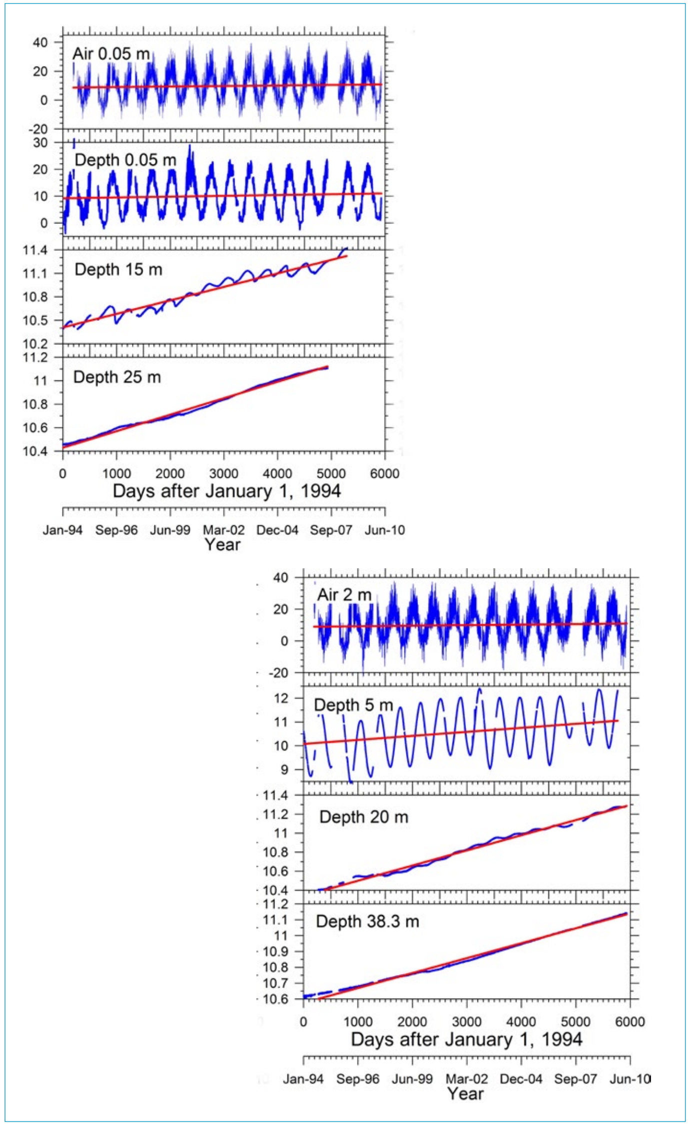

Figure 2: Measured temperature time series monitored at the Spořilov Geothermal Climate Change Observatory.

currence Quantification Interval analysis may provide far finer resolution than the conventional Fast Fourier Transform technique. The results proved considerable similarity for all investigated depth levels. In addition to the annual wave all measured series proved to have a more complex pattern including predominantly 8-year and 11- year periodicities. The results were compared with similar analysis of the meteorological air temperature series as well as with the results of other similar studies.

EFFECT OF POSTGLACIAL WARMING SEEN IN HIGH PRECISION TEMPERATURE LOG DEEP INTO THE GRANITES IN NE ALBERTA, CANADA

The method how to reconstruct surface temperature history from inversions of precise temperature logs done in deep wells is based on the inversion of stabilized, high precision deep borehole temperature logs, which are in thermal equilibrium with surrounding rock. Deep down to some 2-km depth perturbation of the heat flow could be caused by warming since recent glaciations ending some 12–13 ka ago in Canada. Surface temperatures peaked in the Holocene Optimum 6–7 ka ago known to be some 1–2 °C warmer than recent centuries temperature level. Perturbations observed down to 0.1–0.3 km are mainly related to the climate changes of the last 1–2 centuries on large regional and continental scale. All these surface temperature changes influence the subsurface heat flow. The method has been applied to reconstruct timing and amplitude of surface temperature change from latest glacial to postglacial climatic history through many areas inW Eurasia and North America.

Here presented case deals with the reconstruction of the Pleistocene/Holocene ground surface temperature amplitude obtained by inverting temperature log of 2.36-km-deep well drilled deep into some 2- to 2.4-Gyr-year old Precambrian basement rocks just west of Fort McMurray, Alberta, Canada. Drill-cores were collected from granites, which are below 0.55 km and to the well bottom of 2.36 km. The borehole was drilled in 1994 and deepened in 2003. Its logging occurred in June 2011 and, therefore, the measured temperature - depth profile is assumed to be in thermal equilibrium with the surrounding rock and undisturbed by drilling. The temperature profile shows a significant increase in the thermal gradient with increasing depth in the basement rocks (from 18 °C/km at the top of granites to 21 °C/km at the bottom of the well).

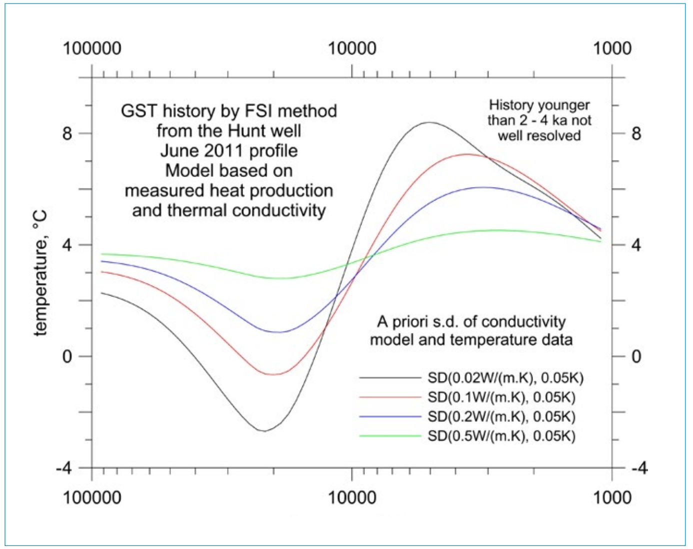

Figure 3: The 100 ka of the ground surface temperature history reconstructed from the Hunt well temperature profile (550 – 2320 m) in the NE Alberta, Canada, for four different values of standard deviation of the a priori thermal conductivity profile. The most realistic results are yielded by the standard deviation of 0.02 W/(m.K).

B.10.4 PRECISE TEMPERATURE MEASUREMENTS IN DEEP BOREHOLES

Amplitude of glacial–postglacial surface temperature change was at first assessed about 10 °C referred to present surface temperature of 5 °C and the glacial base surface temperature during the last ice age at (-4 to -5 °C) (Majorowicz et al. 2012). The refinement of this estimate was done by Majorowicz and Šafanda (2014) based on new information on heat production and thermal conductivity. As a result, the new estimate of the glacial-postglacial amplitude amounts to 10 - 12 K and the minimum values reached during the last ice age some 20 ka ago could be as low as -3 °C.

Acquisition of a temperature-depth log on site of one of boreholes studied in Slovenia

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B.11.1 RESPONSES OF THE BASIC CYCLES OF 178.7 AND 2402 YEARS IN SOLAR-TERESTRIAL PHENOMENA DURING THE HOLOCENE

Time-series reconstructions of solar-terrestrial phenomena (solar, volcanic activities, surface air temperature, etc.) dating several thousands of years back by means of radiocarbon (14C), 10Be, or 18O isotopes, have been employed for study of possible responses of the ordered (trefoil) vs. disordered intervals (types) of the solar inertial motion (SIM) as well as of the 370 years exceptional segments occurring in steps of 2402 years in these phenomena. The trefoil intervals are about 50 years long and the Sun returns to the trefoil intervals always after 178.7 years, on average. During intermediate intervals the Sun follows chaotic (disordered) orbits (Fig. 1).

A reasonably precise basis for study of relationships between SIM, solar-terrestrial and climatic records appeared after the solar orbit had been divided into two basic types: the ordered type (following a trefoil path), lasting c. 50 years and the disordered type, lasting c. 130 years. The prolonged solar and temperature minima coincided with intervals of chaotic SIM. Responses of two basic types of the SIM were described (Fig. 1). Prolonged (grand) minima coincide with the intervals of the chaotic SIM, long-term maxima approximately coincide with the centres of the trefoils.

A response of a stable character of very long (370 years) trefoil intervals of the SIM was also shown (Fig. 2). The deepest and longest solar (temperature) minima (of the Spörer or Maunder types) occurred in the second half of the 2402 yr cycle in accordance with the most disordered types of the SIM there.

It was also found that very long (nearly 370 years) intervals of the solely trefoil orbit of the SIM occurred in steps of 2402 yr. Such exceptional intervals occurred in the years 159 BC - 208 AD, 2561 BC - 2193 BC, 4964 BC - 4598 BC, etc. A stable behaviour of solar-terrestrial phenomena corresponding to a stable behaviour of the SIM during these long segments was demonstrated. It was also found that the deepest and longest solar (temperature) minima (of Spörer or Maunder types) occurred in the second half of the 2402 years cycle, in accordance with the respectively most disordered types of the SIM. The results indicate a primary, controlling role of the SIM in solar–terrestrial and climatic variability.

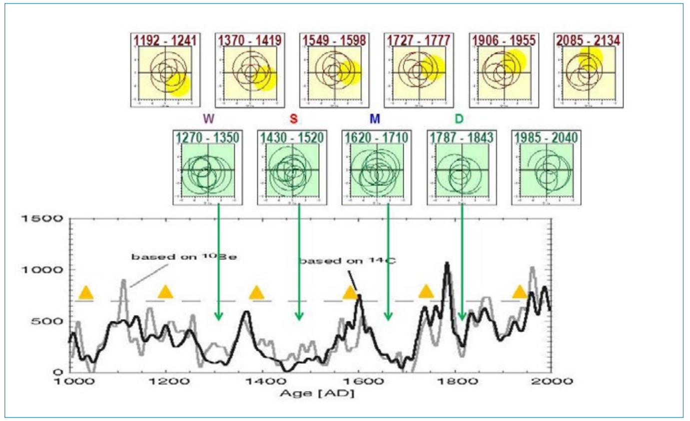

Fig. 1: Solar orbit patterns divided into two basic types, the one ordered in JS (Jupiter-Saturn) trefoils (yellow) and one disordered (chaotic) (green) type. The Sun is returning at the trefoil orbits after 178.7 yr. The Sun moves in the area with a diameter of 4.3 rs, where rs is solar diameter or 3 × 106 km. The yellow circles denote the Sun. Below: a solar modulation record based on 14C and on 10Be since 1000AD (taken from Muscheler et al., 2007). Long-term maxima in these records tend to coincide with the trefoil intervals (yellow triangles mark their centres). Grand prolonged minima occurred in accordance with the intervals of the chaotic motion of the Sun (see lower green orbits), W - Wolf, S – Spörer, M – Maunder, D – Dalton minima. A moderate chaotic (green) type of the SIM (1980–2040) indicates lowered both solar activity and surface air temperature. Y-axis denote solar modulation function

B.11.2 RESPONSES OF THE BASIC CYCLES OF 178.7 AND 2402 YEARS IN SOLAR-TERESTRIAL PHENOMENA DURING THE HOLOCENE

The Sun has a layered structure and the greatest jump of physical parameters was found at the boundary between radiative and convection zones. Satellite observations (SOHO, etc.) found a thin shear layer between the radiative and convection zones, now called the tachocline. This layer is likely to be the place where the solar dynamo operates (Abreu et al., 2012; Mörner, 2013). The layered Sun is forced to move along the given loops and arcs, its velocity ranges between 36 and 64 km.h−1, its mean velocity is about 50 km h−1. It would be interesting to compare a changing velocity of the Sun with a velocity of shear flows in the tachocline.

The SIM is computable in advance based on celestial mechanics, which opens predictive possibilities. The intervals of the nearly identical SIMs will serve as the supporting bases in searching for mutual relations between the SIM and different types of solar–terrestrial phenomena, including climatic ones. Charvátová (2009) showed that the SIMs in the years 1840–1905 and 1980–2045 are nearly identical and of a moderately chaotic type. The forthcoming patterns of solar-terrestrial phenomena are likely to be analogous to those recorded after 1873.

I.G. research staff involved:
I. Charvátová, P. Hejda

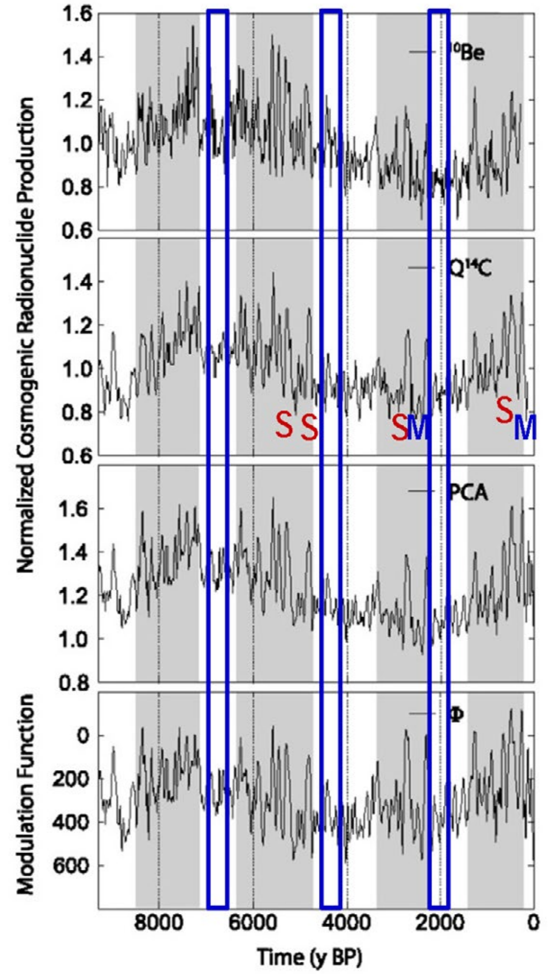

Fig. 2: Normalized cosmogenic radionucleide productions since 9000 BP (taken from McCracken et al. 2013) and the cycle of 2402 years in the SIM („present“ means 1950 AD.) Blue vertical lines denote the exceptional trefoil intervals in steps of 2402 years (long 370 years) and the SIM is therefore of stable type within those lines. The smaller deviations occurred during these intervals while the greatest deviations occurred in the second half of the 2402 years cycle such as S – Spörer or M – Maunder type of prolonged (grand) minima in correspondence with the respúective chaotic intervals of the SIM

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Muscheler, R., Joos, F., Beer, J., Muller, S.A., Vonmoos, M. and Snowball, I., 2007. Solar activity during the last 1000 years inferred from radionuclide records. Quaternary Sci. Rev.26, 82-97, doi: 10.1016/j.quascirev.2006.07.012.

B.12.1 CIRCULATION CHANGES IN THE WINTER LOWER ATMOSPHERE AND LONG-LASTING SOLAR/GEOMAGNETIC ACTIVITY

The relationship between solar activity, or parameters closely related to solar activity and winter lower atmosphere data, changes very strongly in time. For this reason the relationship has often been questioned. The latest research revealed that the Sun is more likely to affect lower atmosphere by multiple means and that the effects of solar and geomagnetic activity occur on different timescales. In a recent study, Bochníček et al. (2012) examined the association between high long-lasting solar/geomagnetic activity and geopotential height (GPH) changes in the winter lower atmosphere, based on their development in the Northern Hemisphere in winter periods (December–March) of 1950–1969 and 1970– 2002. Solar/geomagnetic activity was characterised by the 60-day mean of the sunspot number R/by the 60-day mean of the daily sum of the Kp index. The GPH distributions in the lower atmosphere were described by 60-day anomalies from their long-term daily average at 20 hPa/850 hPa. The data were adopted from the NCEP/NCAR reanalysis. The 60-day mean values of solar/geomagnetic activity and GPH anomalies were calculated in five-day steps over the whole winter period. The analysis was carried out using composite maps which represent their distribution of the GPH anomalies during high solar activity ($R \geq 100$) and high geomagnetic activity ($\sum Kp \geq 20$). Analysis has shown that the distribution of GPH anomalies depends on solar activity, geomagnetic activity and the phase of winter period (early or late winter). The nature of this relationship differs between the time intervals involved, i.e. 1950–1969 vs. 1970–2002. Positive anomalies in the polar stratosphere (20 hPa) were detected during the whole winter periods of the years 1950–1969. Significant anomalies were detected in the lower troposphere (850 hPa) during the second half of the winter period. The distribution of GPH anomalies on the maps compiled with regard to solar activity was similar to the distribution on maps compiled with regard to geomagnetic activity. In the interval 1970–2002, significant negative GPH anomalies were detected in the stratosphere at high latitudes and positive anomalies were detected in the region of low latitudes. The distribution of GPH anomalies in the lower troposphere was substantially affected by situations in which, together with high solar activity, also high geomagnetic activity occurred.

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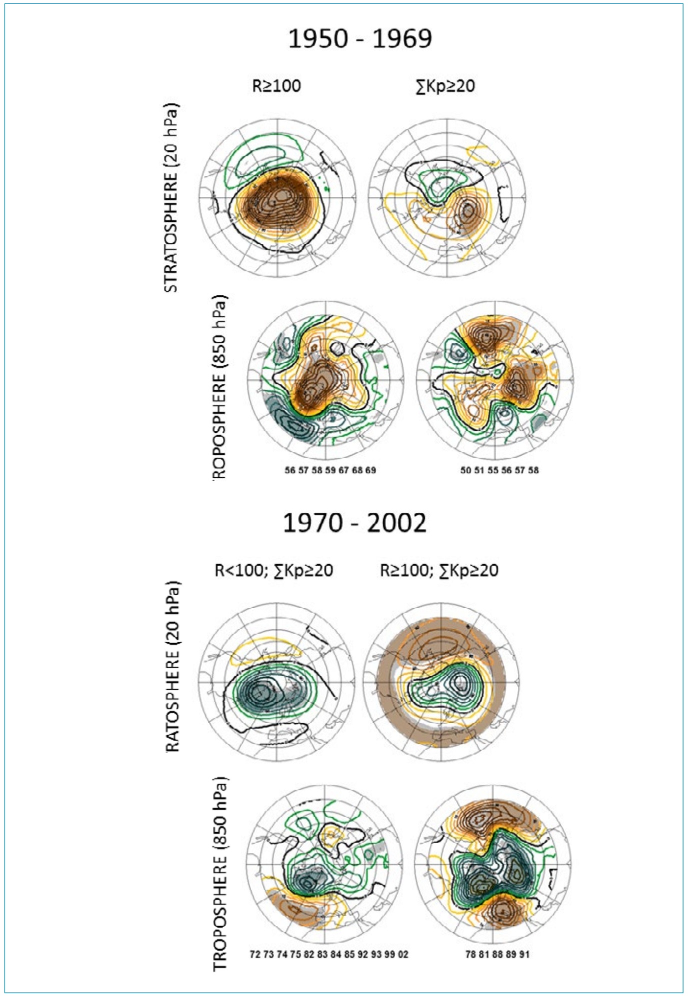

Fig. 1: Composite maps of 60-day winter (31 December–28 February) mean values of GPH anomalies at the geopotential levels of 20 hPa and 850 hPa under high solar activity ($R \geq 100$) and high geomagnetic activity ($\sum Kp \geq 20$). GPH anomalies were computed from the long-term (1950–2002) average. The pairs of numbers below each map indicate the year in which the particular 60-day period started. Positive anomalies are plotted as yellow-brown lines and negative anomalies as green-blue lines. Shadings indicate areas where the Monte Carlo test gave the highest score. The contour intervals are 30m/5m for plots in 20 hPa/850 hPa, respectively.

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B.13.1 GEOMAGNETIC ACTIVITY FORECAST BY NEURAL NETWORKS

A geomagnetic storm can be regarded as an event in which disturbances are triggered by solar eruptions. These features, that have their origin in the magnetic activity of the Sun, propagate through interplanetary space and interact with the terrestrial magnetosphere. The disturbances can influence the performance and reliability of space-and ground-based technological systems at risk, causing temporary disruption or even permanent damage of the systems. For these reasons, there is an increasing demand to predict the conditions in the near-Earth space (Saiz et al., 2013).

Geomagnetic activity strongly depends on the velocity, temperature and particles density of the solar wind and on the orientation of north-south component Bz of the interplanetary magnetic field (IMF). These parameters are continuously measured by the satellites at the Lagrange point L1 situated on the line between the Earth and Sun about 1.5 million kilometers from the Earth. The average warning time of the forecast based on these data is a few hours. This is roughly the time needed for the plasma of disturbed solar wind to travel from L1 point to the magnetosphere, plus the time required for the geomagnetic disturbance to develop. Geomagnetic activity is usually characterized by indices. We have proposed a model to forecast a 1-hour lead Dst index (Revallo et al., 2014). Our approach is based on artificial neural networks combined with an analytical model of the solar wind-magnetosphere interaction. The solar wind parameters have been used to compute analytically the discontinuity in magnetic field across the magnetopause. This quantity has already been shown to be important in connection with ground magnetic field variations. We assessed the predictive capability of the model with a set of independent events and found correlation coefficient CC = 0.74 ± 0.13 and prediction efficiency PE = 0.44 ± 0.15.

The methods of mid-term forecast of geomagnetic activity are based on the information about solar

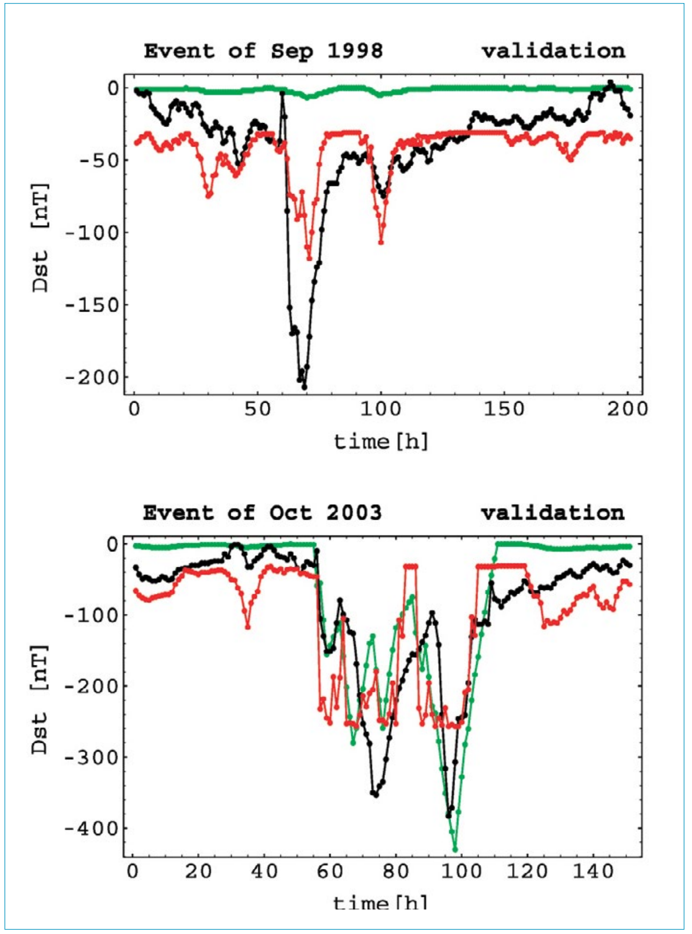

Fig. 1a: Observational (black) and modeled series of the Dst index for validation data sets: purely analytical model (green), artificial neural network combined with the analytical model (red).

flares and coronal mass ejections. As the interval between appearing of the solar flare and interaction of ejected plasma cloud with the magnetosphere ranges from 2 to 4 days, the early warning could be possible. However, it is very difficult to estimate the orientation of Bz in the immediate vicinity of the magnetosphere one day or even a few days in advance. We have therefore proposed a neural-network model, which assumes the worse of the possibilities – the dominant southern orientation of the interplanetary magnetic field (Valach et al., 2014). The model thus provides forecast of potentially dangerous high geomagnetic activity should the interplanetary coronal mass ejections hit the Earth under the most unfavorable configuration of cosmic magnetic fields. It is impossible to know in advance whether the unfavorable configuration is going to occur or not; it could be just said that it will occur with the probability of about 30 %. The method can be used as a preliminary alert that can be later state more precisely by the short-term forecast as explained above.

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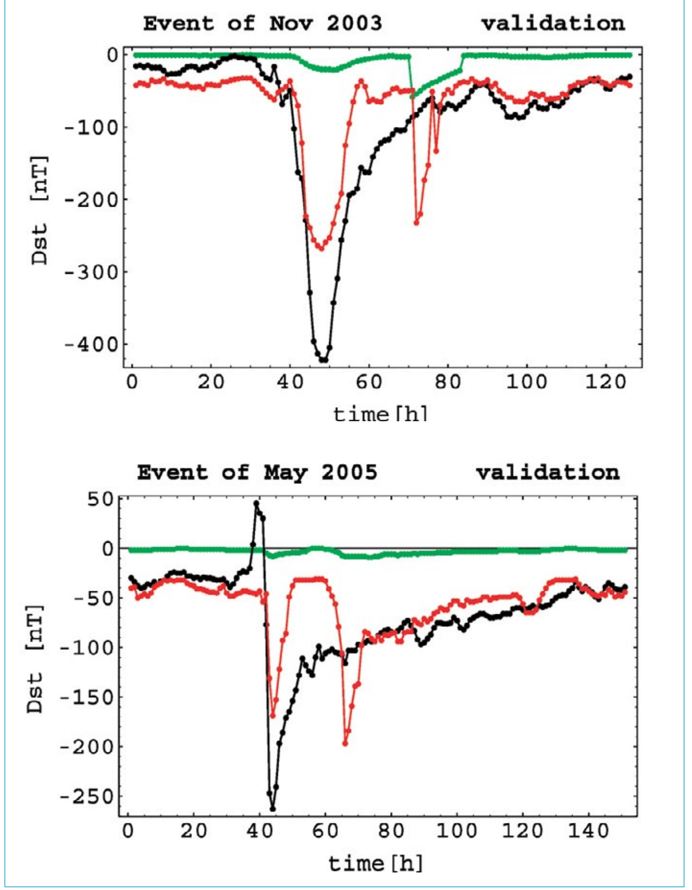

Fig. 1b: Observational (black) and modeled series of the Dst index for validation data sets: purely analytical model (green), artificial neural network combined with the analytical model (red).

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Valach, F., Bochníček, J., Hejda, P. and Revallo, M, 2014. Strong geomagnetic activity forecast by neural networks under dominant southern orientation of the interplanetary magnetic field, Advances in Space Research, 53, 589-598. doi: 10.1016/j.asr.2013.12.005

B.14.1 MAGNETIC FIELDS GENERATED BY HYDROMAGNETIC DYNAMOS AT THE LOW PRANDTL NUMBER IN DEPENDENCE ON THE EKMAN AND MAGNETIC PRANDTL NUMBERS

According to present knowledge, the Earth's magnetic field is generated by a self-sustained homogeneous dynamo operating in the liquid part of the Earth's iron core. The theory of hydromagnetic dynamo is able to describe the origin, spatial and temporal evolution of geomagnetic field and conditions, which must be satisfied for the dynamo action. Numerical modelling of self-consistent dynamos has made noticeable progress in the last 18 years due to progress in computer technology. Results of numerical simulations are very similar to the observations of the recent geomagnetic field and to the paleomagnetic research. However, many geodynamo models are mostly based on the thermal convection, which provides sufficient and a good approximation of real conditions in the Earth's fluid interior. Thus, the superadiabatic radial temperature gradient between the core-mantle boundary and the inner core boundary constitutes the main driving force of convection in most dynamo models. Nevertheless, recent geodynamo models could be based - and many of them already are - on thermochemical convection or on convection driven by the heat flux from the inner core boundary. Although the numerical results agree with observations of the recent geomagnetic field and with paleomagnetic research, numerical simulations of the geomagnetic field are unable to run in the Earth-like parameter regime because of the considerable spatial resolution required. Geodynamo models in the Earth-like parameter regime are still a great challenge. The Prandtl number is the only parameter the geophysical value of which can be directly used in dynamo models.

The study of Šimkanin and Hejda (2013) invsetigated the dependence of hydromagnetic dynamos on the magnetic Prandtl number at low Prandtl number values. In all the investigated cases, the generated magnetic fields are dipolar and neither transition to hemispherical dynamos nor weaker magnetic fields (which are less dipole dominated) were observed, although the inertia becomes important. The magnetic field becomes weak in the polar regions (is “convected out of polar regions”) only for low Prandtl numbers and when the inertia becomes important. However, whether the magnetic field gets weak in the polar regions (is “convected out of polar regions”) or not depends also on the magnetic Prandtl number. The magnetic Prandtl number has to exceed a minimum value in order to sustain dynamo action. If the magnetic diffusion is small (large magnetic Prandtl numbers) then this phenomenon does not exist but if it is large (small magnetic Prandtl numbers) it exists because the strong magnetic diffusion significantly weakens the magnetic field inside the tangent cylinder. The magnetic diffusion and inertia seem to act in the same direction as to weaken the magnetic field inside the tangent cylinder.

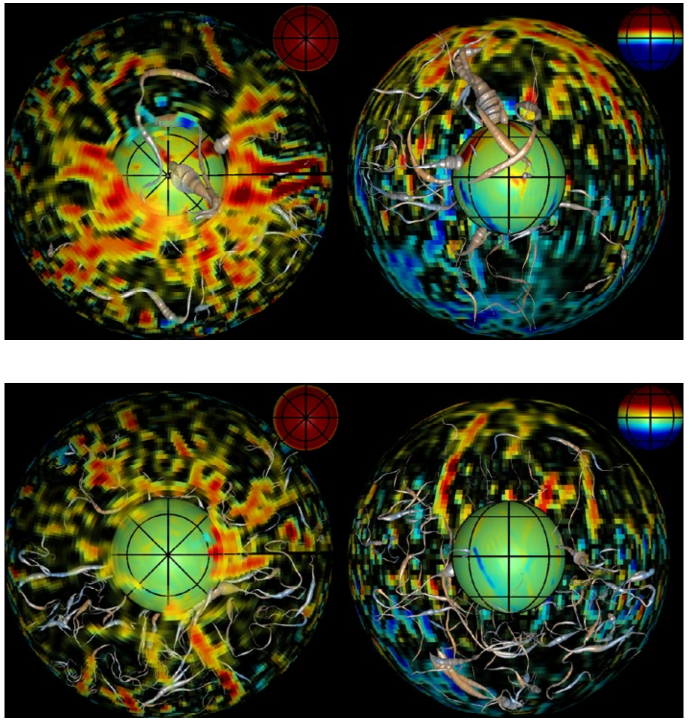

Fig. 1: The space distributions of magnetic field in the case of large magnetic Prandtl numbers (top) and of small magnetic Prandtl numbers (bottom). The left-hand panels provide the top (polar) view, the right-hand panels the side view. The ICB and CMB boundaries are colour-coded with

the radial magnetic field. Red (blue) colours indicate outwards (inwards) oriented field. The field lines are rendered as tubes with a thickness which is proportional to the local magnetic energy. The radial

magnetic field as seen from the Earth’s surface is presented in the upper-right inserts.

I.G. research staff involved:

J. Šimkanin, P. Hejda

References:

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B.15.1 A KINEMATIC MODEL OF VERTICAL GEOMAGNETIC FIELD VARIATION RESULTING FROM A STEADY CONVECTIVE FLOW

Geomagnetic secular variations are variations of geomagnetic field coupled with its generation processes going on in the Earth's core. Among the range of secular variations, the westward drift belongs to the most visible ones. A kinematic hydromagnetic problem was investigated in order to follow the effects of a prescribed three-dimensional convection on an initially given magnetic field. The vertical velocity profile is z-dependent, z being the vertical coordinate and consists of two parts; one appropriate to the diffusionless region of the main volume of the fluid and the other appropriate to the resistive boundary layer at the rigid wall. The induction equation for the vertical component of the magnetic field is solved analytically in Cartesian geometry in these two distinct regions. Besides the horizontal transport of the magnetic field in the main volume, there is also field distortion due to the vertical velocity gradient; the upwelling flow causes it to weaken while the downwelling causes intensification. The resulting form at the surface of the main volume is a time-varying magnetic field, which then penetrates the boundary layer. This thin region, where the velocity rapidly tends to zero, behaves like a solid conductor, thanks to the assumption of a steady flow in the main volume. It generally attenuates the magnetic field. Depending on the velocity field configuration in the main volume, it may also cause a sinusoidal variation of the magnetic field in z. Under appropriate conditions, a reversed magnetic field is obtained on the surface. In the context of the geomagnetic secular variation, this may be an explanation of the westward drift of reversed magnetic flux patches.

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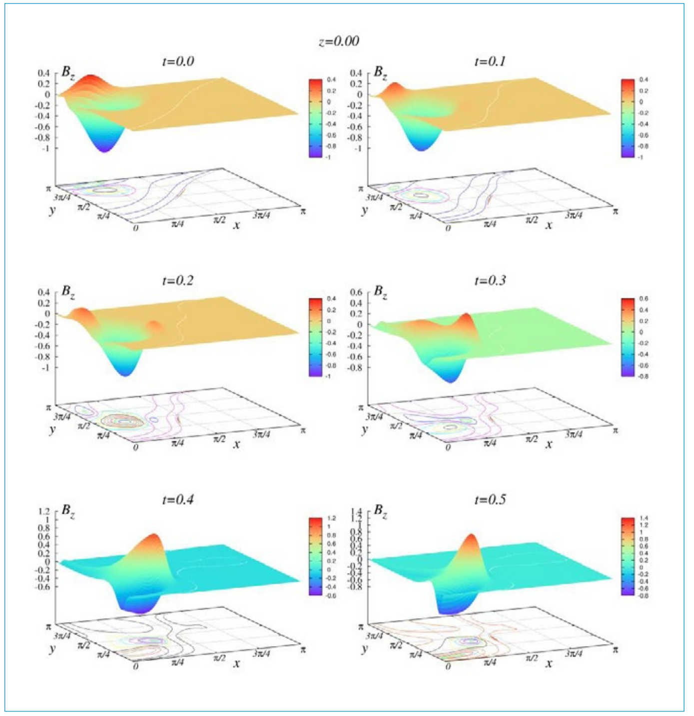

Fig. 1: The vertical magnetic field on the surface z = 0 having passed across the resistive boundary layer.

Reference:

Marsenić, A., 2014. A kinematic model of vertical geomagnetic field variation resulting from a steady convective flow. Geophysical & Astrophysical Fluid Dynamics, 108, 191–212, DOI: 10.1080/03091929.2013.840723

B.16.1 RAY-THEORY COMPUTATIONS OF SEISMIC WAVE FIELDS IN COMPLEX STRUCTURES

The study of seismic wave propagation in three-dimensional (3D) laterally inhomogeneous structures consisting of isotropic and/or anisotropic layers often requires the use of approximate, but sufficiently accurate, approaches. These approaches are expected to be simple, fast and transparent.

One of such approaches is the paraxial ray approximation, a generalization of standard ray theory, which permits approximate evaluation of seismic wave field not only along a ray, but also in its vicinity. It was used for the approximate computation of two-point paraxial travel times,i.e.,traveltimesbetweent-wospecifiedpointsinavicinityofareferenceray(Červený, Iversen&Pšenčík, 2012;bin Waheed,Pšenčík, Červený, Iversen&Alkhalifah,2013).One of the tests of the accuracy of the approximate formula on a model of vertically inhomogeneous, transversely isotropic medium (axially symmetric anistropic medium) whose axis of symmetry varies with depth is shown in Figure 1. The figure is a map of differences of approximate and exact travel times between point S (0, 0) and an arbitrary point in a vicinity of point R (2.5,2.5). Travel times were calculated from the quantities determined at R along the ray (white curve) from S to R. Because no two-point ray tracing were needed to calculate travel times from S to points of the studied region, the procedure is extremely fast.

Another approximate approach is based on the combination of the ray theory and perturbation theory. It was used in computations of seismic wave fields in inhomogeneous, weakly anisotropic media. In the so-called weak-anisotropy (WA) approach, the wave-field quantities in a weakly anisotropic medium were evaluated as perturbations of their counterparts in a reference isotropic medium. The WA approach was used when developing relatively simple and fast procedures for approximate computation of complete wave fields of P waves (Masmoudi and Pšenčík, 2014) or coupled S waves (Pšenčík, Farra and Tessmer, 2012) in smooth media of arbitrary weak or moderate anisotropy. In Figure 2, projections of 3D rays into the vertical section of the orthorhombic BP benchmark model obtained with the use of the WA approach (Masmoudi and Pšenčík, 2014) are shown. Recently, this procedure was extended to P waves in layered media (Pšenčík and Farra, 2014). Accuracy of the procedure seems to be similar to that for smooth media. Certain inaccuracies appear only in a vicinity of critical reflections, see Figure 3, where, however, the ray method yields inaccurate results anyway. In Figure 3, standard ray-theory seismograms (black) are overlain by seismograms (red) computed using the WA approach.

The WA approach played also an important role in the derivation of alternative reflection move out formulae (Farra and Pšenčík, 2013a,b, 2014), used broadly in seismic exploration. In Figure 4, a comparison of relative errors of standard formulae (black) and alternative formulae of varying accuracy (red, green and blue) for travel time of a P wave reflected from the bottom of a homogeneous orthorhombic (anisotropy of lower symmetry than the transverse isotropy) layer along several profiles with varying azimuth is shown. The reflector used coincided with one of the symmetry planes.

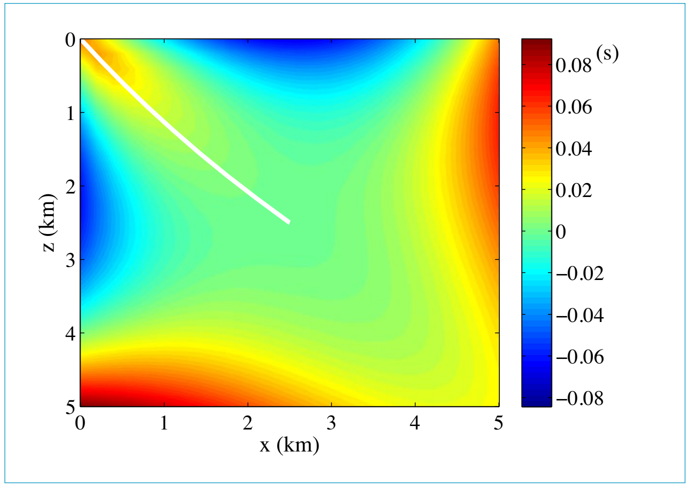

Figure 1: Travel time differences T (R′, S) − Tex(R′, S) (in seconds) in the inhomogeneous model of transversely isotropic medium with horizontal axis of symmetry varying with depth. Tex(R′,S) - exact two-point travel time, T(R′,S) - paraxial two-point travel time. T(R′,S) calculated from quantities determined along the reference ray (white curve) connecting points S at (0,0) and R at (2.5,2.5). Points R′ cover the studied (5 × 5) km region.

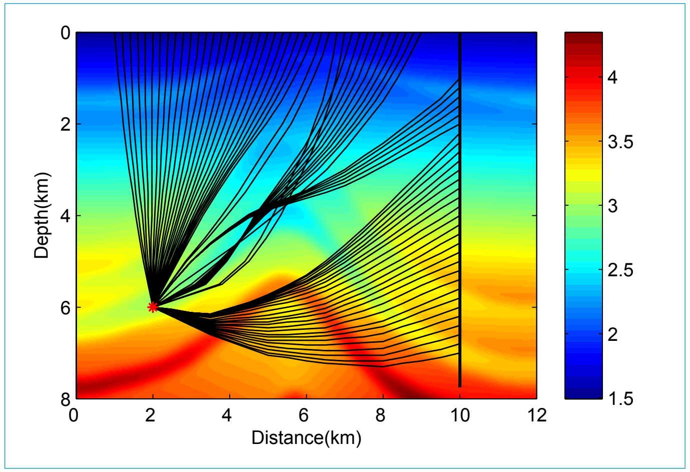

Figure 2: BP orthorhombic model - projections of rays to the plane (x1, x3); vertical phase velocity in the background, the scale in km/s.

Recently, attempts were also made to use the combination of the ray and perturbation theories in the travel time inversion (Růžek and Pšenčík, 2014). It seems that the potential of this combination has not yet been exhausted.

I.G. research staff involved:

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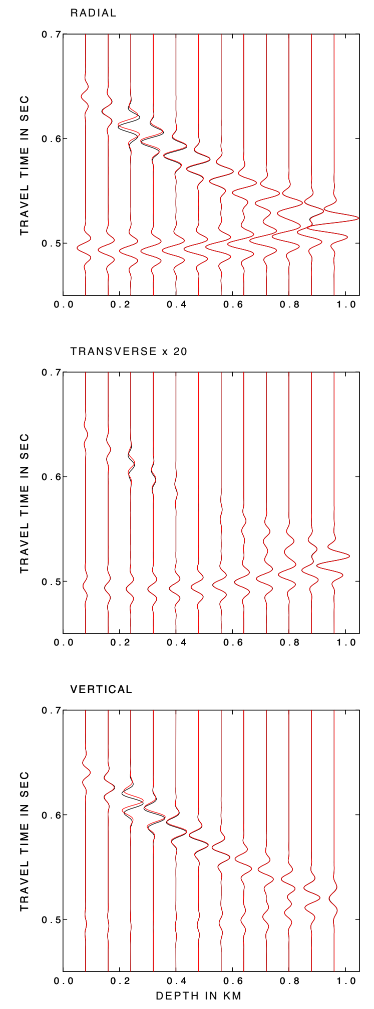

Figure 3: Comparison of exact (black) and first-order (red) P-wave ray synthetic seismograms of direct and reflected waves generated by the vertical single-force source in the model composed of two transversely isotropic layers with horizontal axes of symmetry. The greatest differences can be observed on the third trace, closest to the critical point, where the ray theory does not work properly itself. Note the amplification of the transverse component.

Refences:

bin Waheed, U., Pšenčík, I., Červený V., Iversen, E. and Alkhalifah, T., 2013. Two-point paraxial traveltime formula for inhomogeneous isotropic and anisotropic media: tests of accuracy. Geophysics, 78, C41–C56.

Červený, V., Iversen, E. and Pšenčík, I., 2012. Two-point paraxial travel times in an inhomogeneous anisotropic medium. Geophys.J.Int., 189, 1597–1610.

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Pšenčík, I., Farra, V. and Tessmer, E., 2012. Comparison of the FORT approximation of the coupling ray theory with the Fourier pseudospectral method. Stud. geophys. geod., 56, 35–64.

Pšenčík, I. and Farra, V., 2014. First-order P-wave ray synthetic seismograms in inhomogeneous, weakly anisotropic, layered media. Geophys.J.Int., 198, 298–307.

Růžek, B. and Pšenčík, I., 2014. P-wave traveltime inversion in weakly anisotropic media: a preliminary study. Seismic Waves in Complex 3-D Structures, 24, 17–34, online at www.sw3d.cz

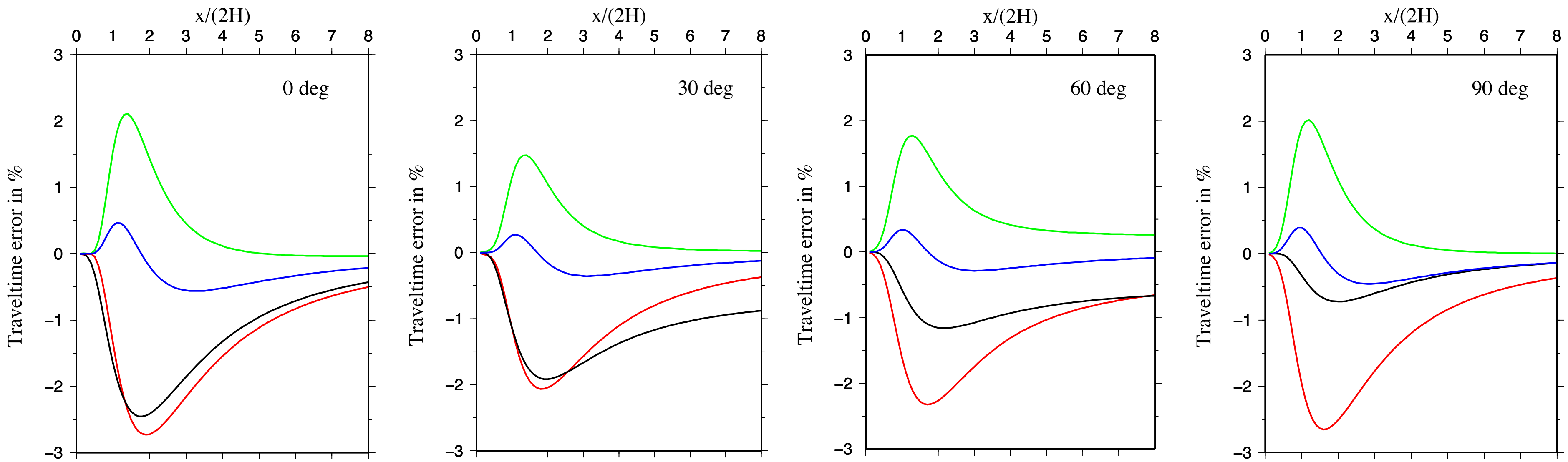


Fig. 4: Relative travel time errors of P waves reflected from the bottom of an orthorhombic layer, with the reflector coinciding with one of the symmetry planes. Errors of the reference formula (black) and of the first-order equation ignoring (red) and considering (green) the difference in directions of slowness and ray vectors and of the second-order equation (blue) are shown.

B.17.1 ITERATIVE JOINT INVERSION FOR STRESS AND FAULT ORIENTATIONS FROM FOCAL MECHANISMS

Stress inversions from focal mechanisms require a knowledge of which nodal plane is the fault. If such information is missing and faults and auxiliary nodal planes are interchanged, the stress inversions can produce inaccurate results. It is shown that the linear inversion method developed by Michael (1984) is reasonably accurate when retrieving the principal stress directions even when the selection of fault planes in focal mechanisms is incorrect. However, the shape ratio is more sensitive to the proper choice of the fault and substituting the faults by auxiliary nodal planes introduces significant errors. This difficulty is removed by modifying Michael's method and inverting jointly for stress and for fault orientations. The fault orientations are determined by applying the fault instability constraint and the stress is calculated in iterations. As a byproduct, overall friction on faults is determined. Numerical tests show that the new iterative stress inversion is fast and accurate and performs much better than the standard linear inversion. The method is exemplified on real data from central Crete and from the West-Bohemia swarm area of the Czech Republic. The joint iterative inversion identified correctly 36 of 38 faults in the central Crete data. In the West Bohemia data, the faults identified by the inversion were close to the principal fault planes delineated by foci clustering (Fig. 1). The overall friction on faults was estimated to be 0.75 and 0.85 for the central Crete and West Bohemia data, respectively.

IG research staff involved:
V. Vavryčuk, F. Bouchaala, T. Fischer

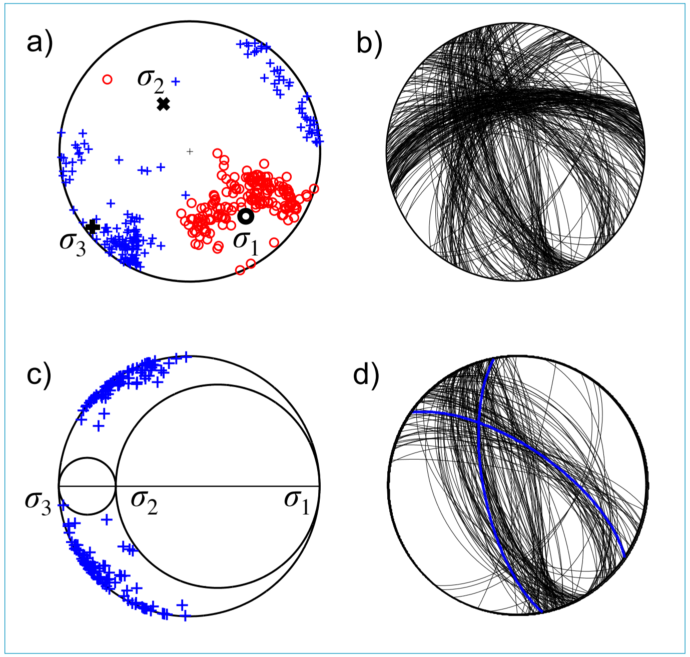


Fig. 1: Iterative inversion for stress using the West Bohemia data. (a) P/T axes with retrieved principal stress directions, (b) nodal lines, (c) Mohr's circle diagram with positions of faults (blue plus signs) and (d) faults identified by stress inversion.. The P and T axes in (a) are marked by red circles and blue plus signs, respectively. The blue lines in (d) define the principal faults in the West Bohemia region identified from foci clustering.

References:

Vavryčuk, V., 2014. Iterative joint inversion for stress and fault orientations from focal mechanisms, Geophys. J. Int., 199, No. 1, 69-77, doi: 10.1093/gji/ggu224.

Michael (1984) doplnit citaci

B.18.1 SECOND-DEGREE MOMENTS – A TOOL TO REFINE THE REGIONAL MOMENT TENSORS

Tectonic earthquakes are caused by predominantly a shear slip along a fault, which implies the mechanism described by two compensated force couples, so called double-couple (DC). Nevertheless, notable amount of moderate and strong earthquakes exhibits considerable percentage of non-double-couple (non-DC) components, as reported by agencies determining earthquake mechanism on routine basis from long-period (LP) seismograms. We hypothesize that it may be due to the methodology applied: the routine LP approach is believed to allow apply point-source approximation, but large earthquake foci are definitely not points. Even LP seismograms may contain finite-source effects, which cause distortion of the mechanism determined in the point-source approach – spurious non-DC appears. Removal of these effects should clean the mechanism – reduce the non-DC. We simulated the situation in a synthetic experiment and searched for it at real earthquakes then.

The situation is sketched in Fig. 1: at distant stations on LP records we look at the earthquake focus as at a point but this "point" does have its fine structure – the rupture propagating along the fault. The suitable tool for its description is the second degree moments (SDM), higher terms beyond the standard moment tensor in the Taylor expansion of the representation theorem (Backus, 1977a, b).

We verified the procedure in synthetic tests mimicking a magnitude 6 event similar to earthquakes on North-Anatolia fault observed by regional stations there. To simulate an inversion made in practice, we compared processing of exact "data" and several inconsistencies – mislocated hypocenter, mismodeled velocity profile and noise in the data. The approach proved to work well: whereas there was a notable non-DC as a result of the point-source inversion of the finite-extent data, the procedure succeeded to shrink it essentially.

Afterwards, we applied the approach to data from 5 moderate to strong earthquakes (Fig. 2), which possess large non-DC in the moment tensor reported by seismological agencies. At the end, in 4 cases the non-DC was reduced significantly and in the remaining one it remained unchanged (Fig. 2). The geometry of the mechanism – orientation of the nodal planes – remained nearly the same everywhere except the Tohoku aftershock. To explain the failure, we performed a sensitivity test in which we explored the stability of the SDM retrieval assuming a noise superimposed on the data. It appeared that the noise level, which was still acceptable for the Solomon, Kobe, Izmit and Bolivia earthquakes, destroyed the solution for the Tohoku aftershock, indicating its instability.

The effect of the source finiteness, which is neglected in the determination of the standard MT, can bias the retrieved mechanism. The SDM tool is just suitable for its cleaning: it removes the spurious non-DC and remains the orientation of the mechanism largely unchanged. The phenomenon is mostly relevant to regional source inversions working with periods of tens of seconds. In the Global CMT solutions obtained from periods of hundreds of seconds, the effect is obviously small.

I.G research staff involved
Adamová, P.

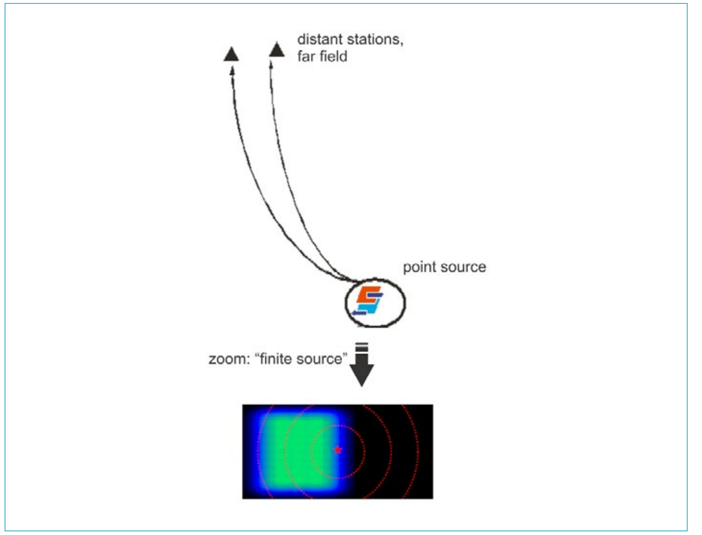


Fig. 1: Sketch of the point-source vs. finite-extent concepts of the earthquake focus. In the zoomed focus, the slip function used for synthesizing the finite-extent data in the synthetic tests.

B.18.2 SECOND-DEGREE MOMENTS – A TOOL TO REFINE THE REGIONAL MOMENT TENSORS

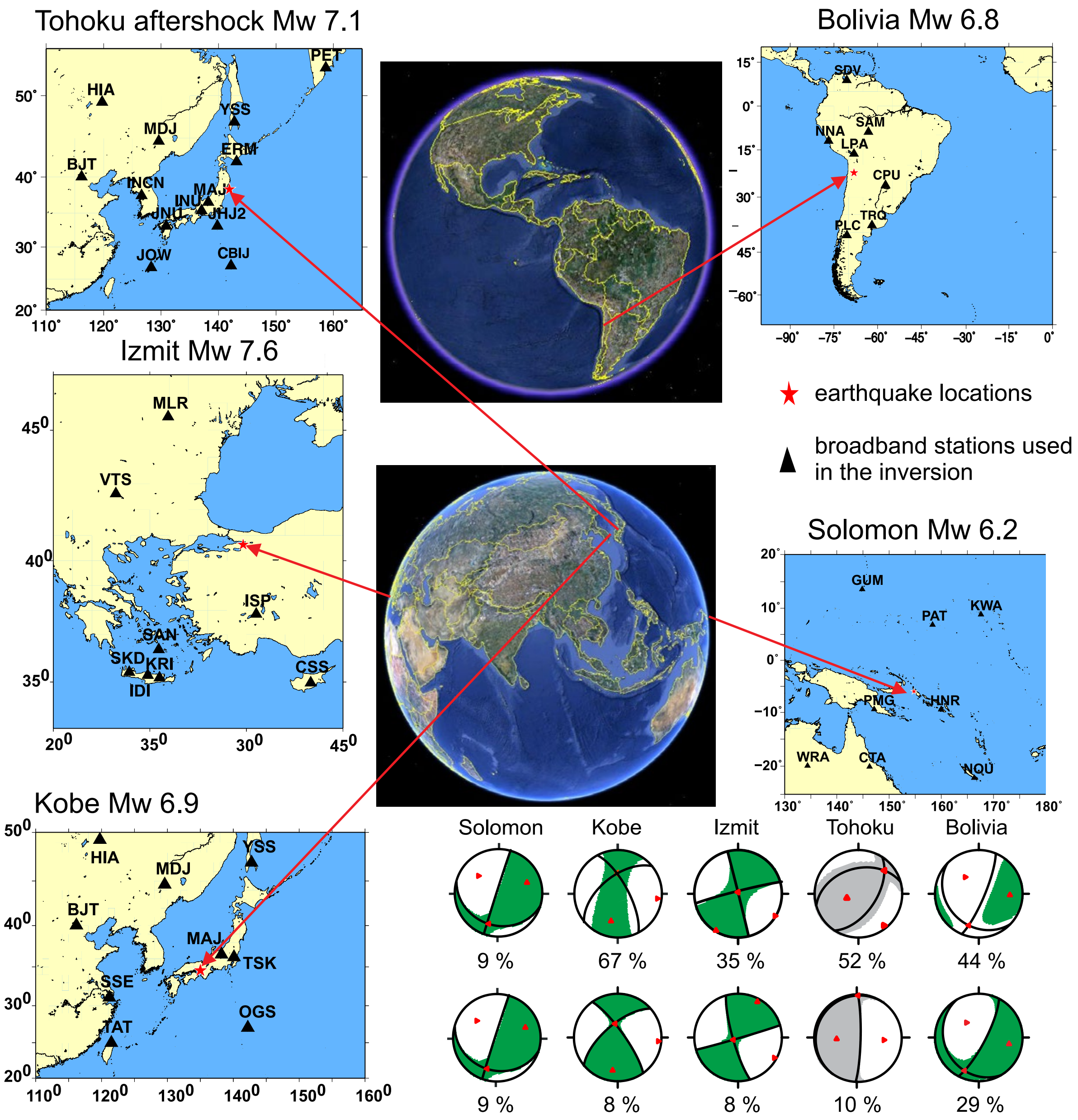


Fig. 2: The earthquakes investigated: Izmit 17/08/1999, Mw 7.6, Solomon 12/06/2003, Mw 6.2, Kobe 16/01/1995, Mw 6.9, Tohoku aftershock 7/04/2011, Mw 7.1, Bolivia 17/11/2005 Mw 6.8. Right bottom: Removal of spurious the non-DC due to a source finiteness from the mechanism: Top line: standard MT solution from the long-period regional data, bottom line: reprocessed MT from records after removing the SDM effects.

References:

Adamová, P. and Šílený J., 2010. Non-Double-Couple Earthquake Mechanism as an Artifact of the Point-Source Approach Applied to a Finite-Extent Focus, Bulletin of the Seismological Society of America, 100 (2), 447{457, doi: 10.1785/0120090097, 2010.

Adamová, P. and Šílený J., 2013. Disputable Non-Double-Couple Mechanisms of Several Strong Earthquakes: Second-DegreeMoment Approach, Bulletin of the Seismological Society of America, 103 (5), 2836{2849, doi:10.1785/0120130014, 2013.

Backus, G. E., 1977a. Seismic sources with observable glut moments of spatial degree two, Geophysical Journal International, 51 (1), 27{45, doi: 10.1111/j.1365-246X.1977.tb04188.x, 1977a.

Backus, G. E., 1977b Interpreting the seismic glut moments of total degree two or less, Geophysical Journal International, 51 (1), 1{25, doi: 10.1111/j.1365-246X.1977.tb04187.x, 1977b.

B.19.1 SHEAR-TENSILE CRACK (STC) – A CONVENIENT TOOL TO DESCRIBE EARTHQUAKE MECHANISM IN INDUCED SEISMICITY

Seismic events induced by man-made activity like mining, extraction of gas and oil, or geothermal energy exploitation, are often more complex that tectonic earthquakes represented by a simple shear slip along a fault. They are originated in a complex stress field due to presence of open spaces like corridors and stopes in mines, or in the presence of an injection of a fluid into the rock mass, which is the case of hydrofracturing of treatment wells and water circulation through the geothermal reservoir. Thus, volume changes and non-shear slip can be expected in the focus of the induced earthquake. Traditional description of sources like these is the moment tensor as a general dipole source. For practice, however such a description may be too general. Problems arise during its (source?) reconstruction from noisy data in the inverse process, which may be additionally ill-conditioned due to inexact hypocenter location and/or availability of a rough velocity/attenuation model only. Then, the retrieved source may be biased, containing artifacts of a low-quality data or the inconsistent inverse problem and, thus, the genuine non-shear slip component may be hidden. It seems therefore reasonable to assume a more simple source model that directly describes the physical phenomena anticipated in the particular focus. A simple combination of shear slip with a tensile crack or 1D implosion (Figure 1) may be a good model both for natural earthquakes and induced events. For the former, the tensile crack simulates a fault opening due to, e.g., its roughness or bending, in foci of volcanic earthquakes it is capable to simulate a change of volume. As for the induced events, its advantage is obvious as tensile fracturing is a plausible physical process there.

The simplification introduced in the shear-tensile crack (STC) source model is crucial in cases of depleted sensor configuration when the moment tensor fails, in single-azimuth monitoring in particular. Among constrained models of the mechanism, the STC is advantageous from a conceptual view and can be considered as the simplest generalization of the traditional DC corresponding to a pure shear slip. If the inversion is not well posed and a constraint is necessary, the STC is capable of resolving the shear slip and, additionally, possibly providing information on the volume change within the focus.

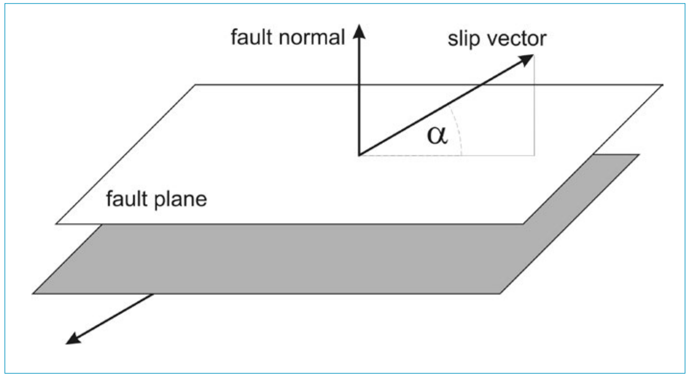


Fig. 1: The STC source model: a combination of shear-slip and tensile opening represented by the slip vector directed from the fault plane by the slope angle α (α = 0° is the pure shear slip and α = 90° is a tensile crack)

B.19.2 SHEAR-TENSILE CRACK (STC) – A CONVENIENT TOOL TO DESCRIBE EARTHQUAKE MECHANISM IN INDUCED SEISMICITY

We performed a detailed testing of the MT vs. STC performance with the set-up of the network monitoring seismic activity during establishing the deep geothermal reservoir in Soultz-sous-Forets in Alsace and during the circulation phase (23 surface stations well covering the area around the wells). In addition to the complete configuration and 4 subsets mimicking a deteriorating coverage, we assumed two steps of mismodeling by simplification of the 8-layer EOST 1-D velocity model into, in turn, 3-layer and 2-layer model. Finally a hypocenter mislocation was considered. In parallel, synthetic data contaminated by a random noise were inverted. The experiments exhibited a clear dominance of the STC over the MT model, especially concerning the DC/non-DC resolution, which is an encouragement and prospect to apply it in the tasks of induced seismicity.

The expectation of a better resolution was demonstrated on several earthquakes from the Soultz reservoir (Figure 2) and from a closed salt mine Ocnele Mari in Romania.

I.G. staff involved:

J. Šílený, Z. Jechumtálová

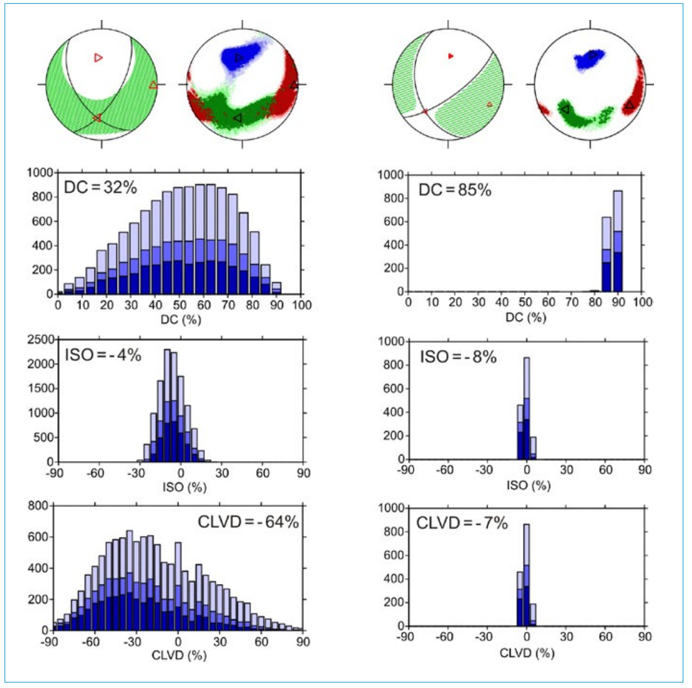


Fig. 2: A sample earthquake M 1.5 from the Soultz geothermal site: inversion of P and S amplitudes into the moment tensor (MT) – left and the shear-tensile crack (STC) source model – right. Top – nodal lines and zone of compression (green), confidence zones of the tension (red), pressure (blue) and null (green) axes; bottom – distribution of the DC, ISO and CLVD components; dark, medium and light colors correspond, in turn, to probabilities of 90, 95 and 99 %. Distributions for the STC are much narrower than those for the MT, which implies markedly better resolution if the STC is applied.

References:

Šílený, J., Jechumtálová, Z. and Dorbath, C., 2014. Small scale earthquake mechanisms induced by fluid injection at the Enhanced Geothermal System reservoir Soultz (Alsace) in 2003 using alternative source models. Pure Appl. Geophys., Vol. 171, Issue 10, 2783-2804, DOI : 10.1007/s00024-013-0750-2.

Jechumtálová, Z., Šílený, J.and Trifu, C-I., 2014. Microearthquake mechanism from wave amplitudes recorded by a close-to-surface seismic array at Ocnele Mari, Romania. Geophys. J. Int. 197 (3): 1608-1626 DOI:10.1093/gji/ggu029

B.20.1 NON-ISOTROPIC SEISMIC RADIATION OF THE 2013 NORTH KOREAN NUCLEAR EXPLOSION

On February 12, 2013, North Korea conducted an underground nuclear test in the north-eastern mountainous part of the country. The explosion reached magnitude mb = 5.1 being recorded at most of seismic stations around the world and becoming one of the best-ever recorded nuclear explosions in history (Fig. 1). Similarly as other underground nuclear explosions in Nevada, Kazakhstan or China, the 2013 North Korean explosion was characterized by a significant non-isotropic seismic radiation. This radiation is manifested by distinct SH and Love waves in the wave field and is inconsistent with the model of a spherically symmetric source. Vavryčuk and Kim (2014) showed that the Love waves were not generated by a tectonic earthquake triggered on a nearby fault structure, but produced by an asymmetry of the explosive source caused by the presence of deviatoric stress in the surrounding rock. The retrieved moment tensor of the 2013 explosion is characterized by the isotropic component of 57±5%, the double-couple component of 17±9% and the compensated linear vector dipole component of 24±7%. The P, T and N axes of the moment tensor are consistent with the principal axes of the regional tectonic stress in the Korean Peninsula (Fig. 2). A comparison of waveforms and particle motions of the 2013 explosion and the previous North Korean nuclear explosion buried in 2009 indicates that the 2013 explosion was slightly more non-isotropic (Fig. 3).

I.G. research staff involved:
V. Vavryčuk

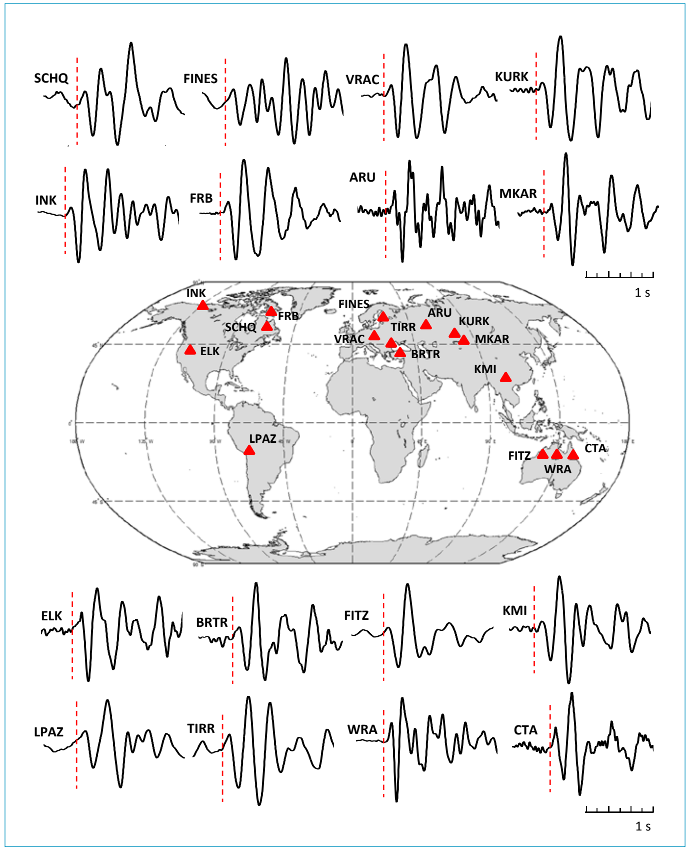


Fig. 1: Teleseismic P waveforms of the 2013 nuclear explosion recorded at selected stations around the world. The velocity records of the vertical component filtered by band-pass filter between 0.7 Hz and 5 Hz are displayed. The red dashed line marks the onset time. Notice a rather unclear and poorly visible positive initial motion at some stations. Time length of 6 s is displayed in seismograms.

References:

Vavryčuk, V. and Kim, S.G., 2014, Nonisotropic radiation of the 2013 North Korean nuclear explosion, Geophys. Res. Lett., 41, doi:10.1002/2014GL061265.

B.20.2 NON-ISOTROPIC SEISMIC RADIATION OF THE 2013 NORTH KOREAN NUCLEAR EXPLOSION

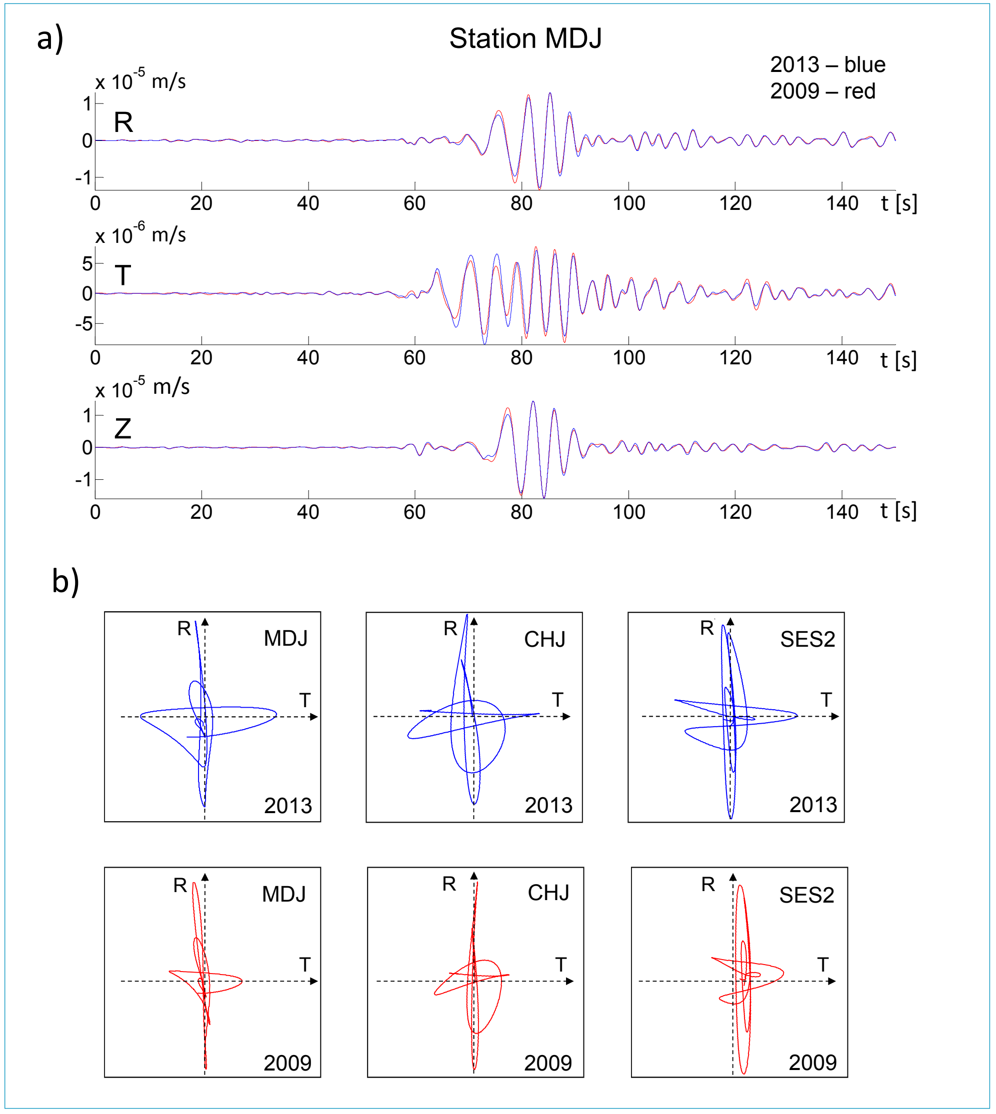


Figure 3: (a) Velocity records of the 2013 and 2009 explosions observed at station MDJ. The records were filtered in the frequency range of 0.02 Hz – 0.25 Hz and rotated into the R-T-Z coordinate system. (b) T-R particle motions of surface waves of the 2013 and 2009 explosions at stations MDJ, CHJ and SES2. The velocity records were filtered in the frequency range of 0.02 Hz – 0.1 Hz. The T, R and Z traces of the 2009 explosion in (a) were multiplied by the scale factors: 2.56, 2.06 and 2.05, respectively.

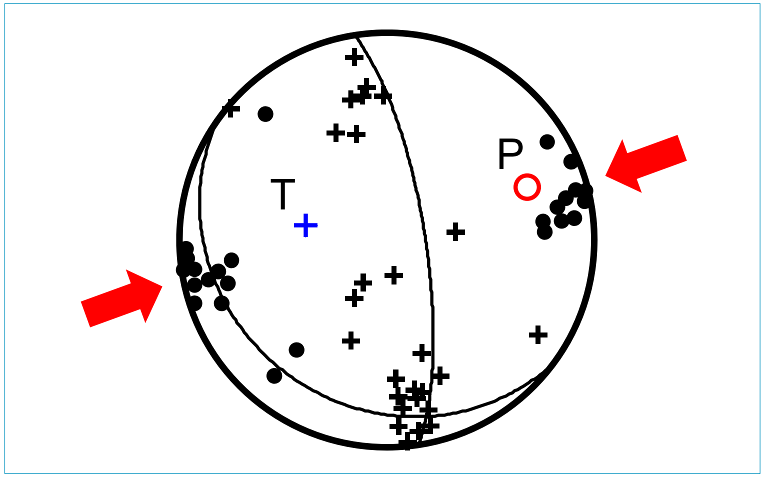


Figure 2: Comparison of the P (black dots) and T (black plus signs) axes of 27 earthquakes from the Korean Peninsula and its surrounding area with the optimum solution for the 2013 nuclear explosion. The red arrows show the maximum compression direction in the region. The P and T axes for the optimum solution of the explosion are marked by the red circle and blue plus sign, respectively. The 27 earthquakes from the period of 1936–2004 with M ≥4.0 are taken from Jin and Park [2007].

B.21.1 PETROPHYSICAL AND GEOCHEMICAL CONSTRAINTS ON ALTERATION PROCESSES IN GRANITES

The hydrothermal alteration of granites has large influence on their petrophysical properties. To reveal the impact of alteration on magnetic and porosity properties of granites we have conducted a complex study of effects of two largely independent alteration processes, related to chemically different fluids, in granites of the Vysoký Kámen stock (the Krudum granite body, Czech Republic). The study included whole-rock geochemical, magnetic and pore-space characterization (Fig. 1).

Flow of hydrothermal fluids through the rock matrix of granite alters substantially not only chemical composition, but also microstructure and physical properties through the metasomatic mineral changes. All these processes (chemical, microstructural and physical) are mutually connected. Alkali feldspathization originated through fluid flow results in leaching of some mafic cations, decomposition of Li-mica and growth of new alkali feldspars. This causes decrease in magnetic susceptibility together with disruption of pore space by its discontinuation and infilling. However, the change of microstructure is not that important to modify, or even disrupt, the orientation of paramagnetic and diamagnetic phases aligned during granitic magma emplacement and thus does not significantly influence the orientation of anisotropy of magnetic susceptibility (AMS).

In comparison, greisenization has considerably larger effect on microstructure and physical properties of granite. Influx of elements of higher atomic weight with hydrothermal fluids induces growth of large amount of new phases (lithium mica, quartz, topaz and K-feldspar). This substantially alters the granite microstructure and mineral density of the rock matrix. The mineral density and microstructural change during the greisenization increase the porosity and size and character of pores to larger, flatter and probably more connected ones. The change of microstructure also leads to complete reworking of the original AMS and probably to decomposition of originally present fine-grained ferrimagnetic phase.

I.G. research staff involved:

Matěj Machek, Zuzana Roxerová, Martin Staněk, Eduard Petrovský

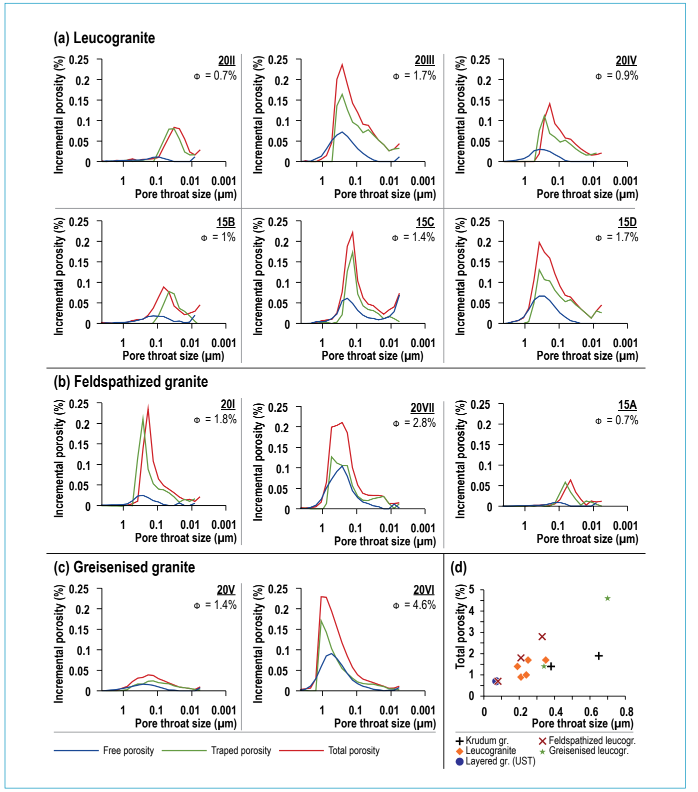


Fig. 1: Results of mercury-injection porosimetry of (a) leucogranite and granite with UST, b) feldspathized leucogranites and c) the greisenized leucogranites. d) graph of relation between pore throat size and porosity.

References:

Machek M., Roxerová Z., Janoušek V., Staněk M., Petrovský E. and René M., 2013. Petrophysical and geochemical constraints on alteration processes in granites. Studia Geophysica et Geodaetica, 57, 710 – 740. DOI: http://dx.doi.org/10.1007/s11200-013-0923-6.

B.22.1 MAGNETIC PARTICLES IN ATMOSPHERIC PARTICULATE MATTER

Magnetic measurements of deposited atmospheric dust can serve as additional parameter in assessing environmental pollution. This method is based on the assumption that atmospherically deposited particles contain a significant portion of ferrimagnetic iron oxides of anthropogenic origin, which can be easily detected. The aim of this study was to identify a clearly magnetic fraction in daily samples of particulate matter less than 10 m in size (PM10), routinely used for air quality assessment and monitoring. Samples of atmospheric PM10, collected at 5 sites with different air-pollution levels and used for standard air quality monitoring, were analyzed from the point of view of presence and basic characteristics of magnetic fraction, which is assumed to be present in form of spherules rich in iron oxides and have thus potential for magnetic monitoring of PM10. The results provide evidence that such spherules are rather abundant at industrial and traffic sites, and, although rare, are found also at a regional background site. Iron oxides were found also in particles of irregular shape, which can be of other sources than combustion of fossil fuel. A relatively low portion of iron revealed using EDAX elemental analyses can be attributed to the masking effect of the Al-silicate surface. Mössbauer spectroscopy proved the presence of Fe3+ in the industrial, traffic and regional background samples. In addition, Fe2+ was detected in the regional background sample. The spectra of the industrial sample, measured at room temperature and 25K, show the same features and are best fitted by sextet, suggesting presence of coarse-grained multidomain magnetically ordered ferric oxides (hematite and/or maghemite). Voltammetry clearly confirmed the presence of iron oxides in the industrial PM10 samples, suggesting coarse hematite/magnetite/maghemite in the former and magnetite in the latter sample. In the other samples these particles were not determined, most probably due to their low concentration, which was beyond the sensitivity limit of the method. Thermomagnetic analyses and decomposition of isothermal remanence acquisition curves confirmed the presence of coarse-grained multidomain magnetite, particularly in the sample from industrial site.

We conclude that samples of PM10, collected at five sites with different environmental stress, contain spherical particles typically of anthropogenic origin. The presence of iron oxides in form of coarse-grained multidomain magnetite in PM10 from industrial site was confirmed by thermomagnetic analyses and decomposition of isothermal remanent magnetization acquisition curves. Although it was not unambiguously proved in samples from other sites, there are indicators suggesting its presence here as well. Our data provide a reliable basis for the interpretation of results of highly-sensitive magnetic measurements of atmospheric PM10 and for air-quality monitoring purposes, especially at industrial, traffic and urban sites.

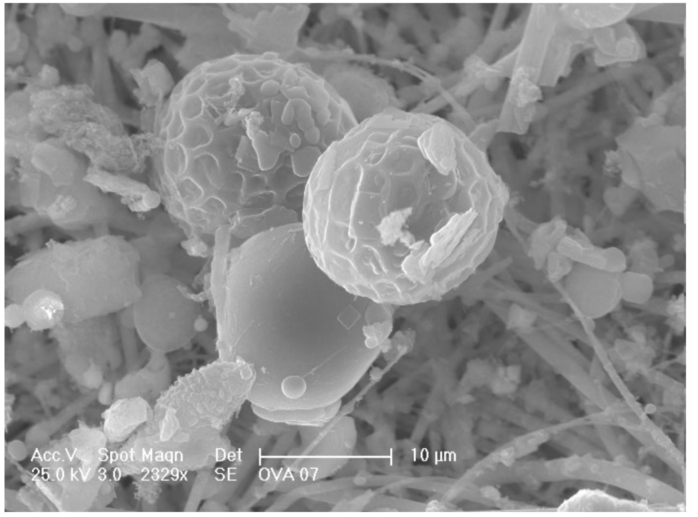


Fig. 1: SEM image of spherical particles rich in iron oxides, observed in sample of PM10 collected at industrial site.

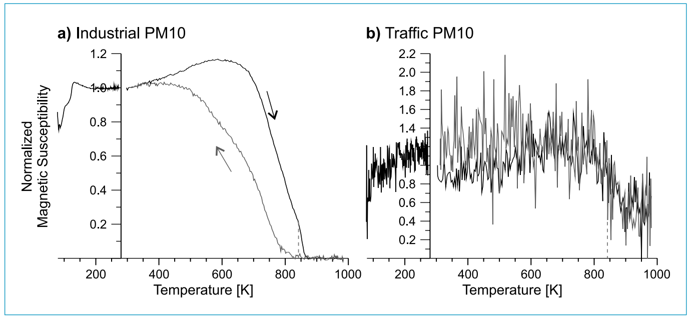


Fig. 2 :Thermomagnetic curves of PM10 samples collected at industrial and traffic sites.

I.G. research staff involved:

E. Petrovský, A. Kapička, H. Grison

Reference:

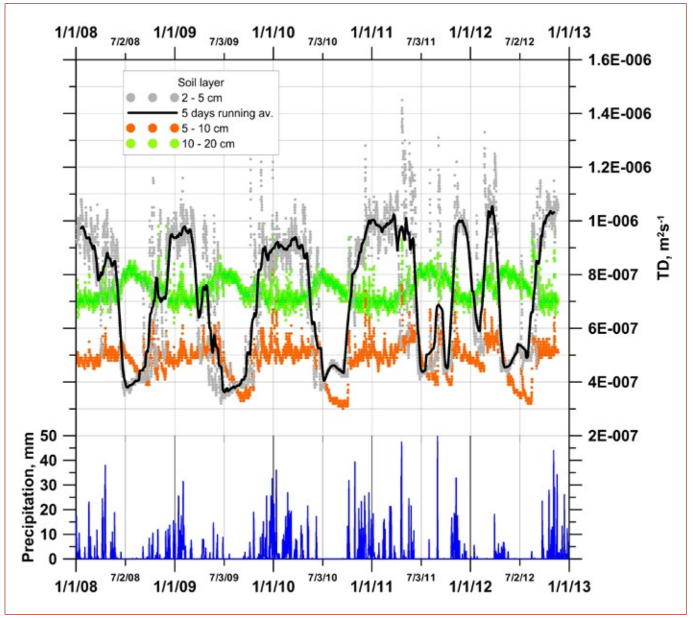
Petrovský E., Zbořil R., Grygar T., Kotlík B., Novák J., Kapička A. and Grison H., 2013. Magnetic particles in atmospheric particulate matter collected at sites with different level of air pollution, Stud. Geophys. Geod., 57 (2013), 755-770, DOI: 10.1007/s11200-013-0814-x

Every year, a number of PhD and MSc – level projects are supervised by the researchers of the Institute of Geophysics and commonly also funded by research grants to the Insitute.
Below, student research projects running or completed between 2012 and 2015 are listed, in alphabetical order of student's names and with the names of supervisors and co-supervisors from the Institute in **bold letters**.

1. PhD-level projects

HEAT TRANSFER IN DIFFERENT KINDS OF SOILS AND ROCKS IN VARIOUS CLIMATIC CONDITIONS

Student: **Petr Dědeček**
Charles University, Prague, Faculty of Science, Institute of hydrogeology, engineering geology and applied geophysics
Supervisor: **Jan Šafanda**
2010 – present
The aim of the doctoral project is to evaluate the relationship between the air and ground temperature of different kinds of soils under different climatic conditions. For that reason the long-term temperature series recorded at observatories in Czech Republic, Slovenia and Portugal will be analyzed to find the most suitable method (algorithm) for estimation of the thermal diffusivity of soils and rocks and to assess relation of conductive and convective heat transfer in shallow subsurface. These findings will be used in second part of the work focused on detection and quantification of the impact of local anthropogenic structures and regional climatic changes on subsurface temperature field.



The crust of the Bohemian Massif derived from Receiver Function method exploiting data from teleseismic passive experiments:

Seasonal changes of apparent thermal diffusivity of soil in connection with daily sums of precipitations (Evora – Portugal)

Publications:

Čermák V., Dědeček P., Šafanda J. and Krešl M., 2010. Climate warming: evidence stored in shallow subsurface. In: Przybylak, R.; Majorowicz, J.; Brázdil, R.; Kejna, M. (Eds.) The Polish Climate in the European Context: An Historical Overview, DOI 978-90-481-3167-9_11, Springer Science+Business Media B.V. 2010

Dědeček P., Rajver D., Čermák V., Šafanda J. and Krešl M., 2013. Six years of ground–air temperature tracking at Malence (Slovenia): thermal diffusivity from subsurface temperature data, J. Geophys. Eng. 10 (2013) 025012 (9pp) doi:10.1088/1742-2132/10/2/025012

Dědeček P., Šafanda J. and Rajver D., 2012. Detection and quantification of local anthropogenic and regional climatic transient signals in temperature logs from Czechia and Slovenia, Climatic Change 113 (3-4), DOI: 10.1007/s10584-011-0373-5

C.1.2 RESEARCH STUDENT SUPERVISION AND CO-SUPERVISION

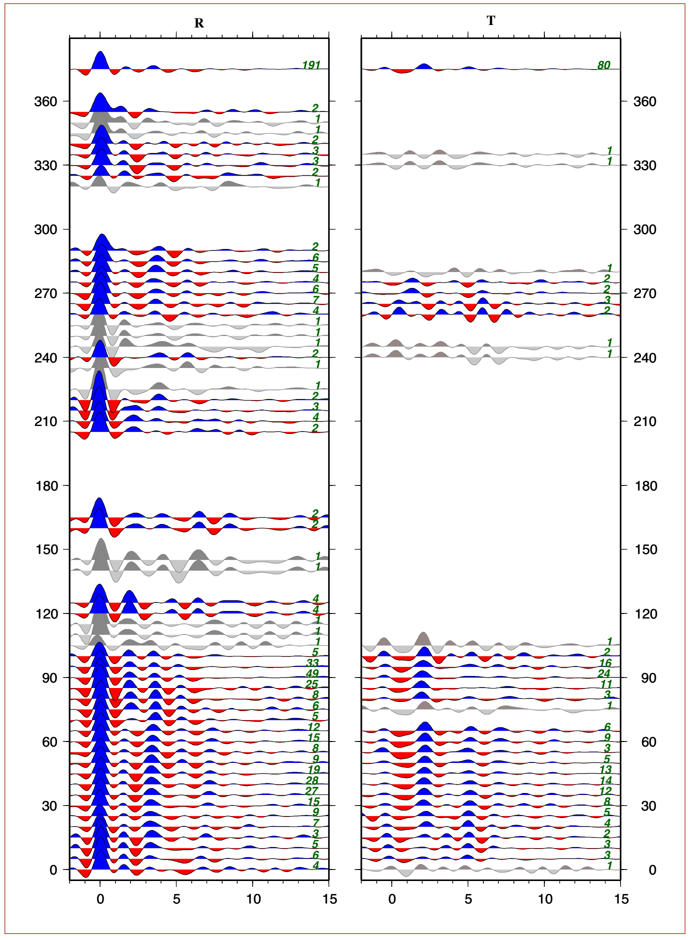
Student: **Kateřina Freyerová**,
Charles University, Prague, Faculty of Science, Department of Physical Geography and Geoecology,
Supervisor: **Jan Šafanda**
2013 - present

The goal of the doctoral project is an improvement of our knowledge about the air-ground-bedrock temperature coupling. This information is needed for a proper interpretation of the ground surface temperature history obtained from the transient component of the temperature – depth profiles measured in deep boreholes. The research will be focused especially on the temporal variability of the annual mean difference between the soil and air temperature and on the factors generating this variability. The current climatic interpretation of the long-term changes of the ground surface temperature is based on the assumption that the annual ground-air temperature difference does not change on the time scale of decades and longer. In order to prove/disprove this hypothesis, the Department of Geothermics of the Institute of Geophysics of the Czech Academy of Sciences established several monitoring sites, where data on air, ground and bedrock temperatures (down to 40 m depth) are collected together with other selected meteorological variables. These observed data will be used in the project.

THE CRUST OF THE BOHEMIAN MASSIF DERIVED FROM RECEIVER FUNCTION METHOD EXPLOITING DATA FROM TELESEISMIC PASSIVE EXPERIMENTS.

Student: **Hana Kampfová Exnerová**,
Charles University, Faculty of Mathematics and Physics, Department of Geophysicsz,
Supervisor: **Jaroslava Plomerová**
2012 – 2014

The doctoral study is focused on crustal structure of the Bohemian Massif, particularly distinct interfaces, with the use of teleseismic P receiver functions (RF). Recordings from both permanent and temporary stations included into passive seismic experiments BOHEMA I - III are processed by the multi-taper correlation method (Park et Levin, 2000). Research supported by grant No. P210/12/2381 of the Grant Agency of the Czech Republic.



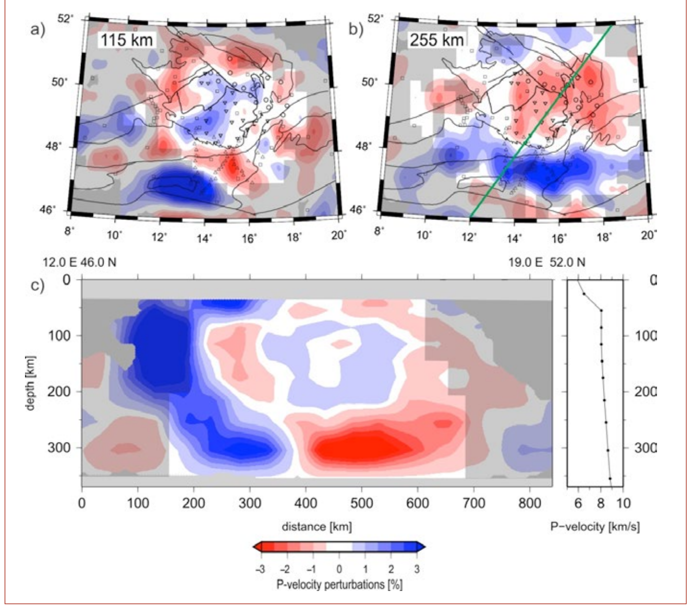
The crust of the Bohemian Massif derived from Receiver Function method exploiting data from teleseismic passive experiments.

Receiver functions characterizing the crust below station Průhonice (PRU). Left frame shows RFs in the frequency-domain in back-azimuth bins of 5° halfwidth for radial components and right one shows transverse components respectively. Large positive pulses on the radial components at zero time delay correspond to direct P waves. Pulses at 3.5 - 3.6 s delays reflect the P-to-S waves converted at the bottom of the crust (Moho). Positive pulses between the two major pulses arae generated by conversions at intra-crustal boundaries.

TELESEISMIC TOMOGRAPHY OF THE UPPER MANTLE BENEATH THE BOHEMIAN MASSIF

Student: **Hana Karousová**, Charles University, Faculty of Mathematics and Physics, Department of Geophysics
Supervisor: **Jaroslava Plomerová**, Co-supervisor: **Vladislav Babuška**
2008 - 2014

The PhD thesis, defended in March 2014, presents results of tomography studies of the upper mantle beneath the north-eastern and southern parts of the BM based on the data from the BOHEMA II and BOHEMA III experiments (2004-2006). Despite the fact that regions with the highest resolution of velocity perturbations differ in the models, tomography images are similar in overlapping parts. Models of the upper mantle show mostly low-velocity perturbations relatively to radially symmetric velocity model of the Earth beneath the BM. Limited high- velocity heterogeneity beneath the Moldanubian unit, extended in the NE-SW direction, reflects thickening of the lithosphere due to a collision of the BM with the Brunovistulian micro-plate during the Variscan orogeny. The tomography based on the data from the BOHEMA III experiment revealed significant high-velocity heterogeneity in the southern margin of the model with a subduction of the lithosphere beneath the Eastern Alps (Fig. 1).
The research was partly supported by grants No. 210/12/2381 of the Grant Agency of the Czech Republic, No. SVV-2013-267308 of Ministry of Education, Youth and Sports, Czech Republic and No.111-926 10/253101 of the Grant Agency of Charles University.



Teleseismic Tomography of the Upper Mantle beneath the Bohemian Massif:

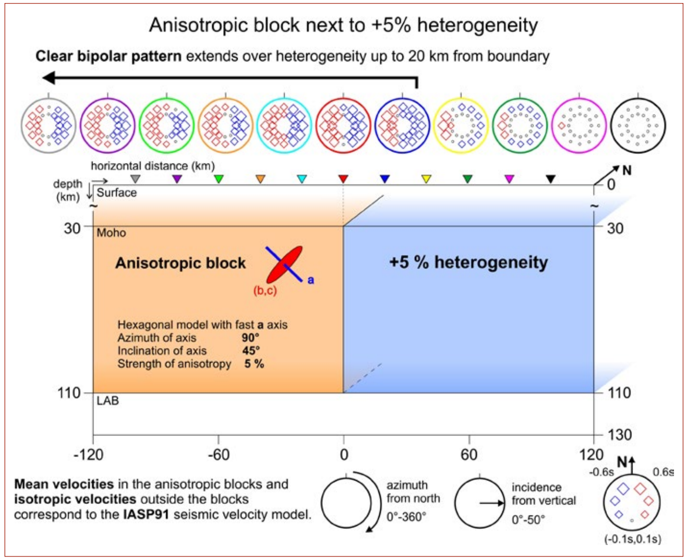
Two horizontal slices at depths of 115 and 255 km and a vertical cross-section through the velocity-perturbation model of the upper mantle based on data from the BOHEMA III experiment and a part of the ALPASS project. Regions with well resolved nodes are illuminated, while fairly and poorly resolved areas are shaded with respect to the values of the diagonal elements of the resolution matrix.

ANISOTROPIC TOMOGRAPHY OF THE UPPER MANTLE BENEATH EUROPE

Student: **Helena Munzarová**,
Charles University, Faculty of Mathematics and Physics, Department of Geophysics
Supervisor: **Jaroslava Plomerová**, Co-Supervisors: **Vladislav Babuška**, **Luděk Vecsey**
2011-present

Considering only isotropic wave propagation in teleseismic tomography studies and neglecting anisotropy is a simplification obviously inconsistent with current understanding of the mantle-lithosphere plate dynamics. Furthermore, in solely isotropic high-resolution tomography results, potentially significant artefacts (i.e., amplitude and/or geometry distortions of 3D velocity heterogeneities) might occur. We have undertaken to develop an anisotropic version (ANITOMO) of frequently used isotropic teleseismic tomography code (TELINV), which will allow us to invert simultaneously for coupled isotropic-anisotropic P-wave velocity models. The new code is currently tested on synthetic datasets and for different anisotropic models. Forward mode of the anisotropic tomography code evaluates travel times of teleseismic P waves propagating through heterogeneous weakly anisotropic models of the upper mantle, which we use to see how a specific structure reflects into directional variations of travel time residuals (Fig. 1). We must carefully test the inversion mode to reveal how different setups of input parameters influence the solutions before application of the new code on real data to evaluate real structure of the upper mantle. Then the anisotropic tomography code will be applied to the datasets from passive seismic experiments that have been carried out in different tectonic settings of Europe, e.g., Bohemian Massif, Scandinavia, TESZ, French Massif Central, Northern Apennines, or which are under preparation, such as experiment AlpArray covering the Alpine mountain belt and surroundings.

Research supported by grant No. P210/12/2381 of the Grant Agency of the Czech Republic; grant No. 111-10/253101 of the Grant Agency of Charles University; and by SCIEX-NMS, Swiss Scientific Exchange Programme.



Anisotropic tomography of the upper mantle beneath Europe:

Synthetic P spheres showing directional terms of relative P-wave travel time residuals visualized in the low-hemisphere stereographic projection, evaluated for a model of the upper mantle. The model consists of an anisotropic block with anisotropy with strength of 5 % whose fast axis is dipping toward the east and an isotropic block with a velocity higher by 5 % than the velocity of the reference IASP'91 radial model. A clear bipolar pattern, often observed in real data, is generated in the synthetic P spheres at the stations located above the anisotropic block. The intensity of the P-sphere pattern increases toward the boundary of the two blocks where the relatively higher velocities of the waves arriving from the east are supported by the high-velocity heterogeneity in the eastern block. Further from the boundary above the heterogeneous isotropic block, the directional variations of relative P-wave travel time residuals disappear.

THERMAL REGIME OF SEASONALLY FROZEN SOILS - MATHEMATICAL SIMULATION AND INTERPRETATION OF THE OBSERVED DATA

Student: **Blanka Pechačová**
Charles University, Prague, Faculty of Science, Department of Physical Geography and Geoecology
Supervisor: **Jan Šafanda**
2013 - present

The doctoral project aims at improving our knowledge of the thermal regime of the seasonally frozen soils. This regime is much more complicated than the thermal regime of soils located in warmer regions, where the soil freezing does not occur. The main "complicating" factor is a release/consumption of the latent heat of freezing/melting of the soil water/ice. The main phenomena connected with the process of freezing/melting are changes of thermal conductivity and diffusivity and convective heat transfer by water migrating due to cryosuction to the freezing front. It is expected that the project will use an extended set of experimental data collected at the laboratory of the supervisor during a long-term soil temperature monitoring, but a use of other data will be welcome, too. Interpretation of the experimental data will involve also their mathematical simulation by software available at the supervisor's laboratory. The results of the project can be useful in studying (i) seasonally melting soils in the permafrost areas, (ii) a formation of the patterned soils and (iii) a difference between the annual averages of air and soil temperatures as a function of depth.

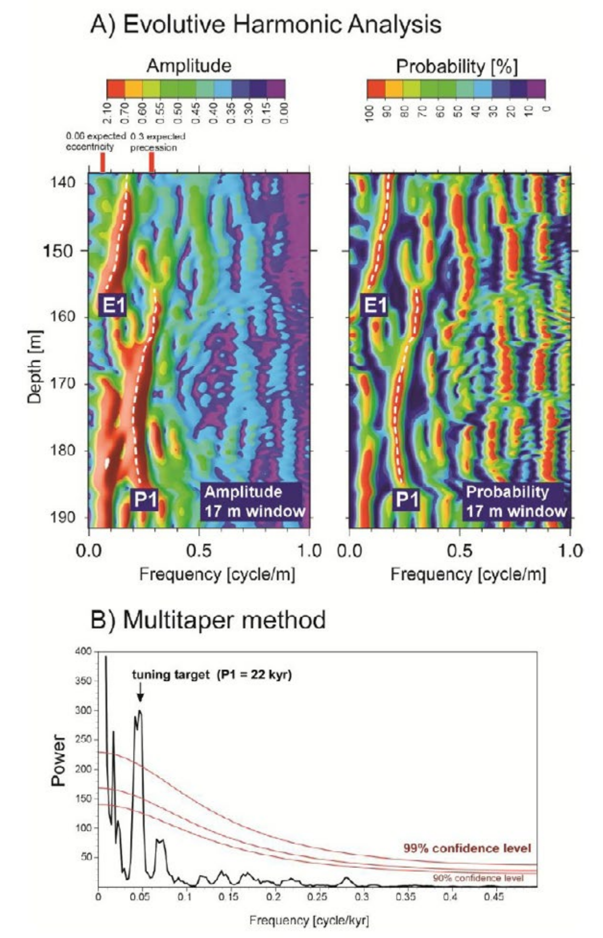
2. MSc-level projects

THE RECORD OF SEA-LEVEL CHANGES, WATER CIRCULATION AND SEDIMENT DISPERSAL IN UPPER TURONIAN HEMIPELAGIC STATA OF THE BOHEMIAN CRETACEOUS BASIN

Student: **Magdalena Hrnková,** Charles University, Prague, Faculty of Science, Institute of Geology and Palaeontology
Supervisor: **Jiří Laurin**
Co-supervisor: **D. Uličný**
2011-2013

A multi-proxy approach was applied to explore in detail a short interval of a markedly cyclic, hemipelagic marine record of the Upper Turonian (Cretaceous) in the Bch-1 research core from the Bohemian Cretaceous Basin. Element ratios, carbonate content, grayscale and magnetic susceptibility data were gathered and used to analyze the origin of lithological variations on several time scales. One of the main objectives was to determine the periodic character of lithological variability through the use of high-resolution datasets and ascertain their possible link to insolation variability. The expanded nature of the Upper Turonian sedimentary record of Bch-1, caused by a temporarily high sediment supply, was particularly favourable for such a high-resolution study. The results cast new light upon the origin of carbonate rhythmicity in Upper Turonian hemipelagic deposits of Bohemian Cretaceous Basin and contributed to the efforts on isolating global climatic signals within these – and similar - successions. On the shortest time scale, quasi-periodic, millennial variations in lithology occurred in response to fluctuating coarse siliciclastic supply, later highlighted by differential diagenesis. Cycles reflecting the Milankovitch precession frequencies were recorded in the clay content variability, most likely reflecting a mixed siliciclastic dilution and carbonate productivity signal. The longest period cyclicity was identified as an eccentricity signal and appears to reflect changes in productivity with a superimposed sediment supply variation, possibly in beat to the sea-level change. The secular onset of hemipelagic sedimentation was confirmed to reflect the changes in paleogeography, circulation and sediment dispersal.

Research supported by grant No. P210/10/1991 of the Grant Agency of the Czech Republic, to D. Uličný.



The record of sea-level changes, water circulation and sediment dispersal in Upper Turonian hemipelagic stata of the Bohemian Cretaceous Basin:

Results of time series analysis of the Bch-1 resistivity log. (A) Amplitude and probability (F-test significance) estimates obtained with a multitaper method (3 2π tapers) applied to a 17-m moving window (Evolutive Harmonic Analysis). Interpreted astronomical signals: E1 = short eccentricity (~100 kyr), P1 = precession (~20 kyr). (B) Multitaper method spectral estimate of resistivity tuned to the P1 signal. 90, 95 and 99% confidence levels of an autoregressive red noise model are indicated.

IRON OXIDES IN SAMPLES OF ATMOSPHERIC DUST COLLECTED AT SITE AFFECTED PRIMARILY BY TRAFFIC (OUTER PRAGUE CIRCULAR)

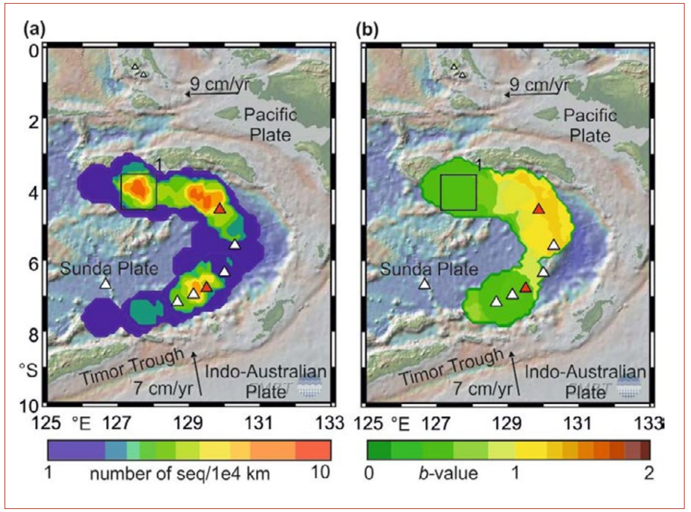
Student: **Gloria Hrušková**
Charles University, Prague, Faculty of Science, Institute of hydrogeology, engineering geology and applied geophysics
Supervisor: **Eduard Petrovský**
2014 – 2015

Samples of atmospheric dust, which were collected in winter and summer on primarily affected sites (at outer Prague circular and beside ironworks in the city of Ostrava) will be studied. Dust samples of size fractions PM1, PM2.5, PM10 and TSP were collected using routine procedure used for assessment of air quality (high-volume samplers). Magnetic properties reflecting the presence of iron oxides, their type, concentration and grain-size distribution will be determined. In addition, magnetic data will be compared with the results of X-ray fluorescence spectroscopy.

TELESEISMIC EARTHQUAKE OCCURRENCE AND SUBDUCTION-INDUCED VOLCANIC ACTIVITY ALONG ISLAND ARCS

Student: **Václav Kuna**
Charles University, Prague, Faculty of Science, Institute of hydrogeology, engineering geology and applied geophysics
Supervisor: **Aleš Špičák**
2011 – 2013

The thesis studied seismo-volcanic interactions at convergent plate margins, focussing on establishing a statistical apparatus appropriate for analyzing seismicity patterns beneath volcanoes. The data base used the EHB catalogue of hypocenter determinations, based on data of the International Seimological Center. The analysis of combined space-time correlation dimension of the EHB catalogue established limits for a definition of seismic sequences related to co-seismic as well as post-seismic stress transfer mechanisms. The analysis of b-value of the Gutenberg-Richter law was carried out to estimate degree of heterogeneity of rock environment. Seismicity pattern beneath subduction-related volcanoes at 14 island arcs was studied by means of seismic sequence density analysis and the b-value analysis. The thesis concentrated on submarine portions of the volcanic arcs, the magmatic/volcanic activity of which is poorly understood. We



Teleseismic earthquake occurrence and subduction-induced volcanic activity along island arcs:

Results of statistical analyses for Banda and Seram volcanic arcs. (a) Analysis of seismic sequence densities. (b) b-value of the Gutenberg-Richter law. Volcanoes are shown by triangles (those active between 1964 and 2008 by red triangles), arrows indicate direction of plate convergence.

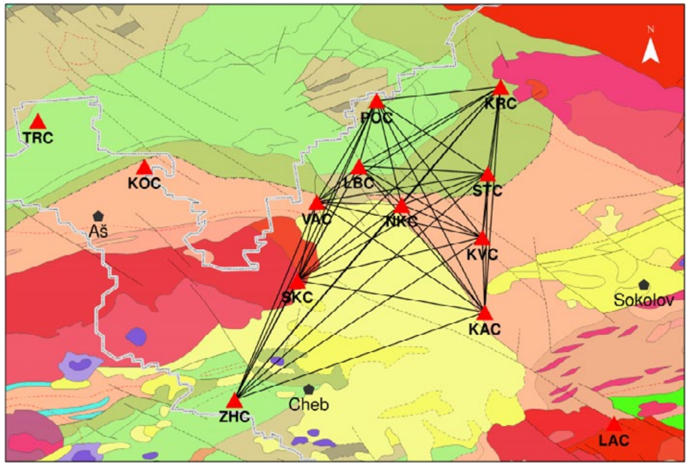
C.1.7 RESEARCH STUDENT SUPERVISION AND CO-SUPERVISION

constrained five areas with specific seismicity patterns and pronounced seafloor morphology in order to find potential volcanic structures. Three of them are situated in the Andaman-Nicobar volcanic arc, one in the southern part of the Ryukyu volcanic arc and one in the Seram volcanic arc. It is highly probable that these areas are sites of recently active magmatic and/or volcanic processes.

DISTRIBUTION OF NOISE SOURCES RECORDED BY THE WEBNET NETWORK AND THE UPPERMOST CRUST S-WAVE VELOCITY MODEL IN THE WEST BOHEMIA SEISMOACTIVE REGION BASED ON SEISMIC INTERFEROMETRY.

Student: **Martin Mityska**
Charles University, Prague, Faculty of Science, Institute of hydrogeology, engineering geology and applied geophysics
Supervisor: **Bohuslav Růžek**
2012 – 2014

The goal of this thesis was to test the properties of ambient short-period seismic noise in the West Bohemia seismoactive region, by applying a modern method of noise processing. The first part of study focused on azimuthslowness analysis for the period range of <3s 6s>, which was conducted by the frequency-wave-number analysis for 10 stations of the WEBNET network. In the second part the surface wave group velocity measurement for every stationtostation pair of 10 WEBNET stations is presented. The interstation group velocity was obtained by crosscorrelating longterm seismic noise records. Pathaveraged Love wave group velocities were processed by the 2D tomography method. Local group velocities are frequency dependent and additional Love waves dispersion analysis for one selected stationtostation pair was performed.



Distribution of noise sources recorded by the WEBNET network and the uppermost crust S-wave velocity model in the West Bohemia seismoactive region based on seismic interferometry.
fig. 1: Geological map of the target region and distribution of the WEBNET stations. Schematic stationtostation lines illustrate relatively sparse ray coverage which should be denser in following investigations.

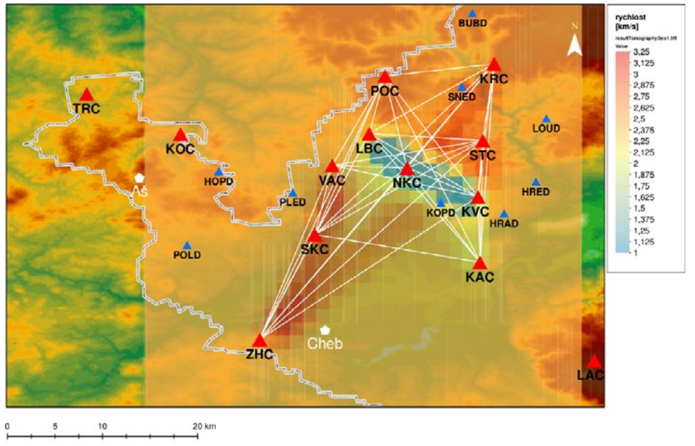


fig. 2: Resulting velocity model of Love waves in the foreground and topography map in the background. The velocity model was calculated using the software “Fast Marching Surface Tomography”

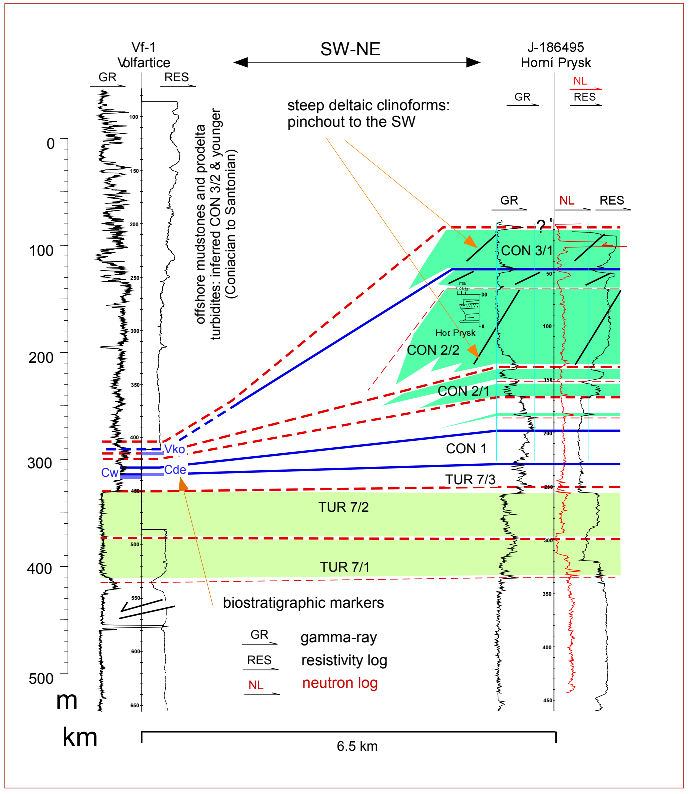
RESEARCH STUDENT SUPERVISION AND CO-SUPERVISION

GENETIC STRATIGRAPHY OF CONIACIAN DELTAIC DEPOSITS OF THE NORTHWESTERN PART OF THE BOHEMIAN CRETACEOUS BASIN

Student: **Roland Nádaskay**
Charles University, Prague, Faculty of Science, Institute of Geology and Palaeontology
Supervisor: **D. Uličný**, co-supervisor: **S. Opluštil**
2011 – 2013

Based on a combination of outcrop and subsurface geological and geophysical data, principal lithofacies and regional-scale depositional geometries were studied in sandstones of early to middle Coniacian age in the northwestern part of the Bohemian Cretaceous Basin. A depositional model of nearhore deposition was developed that interprets the depositional system as dominated by coarse-grained deltas that prograded from the faulted northern basin margin, the present-day Lužice (Lausitz) Fault Zone. Steep, Gilbert-type foresets formed mainly in delta fronts that prograded into deeper water, reaching up to c. 100 m in some units. Regional correlations utilizing well-log and core data made it possible to correlate nearshore sandstone units to their fine-grained time-equivalents in the mud-dominated offshore realm and subdivide the depositional record into genetic sequences, bounded by surfaces of maximum transgression. The transgressive–regressive history of the study area during latest Turonian and Early Coniacian implies two major transgressions coeval with accurately dated events in western North America, suggesting a significant role of eustasy in their formation. In addition, a significant role was played by accelerating subsidence as well as supply from an actively uplifted source area during the early and middle Coniacian. It is likely that the increased tectonic was a precursor to the onset of shortening that eventually led to the inversion of basins in the northern Alpine foreland. The exact kinematic role of individual tectonic structures remain to be understood in the near future, using data on evolution of basin-fill geometries through time, such as provided by this study.

Research partly supported by the Institute of Geophysics, ASCR (IG), as part of activities within the contract SD 162001 between the Czech Geological Survey and the IG.



An example of a cross-section showing correlation between coarse-grained deltaic bodies of units TUR 7 – CON 1 (colour infills) and offshore units (no infill) based on borehole gamma-ray, resistivity and neutron logs, supplemented by outcrop sedimentology and biostratigraphic data. Purple bands indicate volcanic dikes and sills encountered in core. The correlation panel covers a distance of approx. 15 km along depositional dip, from the faulted basin edge. Bold arrow marks direction of sediment supply during most of the Coniacian time.

References:

Nádaskay, R. and Uličný, D., 2014. Genetic stratigraphy of Coniacian deltaic deposits of the northwestern part of the Bohemian Cretaceous Basin. Zeitschrift des deutchen Gesselschafts der Geowissenschaften. Volume 165, Number 4, 547-575. www.dx.doi.org/10.1127/zdgg/2014/002

C.2.1 UNIVERSITY – LEVEL COURSES TAUGHT BY INSTRUCTORS FROM THE I.G.

Specialized as well as fundamental courses are taught by researchers from the Institute of Geophysics at a number of universities in the Czech Republic and abroad..

The list below shows courses taught in 2010-11, fully or partly, by instructors whose main employer was the Institute of Geophysics. The list follows an alphabetical order of names of instructors from the I.G., indicated by **bold letters.**

CLIMATIC CHANGES IN THE EARTH'S HISTORY

Faculty of Science, Charles University, Prague
Course Code: MG421P4
MSc level, 2 hrs./week, winter semester
Instructor: **Jiří Laurin**

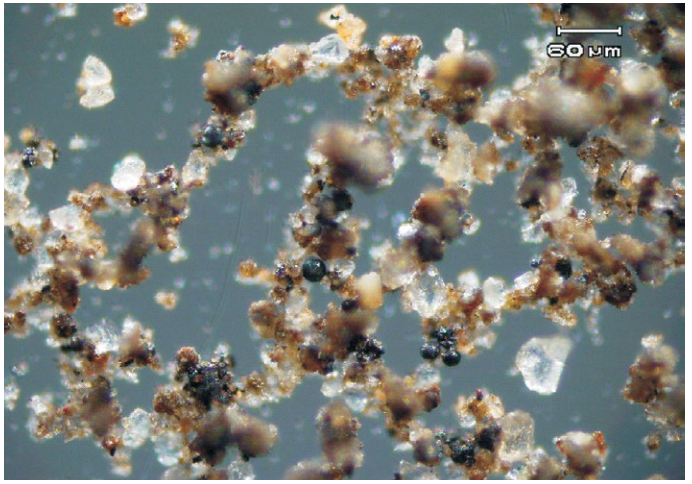
This course describes in detail the key components of Earth's climate system and explains how these components evolved through the geological history, from the Precambrian to the Quaternary. Main focus is on the mechanisms of climate change at the time scales of thousands to millions of years. The origin of the three prominent climatic modes – greenhouse, icehouse and snowball – is discussed in detail. Certain methods of paleoclimate research, such as numerical modeling and time-series analysis, are demonstrated using both synthetic and real geological data.

PETROPHYSICS

Faculty of Science, Charles University, Prague
Course Code: MG452P15
MSc programme, 3 hrs. /week, spring semester
Instructor: **Eduard Petrovský**

Rock as a physical environment. Mass property of rocks: density, porosity, permeability. Magnetic properties of rocks: anisotropy of magnetic susceptibility, paleomagnetic and archaeomagnetic research, magnetostratigraphy. Electrical properties of rocks: resistivity, permitivity, electrochemic activity, special electric properties. Radioactive properties of rocks. Thermal properties of rocks. Mechanical (engineering) properties of rocks. Inelastic and elastic constans of minerals and properties of rocks.

Climatic changes in the Earth's history:
The sedimentary record of permanent and ephemeral lakes provides important information on the past climate. Shortwave infrared through red wavelength image of Lake Carnegie, Australia, courtesy NASA, Visible Earth (http://visibleearth.nasa.gov/).



Petrophysics:
Magnetic extract of topsoil sample from the Ostrava region (N Moravia), with dark spherical magnetite of industrial origin.

C.2.2 UNIVERSITY – LEVEL COURSES TAUGHT BY INSTRUCTORS FROM THE I.G.

MAGNETOMINERALOGY

Faculty of Science, Charles University, Prague
Course Code: MG452P68
MSc programme, 2 hrs. /week, autumn semester
Instructors: **Eduard Petrovský, Aleš Kapička**

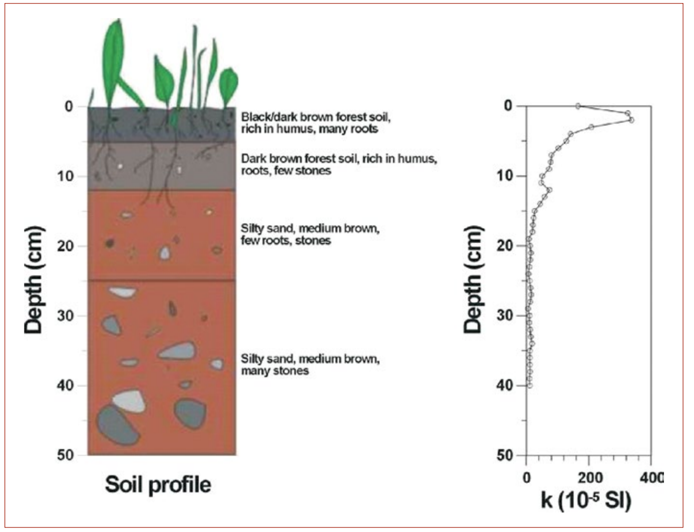
The course is aimed at a general introduction into magnetic minerals as carriers of record of environmental changes. Magnetic record in geomaterials (environmental magnetism) reflects changes in geological histor of the Earth (paleomagnetism), past climatic changes (magnetic paleoclimatology) as well as environmental impact of recent and present human activities, such as industrial pollution. Students will acquire basic knowledge of identification and characterization of magnetic minerals using magnetic methods and will learn to use this knowledge in environmental applications.

Analogous or closely related courses are also run at other universities under the following titles:

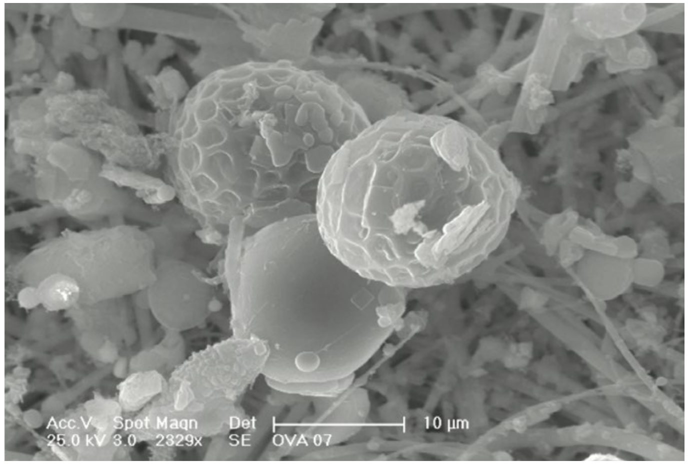
Magnetomineralogy (Applications to Environmental Problems)
Faculty of Science, Masaryk University, Brno
Course Code: G9491
MSc programme, 2 hrs. /week, autumn semester
Instructors: **Eduard Petrovský, Aleš Kapička**

ENVIRONMENTAL MAGNETISM

Faculty of Science, Helsinki University, Helsinki, Finland
Course Code: 535050
MSc programme, 20 hrs., spring semester, each even year
Instructor: **Eduard Petrovský**



Magnetomineralogy:
Typical vertical distribution of magnetic susceptibility in a soil profile, dominated by atmospheric deposition of dust particles.



Environmental Magnetism:
Spherules of industrial origin rich in magnetite ($FeOFe_2O_3$) as part of flight ash.

C.2.3 UNIVERSITY – LEVEL COURSES TAUGHT BY INSTRUCTORS FROM THE I.G.

SEISMIC BODY WAVES IN INHOMOGENEOUS ANISOTROPIC MEDIA

Faculty of Mathematics and Physics, Charles University, Prague
Course Code: NGE063
2hrs./week, winter semester
Instructor: **Ivan Pšenčík**

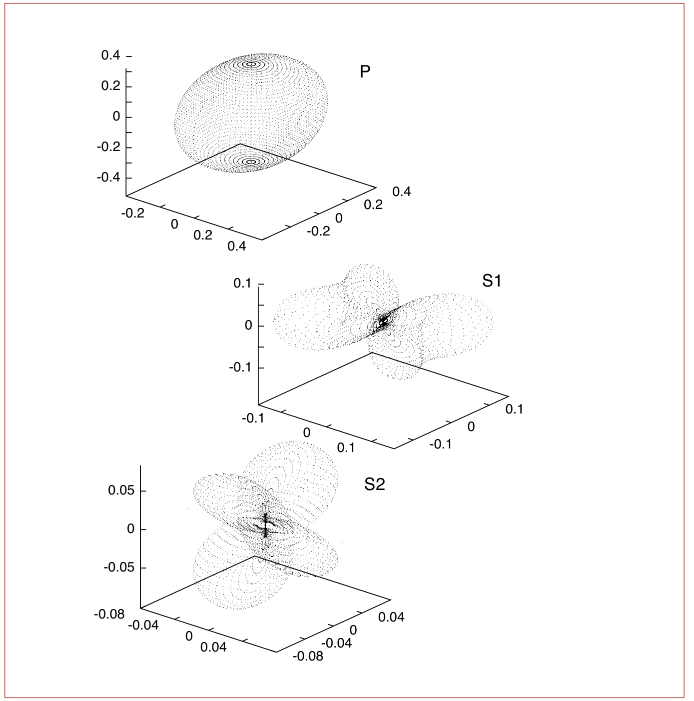
The goal of this advanced course is to introduce students to basics of the theory of seismic wave propagation in complex structures.The following topics are covered: basics of plane wave propagation in homogeneous isotropic or anisotropic media; effects of structural interfaces; differences in wave propagation in isotropic and anisotropic media; basics of the ray method for seismic body waves propagation in laterally inhomogeneous isotropic or anisotropic media with curved interfaces; wave propagation in layered, inhomogeneous, weakly anisotropic media using perturbation approaches; coupling ray theory for shear waves; wave propagation in isotropic or anisotropic, weakly dissipative media.

SELECTED CHAPTERS ON INVERSE PROBLEMS

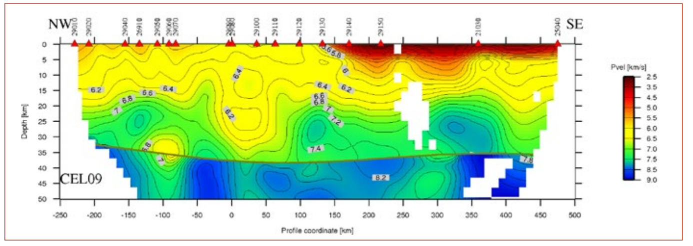
Faculty of Science, Charles University, Prague
Course Code: MGP452P73
2 hrs/week, winter semester
Instructor: **Bohuslav Růžek**

This lecture is aimed at preparing MSc and PhD-level students to work with real data and perform various types of geophysical inversion. Standard level of knowledge of linear algebra, mathematical statistics and numerical mathematics is required. Illustrative examples are solved during the course in MATLAB environment.

Course topics include: the notion of forward and inverse problems; historical development of inverse problems in geophysics; linear algebra; matrix operations; least squares and minimum norm methods; inverse matrix; generalised inversion; matrix regularisation; linear inverse problem; resolution matrix; methods of nonlinear inversion and nonlinear optimisation; genetic algorithms; examples of inverse problems in geophysics; seismic tomography; localization of seismic hypocenter; waveform inversion; inversion of surface-wave dispersion curves.



Seismic body waves in inhomogeneous anisotropic media:
Directivity functions (spreading-free amplitudes at a source) of P (top), S1 (middle) and S2 (bottom) waves generated by an explosive source in an orthorhombic medium. Note that S1 and S2 waves would not be generated if the medium is isotropic.



Selected chapters on inverse problems:
Seismic tomography introduces a classical inverse problem. A typical result looks like the depth-velocity cross-section along the profile CEL09. Careful processing has to take into account all aspects of non-uniqueness and potential instability.

DEFORMATION MICROSTRUCTURES OF ROCKS

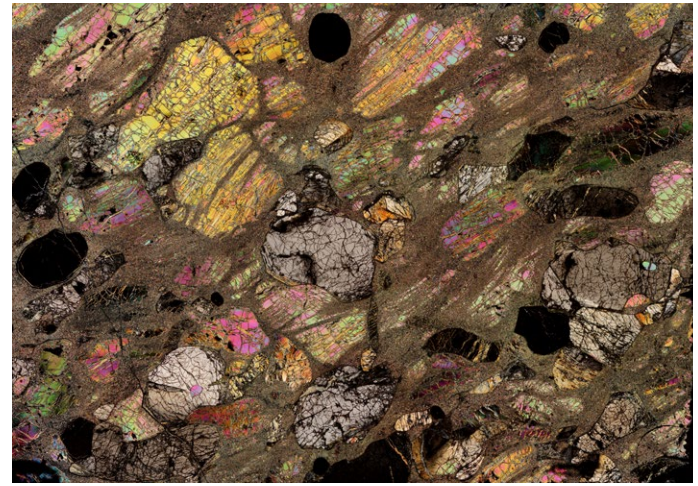
Faculty of Science, Charles University, Prague
Course Code: MG440P26
BSc programme, 3 hrs. /week, winter semester
Instructor: **Stanislav Ulrich**, Petr Jeřábek (Charles University)

An introductory course into the study of deformation microstructures and crystal plasticity. The aim of this course is to clarify physical background of deformation and recrystallization processes occurring in most common rock forming minerals and rocks. In thin sections, students learns to carry out both qualitative (identification of deformation microstructures) and quantitative (Poly LX toolbox) microstructural analyses.

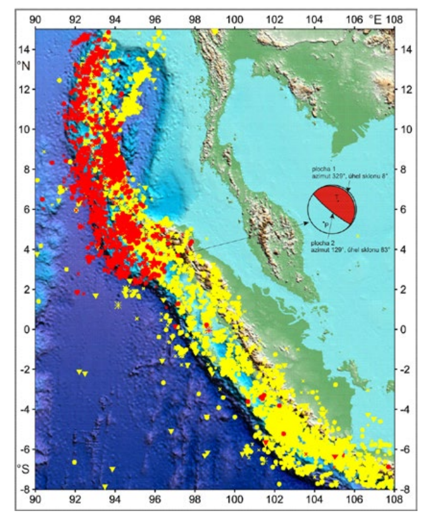
FAULT TECTONICS AND SEISMIC ACTIVITY

Faculty of Science, Charles University, Prague
Course Code: MG440P40
MSc programme, 2 hrs. /week, winter semester
Instructor: **Aleš Špičák**

The course concentrates on the causes of earthquake occurrence (tectonic stress concentration, brittle and inhomogeneous environment, movements of rock masses), explains earthquake distribution in the lithosphere and the phenomenon of deep earthquakes. Classifications of seismic events and seismic waves are discussed. Phenomena and processes accompanying tectonic stress concentration are analyzed from the viewpoint of earthquake prediction. The course gives a detailed view on the most seismically active regions on Earth, e.g. SE Asia, Andean South America, Central America, Tonga-Kermadec, East African Rift, Gulf of California, the Mediterranean, etc. Students analyse professional papers on related topics published recently in major scientific journals (e.g., EOS, Science, Nature).



Dynamic recrystallization of garnetiferous peridotite shown in a thin section, polarized light



Map of epicentres (EHB data) of earthquakes in the Sumatra, Andaman and Nicobar Islands re- gion. Yellow symbols – events from 1964 to Dec. 26, 2004; red symbols – from Dec. 26, 2004, to March 15, 2005. The GCMT focal mechanism of the main shock of Mw 9.1 is shown.

UNIVERSITY – LEVEL COURSES TAUGHT BY INSTRUCTORS FROM THE I.G.

GEOTECTONICS

Faculty of Science, Charles University, Prague, Course Code: MG440P15
BSc programme, 2 hrs. /week, winter semester
Instructor: Petr Jeřábek (Charles University), with guest instructors from the Institute of Geophysics: **Aleš Špičák, David Uličný**

The course provides the basic review of the inner composition of the Earth, in particular its crust and mantle and the physical processes behind the plate tectonics. An introductory part is devoted to a review of main geophysical methods. The main part of the course is focused on the plate boundaries, their tectono-metamorphic evolution, relationships to magmatism and sedimentary basin evolution.

SEDIMENTARY RECORD OF GEODYNAMIC PROCESSES

Faculty of Science, Charles University, Prague, Course Code: MG440P76
primarily MSc level, but also available to BSc students; 2 hrs. /week, winter semester
Instructor: **David Uličný**

The course is focused on the tectono-stratigraphic evolution of sedimentary basins and on the sedimentary record of lithosphere evolution on time scales of basins as well as plate-tectonic cycles. Lectures are combined with exercises (including basics of geological interpretation of seismic reflection data) and reading seminars to provide the students with both theoretical and practical knowledge of the classical concepts as well as current issues in sedimentary basin research. Case studies for seminars and exercises are selected from extensional and foreland basins, passive margins and other tectonic settings.

The Basin and Range province of SW USA be- longs to major continental domains of extensional tectonics

Soft-sediment deformation in Miocene deltaic sediments interpreted as evidence for syndepo- sitional seismic activity in the Most Basin, Czech Republic

D.1.1 OBSERVATORIES AND MOBILE DATA ACQUISITION SYSTEMS

A significant part of the Institute's mission involves acquisition and sharing of primary geophysical data through a number of observatories and mobile measuring equipment. In 2010, a significant new step in these efforts was acomplished by joining the CzechGeo network of geophysical observations.

More information, including technical details and geographic coordinates of the Institute's observatories, can be found at http://www.ig.cas.cz/en/structure/observatories/.

CZECHGEO/EPOS – DISTRIBUTED SYSTEM OF OBSERVATORY AND FIELD MEASUREMENTS OF GEOPHYSICAL FIELDS IN THE CZECH REPUBLIC

The integration of observatory activities, carried out by 7 research institutes and university departments, was initiated by the Institute of Geophysics in 2009. The system consists of permanent observatories, local stations or networks in selected areas significant in the long-term for basic research or applications and mobile stations which serve for repeated observations at selected points, or for field measurements, usually within the scope of large international projects. Data services are an essential part of the system.

CzechGeo is closely connected with the large European research infrastructure EPOS (European Plate Observing System) included in the European Road map in 2008. Czech participants have played an active role in the EPOS Preparatory Phase Project, supported by FP7 Grant from 2010 to 2014. EPOS was now classified by the Council of EU as one of the three priority projects that are pushing the boundaries of scientific excellence, are strategically relevant for Europe, and are ready for implementation.

In the next period we will continue to operate the infrastructure with emphasis on long-term stability and high data quality. The cooperation with EPOS will be aimed at contributing to and taking advantage of thematic and integrated core services. In addition to innovation of existing facilities, new components will be installed.

CZECH REGIONAL SEISMIC NETWORK (CRSN)

The Institute of Geophysics operated ten stations of the CRSN in the period 2012-2014: Průhonice (PRU, since 1957), Kašperské Hory (KHC, since 1961), Dobruška/Polom (DPC, since 1992), Nový Kostel (NKC, since 1997), Úpice (UPC, since 1987), Panská Ves (PVCC, since 2003), Třešť (TREC, since 2005), Králíky (KRLC, since 2008), Příbram (PBCC, since 2013), and Ostrava/Krásné Pole jointly with Technical University and Institute of Geonics, Ostrava (OKC, since 2000). Digital data were transferred continuously from all stations to the IG by Internet. Software packages Antelope and SeisComP were used for automated data acquisition, archiving and exchange with European and global data centers. A virtual network of the IG consists of about seventy real-time seismological stations in central and southern Europe. Broad international cooperation was established in the frame of EC projects Meredian (2000-2005) and Neries (2006-2010) and continued in the Preparatory phase of the research infrastructure project European Plate Observing System (EPOS).

Fig. 1 Castle Třešť, owned by the Academy of Sciences, is not only the venue of numerous international conferences but also the site of one of the stations of the Czech Regional Seismic Network.

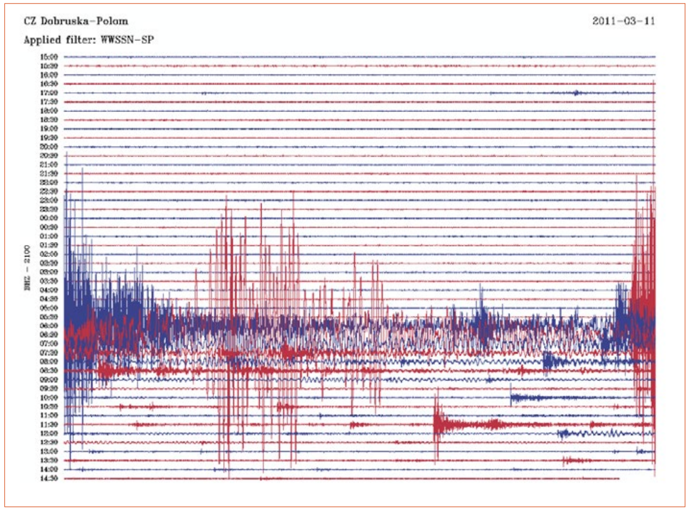


Fig. 2: "Live seismogram" of very-broadband seismological station Dobruska/Polom from March 11, 2011 shows the record of the great Tohoku earthquake Mw=9.0 and numerous aftershocks.

Institute of Geophysics is one of twenty partner institutions from eighteen countries involved in the Preparatory phase of the EPOS project (2010-2014). The CzechGeo/EPOS project (described elsewhere) supported by the Ministry of Education, Youth and Sports for the period 2011-2015 is the national initiative of the EPOS project. More information about EPOS can be found on the web page www.epos-eu.org

Seismicity in the Czech Republic and in neighbouring regions in 2012 is described in more detail in Zedník and Pazdírková, 2013.

Publications:
Zedník, Pazdírková, J., 2014. Seismic Activity in the Czech Republic in 2012. Studia geophys. et geod., 58, 342-348.

Seismological Data Center of the Institute of Geophysics provides the following services:

- Automated near-real time data acquisition of continuous broadband and short-period seismic data by Antelope and SeedLink software packages and archiving on large raid systems.
- Global data exchange of both seismic phase readings and digital records with major international data centers (ISC, NEIC, IRIS, ORFEUS, EMSC) and a number of neighbouring national centers and observatories.
- Daily processing of digital seismograms by analysis program Seismic Handler.
- Compiling and publishing seismological catalogues and bulletins on the web, collection and evaluation of macroseismic reports about earthquakes felt on the territory of the Czech Republic.
- Providing automated locations of seismic events and live seismograms of the CRSN stations on the web pages of the IG.
- Informing the public through the media and web pages about strong and devastating earthquakes in Europe and worldwide.

THE WEBNET NETWORK

West Bohemia/Vogtland earthquake swarm region belongs to the most closely monitored seismically active areas in Europe. The WEBNET network, jointly operated by the Institute of Geophysics (IG) and the Institute of Rock Structure and Mechanics (IRSM) of the ASCR in Prague, is the primary source of seismic data from the whole region at present. It consists of 13 three-component stations and covers an area of about 1000 km^2. Further smaller local networks providing relevant, high quality data have been working in NE Bavaria and SE Saxony.

Fig. 3: The Králíky seismic station, part of the Czech Regional Seismic Network, monitors, among other events, tectonic earthquakes in the region of Sněžník and the Jeseníky Mts. in northern Moravia (NE Czech Republic)

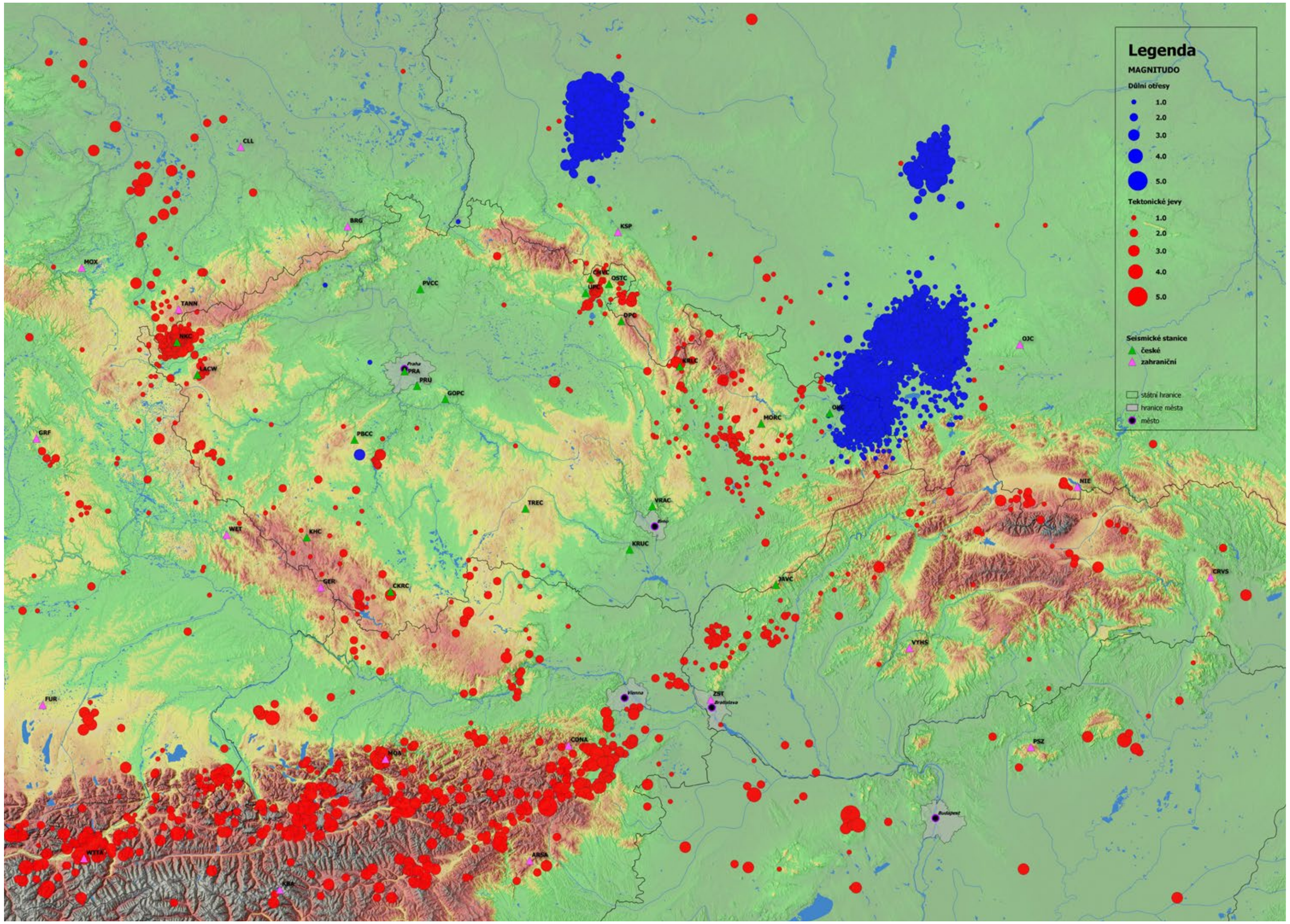


Fig. 4: Stations of the Czech Regional Seismic Network (green triangles) and regional seismic events in central Europe in 2012-2014. Tectonic earthquakes are shown as red circles, mining-induced shocks as blue circles. The size of the circles is proportional to local magnitude.

The individual stations are equipped by the SM-3 short-period seismometers and Janus-Trident/ Nanometrics acquisition systems. In addition, central station Nový Kostel (NKC) and station ZHC (southern part of the seismogenic region) are equipped with the Güralp 40-T broadband sensors. Its configuration and the parameters of the seismograph systems guarantee high-quality recording of West Bohemia/ Vogtland events of magnitudes $0.5 \le M_L \le 5.0$ in a frequency range of 0.5 to 80 Hz with a sampling frequency of 250 Hz. Thus, Webnet makes it posible to record high-frequency waves generated by local events, short-period body waves of regional and distant earthquakes, and surface waves excited by quarry blasts fired in the neighbourhod of the region under study. Data, both continuous and triggered, from all the stations are transmitted via Internet to IG, Prague. WEBNET is interconnected with the CRSN via station NKC (see paragraph Czech Regional Seismic Network).

To provide the best possible area and azimuth coverage with respect to the individual focal zones, ten seismic vaults consisting of a container with a concrete pillar c. 2m below the surface were built in West Bohemia for deployment of mobile stations in case of stronger seismic activity.

The catalogues and seismograms of all tectonic events (about 70,000) recorded by the WEBNET since 1992 and by the temporal stations since 2006 are archived in a joint digital database. Particularly, observations of the 2008 and 2011 swarms (recorded by 13 to 23 stations) represent a unique data set. Data from other networks operating in NE Bavaria and SE Saxony are available on request. The WEBNET data represent a major database for diverse seismic-source and upper-crust-structure investigations performed in the IG ASCR. In addition, they are broadly used by cooperated scientists from all over the world.

REYKJANET SEISMIC NETWORK, ICELAND

In summer 2013, a seismic network of 15 stations was built on the Reykjanes peninsula, southwest Iceland, as part of a research project „Earthquake swarms and their triggering mechanisms in diverse tectonic environments (Bohemian Massif, Mid-Atlantic Ridge, Western Alps)“, supported by the Czech Science Foundation (GAČR). The network has monitored the seismic activity for two years. The data obtained are being used for the study of triggering mechanisms and driving forces of earthquake swarms. Comparative study of earthquake-swarms in West Bohemia/Vogtland (intraplate) and in southwest Iceland (inerplate) should help us to disclose the causes leading to seismic energy release in the form of the earthquake swarms instead of ordinary single events or mainshock-aftershock sequences.

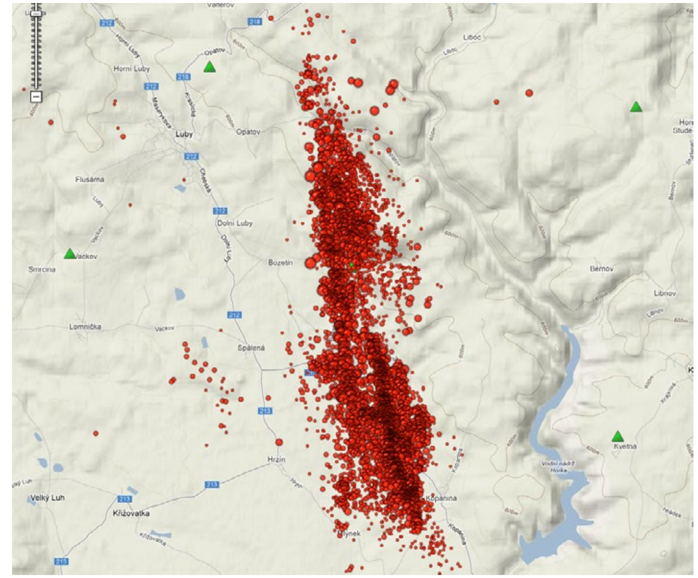


Fig. 5: Locations of epicentres of earthquakes between October 2010 and January 2012, in the West Bohemia/Vogtland region, as recorded by the WEBNET stations (green triangles).

Fig. 6: Instalation of seismic station STH of the network REYKJANET on the Reykjanes Peninsula (southwest Iceland) in September 2013. The REYKJANET stations are equipped with broadband sensors Guralp a Gaia data acquisition systems, and supplied by combination of solar panels wind generators.

GEODYNAMIC AND EARTH TIDE OBSERVATORIES

Tidal observatories have been recording tidal data since 1952. At present, we operate three of them. SKALNA was included into the ICET (Int. Centre for Earth Tides) world network within the frame of the Global Geodynamic Project.

Příbram, Central Bohemia [49.6861N, 13.9972E]

This observatory is located on top of an abandoned deep mine (depth 1300 m). Here, all istruments are maintained and undergo long-term tests in the mine gallery (tiltmeters, gravimeter, barographs, etc.). The data from all other sites are transmitted to this centre for control and processing. Moreover, based on the support of the CzechGeo Project, we decided to establish a complex observation system here at the second floor of the mine, with broadband seismograph (will be included into the Czech National Seismological Network), a couple of tiltmeters and semi-permanent gravity recording.

Jezeří, North Bohemia [50.5553N; 13.5052E]

The observatory was established in 1982 when a complex investigation of the Krušné hory slopes began with the aim of controlling the stability of the slopes of an open-pit coal mine. The observatory is composed of two sites in a horizontal gallery located under the Jezeří castle, equiped with the Ostrovsky's and ASNS tiltmeters with permanent recording of tilts. The target is to record the stability of the marginal block of the basement massif suspected of rotation or sliding into the open-pit mine. This observatory is a part of the monitoring system of the mining company, focused on the mine risk mitigation. We observed striking tilt signal before, during and after a significant landslide that occurred in January 2011. Such events represent hazard for the mine, as well as for the castle located nearby uphill.

Skalná, West Bohemia [50.1688N, 12.3606E]

This complex geodynamic observatory is located in the West Bohemia seismoactive region in an underground gallery inside a granite block in Skalná. The observatory contributes to the monitoring of the ongoing geodynamic processes in the region. It is furnished with a seismograph, a couple of tiltmeters, a barometer and a strainmeter. Occasionally, continuous measurements of gravity are performed to test local changes of the gravity field. Significant gravity signal was recorded during the Sumatra earthquake 2004. In 2008, tilt records were strongly affected by the October earthquake swarm taking place at about 7 km distant focal area.

GEOMAGNETIC OBSERVATORY

The long tradition of geomagnetic observations in Prague dates back to 1839. Due to the increasing influence of urban magnetic noise since the beginning of the 20th century, the Prague observatory was closed down in 1926, and was replaced in 1946 by the Průhonice observatory near Prague. Rapid expansion of the city and construction

Fig. 7: January 2011 landslides on the edge of open-pit coal mine in the immediate vicinity of the Krušné Hory fault scarp, with the Jezeří castle on the horizon.

of DC – powered railways resulted in a deterioration of this location. In 1967, the observatory was moved to Budkov near Prachatice in south Bohemia, a sparsely populated area. Currently the observatory is equipped with two digital systems. CANMOS, installed in 1992 in co-operation with the Geomagnetic Observatory of the Geological Survey of Canada consists of a triaxial Narod S-100 ring-core magnetometer, an ELSEC 820 PPM magnetometer, and a control unit based on MS-DOS operating system. The main parts of GDAS system are DMI suspended fluxgate magnetometer, Overhauser proton magnetometer and Pentium-type embedded PC with QNX4 operating system and SDAS data acquisition software developed by British Geological Survey. Absolute measurements are carried out by DI magnetometer (fluxgate sensor mounted on non-magnetic theodolite Zeiss 010B). New main building – open in 2010 – created better working conditions for the staff taking care of the observatory. The observatory was linked by optical cable to the Czech Academic Network (CESNET). The former data transmission via switched telephone network was thus replaced by state-of-the-art communication tools. The Department of Geomagnetism has been issuing daily forecasts of geomagnetic activity for Central Europe since 1994, weekly forecasts since 1995. Since 1998 the short term forecasts have been regularly sent to Czech TV, where they are presented as part of the Weather Forecast. At present, the forecasts, as well as reports of the actual state of the geomagnetic field in our region, are presented on the web pages of the Regional Warning Centre Prague (http://rwcprague.ufa.cas.cz/).

Fig. 8: New building of the Budkov geomagnetic observatory, open in 2010.

GEOTHERMAL CLIMATE-CHANGE OBSERVATORIES

The geothermal climate-change observatories on the campus of the Institute of Geophysics at Spořilov, at the meteorological station Kocelovice (operated by the Czech Hydrometeorological Institute) and near Potůčky (Krušné Hory Mountains) were established in the years 1993, 1998 and 2002, respectively. The observatories monitor air, soil and bedrock temperatures at a sampling rate of 30 minutes with the aim to provide data on the air-ground temperature coupling and on a propagation of seasonal, interannual and secular surface temperature changes into the bedrock. The monitoring is expected to continue into the future, to map the tracking of the air and ground mean annual temperatures on an interannual time scale. The tracking is crucial for the proper climatic interpretation of the ground surface temperature history reconstructed from borehole temperature profiles.

The influence of vegetation cover on the soil temperatures is studied systematically using data from the fourth observatory located on the premises of the Institute of Geophysics in Prague – Spořilov. The monitoring system launched in 2002 provides data on the soil temperatures to the depth of 0.5 m under different surface conditions, namely under grass, barren soil, sand, and asphalt. The system was upgraded by installation of one pyranometer for monitoring the incoming short-wave radiation and four pyranometers for the short-wave radiation reflected by the individual surfaces. The monitoring provides data for a detailed study of the mean annual difference between air and soil temperatures, its long-term stability and dependence on the vegetation cover and provides useful data for an array of other disciplines like agronomy, forestry, ecological studies or alternative energy sources.

Fig. 9: Air-ground temperature monitoring on the campus of the Institute of Geophysics.

GEOTHERMAL OBSERVATIONAL SITE – SPOŘILOV 3

The observed warming in most air-temperature meteorological records of the past 100-150 years provides an important piece of evidence that the present global climatic system is changing. The increase of air temperature is linked to the increase of the ground surface (soil) temperature and the change in the surface conditions penetrates downwards. The high-frequency component of this transient signal is progressively filtered out and fades out below the depth of about 20-30 m. The ground "smoothes" the temperature extremes and the magnitude of the present day climate warming can be obtained by temperature monitoring at shallow depths just below the penetration reach of the seasonal temperature variations.

An automatic system for monitoring ground temperatures in the I.G. was developed in early 1990s and has been successfully running since then. The obtained record of the subsurface temperatures covering a 40 m depth interval is a unique document, which by far has exceeded the original expectations. It is understandable that after almost 18-year-service some of the thermistor sensors of the operational measuring chain need to be replaced and the whole system to be innovated. Another problem, which arose later, was the construction of a new building erected in the proximity of the observational site in the mid-1990s. The proper existence of the building and heating its basement may affect the pristine ground conditions. Even when this effect seems to be still negligible at present, for the future it signifies an unwanted disturbing effect on the observational results.

To continue the studies a new project P210/11/0183 "Subsurface temperature monitoring – a useful tool to understand the contemporary climate change" was granted for years 2011-15 and a new 50 m deep hole was drilled in May 2011 in the western promontory of the institutional campus (50°2'26"N, 14°28'27"E).

The principal outputs of the project include:

(a) To capture important features of the recent climate change on various time scales together with the studies of the inter-annual variability of soil temperatures and the difference between soil vs. air temperatures and their dependence on the surface type in relation to meteorological variables.

(b) To evaluate the observed present-day warming rate at the site location in Prague in relation to other experimental site located in south-central Bohemia (Kocelovice) and to estimate the potential "city heat island effect" of large agglomeration (Prague).

(c) Together with the simultaneous analysis of the air-temperature records in several local meteorological station in various location of the country to assess the pre-observational surface air temperature conditions of the 19th and 20th century in the Czech Republic to improve the knowledge of the climate evolution on the century long scale.

Fig. 10: Drilling the borehole for the new geothermal observational site – Spořilov 3, in the Geopark of the Institute of Geophysics, May 2011.

D.2

GEOPARK SPORILOV

The GEOPARK of the Geophysical Institute, open to the public, has been built on the premises of the Institute in several phases since 2003, with gener- ous support from the Prague 4 municipal council and thanks to enthusiasm of companies that donated many rock specimens. The aim of the exhibition is to increase the awareness of the general public about processes operating in the Earth interior and on its surface, and about their products. Currently the Geopark features over 40 large specimens of igneous, sedimentary, and metamorphic rocks from the Bohemian Massif and a collection of magmatic rocks from Western Carpath- ians. Explanatory texts and accompanying posters about plate tectonics and the geological history of the Czech Republic are posted in the Geopark and on the Institute's website: www.ig.cas.cz/cz/o-nas/ popularizace/geopark-sporilov/. The rock collection of the Geopark became a basis of the book „Geological processes marked in rocks" written by the staff of the Department of Tectonics and Geodynamics of the In- stitute. The book which introduces basic principles of plate tectonics, Earth's evolution and rock formation is available free to visitors of the Geopark. All visitors – locals, casual visitors, and, commonly, schools – thus have the opportunity not only to appreciate the beauty of the rocks on display, or read the posters and the book, but they can also take part in a quiz-game named „The Alchemists' Stone", as an entertaining way to learn about minerals, rocks, and processes that create them. Public outreach activities, organized by the Institute, such as the Earth Day celebration, take place in the Geopark. Most recently, a new geothermal observational site, situated in a borehole, was set up in the Geopark in 2011.

D.3
PUBLIC OUTREACH ACTIVITIES

The Institute takes part in the annual "Science and Technology Weeks" organized by the Academy of Sciences. This is the main outreach activity of the Academy, aimed at informing the general public about the impact of science on daily life and its benefits (details can be found at www.tydenvedy.cz/). Researchers of the Institute of Geophysics regularly contribute to public lectures given by researchers from all branches of science represented in the Academy of Sciences. www.tydenvedy.cz/program/festival-online/.

In addition, the Institute organizes its Open Days which take place each year in November. Visitors to the Institute – mostly students and general public - can learn about earthquakes, scientific drilling at the continents and ocean bottom, the use of geothermal energy, take a guided tour through the Institute's Geopark, or watch sandbox experiments simulating volcanic eruptions or building of a mountain range.

In 2010, researchers from the Institute of Geophysics, in collaboration with the Centre of Administration and Operations of the ASCR, launched a new public outreach activity, a celebration of the Earth Day (April 22) with the Academy of Sciences, aimed specifically at increasing the public awarness about all branches of Earth Sciences. Since then the Earth Day celebrations have taken place every year, with a rich mix of public lectures, exhibitions, seminars aimed at secondary school teachers. The topics covered range from plate-tectonic processes and their role in the formation of the landscape of the Czech Republic, volcanism, earthquakes, to climate and sea level change. Each year, an exhibition of photographs related to some aspect of Earth and environmental sciences supplements the Earth Day activities. In April 2015, the Earth Day celebrations are preceded by an exhibition devoted to international and Czech scientific drilling projects. A collection of photographs, core samples, replicas of rare core materials from ocean bottom drilling projects, was opened in the Czech Academy of Sciences headquarters at Národní třída street in the centre of Prague. Details of our public outreach activities, including videos of experiments or archive videos of lectures, are available, in Czech, on the web pages: www.ig.cas.cz/cz/o-nas/popularizace/. A video presentation, in English, from the Earth Day 2010 is featured on the web pages of the Institute of Geophysics: www.ig.cas.cz/userdata/files/popular/Den_zeme2010_EN.flv

Researchers from the Institute of Geophysics are frequently featured in the media, in particular in TV and radio broadcasts related mostly to earthquakes, volcanism and other geological hazards, but also to the Earth evolution and other topics of general interest.

Other outreach activities involved, for example, collaboration on the Otevřená Věda (Open Science) project: www.otevrena-veda.cz/. Individual researchers presented talks at high schools, museums, and other public institutions, or led field trips to secondary schools students.

D.4.1 LIST OF SUPPORTED RESEARCH PROJECTS RUNNING IN 2012–2015

Project ID	Project Title	Responsible Investigator at the I.G.	Funding Source	Duration
FP7-230669-AIM	Advanced Industrial Microseismic Monitoring (AIM)	Václav Varyčuk	EU	2009 – 2013
GAP210/10/0296	Earthquake source modelling by second degree moment tensors	Petra Adamová	GACR	2010 – 2012
GAP210/10/0554	Magnetic speciation of atmospheric PM1, PM2.5 and PM10 collected at sites with different air quality	Eduard Petrovský	GACR	2010 – 2012
GAP210/10/1728	Non-double-couple mechanisms: through induced seismicity to fluid-driven earthquakes	Zuzana Jechumtálová	GACR	2010 – 2013
GAP210/10/1991	A new European reference section to study mid-Cretaceous sea-level change, palaeoceanography and palaeoclimate: drilling the Bohemian Cretaceous Basin	David Uličný	GACR	2010 – 2014
GAP210/10/2063	Crustal structure in the seismoactive region of the West Bohemia	Pavla Hrubcová	GACR	2010 – 2012
GAP210/10/2227	Regional and global distribution of the electrical conductivity in the Earth's mantle from ground-based and satellite observations	Josef Pek	GACR	2010 – 2012
GAP210/11/0117	Seismic wave propagation in complex structures – perturbation approaches II	Ivan Pšenčík	GACR	2011 – 2014
GAP210/11/0183	Subsurface temperature monitoring - a useful tool to understand the contemporary climate change	Vladimír Čermák	GACR	2011 – 2015
GAP210/12/1491	Physical processes in an earthquake source: from micro- to macro-scale	Václav Vavryčuk	GACR	2012 – 2016
GAP210/12/2235	Constrained models of seismic source: in between a double-couple and moment tensor	Jan Šílený	GACR	2012 – 2015
GAP210/12/2336	Earthquake swarms and their triggering mechanisms in diverse tectonic environments (Bohemian Massif, Mid-Atlantic Ridge, Western Alps)	Josef Horálek	GACR	2012 – 2016
GAP210/12/2381	Integrated anisotropic tomography of European lithosphere and upper mantle	Jaroslava Plomerová	GACR	2012 – 2016
GA13-08971S	Crustal structure determined from waveforms of local micro-earthquakes	Pavla Hrubcová	GACR	2013 – 2015
GA13-10775S	Quantifying the effect of volcanic parent rock on the magnetic properties of soils	Hana Grison	GACR	2013 – 2016
GA14-15632S	Melt migration and coupled rock deformation dynamics in orogenic lower crust	Prokop Závada	GACR	2014 – 2016
GA205/09/0539	Internal strain fabric and rheology of orogenic peridotites and surrounding crustal rocks	Prokop Závada	GACR	2009 – 2012
GA205/09/1170	Upper mantle beneath the neovolcanic zone of the Bohemian Massif: xenoliths and their host basalts	Petr Špaček	GACR	2009 – 2012
IAA300120801	Seismic waves and sources in anisotropic media II	Václav Varyčuk	GAASCR	2008 – 2012
IAA300120905	Dynamics of crustal fluids in the western part of the Bohemian Massif as a probe of the stress changes	Tomáš Fischer	GAASCR	2009 – 2012

D.4.2 LIST OF SUPPORTED RESEARCH PROJECTS RUNNING IN 2012–2015

Project ID	Project Title	Responsible Investigator at the I.G.	Funding Source	Duration
IAA300120911	Common characteristics of the West Bohemia/Vogtland earthquake swarms and swarm-like seismicity triggered by fluid-injection into the HDR boreholes at Soultz-sous-Forets in Alsace	Josef Horálek	GAASCR	2009 – 2012
LA08036	International Continental Scientific Drilling Program (ICDP) - membership fee of the Czech Republic	Aleš Špičák	MEYS	2008 – 2012
LA09015	Activities within IAGA (International Association of Geomagnetism and Aeronomy)	Eduard Petrovský	MEYS	2009 – 2012
LA10013	Czech activities within the IUGG 2010-2012	Vladimír Čermák	MEYS	2010 – 2012
LG13040	Activities in the IUGG 2013-2015	Vladimír Čermák	MEYS	2013 – 2015
LG13041	Support of activities in the International Continental Scientific Drilling Program	Aleš Špičák	MEYS	2013 – 2015
LG13042	Support of activities in management structures of International Association of Geomagnetism and Aeronomy (IAGA)	Eduard Petrovský	MEYS	2013 – 2015
LH12041	Sea-level oscillations and changes in atmospheric CO2 concentrations during the peak Greenhouse (Cenomanian-Turonian, Western Interior basin)	Jiří Laurin	MEYS	2012 – 2015
LM2010008	CzechGeo/EPOS – Distributed system of permanent observatory measurements and temporary monitoring of geophysical fields in the Czech Republic	Pavel Hejda	MEYS	2010 – 2015
ME09011	Subduction Factory: Earthquake Production and Magma Emplacement	Aleš Špičák	MEYS	2009 – 2012
ME10008	Rotational seismometers - design, construction, calibration and field testing.	Jan Kozák	MEYS	2010 – 2012
OC09070	Space weather variability and short-term forecasts of geomagnetic activity	Pavel Hejda	MEYS	2009 – 2012
QJ1230319	Soil water regime within a sloping agricultural area	Aleš Kapička	MAE	2012 – 2015

13TH "CASTLE MEETING" ON PALEO, ROCK AND ENVIRONMENTAL MAGNETISM, ZVOLEN, SLOVAKIA; 17 – 23 JUNE, 2012

This meeting was already the 13th in a series of biennial meetings, held since 1988. Although the meeting was held at the same time as traditional specialised rock-magnetic workshop in Santa Fe, USA, it was attended by 55 active participants from 24 countries worldwide (including North and South America and Asia). 15 participants had the status of PhD students. Student presentations were evaluated by a board of 5 experienced researchers, covering all subject fields of the meeting. Posters and oral presentations were evaluated equally. At the official closing ceremony, 5 students got Certificate of Excellence for outstanding student presentation.

Scientific program consisted of several blocks of oral rpesentations, each of them consisting of 3-4 talks and 2 afternoon poster sessions. The sessions were chaired by two chair-persons, one of them being as a rule a PhD student. Some 40 talks were given and during the two poster sessions, about 20 posters were presented, each of them being introduced by a short oral introduction.

In addition to the scientific program, a half-day tour to the region was performed. The tour included excursion to Banská Štiavnica, a town listed on the UNESCO list of cultural terasures, where we visited mining museum. Banská Štiavnica is well known for silver and gold mining and the first mining university in the world was established here. In the evening, an open-air barbecue took place on the top of Polana mountain, which represents a „benchmark" in the Slovak cultural history. During the barbecue party, performance of Slovak folk music was organized. During the other evenings, we had nice opportunity to taste Slovak wine from part of the famous Tokai region and to listen to sounds of traditional Slovak folk musical instruments.

A public lecture entitled „Geomagnetic field and its importance for the life on Earth" was given by Eduard Petrovsky at the library of Technical University in Zvolen. Some 20 listeners from the university as well as general public took part at the lecture.

International Association for Geomagnetism and Aeronomy (IAGA) financial support was provided to five participants (300 USD each) from Ukraine, Romania, China, Estonia and Italy. Financial support, provided by the sponsors listed below, is highly appreciated and contributed significantly to success of the meeting. The meeting was perfectly co-organised by colleagues from the Geophysical Institute of the Slovak Academy of Sciences in Bratislava.

For more information, see a report published in the IAGA Newsletter No.49 (www.iugg.org/IAGA/iaga_pages/pdf/Newsletters/IAGAnews_49.pdf).

14TH "CASTLE MEETING" ON PALEO, ROCK AND ENVIRONMENTAL MAGNETISM, EVORA, PORTUGAL; 31 AUGUST – 6 SEPTEMBER, 2014

The 14th biannual Castle Meetings took place, for the first time, outside the former Czechoslovakia, running this time at Portugal (City of Évora – UNESCO heritage). The meeting maintained the atmosphere and character developed during the last 26 years, promoting the discussion and sharing of actual scientific knowledge in paleomagnetism, archeomagnetism, magnetostratigraphy or environmental magnetism and physical principles of rock magnetism.

This event was attended by a total of 114 participants from 27 countries from all the inhabited continents. 16 of the participants had the status of PhD students. Student presentations were evaluated by a board of 5 experienced researchers, covering all subject fields of the meeting. Posters and oral presentations were evaluated equally. At the official closing ceremony, 5 students got Certificate of Excellence for outstanding student presentation. Maria Mendakiewicz from the Polish Academy of Sciences (Zabrze, Poland) is nominated for the International Association for Geomagnetism and Aeronomy (IAGA) Young Student Award for her presentation entitled "Technogenic magnetic particles in soils as an evidence of historical human activity".

Scientific program consisted of several blocks of oral presentations, each of them consisting of 5-6 talks and one day of poster session. The sessions were chaired by two chair-persons, one of them being usually a PhD student. 63 talks were given and during the poster session, 53 posters were presented. Five invited speakers, Miguel Miranda (Lisbon, Portugal), Pedro Madureira (Évora, Portugal), Julie Carlut (Paris, France), Adrian Muxworthy (London, Great Britain) and Rob Van der Voo (Michigan, USA) presented their works on actual and future key subjects of research. The VI MAGIBER workshop took place during the meeting. This workshop aims at sharing the expertise within the "paleomagnetic" community of Iberia. n addition to the scientific program, two half-day tours to the region were performed. One of the tour included excursion to Monsaraz (ancient Portuguese village) and boat trip on the Alqueva Dam. The second tour included a visit to vineyards followed by the final dinner and taste of wines of the Alentejo region at the Rocim winery. In one of the evenings a vocal concert of medieval music was organized under the sponsorship of the Direcção Regional da Cultura do Alentejo, was organised a vocal concert at the Salvador Church (Évora).

The two days before the meeting (29 and 30th of August), a short course on magnetic susceptibility for PhD students was organised for the first time in the history of these meetings. 17 participants attended the course (mostly young students). The lectures were given by, Dr. Ann Hirt (Zurich, Switzerland), Dr. Eduard Petrovsky (Prague, Czech Republic), Dr. Frantisek Hrouda (Brno, Czech Republic) and Dr. Martin Chadima (Brno, Czech Republic). The sponsorship of AGICO (Ltd., Brno, Czech Republic), is highly appreciated. AGA financial support was provided to five participants from Greece, Slovakia, Ukraine, Indonesia and Poland. The meeting was prefectly co-organized by our colleagues from the University of Lisbon. It is also important to highlight the collaboration with local and national Portuguese institutions, namely the Secretaria de Estado da Cultura (governmental agency for culture).

1ST CENTRAL EUROPEAN MEETING OF SEDIMENTARY GEOLOGY (CEMSEG), OLOMOUC 2014

The Institute of Geophysics co-organized the meeting held in Olomouc, Czech Republic from June 9 to 13, 2014. The main organizer was the Palacký University of Olomouc, supported by the International Association of Sedimentologists and several companies with ties to Earth Sciences. The first meeting of this kind in the region, it aimed to review the state of the art of various branches of sedimentary geology and gather geoscientists and students connected by common working areas and geological fields of Central Europe but also are linked by similar tradition, present-day development, collaborations and friendship. Of the total of 90 participants, 75 came from outside the Czech Republic, mainly from Hungary, Poland, Slovakia, Slovenia, Croatia, Austria, Germany, Russia and Kazakhstan. Five prominent invited speakers covered a broad range of topics from depositional fluid dynamics to Holocene climate change: Gary Kocurek, David Mohrig (University of Texas at Austin), Orsolya Sztanó (Eotvos University, Budapest), Mark Macklin (Aberystwyth University, Wales) and Michael Wagreich (Vienna University). The meeting was held on the recently built campus of the Palacký University, with excellent logistical support provided largely by the university's conference service and the staff and students of the Department of Geology.

Three field trips took place as part of the meeting, two of them led by specialists from the Institute of Geophysics: David Uličný and his collaborators led a two-day, pre-conference trip to explore deltaic depositional systems in Cretaceous and Miocene basins of Bohemia and Jaroslav Kadlec, together with Gary Kocurek and David Mohrig (University of Texas at Austin) devoted a post-conference trip to the record of climate-controlled fluvial, lacustrine and aeolian processes in the Last Glacial and Holocene in Southern Moravian river valleys.

The post-conference field trip, devoted to the record of Quaternary climate change in the river valleys of South Morava, was led by Jaroslav Kadlec (Institute of Geophysics), Gary Kocurek and David Mohrig (both Univ. of Austin, Texas, shown second and third from left).

D.6.1 STUDIA GEOPHYSICA ET GEODAETICA

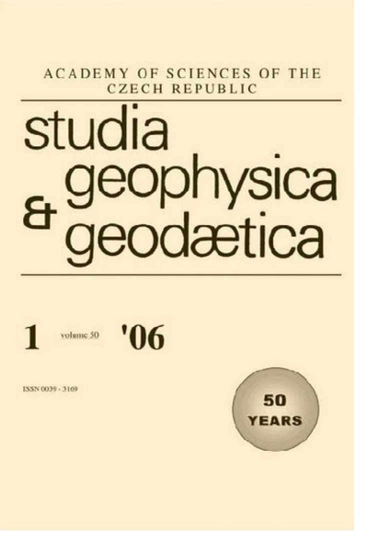
Studia Geophysica et Geodaetica (SGEG), published by the Institute of Geophysics since 1956, is an international scientific journal covering all aspects of geophysics, geodesy, meteorology and climatology. In 2012-2014, the Editorial Board consisted of 24 experts from 13 countries (see the list below). Electronic and printed versions of the journal are distributed by Springer.

At present, between 40 and 50 original reviewed papers are published per year. The mean submission to acceptance time is about 6 months (it strongly depends on the quality of the submission and willingness of potential referees to review it). Rejection rate in the last three years was about 33%. Special issues are published on various occasions, commonly as proceedings from scientific meetings. In the years 2012-2014, five special issues were compiled and published. Issue 1/2012 combined regular submissions and papers presented at the workshop "Seismic Waves in Laterally Inhomogeneous Media VII", held in 2010 at Teplá, Czech Republic. Issue 2/2012 was devoted to the eightieth birthday of a distinguished scientist, Prof. Vlastislav Červený. Issue 3/2012 combined regular submissions and papers presented at the 12th "Castle Meeting" on Paleo, Rock and Environmental Magnetism, held in 2010 at Nové Hrady, Czech Republic. Issue 4/2013 consisted of 8 papers presented at the session "Recent advances in paleomagnetism and magnetic properties of rocks", during the annual congress of Mexican Geophysical Union (Puerto Vallarta, Mexico, 2012) and 3 other contributions presented at the 13th Castle Meeting on Paleo, Rock and Environmental Magnetism (Zvolen, Slovakia, 2012). Finally, papers in the special issue 4/2014 were selected from contributions presented in session G1.1 on Recent Developments in Geodetic Theory held at the European Geosciences Union General Assembly, Vienna 2013.

The Impact Factor for the period 2004-2013 is shown in Fig. 1, see also the ISI Journal Citations Report (www.jcrweb.com). According to IF in 2014, the journal is ranking as 21st among the total of 40 journals with Impact Factor published in the Czech Republic. The journal is abstracted or indexed in Current Contents: Physical, Chemical and Earth Sciences; ISI Alerting Services; Meteorol. and Geoastrophys. Abstracts and Elsevier/Geo Abstracts.

All the articles published in SGEG since 1956 can be found on the web page:
www.springerlink.metapress.com/content/109194/

The most cited paper since 2000: Egli R., 2004. Characterization of individual rock magnetic components by analysis of remanence curves, 1. Unmixing natural sediments. Stud. Geophys. Geod., 48, 391-446 (74 citations by November 2014 on Web of Science). The h-index of the journal is 29 (as by November 2014, Web of Science).



D.6.2 STUDIA GEOPHYSICA ET GEODAETICA

EDITORIAL BOARD OF STUDIA GEOPHYSICA ET GEODAETICA, 2012-2014

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Ralph Stephen, Woods Hole, USA
Peter J.G. Teunissen, Delft, The Netherlands
Colin Thomson, Cambridge, U.K.
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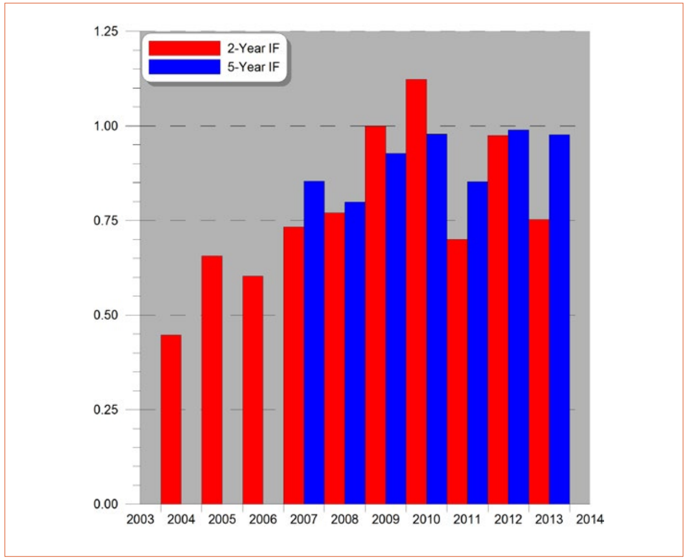


Fig. 1: Impact factor of Studia Geophysica et Geodaetica between 2004 and 2013.

D.7.1 INTERNATIONAL PUBLICATIONS

The following list contains references to original scientific publications authored or co-authored by emlployees of the Institute of Geophysics, only in journals with the ISI Impact Factor. Publications from years 2012-2014 and through the first quarter of 2015 are listed separately for each year, in alphabetic order of names of the authors employed by the Institute of Geophysics (**bold letters**).

A complete list of all publications is available at www.ig.cas.cz/en/research-teaching/publications-0 and on the homepages of individual researchers.

2012

Ackerman, L. - **Špaček, P.** - Medaris Jr., G. - Hegner, E. - Svojtka, M. - Ulrych, J.
Geochemistry and Petrology of pyroxenite xenoliths from Cenozoic alkaline basalts, Bohemian Massif.
Journal of Geosciences. Vol. 57, No. 4 (2012), p. 199-219. DOI: 10.3190/jgeosci.125

Bochníček, J. - Davídkovová, H. - Hejda, P. - Huth, R.
Circulation changes in the winter lower atmosphere and long-lasting solar/geomagnetic activity.
Annales Geophysicae. Vol. 30, No. 12 (2012), p. 1719-1726.
DOI: 10.5194/angeo-30-1719-2012

Bouchaala, F. - Guennou, C.
Estimation of viscoelastic attenuation of real seismic data by use of ray tracing software: Application to the detection of gas hydrates and free gas.
Comptes Rendus Geoscience. Vol. 344, No. 2 (2012), p. 57-66.
DOI: 10.1016/j.crte.2011.12.006

Brož, P. - Hauber, E.
A unique volcanic field in Tharsis, Mars: Pyroclastic cones as evidence for explosive eruptions.
Icarus. Vol. 218, No. 1 (2012), p. 88-99.
DOI: 10.1016/j.icarus.2011.11.030

Bucha, V.
Changes in geomagnetic activity and global temperature during the past 40 years.
Studia geophysica et geodaetica. Vol. 56, No. 4 (2012), p. 1095-1107.
DOI: 10.1007/s11200-011-0473-8

Dědeček, P. - Šafanda, J. - Rajver, D.
Detection and quantification of local anthropogenic and regional climatic transient signals in temperature logs from Czechia and Slovenia.
Climatic Change. Vol. 113, No. 3-4 (2012), p. 787-801.
DOI: 10.1007/s10584-011-0373-5

Fischer, T. - Štěpančíková, P. - Karousová, M. - Tábořík, P. - Flechsig, C. - Gaballah, M.
Imaging the Mariánské Lázně Fault (Czech Republic) by 3-D ground-penetrating radar and electric resistivity tomography.
Studia geophysica et geodaetica. Vol. 56, No. 4 (2012), p. 1019-1036.
DOI: 10.1007/s11200-012-0825-z

Reshetnyak, M. - **Hejda, P.**
Kinetic energy cascades in quasi-geostrophic convection in a spherical shell.
Physica Scripta. Vol. 86, No. 1 (2012), 018408/1-018408/5.
DOI: 10.1088/0031-8949/86/01/018408

Hejda, P. - Horáček, J. - Bayer, T.
Secular variation on the territory of the Czech Republic and reduction of the magnetic survey to the epoch 2010.5.
Annals of Geophysics. Vol. 55, No. 6 (2012), p. 1095-1099.
DOI: 10.4401/ag-5445

Holub, K. - **Růžek, B.** - Rušajová, J.
A simple smoothed velocity model of the uppermost Earth's crust derived from joint inversion of Pg and Sg waves.
Acta Geophysica. Vol. 60, No. 2 (2012), p. 487-497.
DOI: 10.2478/s11600-011-0023-3

Chum, J. - Hruška, F. - **Zedník, J.** - Laštovička, J.
Ionospheric disturbances (infrasound waves) over the Czech Republic excited by the 2011 Tohoku earthquake.
Journal of Geophysical Research. Vol. 117, A8 (2012), A08319/1-A08319/13.
DOI: 10.1029/2012JA017767

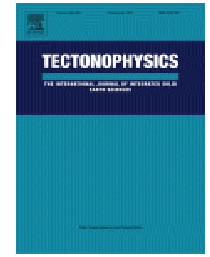
Jedlička, P. - Kozák, J. - Evans, J. R. - Hutt, C. R.
Designs and test results for three new rotational sensors.
Journal of Seismology. Vol. 16, No. 4 (2012), p. 639-647.
DOI: 10.1007/s10950-012-9293-8

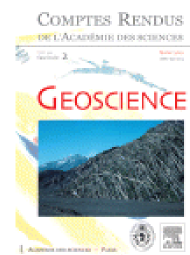
Karousová, H. - Plomerová, J. - Vecsey, L.
Seismic tomography of the upper mantle beneath the north-eastern Bohemian Massif (central Europe).
Tectonophysics. 564-565, Sep 5 (2012), p. 1-11.
DOI: 10.1016/j.tecto.2012.06.03

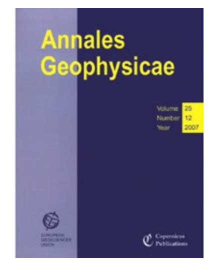
Karousová, H. - Plomerová, J. - Babuška, V.
Three-dimensional velocity model of the crust of the Bohemian Massif and its effects on seismic tomography of the upper mantle.
Studia geophysica et geodaetica. Vol. 56, No. 1 (2012), p. 249-267.
DOI: 10.1007/s11200-010-0065-z

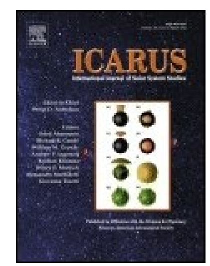
Kolář, P. - Růžek, B.
Finite seismic source parameters inferred from stopping phases for selected events of West Bohemia 2000 swarm.
Acta geodynamica et geomaterialia. Vol. 9, No. 4 (2012), p. 435-447.

Kozák, J. - Vaněk, J.
Early geophysical maps published by A. Petermann.
Studia geophysica et geodaetica. Vol. 56, No. 4 (2012), p. 1109-1122.
DOI: 10.1007/s11200-012-0800-8









D.7.2 INTERNATIONAL PUBLICATIONS

Kratinová, Z. - Schulmann, K. - Edel, J.-B. - Tabaud, A.-S.
AMS record of brittle dilation, viscous-stretching and gravity-driven magma ascent in area of magma-rich crustal extension (Vosges Mts., NE France).
International Journal of Earth Sciences. Vol. 101, No. 3 (2012), p. 803-817.
DOI: 10.1007/s00531-011-0711-x

Silva, P. F. - Henry, B. - Marques, F. O. - Hildenbrand, A. - Madureira, P. - Mériaux, C. A. - **Kratinová, Z.**
Palaeomagnetic study of a subaerial volcanic ridge (Sao Jorge Island, Azores) for the past 1.3 Myr: evidence for the CobbMountain Subchron, volcano flank instability and tectonomagmatic implications.
Geophysical Journal International. Vol. 188, No. 3 (2012), p. 959-978.
DOI: 10.1111/j.1365-246X.2011.05320.x

Novotný, M.
Depth-recursive tomography of the Bohemian Massif at the CEL09 transect—Part B: Interpretation.
Surveys in Geophysics. Vol. 33, No. 2 (2012), p. 243-273.
DOI: 10.1007/s10712-011-9155-x

Eken, T. - **Plomerová, J. - Vecsey, L. - Babuška, V.** - Roberts, R. - Shomali, H. - Bodvarsson, R.
Effects of seismic anisotropy on P-velocity tomography of the Baltic Shield.
Geophysical Journal International. Vol. 188, No. 2 (2012), p. 600-612.
DOI: 10.1111/j.1365-246X.2011.05280.x

Geissler, W.H. - Kämpf, H. - Skácelová, Z. - **Plomerová, J. - Babuška, V.** - Kind, R.
Lithosphere structure of the NE Bohemian Massif (Sudetes) — A teleseismic receiver function study.
Tectonophysics. 564-565, Sep 5 (2012), p. 12-37.
DOI: 10.1016/j.tecto.2012.05.005

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Mapping seismic anisotropy of the lithospheric mantle beneath the northern and eastern Bohemian Massif (central Europe).
Tectonophysics. Vol. 564-565, Sep 5 (2012), p. 38-53.
DOI: 10.1016/j.tecto.2011.08.011

Pšenčík, I. - Farra, V. - Tessmer, E.
Comparison of the FORT approximation of the coupling ray theory with the Fourier pseudospectral method.
Studia geophysica et geodaetica. Vol. 56, No. 1 (2012), p. 35-64.
DOI: 10.1007/s11200-010-0086-7

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Two-point paraxial traveltimes in an inhomogeneous anisotropic medium.
Geophysical Journal International. Vol. 189, No. 3 (2012), p. 1597-1610.
DOI: 10.1111/j.1365-246X.2012.05430.x

Růžek, B. - Plomerová, J. - Babuška, V.
Joint inversion of teleseismic P waveforms and surface-wave group velocities from ambient seismic noise in the Bohemian Massif.
Studia geophysica et geodaetica. Vol. 56, No. 1 (2012), p. 107-140.
DOI: 10.1007/s11200-010-9089-7

Schenk, V. - Schenková, Z. - **Jechumtálová, Z.** - Pichl, R.
Crustal deformations in the epicentral area of the West Bohemia 2008 earthquake swarm in central Europe. Journal of Geophysical Research. Vol. 117, B7 (2012), B07408.
DOI: 10.1029/2011JB009053

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Inferred gas hydrate and permafrost stability history models linked to climate change in the Beaufort-Mackenzie Basin, Arctic Canada.
Climate of the Past. Vol. 8, No. 2 (2012), p. 667-682.
DOI: 10.5194/cp-8-667-2012

Majorowicz, J. - Skinner, W. - **Šafanda, J.**
Western Canadian Sedimentary Basin temperature–depth transients from repeated well logs: evidence of recent decade subsurface heat gain due to climatic warming.
Journal of Geophysics and Engineering. Vol. 9, No. 2 (2012), p. 127-137.
DOI: 10.1088/1742-2132/9/2/127

Pesicek, J. D. - **Šílený, J.** - Prejean, S. G. - Thurber, C. H.
Determination and uncertainty of moment tensors for microearthquakes at Okmok Volcano, Alaska.
Geophysical Journal International. Vol. 190, No. 3 (2012), p. 1689-1709.
DOI: 10.1111/j.1365-246X.2012.05574.x

Louis, L. - David, Ch. - **Špaček, P.** - Wong, T. - Fortin, J. - Song, S. R.
Elastic anisotropy of core samples from the Taiwan Chelungpu Fault Drilling Project (TCDP): direct 3-D measurements and weak anisotropy approximations.
Geophysical Journal International. Vol. 188, No. 1 (2012), p. 239-252.
DOI: 10.1111/j.1365-246X.2011.05247.x

Kusbach, V. - Ulrich, S. - Schulmann, K.
Ductile deformation and rheology of sub-continental mantle in a hot collisional orogeny: Example from the Bohemian Massif.
Journal of Geodynamics. Vol. 56-57, May (2012), p. 108-123.
DOI: 10.1016/j.jog.2011.06.004

Vavryčuk, V. - Kühn, D.
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Geophysical Journal International. Vol. 190, No. 3 (2012), p. 1761-1776.
DOI: 10.1111/j.1365-246X.2012.05592.x

Vavryčuk, V.
On numerically solving the complex eikonal equation using real ray-tracing methods: A comparison with the exact analytical solution.
Geophysics. Vol. 77, No. 4 (2012), T109-T116.
DOI: 10.1190/GEO2011-0431.1

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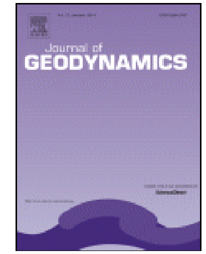
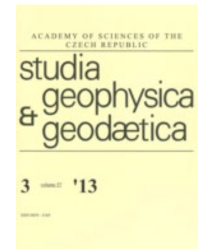
Seismic network calibration for retrieving accurate moment tensors.
Bulletin of the Seismological Society of America. Vol. 102, No. 6 (2012), p. 2491-2506.
DOI: 10.1785/0120120344

Zedník, J. - Pazdírková, J.
Seismic activity in the Czech Republic in 2009.
Studia geophysica et geodaetica. Vol. 56, No. 1 (2012), p. 299-305.
DOI: 10.1007/s11200-012-9002-7





D.7.3 INTERNATIONAL PUBLICATIONS

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Ackerman, L. - Špaček, P. - Magna, T. - Ulrych, J. - Svojtka, Martin - Hegner, E. - Balogh, K.
Alkaline and carbonate-rich melt metasomatism and melting of subcontinental lithospheric mantle: evidence from mantle xenoliths, NE Bavaria, Bohemian Massif.
Journal of Petrology. Vol. 54, No.12 (2013), 2597-2633.
DOI: 10.1093/P.ology/egt059

Adamová, P. - Šílený, J.
Disputable non-double-couple mechanisms of several strong earthquakes: second-degree moment approach.
Bulletin of the Seismological Society of America. Vol. 103, No.5 (2013), 2836-2849.
DOI: 10.1785/0120130014

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Boundaries of mantle–lithosphere domains in the Bohemian Massif as extinct exhumation channels for high-pressure rocks.
Gondwana Research. Vol. 23, No.3 (2013), 973-987.
DOI: 10.1016/j.gr.2012.07.005

Bouchaala, F. - Vavryčuk, V. - Fischer, T.
Accuracy of the master-event and double-difference locations: synthetic tests and application to seismicity in West Bohemia, Czech Republic.
Journal of Seismology. Vol. 17, No.3 (2013), 841-859.
DOI: 10.1007/s10950-013-9357-4

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Journal of Geophysical Research: Planets. Vol. 118, No.8 (2013), 1656-1675.
DOI: 10.1002/jgre.20120

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Trends in cardiovascular mortality and hospitalisations and potential contribution of inhospital case-fatality rates to changes in national mortality in the Czech Republic 1994-2009.
Heart. Vol. 99, No.6 (2013), 409-416.
DOI: 10.1136/heartjnl-2012-303123

Davi, R. - Vavryčuk, V. - Charalampidou, E.-M. - Kwiatek, G.
Network sensor calibration for retrieving accurate moment tensors of acoustic emissions.
International Journal of Rock Mechanics and Mining Sciences. Vol. 62, September (2013), 59-67.
DOI: 10.1016/j.ijrmms.2013.04.004

Dědeček, P. - Rajver, D. - **Čermák, V. - Šafanda, J. - Krešl, M.**
Six years of ground–air temperature tracking at Malence (Slovenia): thermal diffusivity from subsurface temperature data.
Journal of Geophysics and Engineering. Vol. 10, No.2 (2013), 025012/1-025012/9.
DOI: 10.1088/1742-2132/10/2/025012

Dlouhá, Š. - Petrovský, E. - Kapička, A. - Borůvka, L. - Ash, Ch. - Drábek, O.
Investigation of polluted alluvial soils by magnetic susceptibility methods: a case study of the Litavka River.
Soil and Water Research. Vol. 8, No.4 (2013), 151-157.

Farra, V. - **Pšenčík, I.**
Moveout approximations for P- and SV-waves in dip-constrained transversely isotropic media.
Geophysics. Vol. 78, No.6 (2013), C53-C59. DOI: 10.1190/GEO2013-0083.1

Farra, V. - **Pšenčík, I.**
Moveout approximations for P- and SV-waves in VTI media.
Geophysics. Vol. 78, No.5 (2013), WC81-WC92.
DOI: 10.1190/GEO2012-0408.1

Horálek, J. - Šílený, J.
Source mechanisms of the 2000 earthquake swarm in the West Bohemia/Vogtland region (Central Europe).
Geophysical Journal International. Vol. 194, No.2 (2013), 979-999.
DOI: 10.1093/gji/ggt138

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Seismic communication in demon African mole rat Tachyoryctes daemon from Tanzania.
Journal of Ethology. Vol. 31, No.3 (2013), 255-259.
DOI: 10.1007/s10164-013-0374-0

Hrubcová, P. - Środa, P. - **Vavryčuk, V. - Babuška, V.** - Grad, M.
Comment on the seismic method Depth-Recursive Tomography on Grid (DRTG) developed by Miroslav Novotný and recently published in three papers in Surveys in Geophysics.
Surveys in Geophysics. Vol. 34, No.4 (2013), 521-529.
DOI: 10.1007/s10712-013-9228-0

Hrubcová, P. - Vavryčuk, V. - Boušková, A. - Horálek, J.
Moho depth determination from waveforms of microearthquakes in the West Bohemia/Vogtland swarm area.
Journal of Geophysical Research: Solid Earth. Vol. 118, No.1 (2013), 120-137.
DOI: 10.1029/2012JB009360

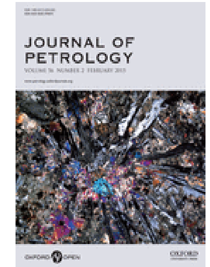
Janutyte, I. - Kozlovskaya, E. - Motuza, G. - **Plomerová, J. - Babuška, V.** - Gaždová, R. - **Jedlička, P.** - Kolínský, P. - Málek, J. - Novotný, O. - **Růžek, B.**
Study of local seismic events in Lithuania and adjacent areas using data from the PASSEQ experiment.
Pure and Applied Geophysics. Vol. 170, No.5 (2013), 797-814.
DOI: 10.1007/s00024-012-0458-8

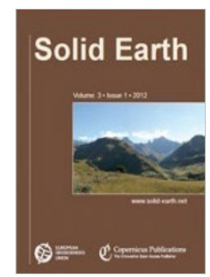
Jordanova, N. - Jordanova, D. - Liu, Q.-Z. - Hu, P. - Petrov, P. - **Petrovský, E.**
Soil formation and mineralogy of a Rhodic Luvisol - insights from magnetic and geochemical studies.
Global and Planetary Change. Vol. 110, Part C - November (2013), 397-413.
DOI: 10.1016/j.gloplacha.2013.08.020

Karousová, H. - Plomerová, J. - Babuška, V.
Upper-mantle structure beneath the southern Bohemian Massif and its surroundings imaged by high-resolution tomography.
Geophysical Journal International. Vol. 194, No.2 (2013), 1203-1215.
DOI: 10.1093/gji/ggt159

Kletetschka, G. - **Fischer, T.** - Mls, J. - **Dědeček, P.**
Temperature fluctuations underneath the ice in Diamond Lake, Hennepin County, Minnesota.
Water Resources Research. Vol. 49, No.6 (2013), 3306-3313.
DOI: 10.1002/wrcr.20261

Knapmeyer-Endrun, B. - Krüger, F. - Legendre, C. P. - Geissler, W.H. - **Plomerová, J. - Babuška, V. - Gaždová, R. - Jedlička, P.** - Kolínský, P. - Málek, J. - Novotný, O. - **Růžek, B.**
Tracing the influence of the Trans-European Suture Zone into the mantle transition zone.
Earth and Planetary Science Letters. Vol. 363, FEB 1 (2013), 73-87.
DOI: 10.1016/j.epsl.2012.12.028





D.7.4 INTERNATIONAL PUBLICATIONS

Kučeráková, M. - Vratislav, S. - Kalvoda, L. - **Machek, M.**
Neutron diffraction study of the crystallographic preferential orientation of metagabro mylonite.
Powder Diffraction. Vol. 28, S2 (2013), S276-S283.
DOI: 10.1017/S0885715613000985

Kühn, D. - **Vavryčuk, V.**
Determination of full moment tensors of microseismic events in a very heterogeneous mining environment.
Tectonophysics. Vol. 589, March (2013), 33-43.
DOI: 10.1016/j.tecto.2012.12.033

Macková, H. - Horák, D. - **Petrovský, E.** - Kovářová, J.
Magnetic hollow poly(N-isopropylacrylamide-co-N,N'-methylenebisacrylamide-co-glycidyl acrylate) particles prepared by inverse emulsion polymerization.
Colloid and Polymer Science. Vol. 291, No.1 (2013), 205-213.
DOI: 10.1007/s00396-012-2609-y

Machek, M. - Roxerová, Z. - Janoušek, V. - Staněk, M. - Petrovský, E. - René, M.
P.ophysical and geochemical constraints on alteration processes in granites.
Studia geophysica et geodaetica. Vol. 57, No.4 (2013), 710-740.
DOI: 10.1007/s11200-013-0923-6

Majorowicz, J. - Osadetz, K. - **Šafanda, J.**
Methane gas hydrate stability models on continental shelves in response to glacio-eustatic sea level variations: examples from Canadian oceanic margins.
Energies. Vol. 6, No.11 (2013),. 5775-5806.
DOI: 10.3390/en6115775

Michálek, J. - Fischer, T.
Source parameters of the swarm earthquakes in West Bohemia/Vogtland.
Geophysical Journal International. Vol. 195, No.2 (2013), 1196-1210.
DOI: 10.1093/gji/ggt286

Munzarová, H. - Plomerová, J. - Babuška, V. - Vecsey, L.
Upper-mantle fabrics beneath the Northern Apennines revealed by seismic anisotropy.
Geochemistry, Geophysics, Geosystems. Vol. 14, No.4 (2013), 1156-1181.
DOI: 10.1002/ggge.20092

Novotný, M.
Refraction tomography of the Bohemian Massif structures: a critical review and reply to the Comments of Hrubcová et al. (2013).
Surveys in Geophysics. Vol. 34, No.4 (2013), 531-540.
DOI: 10.1007/s10712-013-9241-3

Novotný, M. - Špičák, A.- Weinlich, F. H.
Structural preconditions of West Bohemia earthquake swarms.
Surveys in Geophysics. Vol. 34, No.4 (2013), 491-519.
DOI: 10.1007/s10712-013-9239-x

Petrovský, E. - Zbořil, R. - Matys Grygar, T. - Kotlík, B. - Novák, J. - **Kapička, A. - Grison, H.**
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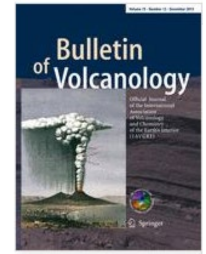

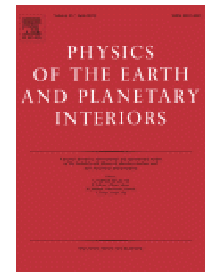

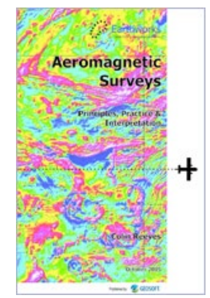

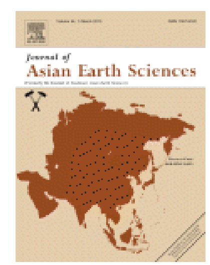

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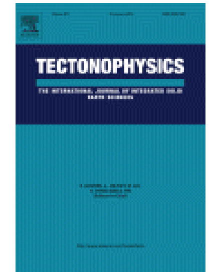

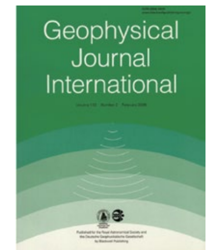

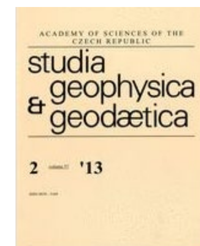

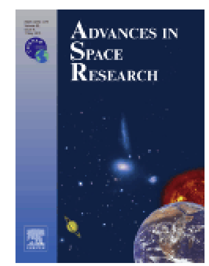

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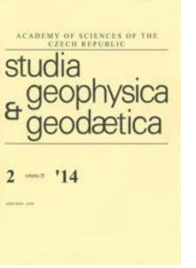

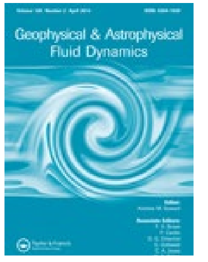

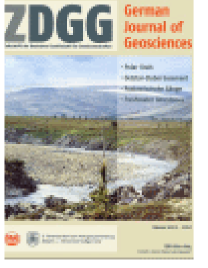

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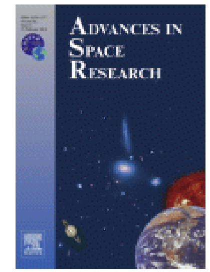

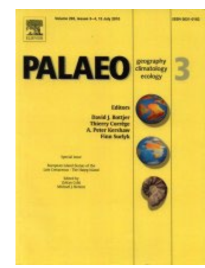

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ART EXHIBITIONS

The Institute of Geophysics has continued in a its series of art exhibitions entitled “ENCOUNTERS” (“Setkávání” in Czech). In cooperation with the Archive of Fine Arts (http://www.artarchiv.cz/), the series was launched in 2002 in order to invite artists whose works apply procedures commonly used in science, such as forethought concept, analogy, variation, similarity etc. By now, exhibitions of 47 artists have taken place at the Institute: Marie Blabolilová, Jiří Hůla, Pavel Rudolf, Josef Procházka, Inge Kosková, Eva Prokopcová, Jana Budíková, Miroslav Koval, Karel Adamaus, Pavla Francová, Václav Vokolek, Ryosuke Cohen, Pavel Wojnar, Pavel Mühlbauer, Jindřich Růžička, Vladimír Gebauer, Pavla Aubrechtová, Ladislav Daněk, Jiří Lindovský, Lubomír Přibyl, Vladimír Havlík, Petr Veselý, Jaromír Zoul, Marie Molová, Pavel Hayek, Zuzana Nováčková, Petr Kvíčala, Jan Kubíček, Asan Fryč, Milan Maur, Daniela Mikulášková, Aleš Svoboda, Jaroslav Rezek, **Václav Malina, Jindřich Zeithamml, Dalibor Chatrný, Jiří Voves, František Hodonský, Martin Kolář, Miloš Šejn, Jaroslav Alt, Josef Hampl, Radomír Leszczynski, Ivan Kafka a Jan Rýz;** the last thirteen exhibitions (denoted by **bold letters**) took place in 2012-2014. Another two exhibitions of the series were topical – Computer Graphics and Visual Poetry (more on the artists and exhibitions at http://www.artarchiv.cz and http://www.ig.cases.cz/cz/o-nas/spolecenske-aktivity). Since 2006, in September-October the Institute of Geophysics has annually offered its exhibition area to local artists of the Spořilov district where the Institute is located.

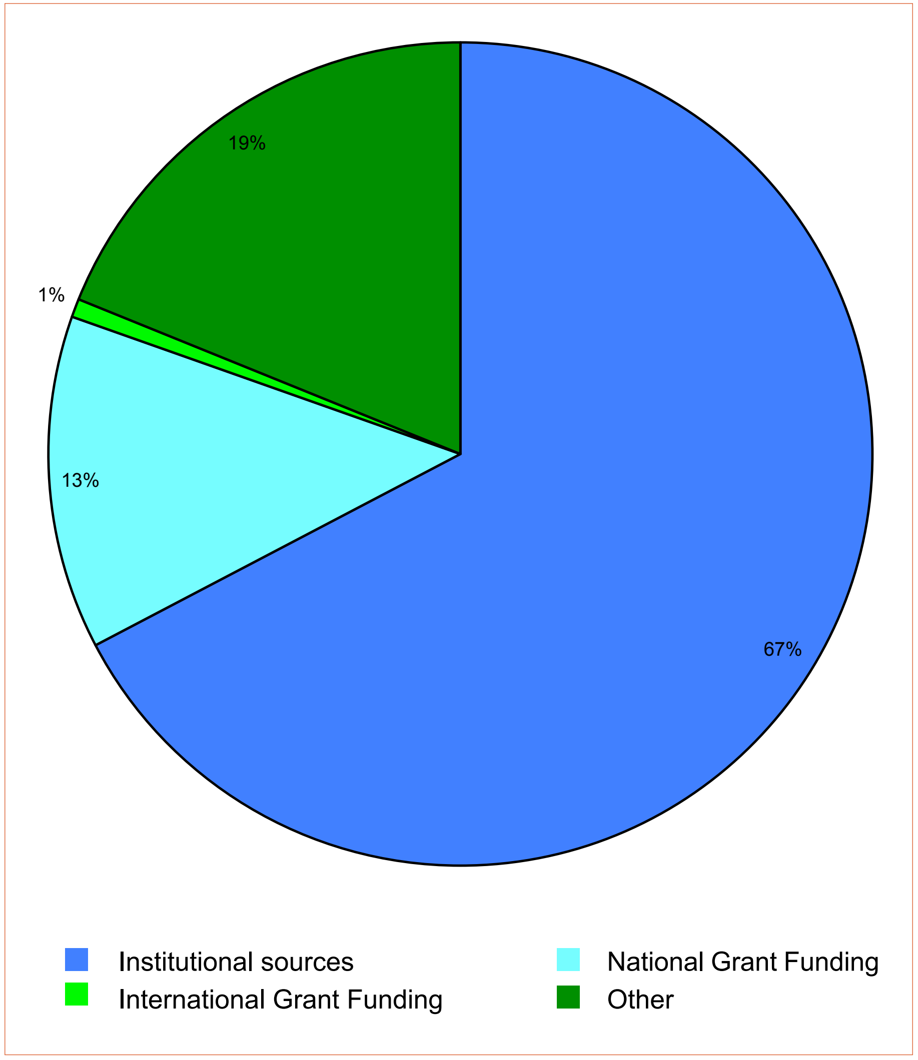
Most recently, the organizers of the “ENCOUNTERS” series of exhibitions were invited by the Academy of Sciences of the Czech Republic to prepare a group exhibition on the occasion of the 125th anniversary of foundation of the Academy in 1890. The exhibition will feature artists who have displayed their works in several institutes of the Academy since the second half of the 20th century. The exhibition will take place in the National Technical Library - itself a masterpiece of modern architecture - in Prague, in October 2015.

Fig. 1: Ivan Kafka: Reality + dream / two realities, 1990; white and yellow blocks of marble, 300 x 750 x 330 cm, weight ca. 35 tons. Installation in Austria, with the peak in Germany (Austrian and German Alps, Salzburg, Austria, 1990). Photo by Ivan Kafka, shown at the Institute of Geophysics as part of exhibition of photographs and other documentation of Kafka’s art.

Fig. 2: František Hodonský (*1945), "Vodní vítr" - Water wind, woodcut, 60 x 90 cm, 2007.

BUDGET

Institute of Geophysics Total Income in 2014
CZK 86, 167, 339



Institute of Geophysics, Total Spending in 2014
CZK 85, 029, 137