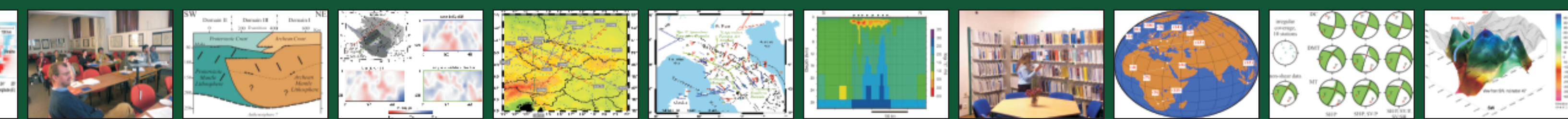
Academy of Sciences of the Czech Republic

Geophysical Institute



report 2004/2005

Academy of Sciences of the Czech Republic

Geophysical Institute

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Table of Contents

Academy of Sciences of the Czech Republic

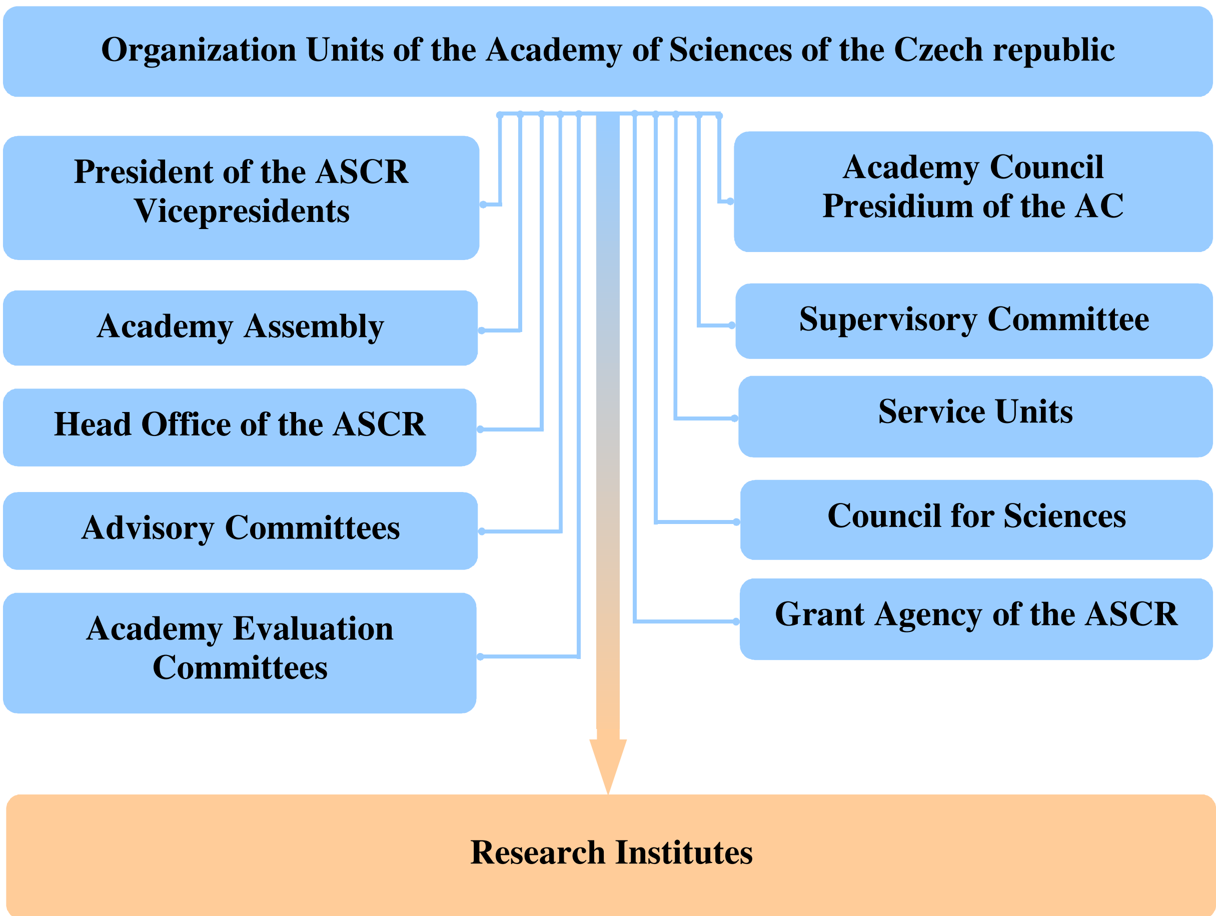
(http://www.cas.cz)

Address:
Národní 3, 117 20 Prague 1
Czech Republic

Tel.: +420 221 403 111
Fax: +420 224 240 512
E-mail: info@cas.cz

The Academy of Sciences of the Czech Republic (ASCR) is a leading non-university research institution in the Czech Republic. It was established in 1992 by the Czech National Council as a Czech successor of the former Czechoslovak Academy of Sciences. The history of the ASCR predecessors may be traced back through the Czechoslovak Academy of Sciences (*1952), the Czech Academy of Sciences and Arts (*1882), the Royal Czech Learned Society (*1784) down to the Privat Society for Sciences (*1773).

Today's ASCR conducts research in many scientific directions and co-operates with numerous scientific institutions, universities, as well as business organizations and cultural establishments in the Czech Republic and abroad. The ASCR is a fully consistent research body open to full-scale integration into the European research space. Both the fundamental and applied research are key areas of the ASCR's activities. About 6300 employees are working in 57 institutes and 4 technical facilities. Research institutes are grouped into three scientific divisions according to their research profiles.



Scientific Divisions of the ASCR

Mathematics, Physics and Earth Sciences	Life and Chemical Sciences	Humanities and Social Sciences
1. Section of Mathematics, Physics and Computer Science	**4. Section of Chemical Sciences**	**7. Section of Social and Economic Sciences**
• Astronomical Institute • Institute of Computer Science • Institute of Information Theory and Automation • Institute of Physics • Mathematical Institute • Nuclear Physics Institute	• Institute of Analytical Chemistry • Institute of Chemical Process Fundamentals • Institute of Inorganic Chemistry • Institute of Macromolecular Chemistry • Institute of Organic Chemistry and Biochemistry • J. Heyrovský Institute of Physical Chemistry	• Economics Institute • Institute of Psychology • Institute of Sociology • Institute of State and Law • Masaryk Institute
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Geophysical Institute of the ASCR

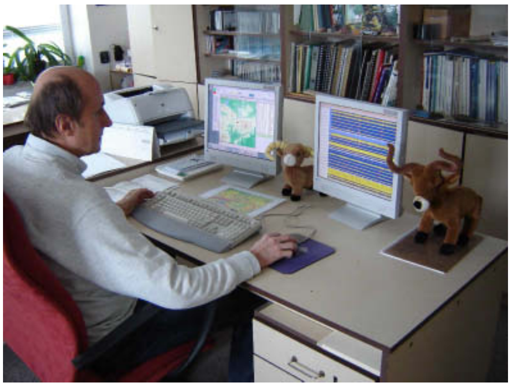
(http://www.ig.cas.cz)

Address:
Boční II/1401
141 31 Prague 4
Czech Republic

Tel.: +420-267103111
Fax.: +420-272761549
E-mail: gfu@ig.cas.cz

The Geophysical Institute of the AS CR conducts fundamental research in a series of directions of the physics of the solid Earth and of its immediate cosmic environment, carries out investigations of geophysical fields on various space and time scales and participates in complex geoscientifical interpretations of Earth's structures on the territory of the Czech Republic as well as on an over-regional and global scale. The activities of the Geophysical Institute comprise regular observatory monitoring of Earth's physical fields as well as a spectrum of field measurements and experiments for collecting the primary experimental data. A broad co-operation with world-wide network services and data centers is established. Geophysical interpretations include studies of the lithosphere and sub-lithosphere structure, crustal studies, geodynamics of the seismoactive regions, climatic changes, solar-terrestrial relations, environmental geomagnetism and many others. Theoretical modelling and numerical simulations of geophysical fields are integral parts of the research programme of the Institute.

The research staff of the Geophysical Institute consists of 50 scientists and qualified technical personnel who work in five research departments covering the principal geophysical methods: seismology, geothermics, geomagnetism, geoelectricity and gravity and geodynamics. The research activities of the Institute are effectively backed up by a body of 26 workers of the administration, computer center, library and technical services.



Organization Units of the Geophysical Institute

Geophysical Institute, ASCR

Boční II/1401
141 31Prague 4
Czech Republic

Tel.: +420-267103111
Fax.: +420-272761549
e-mail: gfu@ig.cas.cz
URL: http://www.ig.cas.cz

Management

Director:	**RNDr. Aleš Špičák, CSc.**	**Tel: 267 103 327, 272 764 345**	**e-mail: als@ig.cas.cz**
Deputy Director:	**RNDr. Pavel Hejda, CSc.**	**Tel: 267 103 339**	**e-mail: ph@ig.cas.cz**
Economy Deputy:	**RNDr. Marta Tučková**	**Tel: 267 103 089**	**e-mail: tuckova@ig.cas.cz**
Scientific Secretary:	**RNDr. Bohuslav Růžek, CSc.**	**Tel: 267 103 026**	**e-mail: b.ruzek@ig.cas.cz**

Scientific Council

Head

RNDr. Jan Šílený, CSc. (jsi@ig.cas.cz)

Internal members

RNDr. Pavel Hejda, DrSc. (ph@ig.cas.cz)
RNDr. Jan Mrlina (jan@ig.cas.cz)
RNDr. Josef Pek, CSc. (jpk@ig.cas.cz)
RNDr. Ivan Pšenčík, CSc. (ip@ig.cas.cz)
RNDr. Jan Šafanda, CSc. (jsa@ig.cas.cz)
RNDr. David Uličný, CSc. (ulicny@ig.cas.cz)
RNDr. Václav Vavryčuk, DrSc. (vv@ig.cas.cz)

External members

Assoc. Prof. Ondřej Čadek, CSc. (oc@karel.troja.mff.cuni.cz)
RNDr. Luděk Klimeš, DrSc. (klimes@seis.karlov.mff.cuni.cz)
Assoc. Prof. RNDr. Josef Ježek, CSc. (jezek@natur.cuni.cz)
Prof. RNDr. Miloš Karous, DrSc. (karous@geonika.cz)
RNDr. Jan Laštovička, DrSc. (jla@ufa.cas.cz)
Assoc. Prof. RNDr. Oldřich Novotný, CSc. (on@karel.troja.mff.cuni.cz)

Studia geophysica & geodaetica

Editor-in-Chief: RNDr. Ivan Pšenčík, CSc. (ip@ig.cas.cz)
Executive Editor: RNDr. Josef Pýcha, CSc. (studia@ig.cas.cz)
Technical Editor: RNDr. Eduard Petrovský, Csc. (edp@ig.cas.cz)

Scientific departments

- ***Department of Seismology***
  Head: RNDr. Jan Šílený, CSc. (jsi@ig.cas.cz)
- ***Department of Geoelectricity***
  Head: RNDr. Josef Pek, CSc. (jpk@ig.cas.cz)
- ***Department of Geomagnetism***
  Head: RNDr. Eduard Petrovský, CSc. (edp@ig.cas.cz)
- ***Department of Geothermics***
  Head: RNDr. Jan Šafanda, CSc. (jsa@ig.cas.cz)
- ***Department of Tectonics and Geodynamics***
  Head: RNDr. Aleš Špičák, CSc. (als@ig.cas.cz)

Computing Centre

Head: Ing. Marcela Švamberková (mk@ig.cas.cz)

Library

Head: PhDr. Hana Krejzlíková (kniha@ig.cas.cz)

Scientific Departments of the Geophysical Institute

Department	Basic research areas
Department of Geothermics 3 researchers 1 PhD student 2 technicians	• 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 • Research into the air, ground and bedrock temperature coupling and into the thermal regime within the soil and the underlying bedrock.
Department of Geomagnetism 8 researchers 1 PhD student 11 technicians	• Observations of the Earth's magnetic field • Field measurements of secular variations • Geodynamo modelling • Space weather studies • Effect of solar and geomagnetic activites on climatic changes • Rock and environmental magnetism
Department of Tectonics and Geodynamics 10 researchers 3 technicians	• Gravity measurements and interpretations for engineering geology, environment, archaeology and geodynamic investigations • Recording, processing and analysis of tidal data from observatories Lazec and Jezeří • Stratigraphic analysis of sedimentary basins using geological and geophysical data, physical sedimentology of clastic depositional systems • Sea-level fluctuations, palaeoclimate and global change • Post-orogenic tectonic evolution of the Bohemian Massif • Laboratory studies in elastic rock anisotropy • Analysis of the seismicity pattern at convergent plate margins
Department of Geoelectricity 8 researchers 1 technician	• Investigations of the crustal and upper mantle electrical conductivity • Theoretical and methodological research of electromagnetic fields and their numerical modelling • Research of external geoelectro-magnetic fields • Investigations of the solar-terrestrial relations
Department of Seismology 18 researchers 3 technicians 2 PhD students	• Operating the regional network of broadband seismological stations • Monitoring and interpreting the local seismicity in West Bohemia • Study of deep geological structures down to the mantle litosphere • Theoretical research on seismic waves generation and propagation in complex structures • Study of the Earth's crust by using active seismic experiments

Staff of the Geophysical Institute, November 2005

List of researchers

Name	Titles	Tel.	e-mail
BABUŠKA Vladislav	RNDr. DrSc.	049	babuska
BĚHOUNKOVÁ Marie	Mgr.	398	marie
BOCHNÍČEK Josef	Ing. CSc	067	jboch
BOUŠKOVÁ Alena	Mgr.	381	ab
BUCHA Václav	RNDr. DrSc.	393	bucha
ČERMÁK Vladimír	RNDr. DrSc.	385	cermak
ČERV Václav	RNDr. CSc.	354	vcv
DĚDEČEK Petr	Mgr.	054	pd
FIALOVÁ Hana	Ing.	332	hfialova
FISCHER Tomáš	RNDr. PhD.	019	tomfis
HANUŠ Václav	RNDr. DrSc.	346	hanus
HEJDA Pavel	RNDr. CSc.	339	ph
HORÁLEK Josef	Ing. CSc.	076	jhr
HRUBCOVÁ Pavla	RNDr.	070	pavla
HUDOVÁ Zuzana	Mgr.	019	hudova
CHÁN Bohumil	Ing. CSc.	344	bch
CHARVÁTOVÁ Ivanka	Ing. CSc.	080	ich
JEDLIČKA Petr	Ing.	381 011	jepe
JECHUMTÁLOVÁ Zuzana	RNDr. PhD.	121	zs
KAPIČKA Aleš	RNDr. CSc.	341	kapicka
KOLÁŘ Petr	RNDr. CSc.	012	kolar
KOVÁČIKOVÁ Světlana	Ing. PhD.	319	svk
KOZÁK Jan	RNDr. CSc.	018	kozak
KRATINOVÁ Zuzana	Mgr.	074	
KREŠL Milan	Ing. CSc.	048 046 350	mkr
LAURIN Jiří	Mgr.	071	laurin
MACHEK Matěj	Mgr.	017	mates

Name	Titles	Tel.	e-mail
MRLINA Jan	RNDr.	314	jan
NOVOTNÝ Miroslav	RNDr. CSc.	386	mn
PĚČOVÁ Jana	RNDr. CSc.	318	jp
PEK Josef	RNDr. CSc.	320	jpk
PETROVSKÝ Eduard	RNDr. CSc.	333	edp
PICK Miloš	Ing. DrSc.	330	mp
PLOMEROVÁ Jaroslava	RNDr. DrSc.	391 049	jpl
PRAUS Oldřich	RNDr. DrSc.	318	opr
PRIKNER Karel	RNDr. CSc.	354	kpr
PŠENČÍK Ivan	RNDr. CSc.	383	ip
RŮŽEK Bohuslav	RNDr. CSc.	026	b.ruzek
STŘEŠTÍK Jaroslav	RNDr. CSc.	321	jstr
ŠAFANDA Jan	RNDr. CSc.	384 350	jsa
ŠIMKANIN Jan	PhD.	351	jano
ŠÍLENÝ Jan	RNDr. CSc.	016	jsi
ŠPIČÁK Aleš	RNDr. CSc.	345	als
ŠPIČÁKOVÁ Lenka	RNDr. PhD.	343	spicka
ULIČNÝ David	RNDr. CSc.	326	ulicny
ULRICH Stanislav	RNDr. PhD.	017	stano
VANĚK Jiří	RNDr. DrSc.	346	
VAVRYČUK Václav	RNDr. DrSc.	020	vv
VECSEY Luděk	Mgr. PhD.	021	vecsey
ZEDNÍK Jan	RNDr.	015 365	jzd

As regards telephone number, full number is +420267103*xxx*, for *xxx* substitute the number from the column Tel. As regards e-mail, append @ig.cas.cz to any address in the column e-mail.

Observatories of the Geophysical Institute

Czech Regional Seismic Network (CRSN)

Seismological observations of the Geophysical Institute (GI) have a long tradition and form the basis of its research. Numerous projects are based on using the data provided by the observatories of the GI. The Geophysical Institute operated seven stations of the CRSN in 2004-2005: 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). Digital data from all stations are transferred to the GI in real time by Internet. Software packages Antelope and SeisComP are used for automated data acquisition and exchange. The GI is largely involved in international data exchange with global data centers and a number of European national data centers and observatories.

Virtual network of the GI consists at present of about 40 real-time seismological stations in central and southern Europe. About 20 new stations have been added to the virtual network in 2004-2005 as a result of broad international cooperation of the GI in the frame of EC project Meredian (2000-2005). Improved reliability of the automated regional locations of the virtual network of the GI has been achieved.

Seismological Data Center of the GI provides the following services:

- Automated near-real time data acquisition of continuous broadband and short-period seismic data by Antelope and SeedLink software packages.
- 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 observatories,
- Daily analysis of digital seismograms by Unix program Seismic Handler. Rapid location of strong seismic events in Central Europe by program LocSat.
- Archiving of digital records: continuous records are stored on a large raid system and archived on a tape robot device with a capacity of 2 TB.
- 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.
- Recent automated locations of the CRSN and live seismograms of selected stations are displayed on the web pages of the GI (http://www.ig.cas.cz).
- Informing the public through TV and radio interviews and articles in press about prominent strong earthquakes and strong regional events.

Geographic co-ordinates of the stations of the CRNS

station code	latitude	longitude	altitude	station code	latitude	longitude	altitude
PRU	49.988	14.542	302	PVCC	50.528	14.569	311
KHC	49.131	13.578	700	UPC	50.507	16.012	416
DPC	50.350	16.322	748	TREC	49.295	15.487	559
NKC	50.233	12.448	564	OKC*	49.837	18.147	272

* Station OKC is operated jointly with the Institute of Geonics, Ostrava and with the Technical University, Ostrava

WEBNET network

West Bohemia/Vogtland earthquake swarm region is among the best-monitored seismically active area in Europe. Network WEBNET, jointly operated by the Geophysical Institute (GI) and the Institute of Rock Structure and Mechanics (IRSM) of the ASCR in Prague, and smaller net KRASNET, operated by the Institute of the Physics of the Earth of the Masaryk University in Brno, are located in the West Bohemia seismoactive region. Further networks providing relevant, high quality data have been working in NE Bavaria and SE Saxony.

At present, WEBNET is primary in the whole region. It consists of thirteen broad band three-component digital seismic stations consisting of the SM-3 short-period seismometers and Janus-Trident/Nanometrics acquisition systems, and covering an area of about 900 km2. Its configuration and the parameters of the seismograph systems guarantee high-quality recording of West Bohemia/Vogtland events of magnitudes $-0.5 \leq ML \leq 5$ in a frequency range of 0.5 to 80 Hz with sampling frequency of 250 Hz. Thus, WEBNET makes possible 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 neighbourhood of the region under study.

Data from all the stations are transmitted via Internet to GI, Prague. Besides, a three-component very broadband (VBB) system providing continuous digital records of seismic signals with periods up to 120 seconds has been operating at stations NKC (in the centre of the NK zone) and LAC (southern part of the seismoactive region). 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 about 2 m below the surface were built in the West Bohemia for deploying mobile stations in the case of enhanced seismic activity. The seismograms of all tectonic events (about 25000), recorded by the WEBNET net and the VBB stations since, respectively, 1992 and 1998 are archived in a digital database. Data from other nets operating in the region are available on request.

The geothermal climate-change observatories

The geothermal climate-change observatories on the grounds of the Geophysical Institute 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 (in the heights of 2 m and 5 cm above the surface), soil (2, 5, 10, 20, 50 and 100 cm below the surface) and bedrock temperatures (down to the depth of 40 m) 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 for at least several years 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.

Geographic co-ordinates of the geothermal observatories

Code	*Latitude*	*Longitude*	*Altitude*
Spořilov	50.040	14.478	275
Kocelovice	49.467	13.839	518
Potůčky	50.434	12.778	864

The air-ground temperature monitoring on the campus of the Geophysical Institute at Prague – Spořilov.

Beside the problem of the long-term stability of the mean annual difference between air and soil temperatures, which is being studied in the three stations mentioned above, the influence of the vegetation cover on the soil temperatures is studied systematically at the fourth observatory located also on the campus of Geophysical Institute at Prague - Spořilov. The monitoring system launched in the year 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 soil temperatures at the depths of 2, 5, 10, 20 and 50 cm below and the air temperatures at 5 cm above each of the 4 different surfaces are recorded every 5 minutes together with the air temperature of the site at 200 cm. The soil moisture is measured in the sand at the depth of 20 cm. The monitoring allows for a detailed study of a mean annual difference between the 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.

Geomagnetic observatory

The first systematic magnetic observations in central and eastern Europe were started in Prague in 1839 by Karl Kreil (1798-1862), who was Assistant Director, and since 1845 Director of the Prague Observatory and Professor of astronomy at the Prague University. The observatory, located in the city centre, was since the beginning of the 20th century more and more influenced by urban magnetic noise and was finally closed in 1926.

The Prague observatory was replaced in 1946 by the observatory Průhonice near Prague but rapid expansion of the city and construction of D.C.-powered railways resulted in a deterioration of conditions of this location. The observatory was moved to Budkov (BDV) in south Bohemia, to a sparsely populated area, in 1967. It has been equipped with Bobrov-type variometers with photographic registration.

The first digital system was installed in 1992 in cooperation with the Geomagnetic Observatory of the Geological Survey of Canada as a modification of the CANMOS system and the observatory became part of the INTERMAGNET Network in 1994 (www.intermagnet.org). The system 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. In order to further enhance data reliability and stability, another digital system – GDAS – was installed in autumn 2003. The main parts of the system are DMI suspended fluxgate magnetometer, Overhauser proton magnetometer and a Pentium-type embedded PC with QNX4 operating system and SDAS data acquisition software developed by the British Geological Survey. Absolute measurements are carried out by a DI magnetometer (fluxgate sensor mounted on non-magnetic theodolite Zeiss 010B).

The data are transmitted via telephone network to the Geophysical Institute, Prague. They are stored and processed on the network server and one-minute values of three components of the magnetic field are transmitted via e-mail to the Geomagnetic Information Node (GIN) in Edinburgh. Yearly collections of final data are published on the INTERMAGNET CD-ROM.

The Geomagnetic Department has been issuing daily forecasts of geomagnetic activity for Central Europe since 1994, weekly forecasts started in the spring of 1995. Since 1998 the short term forecasts have been sent to Czech TV. They are presented as a part of the Weather Forecast and displayed on the teletext pages of the Czech TV. At present, the forecasts, as well as reports of the current state of the geomagnetic field in our region, are available on the web pages of the Regional Warning Centre, Prague (http://rwcprague.ufa.cas.cz/).

Gravity and Earth tides observatories

The observatory Jezeří 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. It consists of two tiltmeter sites with permanent recordings of tilts in a horizontal gallery. Station 1 is located at the depth of 410 m in the mountain crystalline massif, and has been operating since 1982. The target is to record the stability of this deep block of the massif suspected of rotation or sliding movements. Station 2 was set up 5 years ago in order to monitor the weak zone of the crystalline basement close to the contact with Tertiary sediments containing a coal seem. This station is a part of a fast geomechanic processes monitoring system of the mining company. It has clearly recorded, e.g., the 2002 flood effect on the block stability with anomalous tilts caused by an enormous water infill in a support pillar of sedimentary formation.

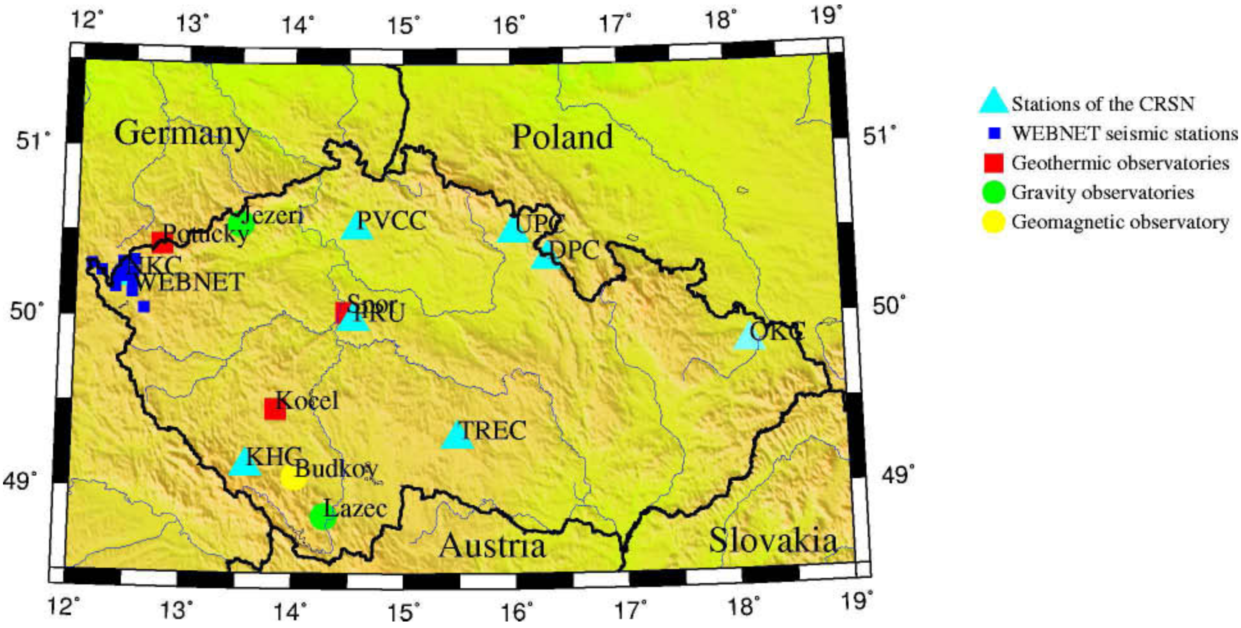
This observatory has been technically upgraded for automatic data transmittion and nowadays is being prepared for real-time monitoring. The aim of the system is to provide real-time continuous information on the stability of the mine slopes suspected of possible sliding. Day-to-day evaluation of the data, together with all other observed parameters, should provide indications of slope instability and warning signals for the mine authorities. At the same time, the data are a subject to long-term earth tide effects investigation.

The new observatory Skalná is located in the West Bohemia seismoactive region in an underground gallery in a granite block in the town of Skalná. The observatory should contribute to the monitoring of the ongoing geodynamic processes. It is furnished with a couple of tiltmeters, a seismograph, a barometer and a special deformation meter. Except the seismograph, the other equipment is still in a testing period, mainly due to stabilisation of the tiltmeters in local temperature conditions and their stable setup on the rock. Ocassionally, continuous measurements of gravity are performed to test local changes of the gravity field. A significant signal was recorded during the Sumatra earthquake in Dec. 2004, when the trend of the gravity variations changed for a long time.

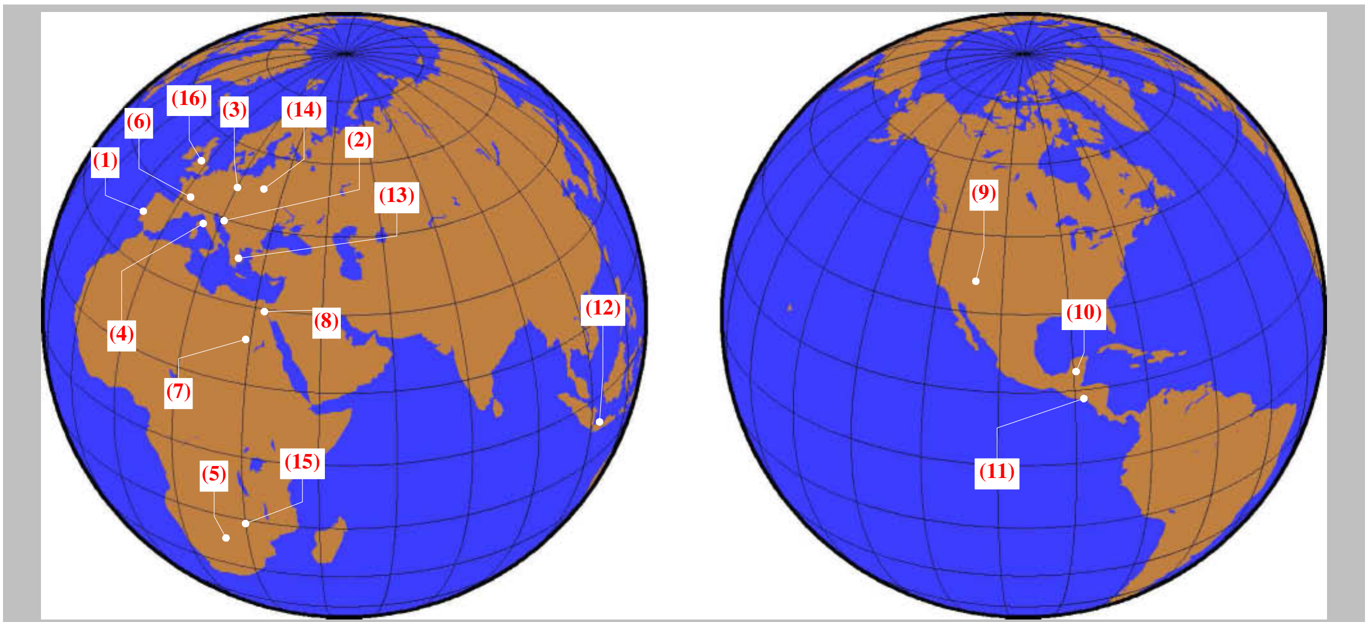
Geographic co-ordinates of the gravity observatories

Code	*Latitude*	*Longitude*	*Altitude*
Jezeří	50.555	13.505	280
Skalná	50.170	12.361	45

Geographic locations of the observatories of the Geophysical Institute



Current research activities of the Geophysical Institute abroad



(1) Geothermal climate change observatories in Portugal
(2) Geothermal climate change observatories in Slovenia
(3) Deep electromagnetic soundings across the Teisseyre-Tornquist Zone in Ponserania, NW Poland
(4) Passive seimological experiment in Italy
(5) Study of petrological properties and rheology of upper mantle eclogite
(6) Paris - world calibration campaigns of relative and absolute gravity meters
(7) Gravity measurements in Aswan
(8) Gulf of Suez - gravity and GPS investigation of onshore faults geodynamic activity
(9) Structural and sea-level history of the Cretaceous Western Interior
(10) Geothermal research of the impact structure Chicxulub
(11) Geodynamics of the Middle America region
(12) Geodynamics of the Indonesia region
(13) Structural and geodynamics research in the Gulf of Corinth region using gravimetry
(14) Geothermal evidence of recent decay of permafrost
(15) Investigation of rockbursts in DRIEFONTEIN mines
(16) Co-operation with Schlumberger Cambridge Research: seismicity induced by hydrofracks

Key Research Projects in 2004-2005

Geothermal research of the impact structure Chicxulub

As one of the ICDP projects, the 1.5 km deep borehole Yaxcopoil-1 was drilled in December 2001 through February 2002 within the impact structure Chicxulub on the Yucatan peninsula, Mexico. Temperature-depth profiles obtained during four temperature loggings of the borehole in the period 2002 – 2004 (March 2002 and February 2004 – University of Karlsruhe, Germany; May 2003 and December 2004 – Geophysical Institute Prague) display effects of a thermal fluid convection

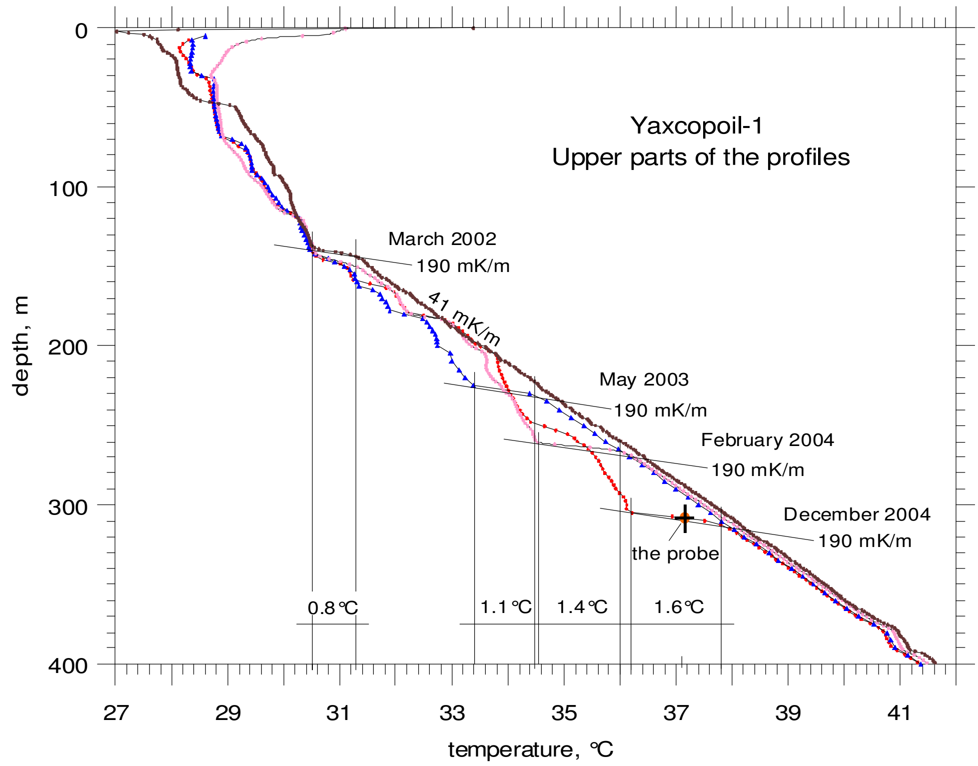


Fig. 1. Upper 400 m sections of the four temperature logs of borehole Yaxcopoil-1 measured within 34 months after the hole shut-in. The high gradient zone is marked in each log by a line of the 190 mK/m slope and by a value of its amplitude. The cross shows a position of the probe on the temperature profile at the beginning of the 20-day temperature monitoring at 307 m.

gradually propagating downward (see Fig. 1). The convective features were limited within the uppermost 145 m of the hole during the first logging campaign in March 2002, starting 10 days after finishing the driling and the temperature was increasing linearly between 145 and 370 m with a gradient of 41 mK/m, consistent with the heat flow density observed below 400 m and with the expected thermal conductivity. The lower front of the convective section, marked by a sharp jump on the temperature curve before its connection with the linear part, had proceeded to the depth of 230 m by the time of the second logging in May 2003 (the propagation rate of 6.1 m/month). This process has been going on to the present. The third (February 2004) and the fourth (December 2004) loggings found the front at a depth of 265 m and 310 m, respectively, which means the propagation rate of 3.9 m/month and 4.2 m/month. An amplitude of the temperature jump at the front has been increasing in time from 0.8°C at the first logging via 1.1°C at the second, 1.4°C at the third to 1.6°C at the fourth logging, whereas the gradient within the jump was about 190 mK/m all the time. The temperature is generally below the initial linear curve in the depth section engulfed by a convection since the first logging. We observed directly a downward spreading of the convective front by a several day temperature monitoring in the middle of the jump in the depth of 307 m started immediately after the fourth logging. A passage of the front was marked by cooling, the rate of which was consistent with the observed long-term propagation of the front (4 – 6 m/month) and the gradient within the jump (190 mK/m). Possible driving forces of this unusual phenomenon might be (i) a drilling disturbance of the fresh/saline water interface, initially at the depth of about 50 – 80 m and/or (ii) a downward migration of the drilling mud accumulated within the highly porous and permeable karstic rocks during the drilling.

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Geophysical evidence of a deep Weichselian permafrost in NE Poland

A precise temperature logging of several boreholes in the northeastern Poland was carried out in 2003 and 2004 within the Czech – Polish project "Present and past climatic changes derived from borehole temperature logs and hydrogeological analysis". The measurements confirmed an anomaly matchless in Europe, when a temperature decrease with depth is observed between the surface (the mean annual ground temperature of about 8°C) and the depth of 400 m (5°C measured in 460 m deep borehole Sidorowka) in the area of the Krzemianka-Udryn anorthosite intrusion (horizontal dimensions 16 km by 8 km) hidden below more than 800 m of sediments (Fig. 2). There are indications based on other temperature logs from 250 – 300 m deep boreholes that a value of the present-day subsurface temperature minimum at the depth of 400 m is as low as 3°C in the central part of the area, some 7 – 9 km to the NE from borehole Sidorowka. Combining the new data from borehole Sidorowka with industrial temperature logs from more than 2 km deep boreholes logged in the 80's and with results of the basic geothermal research in the area, we were able to analyse in detail the observed phenomenon, especially to compile a geothermal model of the site, to estimate a mean surface temperature of the region during the last ice age, to reconstruct a temperature – depth profile for the end of the glacial and to simulate the time evolution of the profile onward to the present by solving numerically the heat conduction equation. The resulting model, consistent with the observed facts, indicates that a mean glacial surface temperature attained -10°C, a thickness of permafrost was 520 m, an onset of the post-glacial warming with a mean temperature of +7°C occurred about 14 ka ago, last remnants of the interstitial ice thawed only 4 ka ago in the depth of 300 – 400 m and the surface temperature has increased by another +1° in the last 150 years bringing an overall amplitude of a warming since the last ice age to +18°C. A main reason for vanishing of subsurface glacial conditions above the anorthosite intrusion more slowly than in the surrounding area (where no decrease of temperature with depth is observed) is probably an extremely low radiogenic heat generation of the anorthosite, which conditioned a smaller vertical temperature gradient and therefore formation of a permafrost layer thicker than that outside the intrusion.

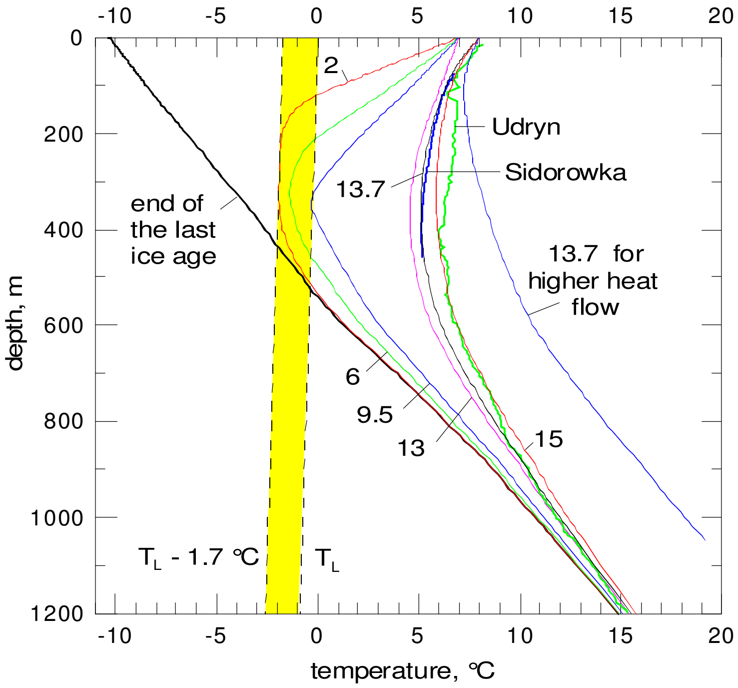

Fig. 2. Temperature-depth profiles measured in boreholes Udryn and Sidorowka in the temperature anomaly region and a numerical simulation of their time changes. The initial temperature–depth profile at the end of the last ice age (a start of the simulation, time 0) is in an equilibrium with a surface ground temperature of -10.3°C and a deep heat flow of 40 mW.m^{-2}. The right-hand side profile corresponds to the higher heat flow of 50 mW.m^{-2} outside the anomalous region. Curves T_L -1.7°C and T_L delineate a depth-dependent interval of the thawing temperature of the underground ice. Curve labels are in thousands of years since the beginning of the simulation.

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Recent subsurface temperature changes in the Czech Republic, Portugal and Slovenia and their coupling to air temperatures

Climatic interpretation of the ground surface temperature history obtained from present-day temperature-depth profiles measured in deep boreholes is based on an assumed long-term tracking of the mean annual surface air temperature and the ground surface temperature. To explore this assumption, we have started a project on a long-term monitoring of the coupling between air and soil temperatures in three different climatic provinces of Europe, namely in the Czech Republic, Slovenia and Portugal. The “borehole climate” stations have been established and the monitoring launched at three Czech sites, namely at Prague-Spořilov (in 1993), at the meteorological station Kocelovice (1998) and near town Potůčky (Krušné Hory Mountains, in the year 2002), at Slovenian Kostanjevica (2003) (Fig. 3) and at Portuguese Évora (2005). The observatories monitor air (2 m and 5 cm height), soil (2, 5, 10, 20, 50 and 100 cm depth) and bedrock temperatures (down to the depth of 40 m) 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 for several years to map the tracking of the air and ground mean annual temperatures on an interannual time scale.

Fig. 3. The borehole climate change station near Slovenian Kostanjevica established in 2003 monitors the air, soil and bedrock temperatures down to the depth of 40 m with a sampling interval of 30 minutes.

Another method of checking the air-ground temperature coupling is based on a repeated temperature logging of boreholes. The present rate of the surface warming is large enough for a reliable detection of the subsurface temperature time changes in the temperature- depth profiles obtained by the repeated logging during several years. The difference between the logs can be compared with the difference of the synthetic temperature - depth profiles based on the surface air temperature series observed at nearby meteorological stations. The results of the repeated logging with a time span of 7 – 17 years in several boreholes in the three countries clearly document a transient character of the subsurface temperature field. The observed time changes of the subsurface temperature agree reasonably well with the time changes simulated by using the surface air temperature series as a ground surface forcing function.

Beside the problem of the long-term stability of the mean annual difference between air and soil temperatures, which is being studied at the three stations mentioned above, the influence of the vegetation cover on the soil temperatures is studied systematically at the fourth observatory located also on the campus of the Geophysical Institute at 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 soil temperatures at depths of 2, 5, 10, 20 and 50 cm below and the air temperatures at 5 cm above each of the 4 different surfaces are recorded every 5 minutes together with air temperature of the site at 200 cm height. The soil moisture is measured in the sand at the depth of 20 cm. The monitoring allows for a detailed study of a 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.

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Borehole climate change

The annual seasonal changes are accompanied by the corresponding changes of the air temperature. The varying surface temperature conditions then propagate downwards and affect the shallow subsurface temperature field. The amplitude decreases with depth and at the depth below approx. 30 – 40 meters the response to the surface changes is negligible being smaller than 0.001 K (as example see soil temperatures recorded in the Sporilov hole in 2003, Fig. 4). The response to the long-term climate changes, however, may penetrate much deeper and changing climate may leave behind tiny transient temperature perturbations of the steady-state temperature field. By precise temperature logging these perturbations can be measured and the “climate recollections” interpreted in terms of the paleoclimate evolution of up to several past centuries. In the last 10 – 15 years the inversion technique to infer the climate history from temperature-depth records became a useful alternative method of general paleoclimate reconstruction studies.

The inversion results from almost 100 boreholes from the Czech territory were interpreted and the past climate scenario proposed for the last millennium reflecting also some regional characteristics (*Čermák and Bodri, 1999, Šafanda et al., 1997*). As a continuation of these studies three experimental sites were selected to monitor shallow subsurface temperature-time variations to quantitatively assess the magnitude of the present-day (global) warming. In 2004 two research projects have been solved, both addressing the air-soil temperature coupling and the possibility to distinguish between the natural and anthropogenic components of the warming. The main objectives of the GAAV grant A3012005 "Recent Climate Change and Its Contingent Component Revealed by Inversion of Present Temperature Data Measured in Boreholes" (2000 – 2004) covered year-long temperature monitoring in two of these sites up to 40 m depth to complete the inverted ground surface temperature histories (GSTHs) by information on the regional trends and to correlate the results with meteorological data. The GAČR grant „Climate Change and Global Warming – Evidence From the Underground“ (2003 – 2005) completed the previous investigations by a new observational site, located in one of the most environmentally polluted area of the Krušné Hory Mts., where the maximum warming rate should be observed supposedly.

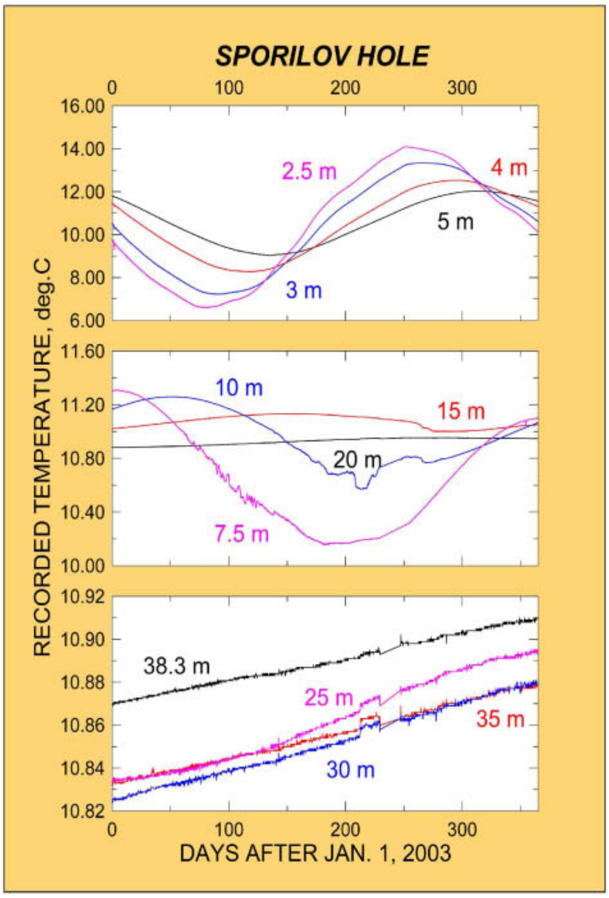

Fig. 4. Monitoring results from the Spořilov hole demonstrating the gradually diminishing surface "climate" signal with depth.

The important part of the paleoclimate investigations are the studies of the time succession of the climate extremes and of the high-frequency climate variation. The knowledge of the existing climate variability can help in the climate prognosis, e.g. in the estimate of the number of climate extremes and their tendency to grow or fall. The climate models incorporating the increasing concentration of the green-house gases suggested that the present climate warming might be connected with the decreasing high frequency temperature variability. The monitoring temperature results from both experimental boreholes were used to assess the variability at several selected frequencies, when the absolute differences between the mean temperature anomalies at various intervals were taken as the variability measure (*Bodri and Čermák, 2003b*).

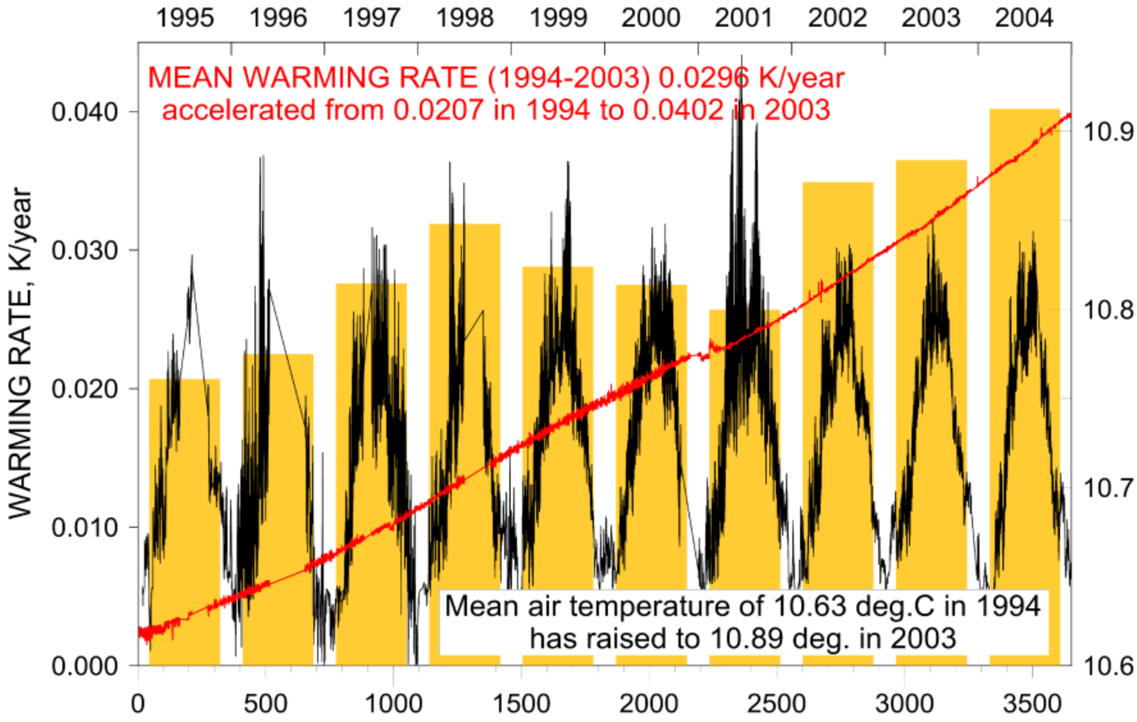

Fig. 5. Monitoring results (1995-2004) from the Spořilov hole showing the warming rate corresponding to the individual years and the increasing temperature at the borehole of 38.3 m (.i.e. below the penetration depth of the surface signal).

Major results

i. The monitoring system in two experimental sites was completed and is now fully automated and autonomous. Soil temperatures in the 0 – 40 m depth interval together with the air temperature are registered together with other meteorological parameters (see 10-year record of air temperature and warming rate record at 38.3 m depth in the Spořilov hole, Fig. 5). For the whole observation period (1994 – 2004 for Spořilov hole and 1998 – 2004 for Kocelovice hole) the characteristic annual smoothed courses were set by the Gaussian transformation as the reference value to define the deviations. In all cases the temperature increase is obvious, its amplitude decreasing with depth. As the registered air temperatures showed good correlation with the meteorological evidence from the Prague-Karlov meteorological station, the time series could have been extended back to the year 1940 and used as the forcing function for the comparison with the measured borehole data in modeling shallow subsurface.

ii. The present climate changes can be also accompanied by extreme events in the precipitation character. The results of the 38-year series from 6 Czech and 4 Hungarian meteorological stations were analyzed by the Artificial Neural Network (ANN) method and used for the mid-time flood forecast (*Bodri and Čermák, 2001; Bodri et al., 2005*).
Special attention was paid to the relation of the climate change and the development of the meteorological situation on the continental scale (North-Atlantic oscillation) The results confirmed the frequency dependence, for the 24-hour intervals has irregular character but decreases in all 8 year observational interval, in the 6-hour intervals no dominant time dependence was found but suggested certain quasi-seasonal oscillation and correlation with the NAO, higher NAO-indices at all frequencies correspond to higher variability(*Bodri and Čermák, 2003a*).

iii. The 40-year air temperature-time series from 30 Czech meteorological stations were analyzed and the results were subdivided into three formal groups: (a) stations in predominantly industrial regions, (b) "mixed" regions and (c) predominantly farming regions. The mean warming rates for the last couple decades (1960 – 2000) decreases from "industrial" to "farming" regions: 0.031±0.008 K/yr, 0.022±0.005 K/yr and 0.018±0.006 K/yr and agrees with the monitoring results.

It is thus possible to roughly estimate that about one third of the contemporary warming may have its origin in the local environmental pollution (*Čermák et al., 2004*).

iv. The practical use of the "geothermal" inversion method is based on the assumption, that the heat transfer in the subsurface is managed by the heat conduction, i.e. the temperature field is not affected by local hydrogeological conditions. We have inverted *T(z)*-records from four closely spaced boreholes at Tachlovice (15 km SW of Prague) when the heat conduction equation was completed by an additional assumption of the existence of a horizontal water migration, the measured temperature were then correlated with the theoretical response on the changing surface (climate) condition simulated by the air temperature-time series from the Karolinum meteorological station. It was possible then to estimate the so-called "pre-observational mean" POM-temperature, the conditions existing before the registration had started (before year 1791) and also the (Darcy) velocity of the hypothetical water movement. It could be proved that for a slightly advectively disturbed case the difference between the POM-value for the pure conduction and combined conduction/convection amounted to 0.3 – 0.5 K and approximatelly equaled to the generally accepted warming for the 20th century based on the long-term meteorological records (*Bodri and Čermák, 2005*).

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Structural aspects of the evolution of volcanic centres: the České středohoří Mts. as an example

Former geophysical surveys performed in the region of the volcanic centre of the České středohoří Mts. in North Bohemia (the Ohře/Eger Rift zone) showed that anomalous volcanic bodies and features can be effectively identified within a sedimentary environment. For this reason we carried out new geophysical measurements in the area of the main mafic intrusion of essexitic character. The target was the exact location and geometry of the intrusion and its relation to other components of the volcanic centre.

We used gravity, magnetic, shallow seismic and electromagnetic techniques. The new gravity and magnetic data were tied to the old databases so that we could investigate the area as a whole complex. Residual gravity fields enhanced the image of trachytic breccia collapse structure to the north of the intrusion and the impressive positive anomaly of the intrusion itself. As well, other volcanic bodies were expressed in these maps and contributed to the volcanic sequences extent limitation. Electromagnetic measurements were applied in the area of the expected extent of the intrusion, and the seismic measurements in the central part of the intrusion.

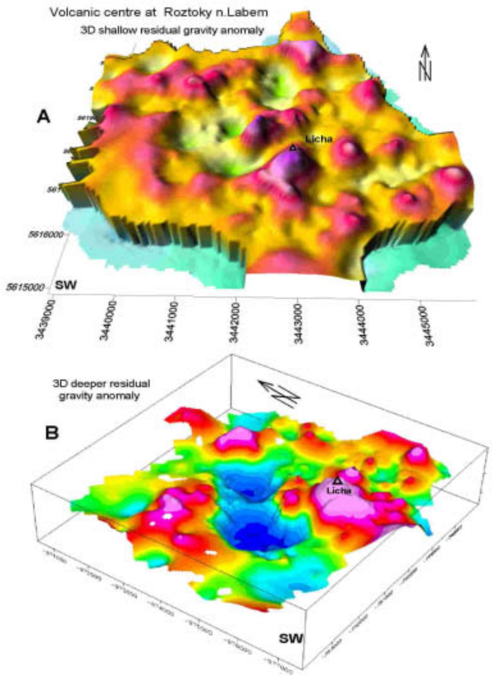

Fig. 6. Residual gravity anomalies – 3D image of shallow A (linear convolution filter designed) and deeper B (3rd order polynomial) residuals calculated by different software (Surfer and Geosoft); A – view from South, B – view from SW. Principal anomalies are presented in part B – negative blue anomaly of the trachytic breccia and positive red-violet anomaly of the Lícha intrusion.

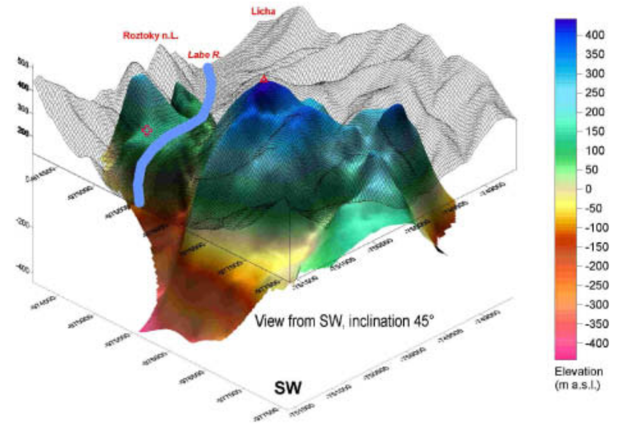

Fig. 7. 3D presentation of the interpreted relief of the essexite/monzodiorite intrusion under the surface topography model. Principal elevation of the intrusion is forming Lícha Hill.

Based on all the data, but mainly on gravity 2.75-D modelling, we delineated not only the surface and subsurface extent of the intrusion, but also we defined the hidden relief of the intrusion (Fig. 6,7). It was found that the intrusion is formed by a single body that has a few elevations, and not by a set of separate particular intrusions, as indicated by surface outcrops. The depth of the body was determined by modeling below the basement/sediments boundary level. The body of the intrusion is, however, affected by a major fault that caused lithological differences on both sides (essexite/monzodiorite) that reflect vertical displacements in the post-volcanic period. In detail we show from the seismic lines interpretation what is the depth of the debris cover and the thickness of the weathered zone in the central part of the essexite body. It ranges from first metres to 25 – 30 m. From the electromagnetic technique (VLF – very low frequency) we also derived indications of tectonic elements in the area of the intrusion in the main NE-SW structural/tectonic direction in the region. These data will be correlated with the trends of dike system of the volcanic centre.

The results of geophysical measurements will be utilized to establish a 3D geological model of the whole volcanic centre.

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Experimental measurement of seismic velocity, porosity and permeability

Crystalline rocks of metamorphic and magmatic origin are usually of very low porosity (below 3%). Porosity corresponds to grain boundaries, cleavage planes of rock forming minerals and microfractures of different shape and length that can be either sealed or open. Orientation and connectivity of microscopic pores in these rocks and its closure with respect to increasing confining pressure is of great interest as they are important parameters of dangerous waste disposal sites, yet only a limited number of methods exist of their investigation. Within this project, we examine the origin and spatial orientation of the microporosity in rocks of different microstructure and grain size by using 1) experimental measurements of elastic P-wave velocities (V_P) on spherical samples in 132 directions under various confining pressures up to 400 MPa (ultrasound pulse transmission technique, *Pros et al., 1998*), and processing of the measured data into **D**V_P (**D**p) differential diagrams (Fig. 8), 2) measurement of lattice preferred orientation using the electron backscatter diffraction method, and, 3) quantitative microstructural analysis of the grain boundaries orientation in thin sections parallel to the *xz*, *xy* and *yz* planes of the finite strain ellipsoid. Various types of monomineralic, bimineralic and polymineralic low-porosity rocks are measured. The first results show that experimental pulse transmission technique is a useful tool for the analysis and visualization of oriented microporosity in 3D (Fig. 9) and provides important basis for further study of permeability anisotropy through studied rocks. The complex research of physical properties and microstructure improves our understanding of the contribution of individual microstructures to the bulk microporosity and permeability (*Špaček et al. 2004*).

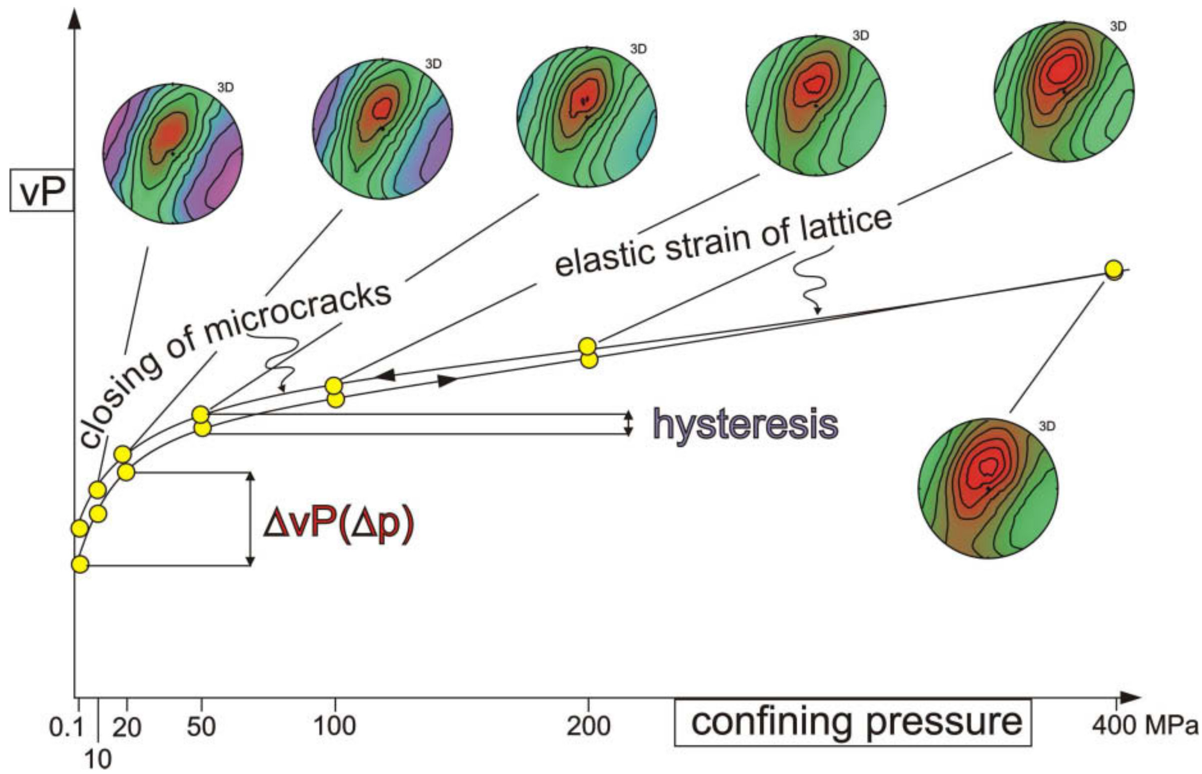

*Fig. 8. Principles of 3D acoustic measurements under varying pressure and data processing. Under low confining pressures the change in P-wave velocity is mainly due to closing of microfractures which define the porosity. Information on the orientation and amount of microfractures is obtained by comparing the velocity change under various pressures (**D**V_P(**D**p)) or through the analysis of hysteresis.*

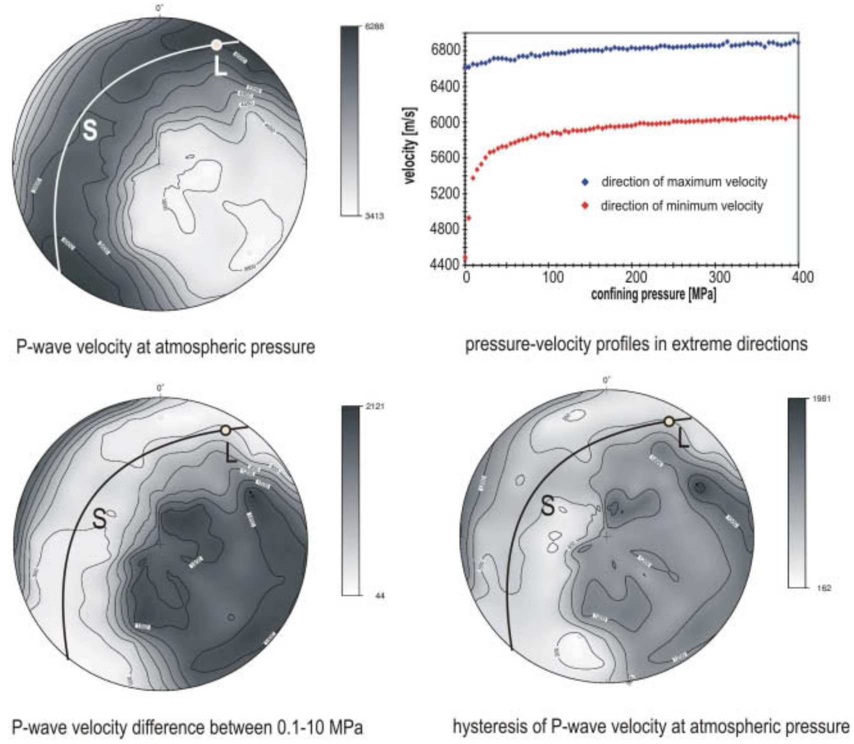

Fig. 9. Example showing measured P-wave velocities at atmospheric pressure, velocity difference between the atmospheric pressure and 10 MPa and hysteresis at atmospheric pressure of mylonitized limestone. Macroscopically estimated microstructure is shown (S-foliation, L-lineation).

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Petrophysical properties of upper mantle eclogites

Lattice preferred orientation (LPO) of omphacite and garnet in different microstructural types of upper mantle eclogites from the Roberts Victor mine in South Africa have been studied using the electron back-scattered diffraction method. These data complete the database of lattice preferred orientations of main mantle minerals and help to understand the rheology of basaltic parts of a subducting lithosphere.

In the non-foliated eclogites, the measured omphacite LPO disagrees with the cation ordering model of its development (*Brenker et al., 2002*). Petrological data shows that this LPO has been developed at 1000 – 1150ºC and omphacites are in the high temperature disordered structure. To further test the cation ordering model we conducted visco-plastic self-consistent simulations of the LPO development. It has been concluded that the cation ordering in omphacite cannot have a prime control on the LPO development. Finally, the LS index has been introduced as a quantitative indicator of the finite strain ellipsoid (Ulrich and Mainprice, 2005). A new type of clinopyroxene LPO has been measured in foliated eclogites and it is associated with grain growth. The new type of LPO occurs also in clinopyroxene megacrysts bands that show exsolution lamellae of garnet. Presented microstructural relationship suggests that LPO in clinopyroxenes has developed at temperatures close to melting (1450ºC). Numerical models using all known slip systems in the clinopyroxene did not help to simulate the new LPO, hence exact reasons of the new LPO development remained unclear from the mechanical point of view (Ulrich and Mainprice, in review). A garnet LPO is generally weak even if grain shapes are strongly flattened and define a foliation plane. It is in agreement with numerical models. Clinopyroxene and garnet LPO's have been used for the calculation of anisotropy and distribution of seismic waves in eclogites. The results showed very weak anisotropy and similarity in the distribution of seismic waves, which is due to a high percentage of garnet with weak LPO. The calculated reflection coefficient shows that mantle eclogites are barely detectable inside peridotites.

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Stratigraphic architecture of Cenomanian strata of the Bohemian Cretaceous Basin: relationships of depositional systems and reactivation of basement fault zones

In 2004, a multi-disciplinary study of Cenomanian (Upper Cretaceous) strata was finalized in the central and western part of the Bohemian Cretaceous Basin (Fig. 10). The aim of the project, supported by the Ministry of Environment, was to reconstruct the kinematic evolution of the reactivated basement zones during the initial phase of filling of this basin, which occupies the Elbe Zone, a major crustal weakness of Central Europe. The basin recorded the most significant reactivation of this and other deep-seated tectonic structures of the Bohemian Massif between the early post-orogenic phase in Late Paleozoic and the Eger Graben formation in the Cenozoic. The detailed insight into the formation and tectonic and paleogeographic evolution of the Bohemian Cretaceous Basin (BCB) is therefore fundamental for understanding the causes and mechanisms of the far-field reactivation of major structures of the Bohemian Massif during the postorogenic phase.
The Cenomanian-age (c. 99 – 93.5 Ma) strata of the Bohemian Cretaceous Basin, of fluvial, paralic, and shallow-marine origin, are particularly interesting for the proposed type of study because they were deposited during the initial phase of basin formation and record an interplay of reactivation of inherited basement fault zones and the long-term global sea-level rise that culminated near the Cenomanian-Turonian boundary (e.g., *Uličný et al., 1997, Uličný et al., 2004*).
The broad range of methods used included genetic sequence stratigraphy based on well-log, core, and outcrop sedimentological data, biostratigraphy (macro- and micropalaeontology) and palynological analysis, heavy mineral analysis, evaluation of regional gravity maps, structural maps, digital elevation models, and archive seismic reflection profiles. A grid of 2D stratigraphic correlation sections was used for construction of isopach maps for the newly defined genetic stratigraphic units (CEN 1 – 6), and the comparison of these data with the structural framework of the basin allowed the syn-depositional activity of the basement faults to be interpreted.
The main control on formation of topography and on distribution of subsidence and uplift was the reactivation of the conjugate set of two main fault systems. The "Elbe" system faults (WNW to NW-directed) acted as dextral oblique-slip faults whereas the "Jizera" system faults (NNE-directed, such as the Blanice-Rodl lineament) has a sinistral sense of slip. The principal horizontal stress vector had a generally northwestern orientation.

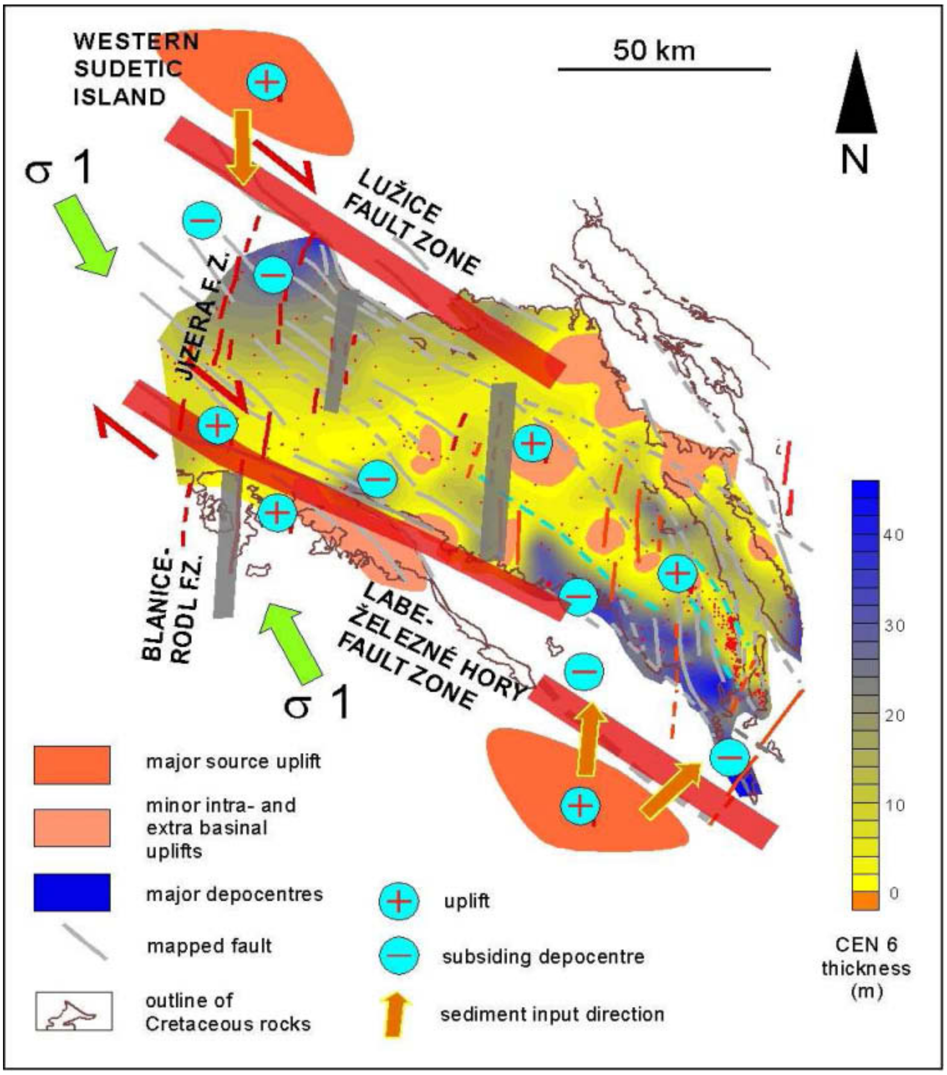

Fig. 10. A simplified sketch showing the interpreted kinematic picture of the central and eastern parts of the Bohemian Cretaceous Basin during the Late Cenomanian. Isopachs of unit CEN 6 show the distribution of subsiding depocentres and uplifted palaeohighs (including the source areas) during that time. Bold lines in red and grey colours indicate the main active strands of the Elbe and Jizera fault systems. Green arrows indicate the interpreted orientation of the principal horizontal stress.

The evolution of the central and eastern parts of the basin can be divided essentially into three parts that differ in the palaeogeographic and structural picture. The initial phase (units CEN 1 and CEN 2, lower to middle Cenomanian) is characterized by filling of palaeovalleys that followed the Jizera fault system as well as the Elbe system fractures. In the basin centre, a major NNE-trending drainage was established, with minor tributaries along the Elbe system faults. In the eastern part of the basin the Elbe system faults formed the structural basis for the preserved drainage system. This phase was followed by a period dominated by further flooding of the drainage system, establishment of estuaries and shallow-marine straits, and their filling by commonly tide-dominated deposits (units CEN 3-CEN 5). The terminal phase of Cenomanian deposition is characterized by a major change in the stratal architecture at the beginning of the Late Cenomanian time (unit CEN 6). Shallow-marine and possibly deltaic sandstones formed prograding wedges sourced from newly emerged uplifts along the Lužice and Labe-Železné Hory fault zones, main parts of the Elbe fault system. These wedges filled new subsiding depocentres adjacent to these fault zone, and thus defined a basin fill style that persisted for the rest of the basin lifetime. Contemporaneous intrabasinal uplifts led to partial deformation and erosion of units deposited during the earlier phases of basin evolution. This change, with the concentration of displacement at the two main parts of the Elbe fault system, is interpreted as a transition toward higher strain rates, leading to development of a more strongly transtensional setting.

In general, these results indicate that even in an intracontinental basin with generally low rates of subsidence, reactivation of basement structures with relatively minor displacement can lead to significant changes in the stratigraphic architecture.

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Depositional distortions of orbitally driven climate signals: a new tool for analysis of sea-level change

Two-dimensional computer modeling of marine depositional systems was used to explore possible distortions of orbitally driven climatic signals that may occur during their incorporation in the geological record. The results suggest that systematic changes in the amplitude of short-period cycles are inherent to multi-order climatic cycles transferred into the geological record via changes in sea level (Fig. 11). This amplitude modulation provides a signature of sea-level change and represents a potential tool for detection and analysis of orbitally driven eustatic oscillations in poorly understood intervals of the Earth's past, such as the greenhouse Cretaceous.

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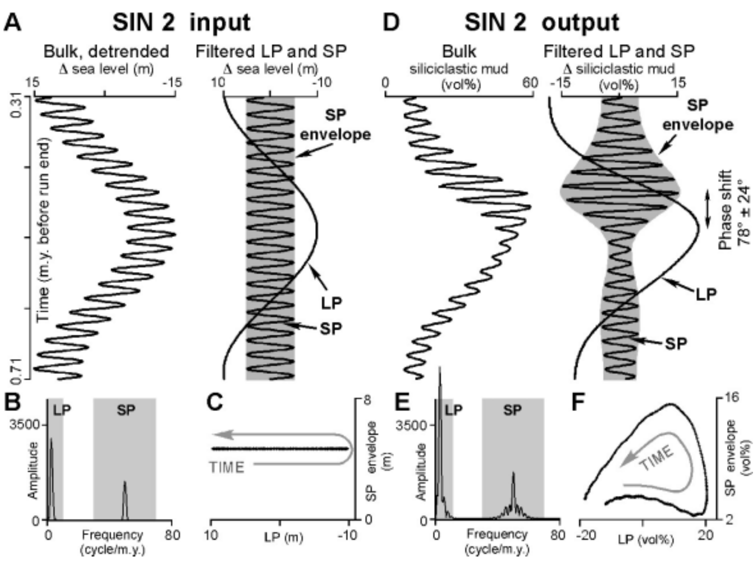

Fig. 11. Selected input and output parameters of SIN 2 models. (A) Input signal is represented by 20 k.y. (SP) and 400 k.y. (LP) sinusoidal oscillations in relative sea level. (B) Periodogram of the input sea-level curve. (C) Demodulated SP cycles of the input signal plotted against LP component of the input signal. Note that input SP amplitudes are invariable. (D) Model output (vol% mud) plotted against time. (E) Periodogram of the output vol% mud curve. (F) Demodulated SP cycles of the output signal plotted against LP component of the output signal. Note that amplitude envelope of the output SP signal (grayed in D) differs from amplitude envelope of the input SP signal, and is distinctly (~78°) phase-shifted relative to the output LP signal.

Deep structure, seismotectonics and volcanism at convergent plate margins

Seismotectonic studies at convergent plate margins have been performed by analysis of global seismological data – hypocentral determinations 1964 – 2002 of International Seismological Centre relocated by *Engdahl et al. (1998)* and fault plane solutions 1976-present of Harvard seismological group (HCMTS). The following key problems related to the process of subduction were studied: a) application of the seismicity pattern beneath active volcanoes for finding the source region of calc-alkaline volcanoes, b) newly starting subduction cycle revealed by specific earthquake distribution along the Java trench, and c) internal tectonic structure of the subducting slab of the Cocos plate by means of aftershock sequence analysis.

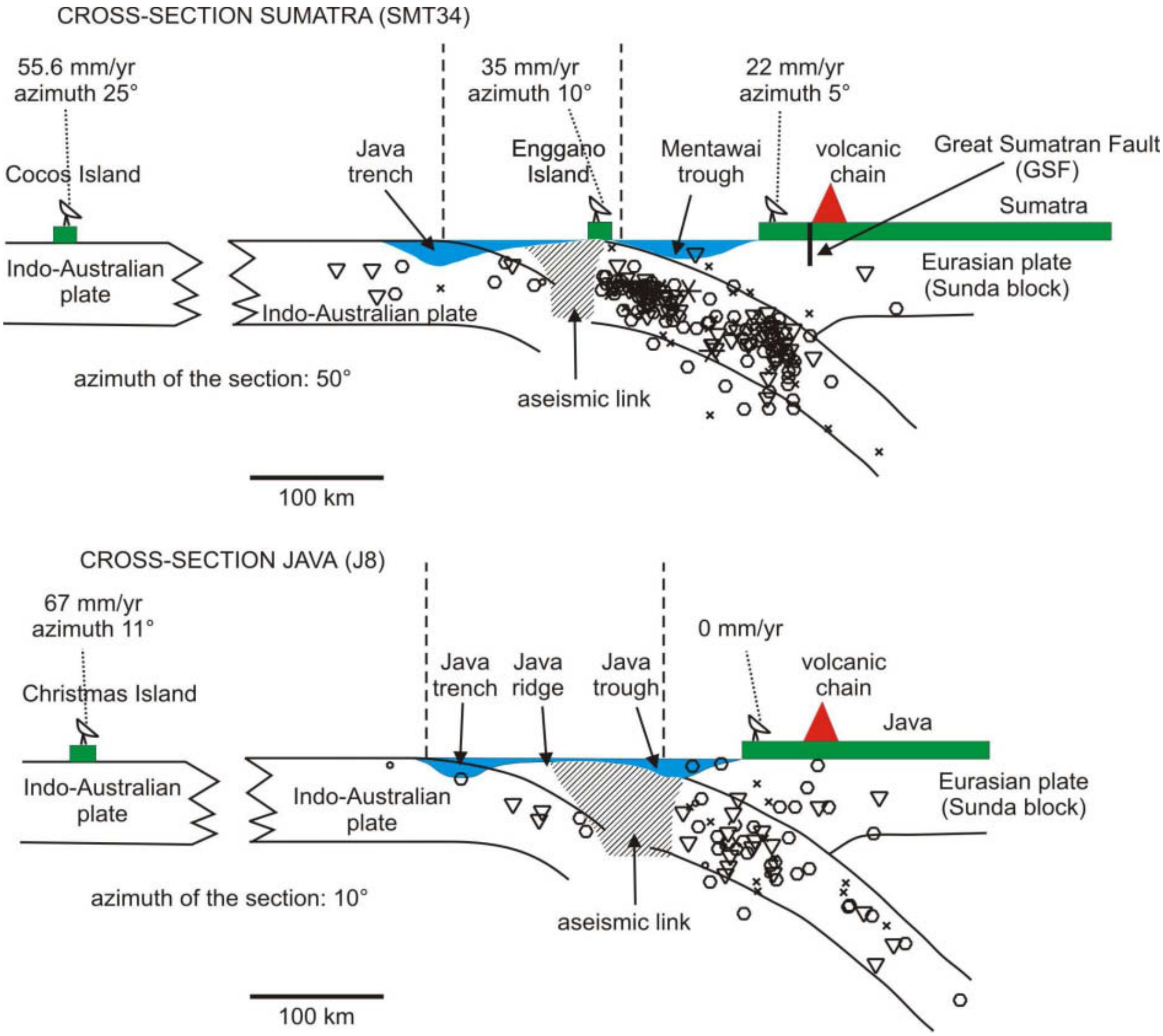

Fig. 12. Schematic expression of the conclusions implying the discontinuous character of recent Sunda subduction. Seismic data are real, as well as the position of the main morphological units. Boundaries between the main structural units forming the convergent margin are denoted by dashed lines, aseismic link by a hatched area. Depths of trench and trough are exaggerated. Symbols of earthquakes with ISC magnitude m_b:

◦ $m_b \leq 4.0$; × $4.0 < m_b \leq 4.5$; ○ $4.5 < m_b \leq 5.0$; ▽ $5.0 < m_b \leq 6.0$; ✳ $m_b > 6.0$.

Values of velocity of movements of the respective units are taken from Tregoning et al. (1994) and Bock et al. (2003).

a) The analysis of global seismicity pattern was used as a tool for finding the source region of primary magma for active calc-alkaline volcanoes in Central America as well as in the central part of the Sunda Arc (Java, Nusa Tenggara). The detailed analysis of the geometry of distribution of earthquake foci allowed to establish an aseismic gap in the subducting oceanic lithosphere in the depth between 100 – 200 km and numerous seismically active columns in the continental wedge above the slab. Both phenomena are spatially and probably also genetically related to active volcanism and favour the concept of generation of calc-alkaline magma inside the subduction zone. We interpret the aseismic region in the Wadati-Benioff zone, found beneath Central American volcanic domains and also beneath volcanoes of Java and Nusa Tenggara, as a partially melted part of the slab that serves as main source region of magma for active volcanoes in the region. On the other hand, the relatively strong seismicity in the continental wedge beneath several volcanic domains (seismically active columns) points to brittle character of the mantle and excludes the generation of larger amounts of magma in the wedge overlying the subduction zone.
b) Spatial distribution of earthquake foci in the central part of the Sunda Arc was analysed using global seismological data. The analysis revealed the existence of a distinct strip of earthquake foci distributed along the Java trench, separated by a trench-parallel, 50 – 150 km wide aseismic link from seismicity belonging to the Wadati-Benioff zone of the recently subducting slab. The seismicity pattern at the plate margin corresponds well with the morphology of the seafloor – the along-trench seismicity correlates with the position of the Java trench and the onset of the Wadati-Benioff zone correlates with the Java trough. The GPS measurements performed at three analogous structural units of the neighbouring Sumatran convergent margin point to substantial differences in velocities of movement of the respective units and correlate with the spatial distribution of earthquake foci. We interpret the distinct along-trench seismicity as a consequence of an onset of a new subduction cycle due to the rapid convergent movement of the Indo-Australian plate relative to the aseismic lithospheric link (Fig. 12).
c) High seismic activity observed in the Wadati-Benioff zones points to intense fracturing of subducting slabs. In spite of this fact, little is known about the internal tectonic structure of slabs. We may anticipate that earthquake foci are not randomly distributed in the Wadati-Benioff zone. The processes of plate convergence and subduction most probably activate planes of weakness with certain preferential orientations; such a system of loaded faults should generate earthquakes, the hypocentres of which should reflect the fault geomety. However, most seismologists are not convinced that the accuracy of present global locations of earthquake is sufficient for a successful delimitation of the internal tectonic structure of a subduction zone. Nevertheless, it is generally proved that seismically active fracture zones in the Earth crust are reliably revealed by spatial distribution of hypocentres of earthquakes belonging to aftershock sequences. Therefore, we have attempted to study the internal tectonic structure of the slab on the basis of 11 aftershock sequences that occurred in the Wadati-Benioff zone of the subducting Cocos plate in the period between 1970 and 2001. We concluded that (1) earthquakes of each aftershock sequence are distributed in a narrow plane-like body; parameters of such a plane (azimuth, dip) were found for each sequence; (2) the parameters (azimuth, dip) of planes characterising individual sequences are almost identical; (3) great majority of available HCMTS offers fault planes oriented parallel to the plate margin; this direction does not coincide with distribution of hypocentres of earthquakes belonging to aftershock sequences; (4) the occurrence of aftershock sequences in the Wadati-Benioff zone does not seem to be a phenomenon common to all subduction zones; it probably reflects specific mechanical parameters and/or tectonic history of the Cocos plate; (5) planes controlling the distribution of hypocentres of aftershock sequences are probably inherited planes of weakness that originated during the development of the lithosphere of the Cocos plate and are recently activated by the process of subduction; (6) fault planes, along which the seismic slip of individual earthquakes of the aftershock sequences was observed, probably originated in the process of Cocos plate bending and subduction; (7) the analysis of aftershock sequences points to very high precission of EHB hypocentre determinations.

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Deep structure of the lithosphere-asthenosphere system

Systematic investigations based on data from passive seismic experiments used in teleseismic tomography and joint inversion of anisotropic parameters derived from travel-time deviations expressed in P-residual spheres, fast shear-wave polarisation and split delay times – focused on the following regions: a) western Bohemian Massif, b) south-eastern Fennoscandia and c) Northern Apennines.

a) An international passive seismic experiment BOHEMA (BOhemian Massif HEterogeneity and Anisotropy) has brought together geophysicists from 10 institutions in the Czech Republic, Germany and France for a cooperative study of the structure and dynamics of the lithosphere and asthenosphere in a geodynamically active part of the western Bohemian Massif (BM, *Babuška et al., 2003; Plomerová et al., 2003*). One of major aims of the project was to find out whether a plume structure exists beneath the western BM, similarly to the French Massif Central or the

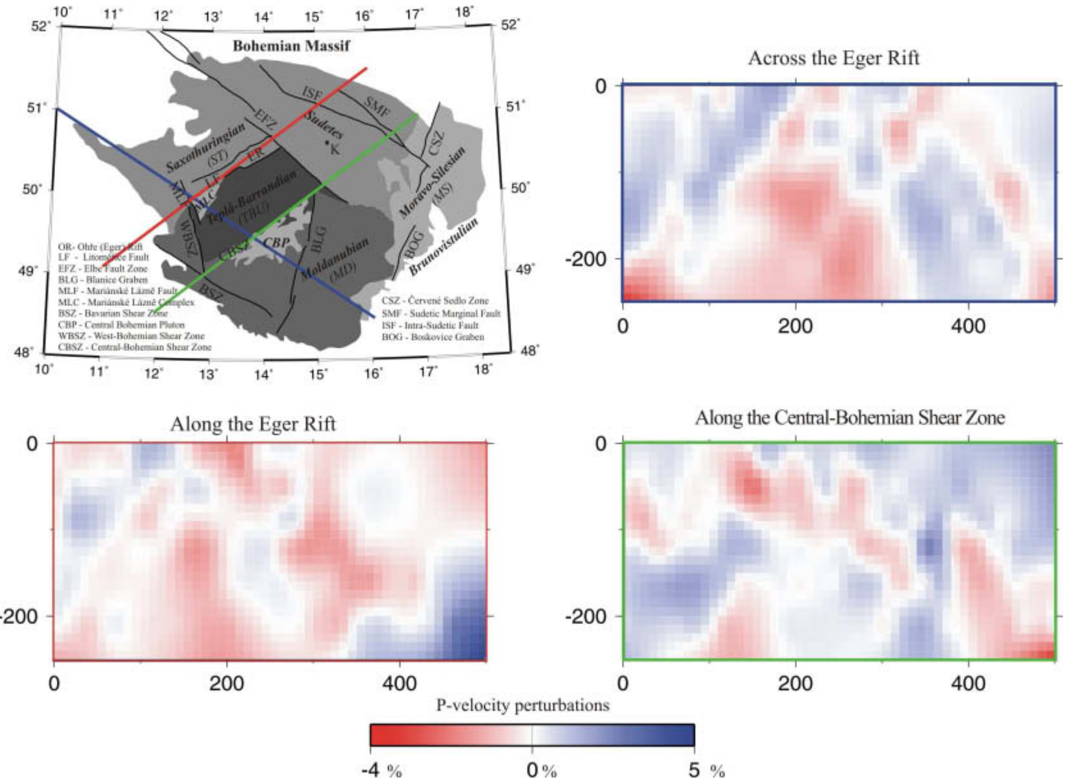

Fig. 13. Cross-sections through tomographic images of P-velocity perturbations down to 250 km, as derived from the BOHEMA array.

Eifel in Germany. We have found reduced velocities namely in depths between 100 and 250 km (Fig. 13) along the Ohře (Eger) Rift (OR), with maximum in its western part, which is the region characterized by gas exhalations rich in CO_2 and He of mantle origin. The low-velocity perturbations attain values between 1 and 2%, which are comparable to other parts of the investigated region. The region with reduced velocities does not form a narrow well-defined subvertical heterogeneity, which could be interpreted as an upwelling hot material of a plume-like structure. In accord with our previous studies, we interpret the low-velocity anomaly beneath the western OR by an upwelling of the lithosphere-asthenosphere transition, which is the most distinct beneath the crossing of the OR with the Mariánské Lázně fault (MLF, Fig. 13). Besides the isotropic velocity tomography, an intensive research of body-wave anisotropy has been conducted (*Babuška et al. 2005; Plomerová et al., 2005a*). Three lithosphere domains with differently oriented P-wave anisotropy are characteristic of the Saxothuringian, the Moldanubian and the north-western part of the Teplá-Barrandian Unit (Fig. 14). An inter-growing of three lithospheres caused by step-wise collisions of the microcontinents observed also in other parts of the European Variscides (*Babuška and Plomerová, 2004*), followed by a later rifting and lithosphere thinning beneath their complicated contacts, probably predestined the present-day geodynamic activity of the western BM.

b) Lateral variations of seismic anisotropy of body waves allow us to detect the Archean-Proterozoic boundary in the upper mantle beneath the south-eastern Fennoscandia (*Plomerová et al., 2005b*), though isotropic P-velocity perturbations in teleseismic P tomography or shear-velocity variations

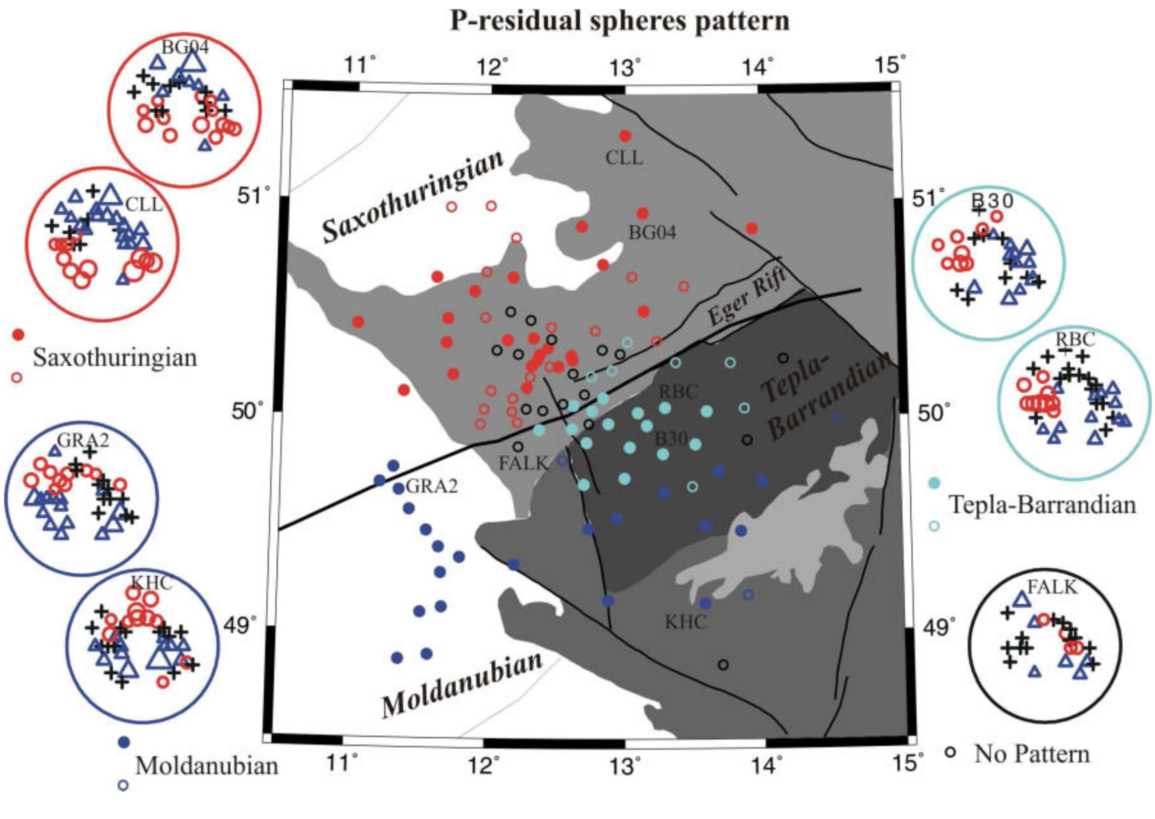

Fig. 14. Anisotropic domains of the western part of the Bohemian Massif, characterized by travel time deviations, derived from the P spheres showing directional terms of relative residuals (directional means subtracted from the relative residuals). The blue triangles represent early arrivals (high-velocity directions) and the red circles represent late arrivals (low-velocity directions). While the Saxothuringian and the Moldanubian show relatively high velocities in the mantle lithosphere from the north and the south, respectively, the north-western part of the Teplá-Barrandian shows high velocities mainly from the east. Full circles mark a clear-cut pattern, open circles indicate a tendency to the pattern. Black plus signs belong to residuals within <-0.1 s, 0.1 s> interval. The perimeter marks the incidence angle of 60º.

retrieved by inversion of surface waves by other authors do not noticeably differ in the Proterozoic and Archean mantle beneath the SVEKALAPKO array. The boundary inclines to the SW, in general, and it is very complex, forming a broad transition zone. This zone appears in the P residuals, which accumulate the velocity deviations along the ray path, as almost isotropic structure due to superposition of pieces of the mantle lithosphere with differently oriented anisotropy. The shear-wave splitting is consistent for groups of stations within the Archean and Proterozoic domains. The shear-waves split even above the Proterozoic-Archean contact and thus detect anisotropy also in the central transitional domain, which may reflect anisotropy of the thickest lithosphere wedge. In general, variations of the splitting parameters indicate a very complicated structure, which cannot be approximated by a single layer with horizontal symmetry axis or a simple contact of two mantle lithosphere blocks. We propose three potential candidates for a mantle lithosphere model around the Proterozoic-Archean contact (Fig. 15).

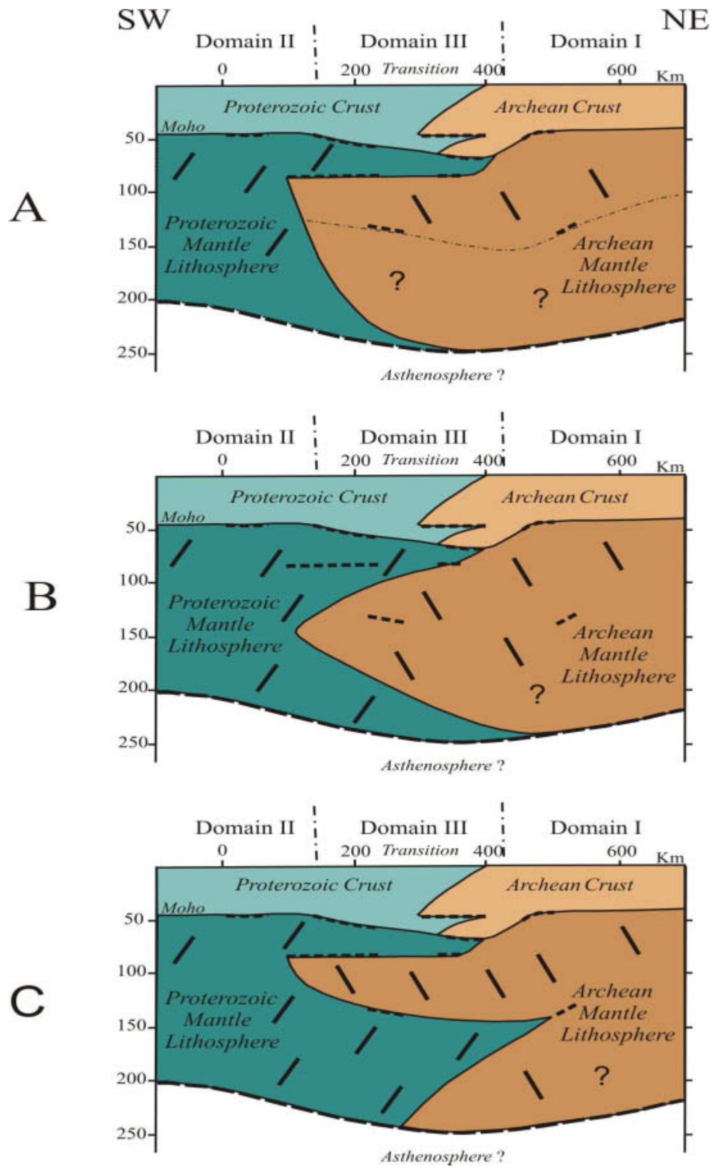

Fig. 15. Sketch of three possible candidates of a model of the mantle lithosphere of the Proterozoic-Archean transition in central Finland: A – a smooth contact and a two-layer Archean mantle lithosphere, B – a single mantle wedge and C – a multi-wedge mantle. Thick inclined lines within the mantle lithosphere show schematically dipping relative high velocities derived from the P residuals, the dashed lines indicate reflections determined by previous DDS studies.

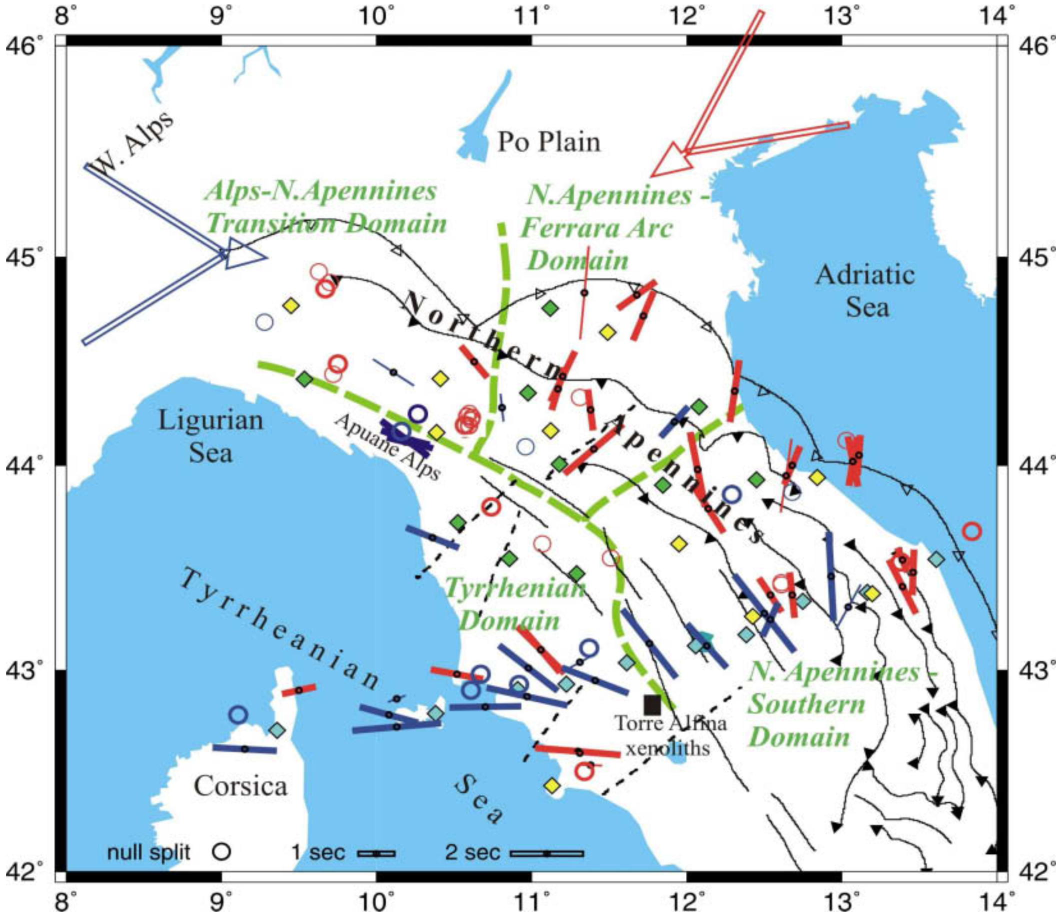

Fig. 16. Initial results of the shear-wave splitting measurements evaluated from data of the RETREAT array (green diamonds), permanent observatories (yellow diamonds) and the NAP (North Apennine Profile – blue diamonds). Thick symbols are the very high quality measurements, thin symbols are fair measurements. The big arrows on the top mark the SW-NW (blue) and N-E (red) azimuths of arriving shear waves. The green dashed lines mark boundaries of domains of the mantle lithosphere with similar orientation of anisotropic structures resulting from the initial stage of our study.

c) We have applied the three-dimensional analysis of anisotropic parameters of body waves to the Northern Apennines, the tectonically active region affected by a progressive collision between the Eurasian and African plates, associated with a steady growth of the mountain range. Simultaneous extension in the convergent margin of the Adriatic and Tyrrhenian domains results in a retreat of the subducting Adriatic plate from the orogenic front caused by sub-lithosphere mantle processes. The study will contribute to developing a 3D self-consistent dynamic model of the syn-convergent extension in the Northern Apennines within the multidisciplinary international project RETREAT. Shear-wave splitting evaluated from recordings of the RETREAT array, formed by the network of permanent and 35 portable stations, evidences seismic anisotropy within the upper mantle. Ten of the portables are equipped by STS2 seismometers and GAIA data acquisition systems belonging to the MOBNET of the GI. Initial analysis of the splitting reveals both distinct lateral variations of anisotropic parameters and their dependence on the direction of propagation within the upper mantle (Fig. 16). Variations of the splitting time delays and orientation of the fast shear waves exclude a simple sub-lithosphere mantle flow, associated with the Apennines subduction, as the only source of the observed effective anisotropy. A part of the anisotropic signal, observed both in the shear-wave splitting and the P-residual spheres, can be generated by a frozen-in fabric of the Adriatic and Tyrrhenian lithosphere domains (*Plomerová et al., 2005c*).

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SLICE: Seismic velocity models

Project SLICE (Seismic Litospheric Investigations of Central Europe) was using the data of two international seismic refraction experiments ALP 2002 and SUDETES 2003 (*Brückl et al. 2003, Grad et al. 2003*) to study the deep structure of Central Europe. The field work for this ambitious project

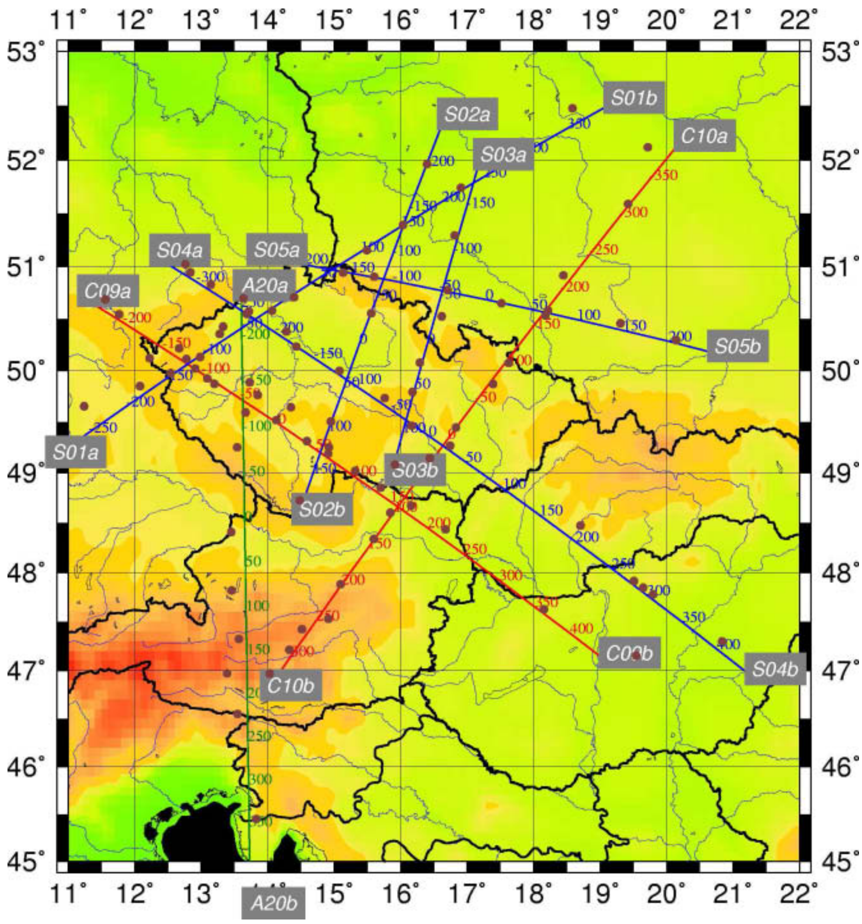

Fig. 17. Schematic map of profiles used in inversions: (i) measured during the Celebration 2000 experiment (in red, labeled as C09a\b and C10a\b), (ii) Alp 2002 experiment (in green, labeled as A20a\b) and (iii) Sudetes 2003 (in blue, labeled as S01a\b – S05a\b). Numbering along profiles denotes the relative in-profile distance in km. Shot positions are depicted by violet circles.

was designed to continue previous experiments Polonaise'97 and CELEBRATION 2000 (*Guterch et al. 1999, 2003*) and it was prepared in the same geometry. Scientific organizations involved were led by the experiment teams from geophysical and geological communities in the Czech Republic, Poland, Austria, the USA, Canada, the Slovak Republic, Hungary, Denmark and Finland. In the Czech Republic, experts from the Geophysical Institute of the ASCR, Institute of Rock Structure and Mechanics of the ASCR, and Institute of the Physics of the Earth MUNI Brno participated in the project.

The layout of each experiment was a network of interlocking recording profiles (Fig. 17). Shots were fired along each profile with the average distance of 30 km, data were sampled at intervals of 10 ms and were recorded mainly by one-component stations TEXANs with station spacing 3 km. For more details about SLICE project refer to *Brož et al. 2005*.

Interpretation of a large set of refraction and wide-angle reflection data involved three different approaches: (i) tomographic inversion of the first arrivals of P waves; (ii) parametric kinematic inversion of travel times of Pg, Pn and PmP waves; (iii) trial-and-error forward modelling of the entire wave field with SEIS83 program package (*Hrubcová et al., 2005*). The results of these three methods gave 2-D velocity models down to the depth of 40-50 km with P-wave velocities ranging around 3.5 km/s in sedimetary basins to 8.5 km/s for the uppermost mantle parts (Fig. 18). Relative velocity errors were in range of 5% depending on ray coverage, the uncertainties in the Moho depth determinations were less than ± 2.5 km. The differentiation of the wave field, velocity models and the depth of Moho in different areas enabled to determine three types of crust-mantle transition in the Bohemian Massif reflecting variable crustal thickness and delimiting contacts of tectonic units in depth. These models are consistent with hypothesis of laminated Moho, sharp or gradual velocity transition at Moho depth or indications of low velocity anomalies in lower crust.

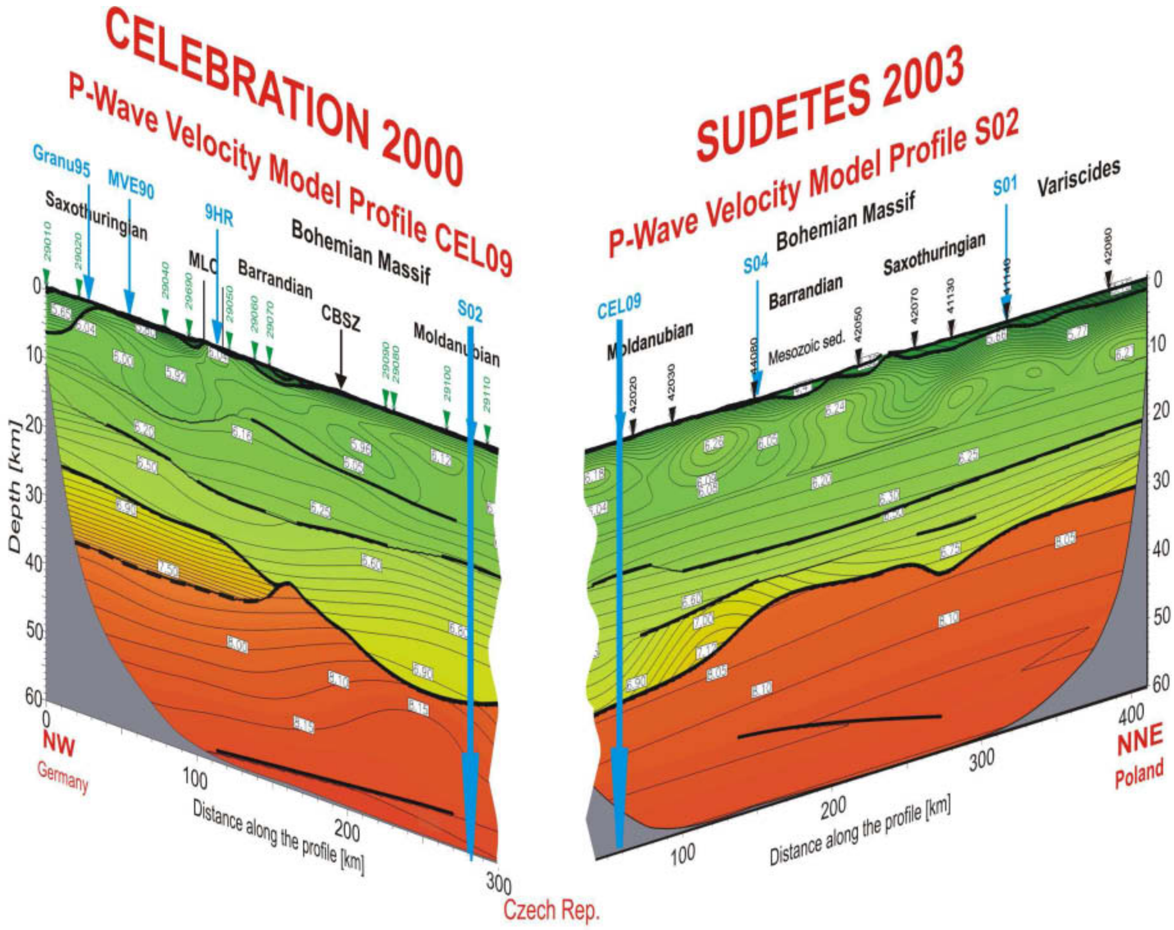

Fig. 18. Comparison of two depth-velocity cross-sections.

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Azimuthal variation of Pg velocity in the Moldanubian, Czech Republic

The azimuthal velocity variation of Pg waves was observed in the Moldanubian, which is a crystalline segment within the Bohemian Massif in the Czech Republic. We used the data from a multi-azimuthal common-shot experiment performed as a part of the ALP 2002 refraction experiment, complemented by profile refraction data from the CELEBRATION 2000 experiment. We analyzed the travel times of waves recorded by 72 portable seismic stations deployed along two circles with radii of 35 and 45 km around a shot. The observed travel times display an azimuthal variation indicating anisotropy of 2% (Fig. 19). The minimum and maximum velocity values are 5.83 and 5.95 km/s, respectively. The direction of the maximum velocity is ~N50°E. These values characterize horizontal anisotropy of the uppermost crust down to 3 km. The strength and orientation of uppermost crustal anisotropy in the Moldanubian is consistent with the overall upper crustal anisotropy in the entire Bohemian Massif. The high-velocity direction is roughly perpendicular to the present-day maximum compressive stress

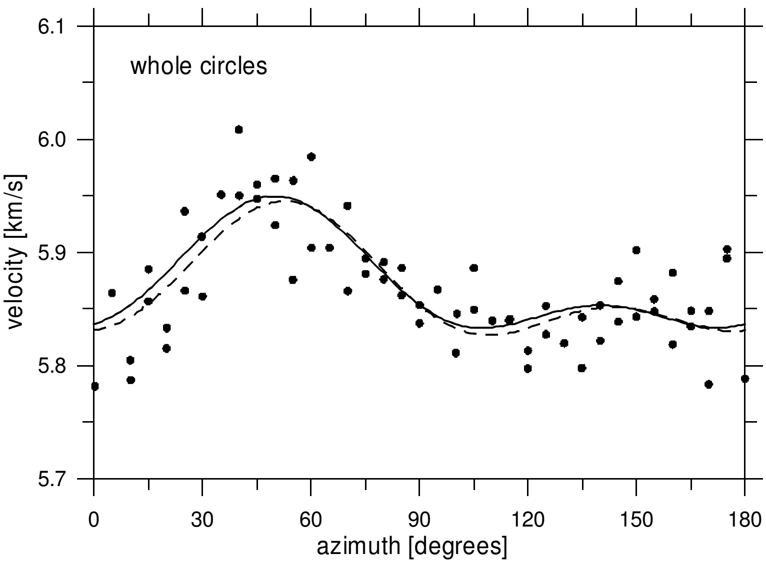

Fig. 19. Velocity variation of Pg waves as a function of azimuth for the Moldanubian unit of the Bohemian Massif, Czech Republic. The full line shows the variation predicted by optimum weak anisotropy, the dashed line shows the variation predicted by optimum weak transverse isotropy.

in the Bohemian Massif and Central Europe and coincides with the results of the main Variscan tectonic events in that area. This indicates that the anisotropy is caused predominantly by alignment of textural elements and minerals in the rocks, which developed in early geological stages rather than by a preferred orientation of cracks or microcracks due to present-day stress.

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Search for triggering mechanisms and driving forces of earthquake swarms in the western part of the Bohemian Massif by the WEBNET group

Forces and mechanisms accountable for origin and development of the earthquake swarms in the West Bohemia/Vogtland region are the issue for understanding the geodynamics of the Western Part of the Bohemian Massif. Seismic observations of the recent intensive 2000-swarm, which occurred in the main focal zone of the West Bohemia/Vogtland earthquake swarms – the area of Nový Kostel in the period from August to December 2000, has been a proper base for investigation of triggering mechanisms and driving forces of the swarm. More than 20 000 earthquakes of magnitudes $ML \leq 3.4$ were recorded by 8 permanent and 3 temporary local stations. The swarm took place in nine swarm phases isolated by quiescence periods and showed a pronounced bottom => top => bottom and north => south migration along the fault plane (*Fischer, 2003*). The recent investigation of the 2000-swarm was focused to (a) precising the earthquake locations and determining the focal mechanisms; (b) search for possible driving forces by analysis of interactions between subsequent events; (c) analysis of multiple-events showing complex rupture process.

a) Over 5400 well-recorded swarm events were relocated by the master event method and for the 133 largest, $M \geq 1.7$ swarm earthquakes focal mechanisms were determined. The majority of focal mechanisms were, respectively, oblique strike-slips with average strike, dip and slip values of 164°, 70° and -30°, which correspond very well to the geometry of the Nový Kostel focal zone, and showed sinistral movements (*Fischer and Horálek, 2005*).
b) The presence of causal relationship of the swarm earthquakes was examined based on the space-time relations between consecutive events – the prior event and the immediate aftershock (IA), (*Fischer and Horálek, 2005*). For this purpose we determined relative position vectors and inter-event times for each consecutive event pair. The spatial distribution of the relative positions evinced two pronounced attributes: (i) a high density of IAs near the origin decaying with distance (Fig. 20) and (ii) preferential occurrence of IAs in the slip-parallel direction. The temporal distribution showed further relevant features: (iii) a notably large span of the inter-event times ranging from less than 1 second to more than 104 seconds, and (iv) speedy interaction of some

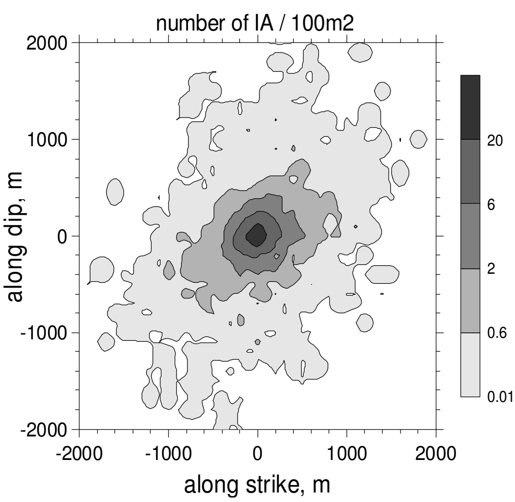

Fig. 20. The areal density of the immediate aftershocks (IAs) projected onto the fault plane striking 169°.

consecutive event pairs occurring systematically at greater distances (called fast IAs as opposed to remaining ones denoted slow IAs). These characteristics point out an evident causal link between consecutive swarm earthquakes and a triggering effect of the coseismic stress perturbation, which is induced by a fault slip during the prior earthquake.

To examine conditions of triggering the aftershocks upon the main fault plane on account of the prior events we calculated the time-space distribution of both dynamic and static components of the Coulomb stress change on the fault plane surrounding a synthetic rupture (see Fig. 21). We found a close relation between the spatial and temporal distribution of the relative position vectors and of the Coulomb stress changes. The static Coulomb stress field decays rapidly with distance likewise the average areal density of the IAs; oval-like character of the isobars and their elongation in the slip direction matches well the spatial distribution of the slow IAs. The dynamic stress changes generated by transient deformation due to passage of the near-field seismic waves decay much slower with distance and show a two-lobe shape resembling the pattern of the fast IAs. This implies that both static and dynamic coseismic stress changes significantly affect the stress field in the surroundings of the rupture and so they have a substantial impact on self-organization of the swarm activity. Majority of subsequent events at smaller distances are presumably triggered by the static stress field, while the fast IAs occurring at greater distances appear to be generated by the dynamic stress transition. The relatively small magnitude of Coulomb stress changes upon the fault plane (a few hundredths of MPa at distances of a few radii of the prior rupture) might still be capable of governing the aftershock distribution as reported e.g. by *Harris (1998)*. Moreover, high-pressured crustal fluids, generally presumed in the region concerned, could locally elevate the pore pressure and thus substantially reduce the shear strength of the fault.

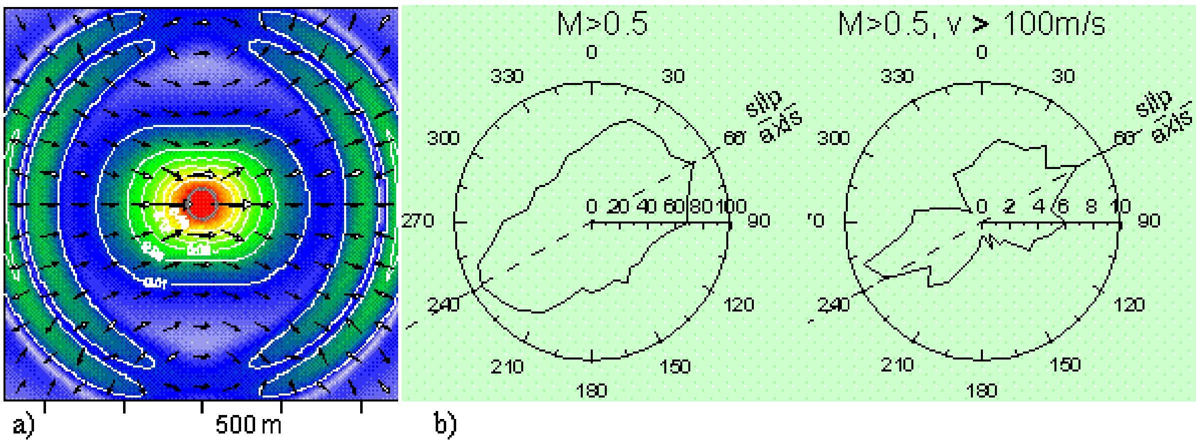

Fig. 21. a) Space distribution of the complete stress field on the fault plane surrounding the rupture induced by an instantaneous stress drop of 10 MPa due to strike slip on a circular area with radius of 100 m in a homogeneous half-space. The shear stress component at the time of 0.35 s after the rupture is depicted (normal stress is zero). The stress field breaks with time into the permanent (static) part as a result of the near-field deformation and the transient (dynamic) part carried by the passage of seismic waves. b) Angular dependence of the rate of IAs. The left panel shows all aftershocks, the right panel shows the fast aftershocks linked by speed higher than 100 m/s.

c) The interactions between subsequent earthquakes of the 2000-swarm at the shortest interevent times were studied by *Fischer (2005)* by the analysis of the multiple-events whose complicated waveforms indicated multiple rupturing episodes. The source-time functions of such earthquakes consist of several pulses whose relative positions provide information on the mutual position of the sub-events. In order to determine the P- and S-wave onsets of the sub-events the waveform modelling method was used (Fig. 22). The P- and S-multiple waveforms were modelled as the sum of waveforms of single sub-events with different hypocentre coordinates and scalar moments, the

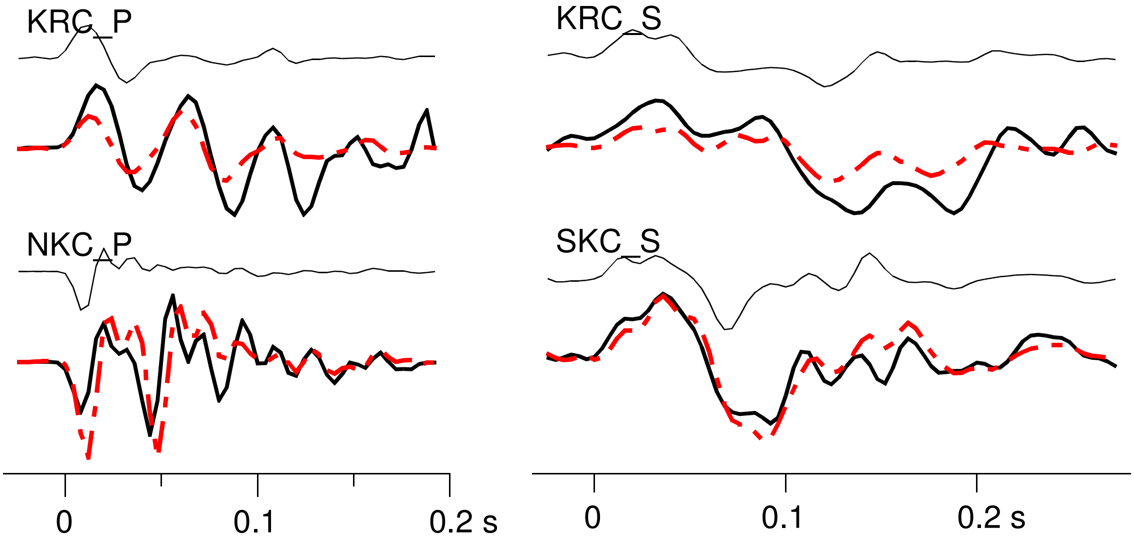

Fig. 22. Example of waveform modelling of a double-event. For the selected P- and S-wave groups three seismograms are shown: empirical Green's function at top, and real (black line) and synthetic (red line) seismograms at bottom. Note the complex waveform character of the real seismograms compared to the EGF ones displayed namely at the P-wave groups.

waveform of a colocated small event was used as an empirical Green's function. Thus, assuming similar focal mechanisms of the sub-events, the coordinates and origin times of the sub-events were searched. As a result the geometry and timing of the sub-events were obtained for 18 of the 54 analyzed multiple-events.

It was found that the average speed of the link between sub-events equals 3.0±0.9 km/s, a value typical for rupture propagation of large earthquakes. The later sub-events occurred farther than the rupture radius of the first sub-event, and their mutual distance scaled with magnitude. It suggests that the multiple-events share a common fault surface and that their sub-events represent individual rupture episodes. The angular distribution of the position vectors of later sub-events indicates that many of them result from a slip-parallel rupture growth.

The obtained results imply that the 2000-earthquake swarm corresponds, as a matter of fact, to a progressive rupturing on one nearly vertically dipping fault plane. The swarm activity proved a substantial self-organization due to a significant impact of the Coulomb stress changes induced by slips of prior events on the ensuing ones; both static and dynamic stress field changes are concerned in triggering of subsequent swarm earthquakes. The self-organization appears to act at a wide range of interevent times, from fractions of second for multiple-events to hours for immediate aftershocks. The Coulomb stress perturbations act very likely in a co-action with a high pore pressure of fluids injected from a deep-seated source, which locally decreases the strength of rock at the fault. This results in lateral stress heterogeneities along the fault plane, whose temporal variations might be responsible for the observed migration of the earthquakes during the swarm.

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Harris R. A., 1998. Introduction to special section: Stress triggers, stress shadows, and implications for seismic hazard. *J. Geophys. Res*., **103**, 24,347-23,358.

Amplitude ratios for complete moment tensor retrieval

The mechanism is one of the most important parameters of earthquake focus and of the foci of artificially induced events as well. Its determination from seismic data is usually not easy because its signature into the data is coupled with the effect of propagation from the focus to the point of observation. To decouple the latter, we need to know the response of the medium – the Green's function – in sufficient detail, which is rarely available. This hampers the resolution of the source parameters including the mechanism. They are biased the more the higher is the frequency of seismic records. Thus, whereas in the long periods available in teleseismic and regional distances the waveform inversion is straightforward and has become a routine task, for local data we are usually unable to simulate the waveforms well. Then, it is necessary to parametrize the waveforms and invert the parameters which are, e.g., the amplitudes of individual seismic phases. In this way, in fact, the ignorance about the medium hampering the synthesis of accurate Green's functions, is overcome by the skill of the interpreter in picking the amplitudes of a seismic phase. Moreover, the sensitivity to the seismic model of the medium can be further reduced by inverting amplitude ratios instead of amplitudes themselves, because we eliminate unrecognized effects occurring along the common path of the seismic waves involved in the ratio. Additional benefit is lifting the demand for a precise calibration of the instrument. The price paid is a loss of data due to forming the ratios, and non-linearity of the inverse problem. We investigated the consequence of inverting ratios on the resolution of the principal characteristics of seismic moment tensor, which describes a general dipole source – the fault plane solution (FPS) characterising the orientation of the shear-slip in the focus, and the non-double-couple (non-DC) components, which describe the departure of the rupture process from a shear slip.

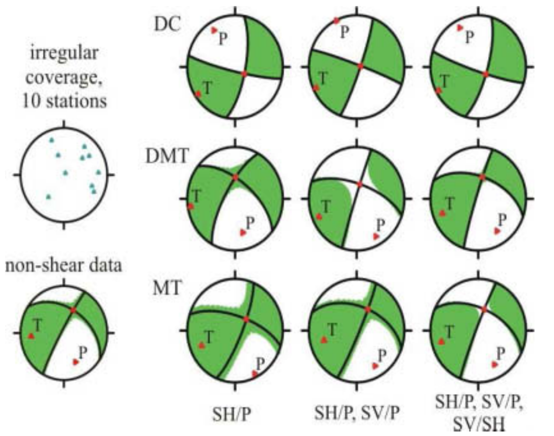

Fig. 23. Synthetic experiment of inversion of non-shear data from 10 stations irregularly covering the focal sphere. Upper row – DC-source model, middle row – source described by a deviatoric moment tensor (DMT), bottom row – source as unconstrained MT. Columns from left to right: SH/P only in the cost function, SH/P together with SV/P, all the ratios included. Left – station coverage and true source mechanism.

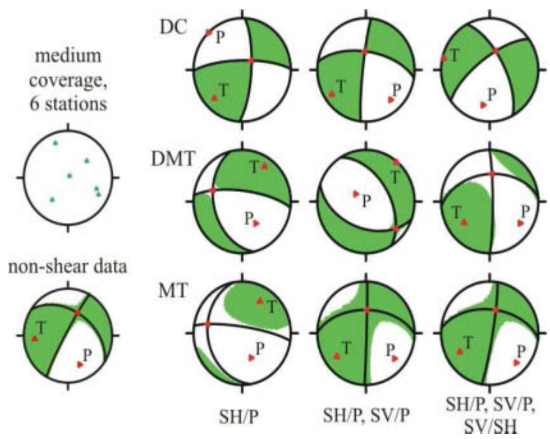

Fig 24. Inversion of non-shear data from 6 stations with a poor coverage of focal sphere. For details see caption of Figure 23.

In the series of synthetic experiments, we tested the resolution of the mechanism in three source models – double couple (DC), deviatoric moment tensor (DMT), and unconstrained moment tensor (MT), provided that, in turn, (i) the ratio SH/P, (ii) SH/P together with SV/P, and (iii) three ratios (SH/P, SV/P, SV/SH) form the dataset (*Jechumtálová and Šílený 2005*). Results are particularly interesting if non-shear data are inverted, i.e. the amplitudes corresponding to a more complex source than in seismology traditional shear slip. We found that with non-shear data, the DC-constrained inversion (which is, e.g., the widespread FOCMEC code) may provide heavily biased FPS, see Figs. 23 and 24. At the same time, the complete MT solution yields a good estimate of the true solution. The resolution is affected greatly by the amount of data employed, i.e. by the number of stations, focal sphere coverage, and the number of amplitude ratios employed. This is demonstrated by comparing Figs. 23 and 24: in Fig. 24 there are less stations and the coverage is degraded with respect to Fig. 23. In the consequence, we need 3 amplitude ratios for a satisfactory resolution of the FPS.

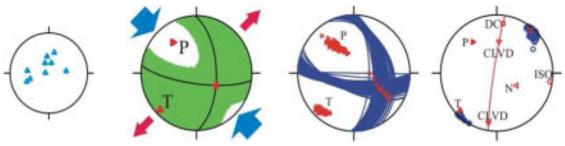

Fig. 25. Inversion of amplitude ratios for $ML=2.34x10^9$ Nm microearthquake from the injection experiment in KTB in 2000. Blue arrow – prevailing NW-SE direction of compressive tectonic stress in Europe, red arrow – tensile single couple dominating the mechanism.

In this way we inverted microseismic data from the superdeep German Continental Deep Drilling Program (KTB). Injection experiment in the KTB borehole in 2000 triggered a weak seismicity which may be non-DC due to injected fluids. In Fig. 25, the mechanism of an event determined from amplitude ratios at 9 stations (all 3 ratios everywhere) is prevailingly non-DC, approaching a single couple along the T-axis. This simulates well a tensile fracturing perpendicular to the prevailing NW-SE direction of compressive tectonic stress in Europe.

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Focal mechanisms in anisotropic media

Not only seismic waves but also seismic sources have more complicated properties in anisotropic media than in isotropic media. For example, planar shear faulting produces pure double-couple (DC) mechanism in isotropy, but generally non-double-couple (non-DC) mechanism in anisotropy. The non-DC mechanism can comprise both the isotropic (ISO) and compensated linear vector dipole (CLVD) components. The amount of the ISO and CLVD depends on strength and symmetry of anisotropy and on the orientation of faulting. This property can by utilized in studies of anisotropy of a source area from seismic moment tensors. For example, we used the moment tensors of the Harvard Moment Tensor Catalog and probed seismic anisotropy of the Tonga subducting slab at depths between 500 to 700 km. This task is particularly difficult and cannot be solved easily by other methods. The inversion for anisotropy showed that anisotropy in the slab is oriented according to the stress in the slab and achieves values of about 7% for P waves and 12% for S waves (see *Vavryčuk 2005* and Fig. 26). The proposed inversion for anisotropy from moment tensors can find many attractive applications. Collecting a sufficiently high number of carefully determined moment tensors we can probe anisotropy in various slabs or explore variations of anisotropy along a slab. The knowledge of anisotropy in a slab can help us to understand better changes in the composition and structure of the slab owing to the 220, 410 and 520 km discontinuities.

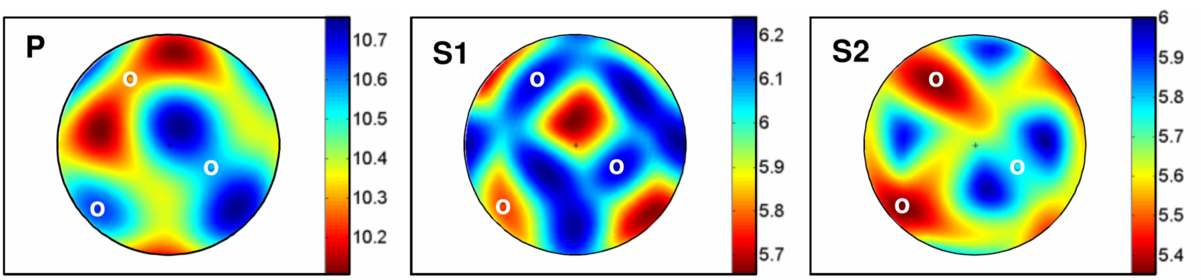

Fig. 26. Spatial variation of the P (a), S1 (b) and S2 (c) phase velocities in the Tonga slab predicted by the optimum anisotropy retrieved from the moment tensors. Equal-area projection is used. Directions of the symmetry axes are marked by circles. Velocities are in km/s.

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Caustics and anti-caustics in seismic anisotropy

Anisotropy of rocks significantly complicates properties of seismic waves propagating in the Earth's crust and in the mantle. It causes effects, which are not observed in isotropic geological structures. For example, it generates so-called parabolic lines, caustics, anti-caustics and singularities. It has been shown that these effects are present not only under strong anisotropy, typical for crystals, but also under weak anisotropy, which is observed in a majority of rocks in the Earth. Using numerical modeling (Fig. 27) we examined basic properties of parabolic lines and caustics present in the vicinity of all types of singularities in homogeneous anisotropic media and we studied their influence on seismic wave-fields. The most complicated singularities in anisotropy are the conical and wedge singularities, which generate caustics and anti-caustics in their vicinity. The parabolic lines cannot touch or pass through a conical singularity, but they touch each wedge singularity. The size of caustics and anti-caustics depends on strength of anisotropy. Caustics and anti-caustics strongly influence geometry of rays of seismic waves and induce anomalous properties of seismic wave fields. Caustics cause the concentration of energy of seismic waves, while anti-caustics cause its dissipation. Knowledge of geometry of caustics and anti-caustics is essential for a correct modeling of seismic waves generated by an earthquake source.

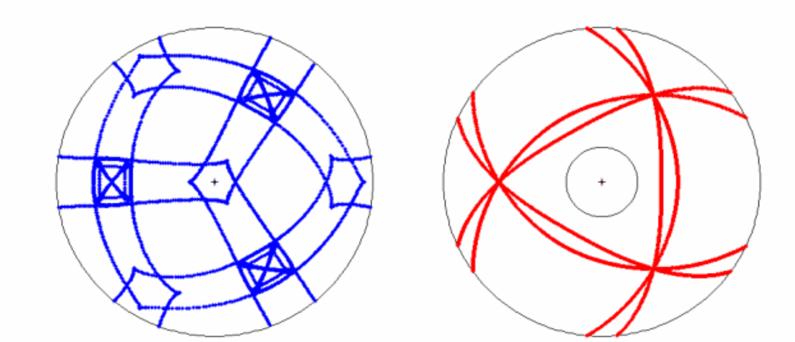

Fig. 27. Caustics on the wave sheets for the S1 (right) and S2 (left) waves in strong cubic anisotropy. The inner circle on the S1 sheet denotes anti-caustic. Equal-area projection is used. The plus sign corresponds to the vertical direction, the outer circles correspond to horizontal directions.

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Vavryčuk, V., 2003c. Generation of triplications in transversely isotropic media. *Phys. Rev.* **B, 68**, art. no. 54107.

Acoustic axes in strong and weak triclinic anisotropy

Calculation of acoustic axes in triclinic elastic anisotropy is considerably more complicated than for anisotropy of higher symmetry. While one polynomial equation of the 6th degree is solved in monoclinic anisotropy, we have to solve two coupled polynomial equations of the 6th order in two variables in triclinic anisotropy. Furthermore, some solutions of the equations are spurious and must be discarded. In this way we obtain 16 isolated acoustic axes, which can run in real or complex directions. The real/complex acoustic axes describe the propagation of homogeneous/inhomogeneous plane waves and are associated with a linear/elliptical polarization of waves in their vicinity. The most frequent number of real acoustic axes is 8 for strong triclinic anisotropy and 4 to 6 for weak triclinic anisotropy. Acoustic axes can exist even under an infinitesimally weak anisotropy, and occur when slowness surfaces of the S1 and S2 waves touch or intersect. The maximum number of isolated acoustic axes in weak triclinic anisotropy is 16 as in strong triclinic anisotropy. The directions of acoustic axes are calculated by solving two coupled polynomial equations in two variables. The degree of the equations is 6 under strong anisotropy and reduces to 5 under weak anisotropy. The weak anisotropy approximation is particularly useful, when calculating the acoustic axes under extremely weak anisotropy with anisotropy strength less than 0.1%, because the equations valid for strong anisotropy might become numerically unstable and their modification, which stabilizes them, is complicated. The weak anisotropy approximation can also find applications in inversions for anisotropy from the directions of acoustic axes.

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First-order ray tracing for smooth inhomogeneous weakly anisotropic media

Ray tracing procedures represent basis of many seismic processing techniques as, e.g., prestack Kirchhoff depth migration or AVO. Since majority of rocks are often anisotropic, and specifically weakly anisotropic, development of ray tracing procedures for such kinds of media is desirable. Using the perturbation theory, in which deviations of anisotropy from isotropy are considered to be the first-order quantities, we derived first-order ray-tracing equations for P waves, see *Pšenčík and Farra (2005)*. The traveltimes calculated along these rays are also of the first order. In order to increase the accuracy of the traveltimes, a simple second-order correction calculated along rays can be used. All equations are expressed in terms of weak anisotropy parameters, which represent a more natural parameterization of weakly anisotropic media than standard elastic parameters. Only 15 weak anisotropy parameters describing P-wave propagation are involved.

Results of numerical tests in medium whose horizontal axis of symmetry rotates with increasing depth, called HTI-ROT are shown in Fig. 28. A VSP experiment is considered, in which the source and the borehole are situated in a vertical plane. The borehole is vertical, the source is located on the surface, in the distance of 1 km from the borehole. Results obtained with exact ray tracing and FORT coincide so well that no differences are visible. The differences are made visible in Fig. 29, where the relative travel time differences (from exact travel times) corresponding to the first- (black) and second-order (red) traveltimes are plotted.

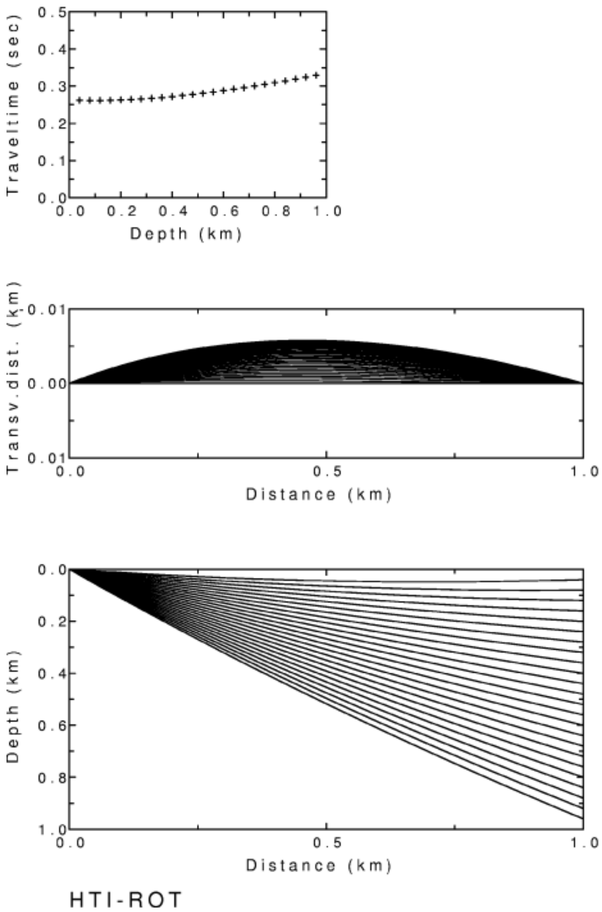

Fig. 28. Projections of the 3D ray diagram into vertical plane containing the source and the borehole (bottom), into horizontal plane (middle) and traveltime curve (top) for the model HTI-ROT.

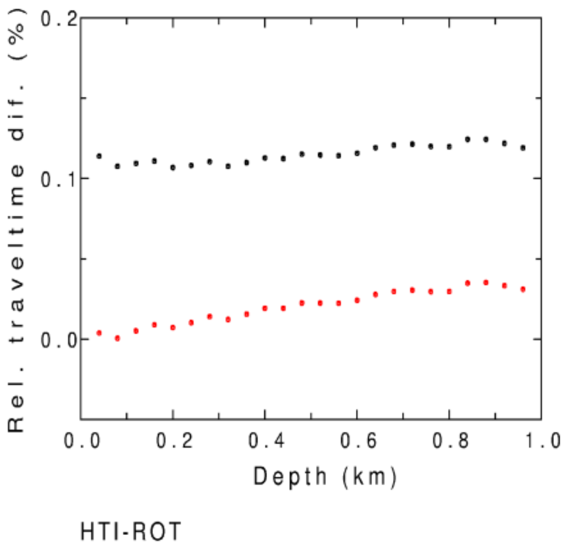

Fig. 29. Relative traveltime differences of the first-order (traveltimes calculated along FORT rays – black) and of the second-order (red) approximation for the model HTI-ROT.

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Comparison of synthetics calculated by the QI approximation of the coupling ray theory and by the Fourier pseudospectral method

A possible test of accuracy of an approximate method is comparison of its results with results of a more accurate method on models, at which both methods are applicable. The approximate method in our case is the quasi-isotropic (QI) approximation, see *Pšenčík and Dellinger (2001)* of the coupling ray theory (see, e.g., *Bulant et al., 2004*). The QI approximation was designed to study S-wave propagating in inhomogeneous weakly anisotropic media, in which neither the ray theory for isotropic media nor the ray theory for anisotropic media work properly. The QI approximation is also expected to work in directions, in which S-wave phase velocities are close to each other, it is in singular directions of S waves and in their vicinities. In these directions, the standard ray theory fails. The Fourier method is assumed to be the more accurate method. It does not suffer from limitations of the ray methods. It can be, for example, applied, in singular directions of S waves.

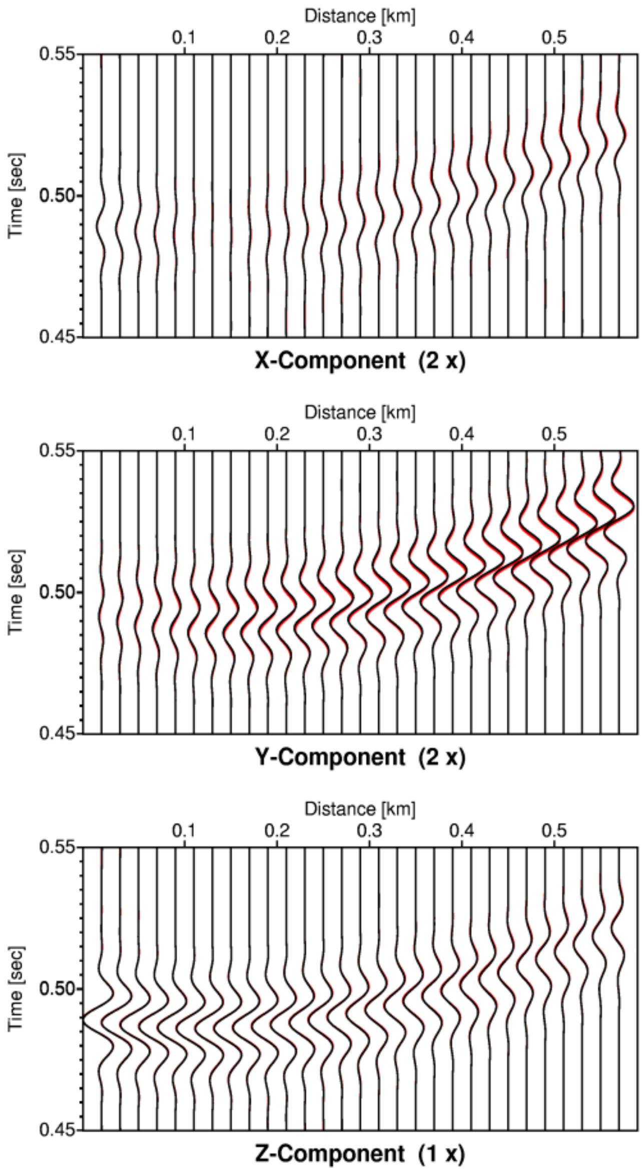

Fig. 30. Comparison of QI (red) and Fourier (black) seismograms generated by a vertical point force in a VSP experiment in a vertically inhomogeneous HTI model with the axis of symmetry deviating from the vertical plane containing the source and the borehole.

Fig. 30 shows comparison of QI (red) and Fourier (black) seismograms calculated for the VSP configuration and model WA described by *Pšenčík and Dellinger (2001)*. It is clearly visible that for the VSP configuration and considered anisotropy, the QI approximation yields sufficiently accurate results. For more details see *Pšenčík and Tessmer (2005)*.

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Inhomogeneous time-harmonic plane waves in viscoelastic anisotropic media

An algorithm for the computation of various quantities characterizing propagation of time-harmonic plane waves was proposed and tested, see *Červený and Pšenčík (2005a, 2005b)*. The algorithm can be applied to arbitrary homogeneous or inhomogeneous plane waves propagating in media of unrestricted anisotropy and viscoelasticity. The algorithm has been used recently to investigate properties of the complex-valued Poynting vector of homogeneous and inhomogeneous time-harmonic plane waves, propagating in unbounded viscoelastic anisotropic media (*Červený and Pšenčík, 2005c*). The real-valued part of the Poynting vector represents the time-averaged energy flux,

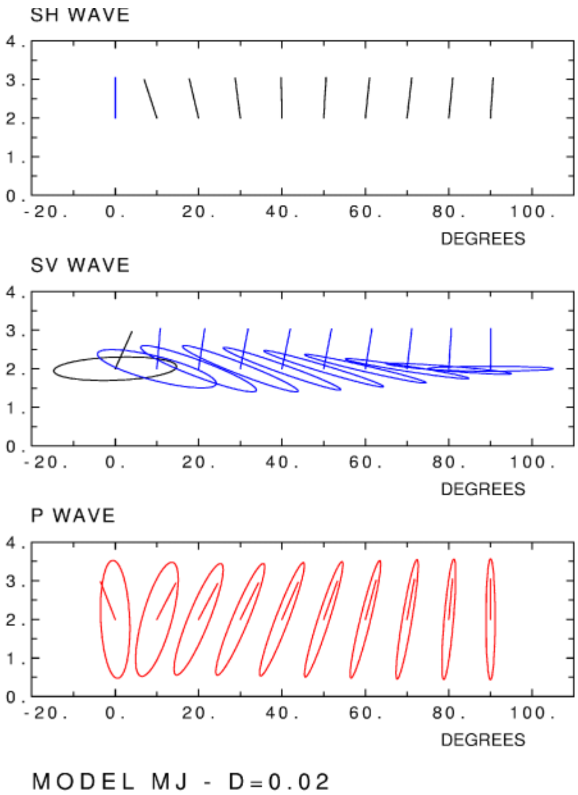

Fig. 31. Directions of the energy flux (short lines) and of the polarization ellipses of time-harmonic plane waves propagating in a viscoelastic anisotropic medium. Normals to the wavefront are vertical in this display. Red color – the fastest, black – the intermediate, and blue – the slowest wave.

and its imaginary-valued part is closely related to the dissipated energy. Fig. 31 shows comparison of the energy flux (short lines) and of the polarization ellipses of time-harmonic plane waves propagating in a viscoelastic anisotropic medium. Wave normals are vertical. Values along the horizontal axes correspond to the angles of the wave normal. The angle of 0° corresponds to the direction along the axis of symmetry. Red color corresponds to the fastest, black to intermediate and blue to the slowest wave. Note parallel (P wave) and perpendicular (SV wave) orientation of the energy flux and of the polarization ellipses for directions different from 0°. Also note interchanged phase velocities of the SV- and SH-wave velocities for directions close to 0°.

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Estimates of P-wave anisotropy from the P-wave slowness and polarization measurements

Inversion scheme for the determination of anisotropy in a vicinity of a receiver situated in a borehole from the data obtained during a multi-azimuth multiple-source offset VSP experiment has been further studied. Synthetic data were generated, which consisted of travel times and of polarization vectors of direct and reflected P waves recorded at several nearby receivers and generated along a single profile. The tests were inspired by the inversion of real data from the Java Sea region, see the contribution by *Gomes et al. (2004)*. Effects of the choice of a reference medium, of the wave normal, of the strength of anisotropy, of different levels of noise on the results of inversion were analyzed. Sensitivity of the inversion scheme to the number of sources along the profiles, to the number and type of waves considered was also studied. Study of sensitivity and stability of the inversion scheme indicates that only some from the recoverable parameters can be recovered reliably. The tests showed that the use of a single profile limits the possibility of the inversion scheme considerably. In inversions of data from a single profile, it is impossible to determine the type of anisotropy of the medium. It is, however, possible to distinguish which of proposed models of medium satisfies better the observed data. It was also found that the determination of parameters of the medium depends strongly on the choice of the P-wave velocity in the reference isotropic medium and only slightly on the choice of the normal to the wavefront in the reference medium.

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Electromagnetic depth soundings

A contribution to investigations of the deep electrical structure across the Trans-European Suture Zone (TESZ) in NW Poland has been the main target of our electromagnetic depth sounding experiments in the last two years. Within the international initiative EMTESZ, a regional-scale experiment has been started in 2001, focused on revealing the electrical conductivity distribution of both the thick sedimentary cover and the underlying crustal and mantle structures, down to the transition zone at lithospheric depths, across the TESZ from the West to the East European Platform by applying broad-band electromagnetic measurements, i.e., audio-magnetotelluric (AMT) and magnetotelluric (MT) soundings. Up to now, 77 long-period MT and 56 AMT curves have been collected throughout the region of the NW Poland segment of the TESZ in cooperation of teams from Germany, Poland, Sweden, Finland, Russia and Czech Republic (Fig. 32). As DC operated trains and

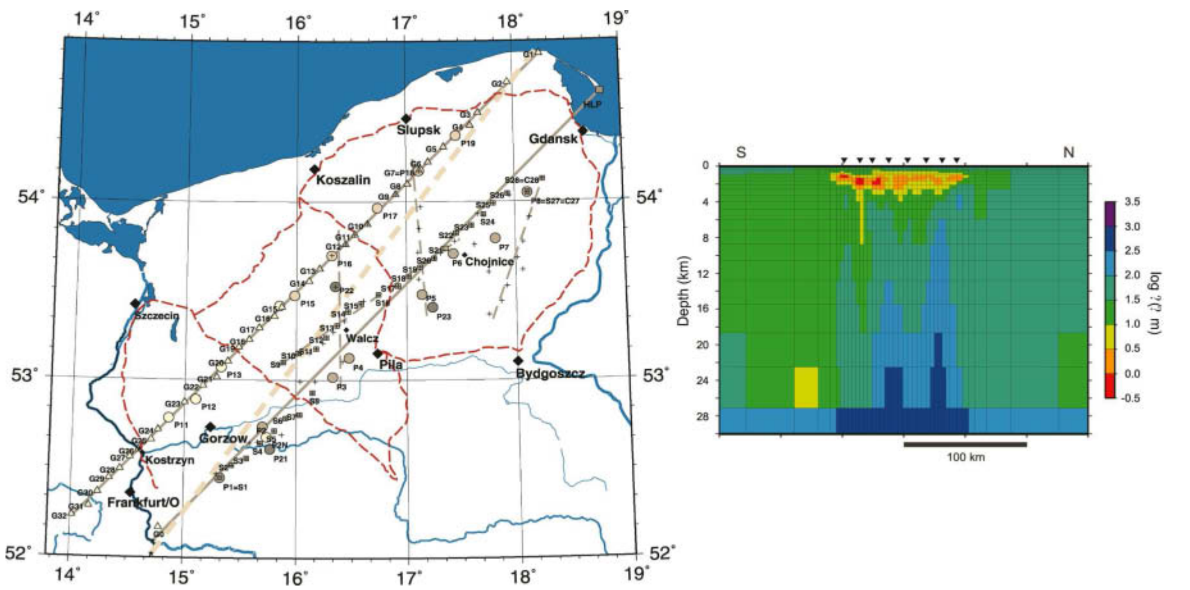

Fig. 32. Left: Profiles of MT/AMT sites of the EMTESZ project, sites finished by the summer of 2005. Right: Electrical conductivity distribution in the crust beneath the SE part of the region.

a high population density in Poland contribute to a relatively high level of cultural noise in the electromagnetic records, sophisticated data processing techniques have been employed to provide sufficiently reliable estimates of the MT transfer functions throughout the period range from 10^{-3} to 10^{4} s, including methods utilizing a multi-reference setup and an additional magnetic control as well as those based on a robust analysis with a high breakdown point. A joint analysis of all the data sets acquired so far has made it possible to reveal the main features of areal conductivity/conductance variations down to subcrustal depths beneath the region of interest, which may be summarized as follows: (i) the subsurface geoelectrical structure complies with the surfrace geology of the TESZ striking 45 deg NW with two conducting troughs and a resistive central block, (ii) the deeper crustal structure is close to 2-D with the strike of approximately 60 deg NW and it seems to include two separated conducting channels within the suture zone, (iii) an increase of the upper mantle conductance from NE to SW is indicated. Detailed 2-D and 3-D modelling and inversion results from various segments of the region under study are being compiled at present to further enhance the interpretation in terms of the causative physical and geological conditions for the domains of the anomalous induction within the models. Within this investigation, an attempt for a joint interpretation of crustal and upper mantle conductivities in a larger continental neigbourhood of the TESZ has been started within the Polish and international project CEMES (Central Europe Mantle Electromagnetic Soundings, *Semenov et al., 2003*).

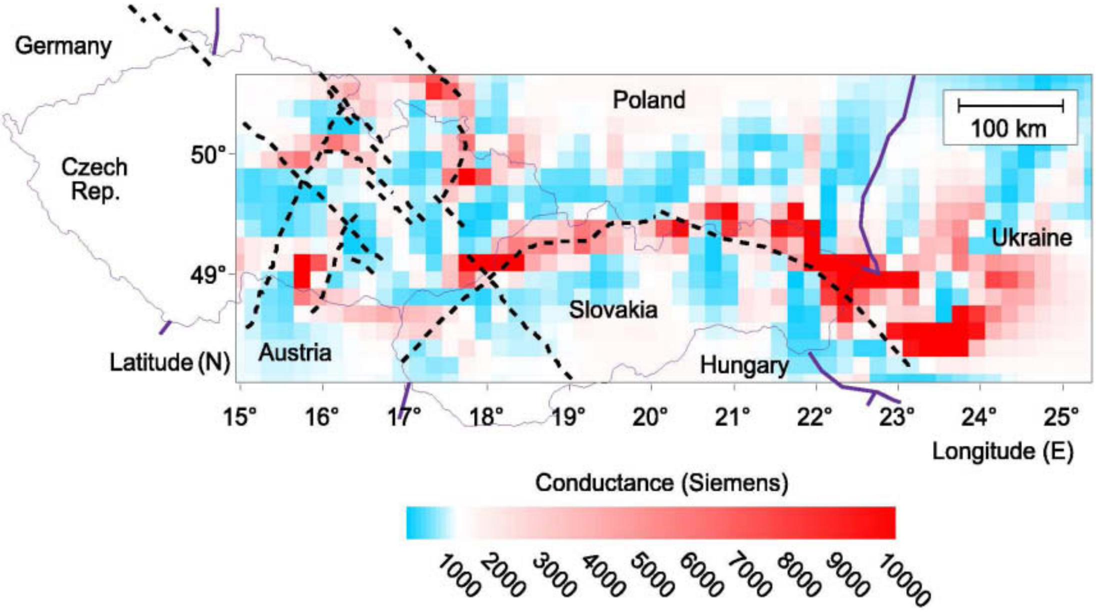

Fig. 33. Model of the conductance across the Carpathian region along with a pattern of principal fault zones at the transition zone between the Bohemian Massif and the West Carpathians. The conductance distribution results from a minimum gradient support focussing employed within the thin sheet minimization algorithm.

Long-period geomagnetic induction data within the range of hundreds to thousands of seconds represent a significant source of information with regard to the lateral electrical differentiation of the earth's crust on a scale of first-order geological and tectonic units. Our earlier model studies into the lateral distribution of the crustal conductance in the West Carpathians have been newly extended to encompass also the Ukrainian segment of the Carpathians. The magnetic variation data in the period range of 1000 to 6000 s recorded at 172 sites situated in the eastern part of the Czech Republic and in the Polish, Slovakian and Ukrainian Carpathians were used as inputs for the modelling of the conductance distribution within the Carpathian region (Fig. 33). An original linearized algorithm for the inversion of the geomagnetic induction data for the conductance distribution in a unimodal thin sheet has been applied to the collection of the geomagnetic transfer functions available, and several regularization approaches, both quadratic and non-smooth, have been tested in the inverse procedure so as to spatially focus zones of the anomalous conductance as much as possible as well as to minimize effects of spurious anomalies with only a weak effect on the experimental data.

Models of the integrated conductivity within the thin sheet indicate an anomalous belt corresponding to the Carpathian conductivity anomaly in its western, northern and eastern part and confirm a quasi-linear character of the anomaly. The conductance models also suggest an alternative interpretation of the electrical nature of the contact of the Carpathian plate with Paleozoic structures in the west. Contrary to earlier models that explained the anomalous pattern of the induction arrows above the eastern margin of the Hercynides as a joint effect of a quasi-linear zone of anomalously high electrical conductivity and a hypothetical extensive crustal conductor situated beneath SW Poland, well outside the data coverage domain, the present image rather suggests that this anomaly may be due to several conductive belts intersecting the anomalous zone. These belts follow faults, dividing the transition zone between the Bohemian Massif and the West Carpathians into individual blocks formed by metamorphic and plutonic complexes. In these zones material from the deep layers of the crust might have penetrated and generated domains of the increased crustal conductivity (*Kováčiková et al., 2005*).

Interestingly, the above interpretation of the anomalous induction at the eastern margin of the Bohemian Massif closely resembles one of our recent methodological results obtained from the analysis of effects caused by the electrical anisotropy in laterally non-uniform conductors. Specifically, 2-D structures with oblique electrical anisotropy with respect to the structural strike and with the maximum/minimum resistivity greater/smaller than that of the host medium can largely distort the induction arrows so that they become almost parallel with the strike of the anomaly. This unusual induction pattern can be expected to occur in the vicinity of highly resistive structures that are interspersed with aligned conductive dykes distributed with high enough density so that the electromagnetic field senses the bulk anisotropy only, not the structural details.

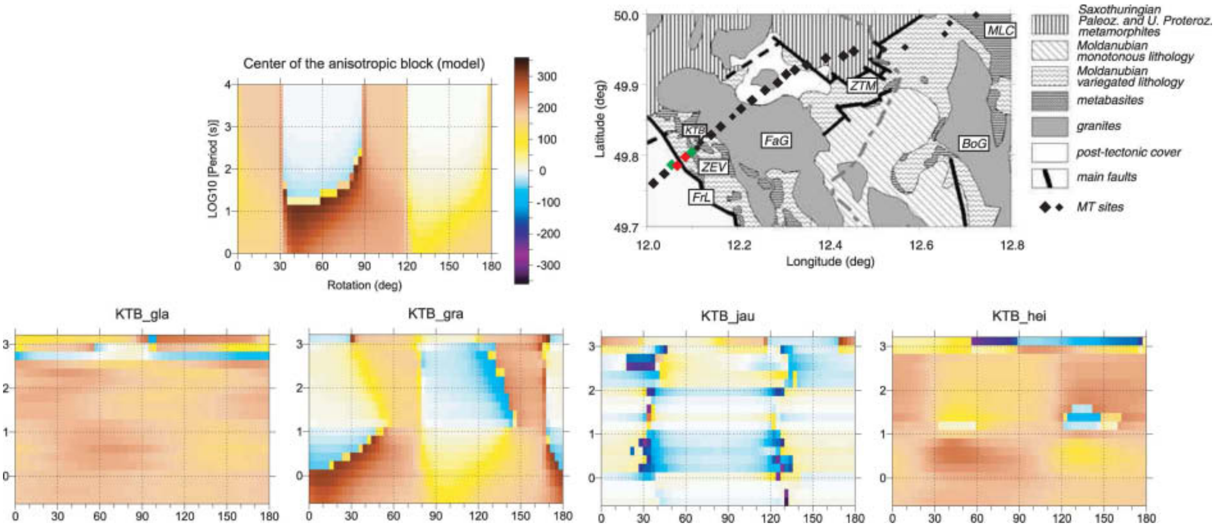

Fig. 34. Color plots of the differences of the MT impedance phases in two perpendicular directions as functions of the rotation angle and the period at four sites close to the Franconian Line compared with the color plot obtained from the model of an anisotropic dyke.

Further exotic manifestations of electrically macro-anisotropic earth's structures have been observed in the course of development of numerical techniques for the direct modelling and inversion in laterally non-uniform generally anisotropic media (*Pek et al., 2005; Li et al., 2005*). A special interest has been paid to the effect of impedance phases that leave their natural range and traverse through quadrants in the phase domain. This phenomenon has been observed frequently in regions with extreme electrical distortions due to interactions of highly conductive and highly resistive structures, and has been mostly explained as an effect of noise in MT data affected by extreme current channelling. The alternative approach via anisotropic structures explains the phase trips in a natural sense, in terms of galvanic distortions due to a channelling caused by the electrical macro-anisotropy in subsurface structures (Fig. 34).

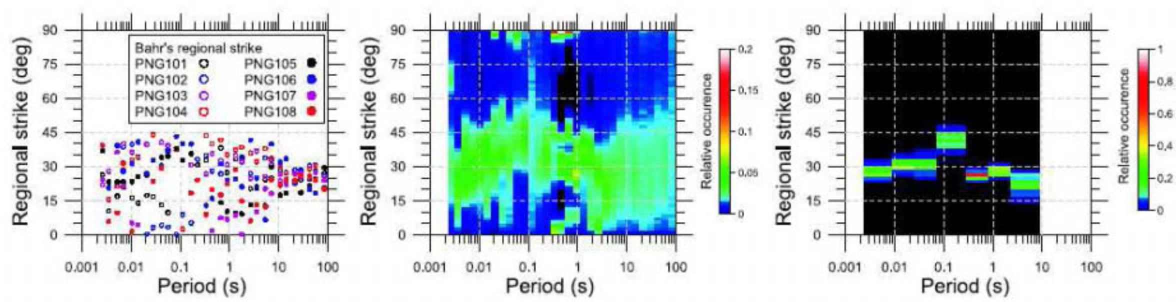

Fig. 35. Sum of strike directions for the benchmark data PNG sites 101 through 108. Left: Strike directions computed by Bahr's formula. Middle: Stacked histograms of the strike directions simulated by the MCMC individually for each site and each period. Right: Histograms of strikes obtained by the multisite multifrequency analysis over all sites and over period bands of half a decade width.

Research into stochastic methods for the magnetotelluric interpretation has been newly extended to deal with problems of the MT tensor decomposition. Magnetotelluric directional analysis and impedance tensor decomposition are basic tools that are employed standardly to validate a local/regional composite electrical model of the underlying structure, as well as to extract quantitative information about both the regional conductor, often with a specific type of symmetry, and the local distorters. As the effect of local galvanic distortions can result in considerably blurring the image of the deeper regional conductor, reliable quantitative estimates of both the decomposition parameters and their uncertainties are needed. Bayesian stochastic methods are particularly suitable for this purpose, as they handle the uncertainties of the estimated parameters in a parametric fashion through the use of posterior model probabilities. We formulated the baysesian approach to the MT decomposition problem within the standard Groom-Bailey decomposition scheme. Construction of the likelihood function was based on the assumption of the experimental impedance estimates being contamined with Gaussian noise. For the decomposition parameters, we used non-informative, flat priors within finite, physically justified intervals. Further, we applied a simple Markov chain Monte Carlo technique with a Gibbs sampler to simulate samples from the posterior distribution of the composite models conditioned on the experimental data, and characterize the estimates and uncertainties of the decomposition parameters by using the respective marginal posterior probabilities (an example shown in Fig. 35). The technique has proved reliable and stable for a wide range of MT decomposition problems, including those with multiple frequency and multiple site data sets, as well as those with static magnetic distortions considered.

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Numerical simulations of the hydromagnetic dynamos.

The theory of the hydromagnetic dynamo seems to be the best explanation of the generation mechanism of the magnetic fields and their temporal and spatial evolution. Due to the complexity and non-linearity of the hydromagnetic dynamo problems, which includes a system of 3D partial differential equations for the magnetic field, momentum equation for velocity, as well as the heat-flux equation, numerical simulations are usually used. The results of numerical geodynamo simulations performed in the last decade, based on spectral methods are in a very good agreement with observations and paleomagnetic studies even though they have been done for the parameters, which are far-away from the Earthlike ones, e.g. Ekman number, as a measure of viscous forces, is extremely high. It is expected that higher spatial resolution and, consequently, lower values of Ekman number could be better achieved by grid methods. We have focused our attention on finite (control) volumes method, which supports the stability of the solutions near the axis of rotation. This method is efficient on a parallel computer because only "nearest neighbor" communication between the processors would be needed – instead of the global communication needed for spherical harmonic codes. Therefore, when much higher spatial resolution is desired to simulate geodynamo action, this method may be a better choice than a spherical harmonic method.

The hydrodynamic part of the problem – thermal convection in a rotating spherical shell - was tested by means of "numerical dynamo benchmark" and the results were in a good agreement with the

spectral methods (*Hejda and Reshetnyak, 2004*). The parallel version of our numerical code is stable and convergent and the tests of the full hydromagnetic benchmark are in progress.
It is well known that all knowledge of the geodynamo comes from the poloidal component of the magnetic field which extends outside the conducting region whereas the toroidal component is confined to the conductor. For an "invisible" dynamo, the entire field is trapped in the conductor and is not detectable for any exterior observer, who has no direct information about it.
The search for an invisible dynamo is one particular instance of the inverse dynamo problem. The inverse dynamo problem asks for a velocity field given a magnetic field observed in the vacuum region surrounding the conducting fluid, such that the magnetic field is maintained by a dynamo process. Solutions to the inverse dynamo are presumably not unique, but no example seems to be known of two velocity fields producing the exactly same magnetic field in the vacuum region. However, an invisible dynamo, if it exists, does provide such an example, because a zero field in the vacuum region could be produced by both the invisible dynamo and fluid at rest.
Our search for an invisible dynamo has started in a cylinder. The model of a vertically unbounded liquid cylinder is considered. The cylinder contains electrically conductive fluid and is surrounded by insulator. The action of an invisible dynamo is situated in the cylinder. The magnetic field of an invisible dynamo does not penetrate the surrounding area.
We have shown that invisible solutions exist. However, the invisible modes are all decaying. No growing modes have been found even though a large portion of paramater space has been explored. It thus remains a challenge to find an example of an invisible dynamo (see *Šimkanin and Tilgner, 2005*).

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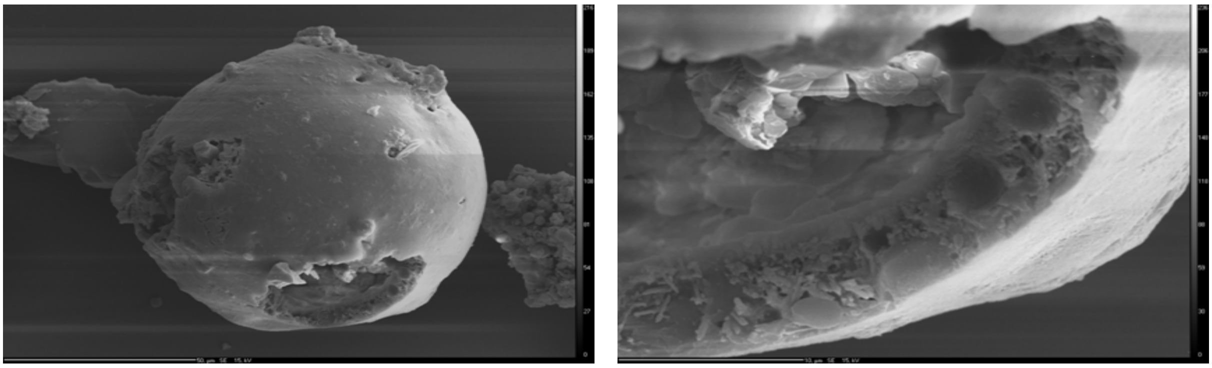
Environmental rock magnetism

Soil represents interface between solid lithosphere on one side, and atmosphere, hydrosphere and biosphere on the other. It is formed by long-lasting weathering of rock basement through physical and chemical processes, resulting from interactions with atmosphere, hydrosphere and biosphere. Soil is thus rich in minerals of various origin, either primary, derived directly from the lithosphere weathering, or secondary, resulting from diagenetic transformations in the soil. Moreover, soil acts as natural sink of atmospherically deposited dust particles, buffering them from penetration to ground waters. Possible mechanisms of magnetic enhancement of soils due to increased concentrations of secondary ferrimagnetic minerals are discussed in, e.g., *Maher and Taylor (1988)*, *Stanjek et al. (1994)* and *Singer et al. (1996)*. Besides pedogenic and biogenic processes, atmospherically deposited ferrimagnetic particles of anthropogenic origin contribute to a great deal to concentration-dependent magnetic properties of soils (e.g., *Kapička et al., 2001, 2003*).
Among soil minerals, magnetic particles (in particular iron oxides and sulphides) play important role. In our research, we focus on soil iron oxides, their origin and fate, and methods of identification. This knowledge is crucial in interpreting various magnetic anomalies observed on, or above the Earth's surface. For instance, atmospherically deposited industrial fly ashes, rich in iron oxides, accumulate in surficial layers and can be detected by surface measurements of soil magnetic susceptibility. However, this interpretation is obscured in cases with strong lithogenic contribution. Therefore, anomalies in spatial distribution of surface soil magnetic susceptibility require much more detailed investigation in order to validate and justify the above assumption.



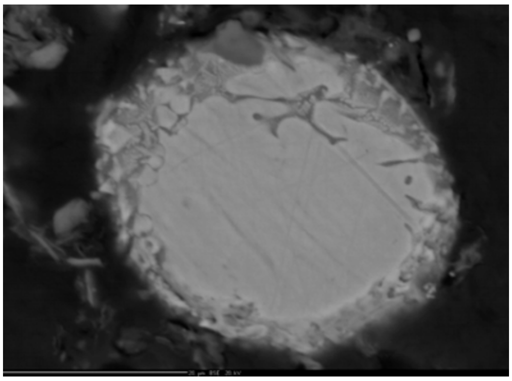


Fig. 36. SEM images of typical magnetic spherules of anthropogenic origin, found in topsoil layers in industrially affected area near Ostrava, along with typical elemental composition.

Present instruments and methods enable very sensitive determination of concentration of strong ferrimagnetics (for instance magnetite), in the order of ppm. Magnetic properties of soils have been recently beneficially used in examining industrial pollution. Methods of "environmental magnetism" are sensitive and enable detection of small changes in concentration of magnetic particles in soils (e.g., *Petrovský and Ellwood, 1999*). Deposited dust of anthropogenic origin comprises high portion (5 – 10%) of highly (ferri)magnetic particles, produced primarily during combustion of fossil fuels containing pyrite. Dissociation and oxidation processes during combustion form ferrimagnetic iron oxides from Fe ions. Resulting anthropogenic magnetite (Fe_3O_4) or maghemite (Fe_2O_3) form specific spherules with diameter from several micrometers to several tens of micrometers and their magnetic properties are different from particles of lithogenic origin. Besides combustion, industrial magnetic particles also result from, e.g., steel and cement industry and from road traffic (e.g., *Petrovský and Ellwood, 1999*).

Magnetic susceptibility represents one of major parameters indicating concentration of (ferri)magnetic particles in soils and sediments. Magnetic mapping (measurements of magnetic susceptibility of top soil layers) can be thus used as fast, effective and low-cost method of approximate determination of contamination of soils due to atmospheric deposition of pollutants. In case of undisturbed soils this magnetically enhanced layer reaches depths of some 5 – 10 cm. In particular, the method can be advantageously used in outlining hot-spots for further (more expensive and time consuming) chemical analysis of contaminated soils. Magnetic susceptibility of contaminated top soils was measured in situ using a portable loop-shaped hand probe Bartington MS2D. Since these measurements are fast and easy, large data sets can be obtained on any grid of measuring points over the area of concern. The data are represented in a form of 2-D maps, delineating magnetic susceptibility of top soils. In order to determine the undesired effect of basement rock (lithogenic contribution), magnetic parameters in dependence of depth were studied on selected sites to depths of 30 – 60 cm. For this purpose, a new unique instrument SM400 was developed (*Petrovský et al., 2004*).

Our recent studies focused mainly on magnetic discrimination between natural soil magnetic minerals of lithogenic origin and anthropogenic ones, produced through industrial processes. This research is a direct continuation of the studies performed within the EU 5FP Project MAGPROX. In cooperation with Polish colleagues from the Institute of Environmental Engineering PAN in Zabrze, large set of vertical profiles of magnetic susceptibility in soils was analysed and 7 typical profiles were classified (*Magiera et al., 2005*). Based on these results, more detailed study of vertical profiles of soil magnetic susceptibility was accomplished on a border-crossing transect in the Třinec-Katowice area. The results confirmed the assumption that topsoil magnetic anomaly, observed in this region, is fully due to atmospheric deposition of industrially derived magnetic particles.

Magnetic discrimination of lithogenic and anthropogenic magnetic particles was also subject of the study done in close cooperation with colleagues from Leoben, Austria. It was shown that using a combination of magnetic parameters, dominant populations of magnetic minerals of natural and anthropogenic origins can be distinguished from each other (*Fialová 2005; Fialová et al., 2005*). However, magnetic methods should be complemented by other observations, e.g. scanning electron microscopy (Fig. 36).

Finally, we started investigation of vertical migration of atmospherically deposited magnetic particles. The results will greatly contribute to the reliability of magnetic mapping, related to soil pollution problems.

Last but not least, magnetic susceptibility of agricultural soils from the whole of the Czech Republic was examined. The samples were obtained from a depository of the Central Institute for Supervising and Testing in Agriculture in Brno. Ploughed topsoils were compared with those from the depth of 40 cm. Magnetic susceptibility was compared with concentrations of heavy metals. The results suggest that, independent of the soil use, agricultural soils are mixed to such extent, that concentration of magnetic minerals and heavy metals in topsoils and subsoils correlates very well and disables distinction of lithogenic and anthropogenic contributions.

It is obvious, that contrast in topsoil magnetic susceptibility can be interpreted in terms of lithogenic, anthropogenic or combined contributions, mainly using vertical distribution of magnetic susceptibility measured on soil cores or in situ (using a newly developed SM400 susceptibility meter), and using other laboratory methods (e.g., geochemical analysis). Magnetic method, once correlated with concentrations of heavy metals at specific site, can serve as fast and low-cost tool for approximate screening and monitoring the pollution load.

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Solar-terrestrial relations

a) The association of solar and geomagnetic activity with events in the troposphere was studied by means of their correlations with the magnitude of the North Atlantic Oscillation (NAO) index, and by the composite maps in the winter periods (January – March) of the years 1963 – 2001 (*Bochníček and Hejda, 2005*). It was shown that the patterns of the pressure, temperature and prevailing wind distributions, given basically by the sign of NAO, are significantly modified by solar and geomagnetic activity. The vertical profiles of deviations of geopotential heights and temperatures averaged over the segments defined by geographic longitudes (30º – 60ºW, 120º – 150ºE; Atlantic-polar region-eastern Asia) and (0º – 30º E, 150º – 180º W; Europe-polar region-Pacific) clearly indicate that more pronounced pressure and consequently temperature deviations occur over the Atlantic than over the European continent, and that under NAO+; ΣKp>21 the Aleutian pressure low fills in and under NAO-; ΣKp<16 deepens over the eastern Pacific. One can also see that the relative cooling (under NAO+; ΣKp>21) and warming (under NAO-; ΣKp<16) over Greenland are related to changes in the lower polar stratosphere, whereas the relative warming (under NAO+; ΣKp>21) and cooling (under NAO-; ΣKp<16) over Europe is restricted to the troposphere only.

Statistically significant temperature and pressure deviations associated with geomagnetic activity occupy larger areas in the composite maps than the deviations associated with solar activity. In the investigated winter periods high geomagnetic activity (ΣKp>21) was nearly always associated with NAO+, low geomagnetic activity (ΣKp<16) tended to couple with NAO-. The fact that geomagnetic activity and the NAO index are more pronounced than solar activity can probably be explained by geomagnetic activity affecting not only the propagation of planetary waves, but also the intensity of the atmospheric vertical current in the "global electrical circuit".

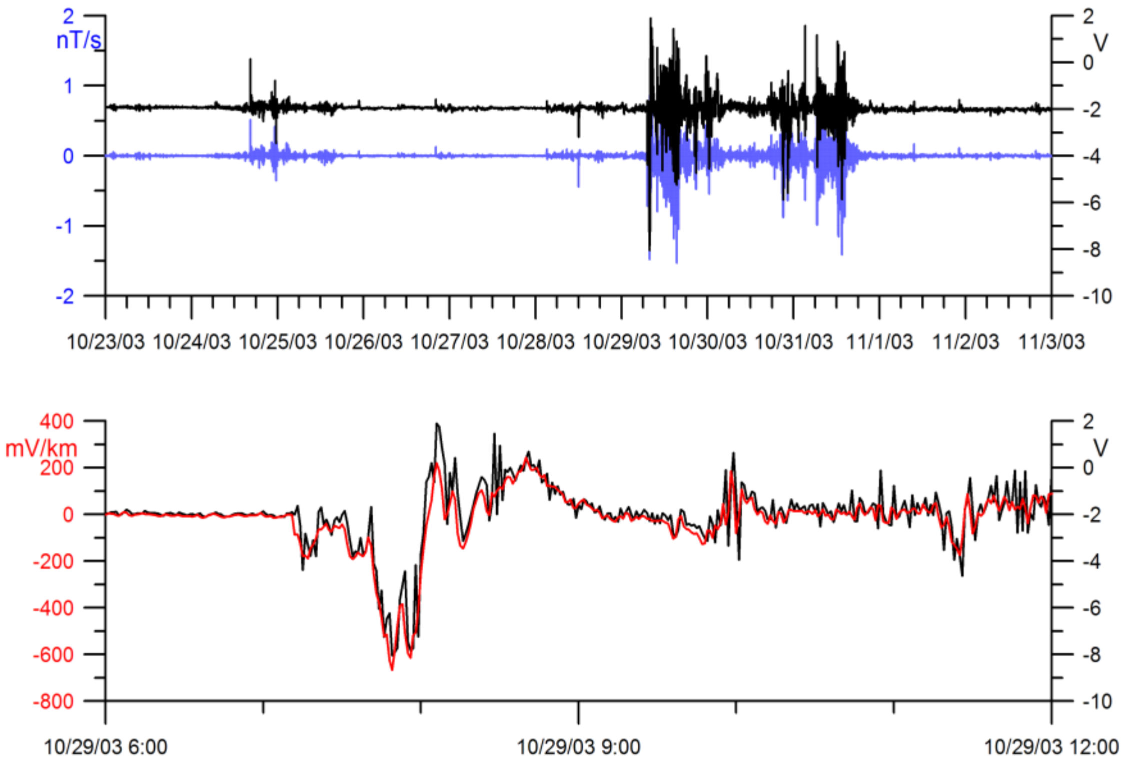

Fig. 37. Top: Pipe-to-soil voltage recorded at the station Sv. Kateřina (black line) and time derivatives of the north component of the geomagnetic field at Budkov observatory (blue) between 23 October and 2 November 2003. Sv. Kateřina is situated on the Ingolstadt-Kralupy nad Vltavou oil pipeline in West Bohemia. Bottom: Fit between the measured pipe-to-soil voltage at Sv. Kateřina (red) and the east component of the computed geoelectric field (black) for the most disturbed period of 29 October 2003.

b) The rapidly varying geomagnetic field occurring in connection with geomagnetic storms may induce electric fields and currents that can affect technological systems such as power transmission grids, telecommunication cables and oil or gas pipelines. Geomagnetically induced currents (GIC's) are a source of problems for technological systems mainly at high geomagnetic latitudes. That is why these phenomena have been studied intensively in Canada, Scandinavia and Scotland. Nevertheless, strong geomagnetic disturbances can have quite strong effects even at mid-latitudes. Irregular currents observed in the oil pipelines in the Czech Republic during the Halloween magnetic storms in October 2003 caused that the pipeline operator contacted the geomagnetic department of the Geophysical Institute.

   In the frame of a pilot study (*Hejda and Bochníček, 2005*), data from three measuring stations were analysed and compared with the geomagnetic field registered at the Budkov observatory (Fig. 37). It was shown that the simplest – plane wave and uniform Earth – model of the geoelectric field corresponds well to the measured pipe-to soil voltage. Although the largest amplitudes of the geomagnetic field were reached on the onset of the geomagnetic storm, largest voltages were also induced in the main and recovery phase due to Pc5 oscillations.

c) The quality of magnetic surveys is essentially influenced by the geomagnetic activity. As the in situ measurements are usually limited to a very short time period, they must be compared with observatory continuous registrations. When reducing measurements one makes an assumption that diurnal variations of the magnetic field are identical at both the station and the reference observatory. During magnetically quiet periods, this assumption is satisfied to an acceptable extent. However, under high geomagnetic activity, the error may easily exceed the acceptable limit. Analysis made by *Hejda et al. (2005)* indicates that, in mid-latitudes, magnetic surveys should not be made, if some of the Kp values are over 5. Basic periodicities of the geomagnetic activity (11-year, half-year and 27-day) should be considered by long-term and medium-term planning of magnetic survey. Short-term forecasts, which are distributed in the frame of Regional Warning Center network, can provide useful information for a few next days.

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Geomagnetic forcing on regional and global temperatures

We show that inter-annual variations of temperature in Europe, North America and over the globe at a time of faster warming of the earth's surface over the past thirty years are influenced by geomagnetic activity indicating the solar wind (*Bucha, 2004, 2005*). The obtained results help to distinguish between the response to geomagnetic and anthropogenic forcing and contribute to useful climate forecasts in Europe and North America up to six months in advance.
High correlation coefficients that were found between geomagnetic activity and meteorological parameters are important for the detection of causes influencing inter-annual and intra-seasonal variations of regional and global temperatures in the past several decades (*Bucha and Bucha, 1998, 2002*). The positive phase of NAO (North Atlantic Oscillation) prevailed from 1973 to 1994. At that time also geomagnetic activity was highest over the past 135 years. We found that the NAO as well as winter temperatures in Europe and in the U.S.A. are positively correlated with geomagnetic activity. Summer temperatures in Europe are also positively correlated (correlation coefficient equals 0.78) while temperatures in the USA are negatively correlated (-0.77) with geomagnetic activity (*Bucha, 2005*).

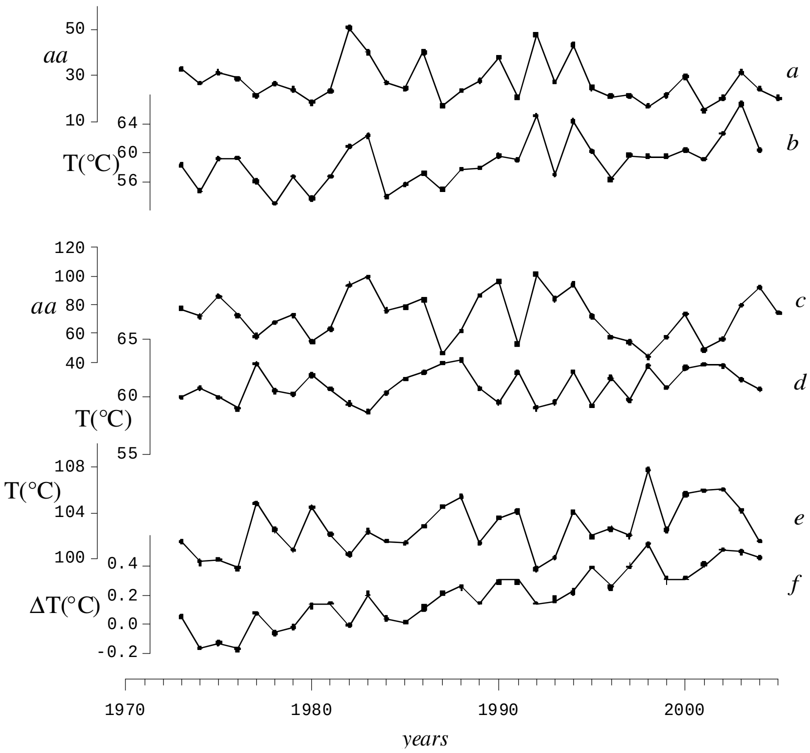

Fig. 38. Time series of (a) geomagnetic activity (aa index) for February, (b) surface air temperature in Europe for the sum of June-August, (c) geomagnetic activity for the sum of December – February, (d) surface air temperature in the U.S.A. for the sum of May – July and (e) for the sum of May – September, (f) annual anomalies of global temperature.

Successful seasonal forecasts up to six months in advance for Europe and the USA could become a good evidence of the validity of evolutionary processes in the atmosphere influenced by geomagnetic forcing. Preliminary predictions based on the positive correlation between geomagnetic activity (Fig. 38, curve a) and summer temperature in Europe indicate that low geomagnetic activity in February 2005 influenced the temperature in central Europe which was below normal in summer 2005 with probability of 70 – 80% (curve b). Vice versa, negative correlation between geomagnetic activity in winter (curve c) and summer temperature in the USA (curve d) shows that the US temperature in summer 2005 probably was higher than was in 2004.

Let us try to answer the question what leads to the strengthening of westerlies and to changes in the distribution of main pressure formations, especially to the stronger Icelandic low and to its eastward shift at times of high geomagnetic activity. Due to processes in the magnetosphere during geomagnetic storms downward winds are generated in the polar thermosphere. It is probable that geomagnetic activity affects the propagation of planetary waves by changing the temperature of the lower thermosphere but also by changing the ozone concentration in the stratosphere. We studied whether there is an atmospheric response to geomagnetic activity and found that downward winds penetrate through the stratosphere to the troposphere and accelerate the subsidence of air especially in some regions along the northern margin of the Siberian High and the west coast North American ridge. This process is connected with an increase of pressure and temperature, of the jet stream and of westerlies (*Bucha and Bucha, 1998*). We show that enhanced geomagnetic activity participates in the strengthening of westerlies and in the eastward shift of main pressure formations (Icelandic Low, Azores and Canadian High) that influence NAO and inter-annual fluctuations of temperature in Europe and North America. As a result, the warm flow prevails in the region of Europe enhancing temperatures here while the cold flow from the northwest participates in below normal summer temperatures in the USA and in Asia. From the positive correlation between the temperature in the USA and the global temperature (correlation coefficient equals 0.72) follows that geomagnetic activity has an influence not only on regional but also on global temperatures (Fig. 38, curves e, f).
Because the summer temperature is for several regions (Europe) positively correlated and for other regions (the USA) negatively correlated with geomagnetic activity we can conclude that this external geomagnetic forcing on fluctuations of temperature is not direct but is realized through significant changes in the distribution of main pressure formations (Icelandic Low, Azores High, Canadian High). The shifts of these systems then participate in changes of wind directions and, as the next step, in temperature changes.
Geomagnetic activity, as follows from a close association (*Bucha, 2005*), has an influence on inter-annual changes of pressure as well as of regional and global temperatures. The long-term gradual increase of average global temperature over the 20th century by about 0.6°C is obviously caused mainly by anthropogenic effects even though some part of these changes can be a reflection of slowly increasing average geomagnetic activity.

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Events

Seismic Waves in Laterally Inhomogeneous Media VI

The international workshop “Seismic Waves in Laterally Inhomogeneous Media VI” was held at the Castle of Hrubá Skála, Czech republic, June 20-25, 2005. The workshop was organized by the Geophysical Institute, Acad. Sci. CR and the Charles University, the Faculty of Mathematics and Physics. As in all previous workshops held under the same name at the Castles of Liblice (1978, 1983 and 1988), Třest (1995) and Zahrádky (2000), the workshop was again oriented mainly on theoretical and computational aspects of seismic wave propagation and generation in complex structures, and on applications involving these aspects in seismic exploration, Earth's crust studies and, newly, also in non-destructive material testing. The main topics were forward and inverse modelling of seismic wave fields in laterally inhomogeneous, isotropic and anisotropic structures. The workshop was attended by about 60 researchers from 14 countries. The next workshop is planned for 2010.

Several of the contributions presented at the workshop are going to be published in a special issue of Studia geophysica et geodaetica in 2006.

Drilling the Eger Rift in Central Europe, Courtyard Býkov, October 3-7, 2004

The workshop, organised in the framework of and financially supported by the International Continental Scientific Drilling Program (ICDP), was aimed at discussing the scientific goals that would justify deep drilling in the western part of the Eger Rift area. The Eger Rift, located in the northwestern part of the Bohemian massif, is a world key site that has attracted the international geoscience community for many decades. The rift is the result of young, deep-seated geodynamic processes manifested by episodic Cenozoic volcanism (the youngest at 0.2-0.5 Ma), repeated earthquake swarms, numerous mineral springs, CO_2 emissions with high ^3He content, and abundant mofettes. The crust-mantle boundary (27 km) and lithosphere–asthenosphere boundary (80-90 km) are uprised compared to the conditions in the Bohemian massif. Also surface heat flow is the highest within the massif (60-80 mWm^{-2}). Owing to the diversity of available data stretching over various fields of geoscience, the area is an ideal place to foster studies on the interaction between an active mantle, crust, and deep biosphere processes.
Thus, the workshop formed a platform on which the state of the art in investigating the rift was summarized and new research targets addressed by drilling were defined.
According to the interacting research fields, the workshop was streamed into six topical blocks: Geology, Tectonics, and Fluids; Evolution of the Lithosphere; Earthquake swarm processes; Fluid-Related Seismic Processes, Deep Biosphere and Drilling and Borehole Monitoring.
At the end of the workshop, a field trip introduced the participants to key sites in western Bohemia including the thermal springs at Karlovy Vary Spa, the potential drilling site in the northern part of the Cheb sedimentary basin (in the vicinity of the seismically dominant Nový Kostel earthquake focal zone), the Bublák mofette (surrounded by seismic stations of the WEBNET (Academy of Sciences, Prague) and KRASNET (Brno University) networks, the CO_2 exhalations at Soos, and the Železná Hůrka volcano and its tephra deposits. 65 participants attended the workshop.

Reference: Špičák, A., Forster, A., Horsfield, B. (2005). Drilling the Eger Rift in Central Europe (workshop report). Scientific Drilling, **1**, 44-45.

(http://www.icdp-online.de/scientific-drilling/SDjournal_no1_final_small.pdf)

9th "Castle Meeting" on Palaeo, Rock and Environmental Magnetism, held in Javorina, Slovakia, 27 June, 3 July, 2004

The 9th meeting on Palaeo, Rock and Environmental Magnetism, organised jointly by the Geophys. Inst. of the Slovak Academy of Sciences in Bratislava and Geophys. Inst. of the Academy of Sciences of Czech Rep. in Prague was held in Javorina, Slovakia, in wonderful surroundings of High Tatras National Park. The meeting was hosted by a hotel Kolowrat (www.hotelkolowrat.sk), originally erected for the purposes of recreation of top communist leaders of former Czechoslovakia. The hotel, only recently reconstructed, offers high comfort, spacious rooms, very good conference hall, and various activities, ranging from swimming pool, through bowling, to hiking and mountaineering. Surrounded by deep forests and green meadows, participants could benefit from calm atmosphere, probably disturbed only by brown bears, occasionally inspecting garbage cans behind the hotel in the night.

Topics of the Meeting included wide range of rock magnetic subjects, such as palaeomagnetism and tectonics, magnetic anisotropy, archeomagnetism, assessment of quality of the palaeomagnetic and rock-magnetic data, general rock magnetism and its physical background, magnetostratigraphy, environmental magnetism, relations between palaeomagnetism and global changes, new techniques and approaches. Several oral and poster presentations resulted from two EU-funded projects: AARCH Research and Training Network, and MAGPROX Research Project. Abtracts of the Meeting were distributed in a form of special issue of a journal *Contributions to Geophysics and Geodesy*, published by the Geophys. Inst. in Bratislava. Some of the contributions were published in an international journal *Studia Geophysica et Geodaetica* (Vol. 49(2005), No.2, www.springerlink.com). The scientific programme was well combined with social activities, such as trips to the region or an evening concert of organ music an a histrocial town of Levoča, as well as following the evening matches at Euro 2004 in Portugal.

Some basic figures about the attendance; the number of active participants was 76, plus 10 accompanying persons. The participants came from altogether 25 countries from Europe, America and Asia. Out of the 76 active participants, 30 were young researchers (PhDs and PostDocs). Gender issue is well reflected by the portion of female participants, which was 42%. A financial support, provided by IAGA, was used to cover partly travel costs of 6 participants, either coming from the former Soviet Union, or young PhD students.

The forthcoming, jubilee 10th meeting (www.ig.cas.cz/Castle2006), will be held at Castle of Valtice in the Czech Republic, in a centre of wine production. We believe that the promising trend of high ratio of female and young participants will be further enhanced.

EC Project „Developing Existing Earthquake Data Infrastructures Towards a Mediterranean-European Rapid Earthquake Data Information and Archiving Network“ (MEREDIAN), 2000-2005

The MEREDIAN project aimed at a significant upgrade of the European seismological data infrastructure built up by the Observatories and Research Facilities for EUropean Seismology (ORFEUS) since 1987 and to disseminate techniques and software to other observatories within Europe and its surroundings. ORFEUS, residing at the Royal Netherlands Meteorological Institute, had the central role of a coordinator of the project. The aim of MEREDIAN was one homogeneous European-Mediterranean seismological data infrastructure allowing rapid and free access to earthquake data and information for basic research and reliable and fast access to earthquake information for decision-makers and the public. The project included a significant investment in co-ordinating and providing modern standardised software to enable data users to access, view and perform basic analysis on the earthquake data. The original MEREDIAN consortium consisted of 10 European countries (France, Germany, Netherlands, Switzerland, Austria, Norway, Spain, Slovenia, Greece and Italy). Eight newly accepted states to EC (Czech Republic, Slovakia, Poland, Hungary, Bulgaria, Romania, Estonia and Malta) joined the project in April 2002.

High-quality broadband data from 5 seismological stations operated by the Geophysical Institute ASCR (GI-ASCR) are transferred in real-time to the ORFEUS Data Center and included into the Virtual Europenan Broadband Seismograph Network. All continuous broadband data since 2000 to present are available at GI-ASCR on request through the AutoDRM service by email. The archiving capacity of the GI-ASCR data center increased considerably during the Meredian project. GI-ASCR organized 3 regional meetings attented by most of the participating countries.

INHIGEO Symposium, Prague, July 2-11, 2005

In July 02 - 11th, 2005, an annual symposium of the International Commission on the History of Geological Sciences (INHIGEO) was held in Prague and in Valtice in south Moravia under the auspices and with the support of the Geophysical Institute.

The symposium entitled ‘History of Geophysics’ was focused on the origin and development of individual geophysical sub-disciplines. During three days of oral and poster presentations 42 participants from 14 countries listened to 26 communications in total. Seven of the principal presentations have been selected for publication in a special issue of the Earth Science History (ESH) entitled ‘History of Geophysics’, to appear in 2006. In this collection, a modern definition of geophysics in relation to the present geology will be given, and historical advancement of the main geophysical disciplines will be expounded.

According to the INHIGEO symposia tradition seven geophysical and geological excursions throughout the Czech Republic were organized during the meeting. Those were a two day excursion to the earthquake-swarm region in the west and northwest of Bohemia and six single day excursions, leading specifically to the Bohemian Cretaceous Basin (the Central Bohemian Uplands), to the Lower Paleozoic of Bohemia (Barrandian), to the medieval silver mining town of Kutná Hora, to the Central Moravian Karst, with the deepest gorge in the Czech Republic, Macocha (138.5 metres), to the South Moravian Karst and world-known archeological sites (Věstonice), as well as to the famous caves of the Czech Karst in the surroundings of the town of Beroun in Central Bohemia.

The symposium was a financially self-supporting event. The lecture part of the symposium was held in the campus of the Geophysical Institute, in the building of the Institute of the Physics of the Atmosphere AS CR.

The Symposium Local Organizing Committee (LOC), Jan Kozák, Ondřej Jäger, Josef Haubelt and Michal Pondělíček wish to express their cordial thanks and appreciation to the directors of both the Institutes, Aleš Špičák and Jan Laštovička, for their much welcome support and assistance.

2005 Fulbright Scholarship, Prof. Gary Kocurek

In the Autumn semester of the 2005/6 academic year, the Geophysical Institute hosted Professor Gary Kocurek (University of Texas at Austin), supported by a Fulbright Scholarship to teach two full courses fo students of the Charles University and audience from other Czech institutions. His teaching at the Charles University was organized in collaboration with their Institute of Petrology and Structural Geology of the Faculty of Science.
Gary Kocurek is one of world's leading specialists in the field of sedimentary processes. In his research he specializes on aeolian (wind) sedimentation and evolution of desert systems. Currently he is involved in studies of complex-system behaviour of dune fields on the Earth as well as on Mars. At the university of Texas at Austin he hold the J.E. "Brick" Elliott Centennial Endpwed Professorship in Geological Sciences. He has recently finished his term as the Chairman of the Department of Geological Sciences.

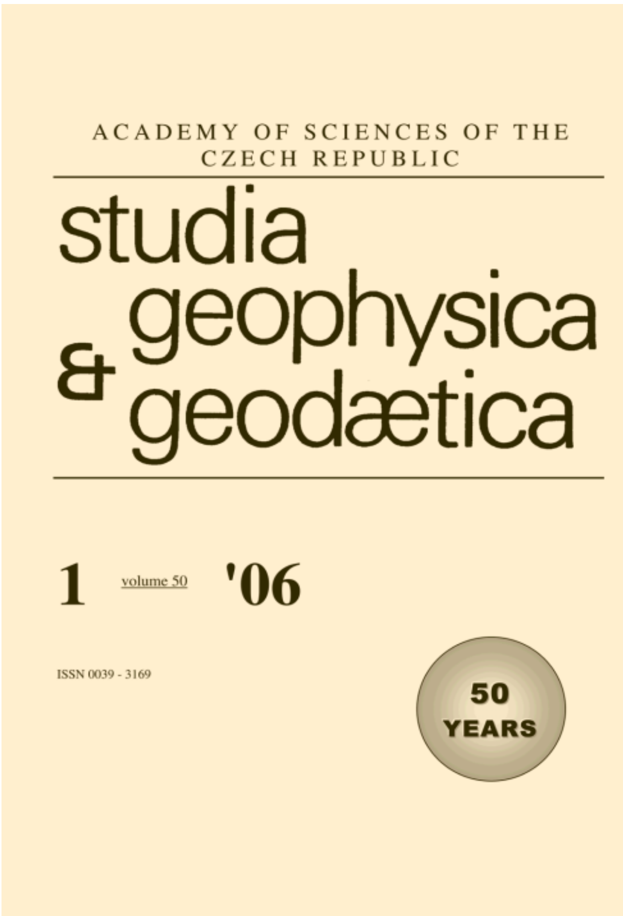
The course "Living with a Planet" covered a wide range of environmental change on local and global scales as a result of both natural and man-made causes. The course topics included the history of Earth and its environment, the water cycle, sediment cycle, atmosphere, and climate. Geologic records of environmental change, from billion-year to El Nino time scales were examined, and the human dimension of global change was a primary focus of the course. "Sedimentary Processes" was a physics-based course, building upon fundamental principles to address fluid flow, grain transport, bedforms and the sedimentary structures they create, and basin-scale processes. The course concluded with an exploration of complex systems and self-organization, offering an alternative paradigm to the reductionism manifested in the first part of the course. Guest lecturers from the U.S. and Europe, leading specialists in various fields related to physical sedimentology, supplemented selected themes with specialized lectures: Michael Blum (Louisiana State Univ., USA), David Mohrig (MIT, Massachusetts, USA), Jim Best (University of Leeds, UK), and Andreas Baas (King´s College, London, UK).

Studia geophysica et geodaetica

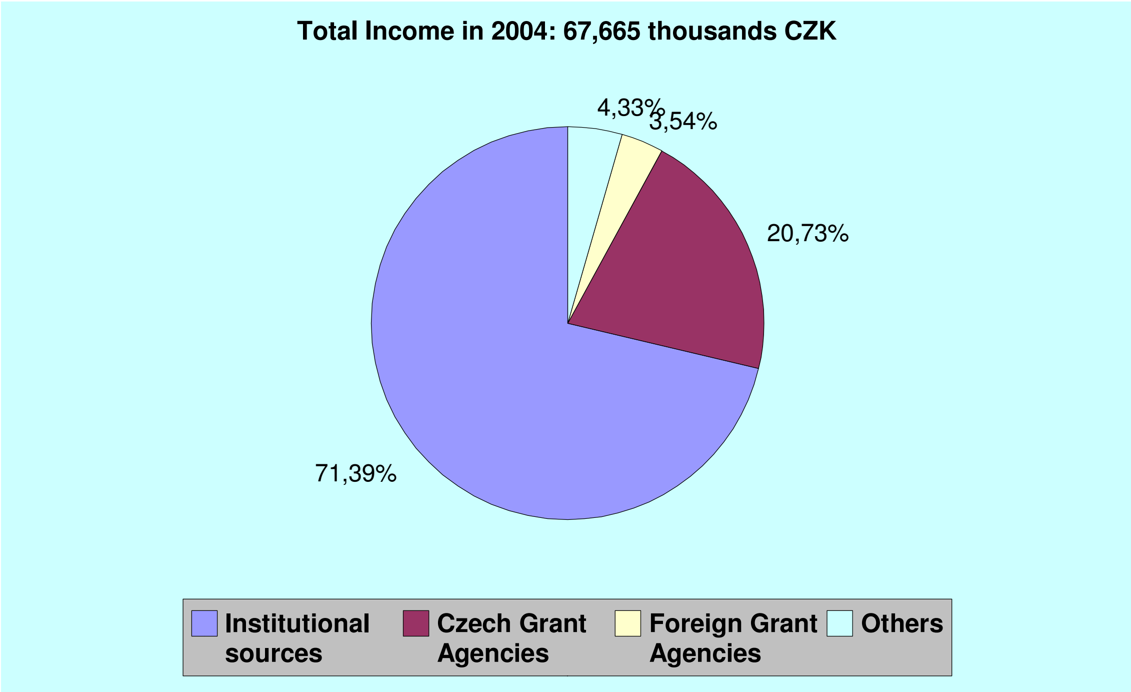
Studia geophysica et geodaetica is an international scientific journal covering geophysics, geodesy, meteorology and climatology. It has been published since 1956. Since January 2002, the journal has been included again into the list of Scientific Citation Index. Its impact factor was 0.426 and 0.447 in 2003 and 2004, respectively, see the Journal Citations Report (www.jcrweb.com). At present, about 40 to 50 original reviewed papers per year are published, with the authors coming from all around the world. The recent trend of increasing the general quality of the journal is mainly due to the involvement of top international experts as associated editors.

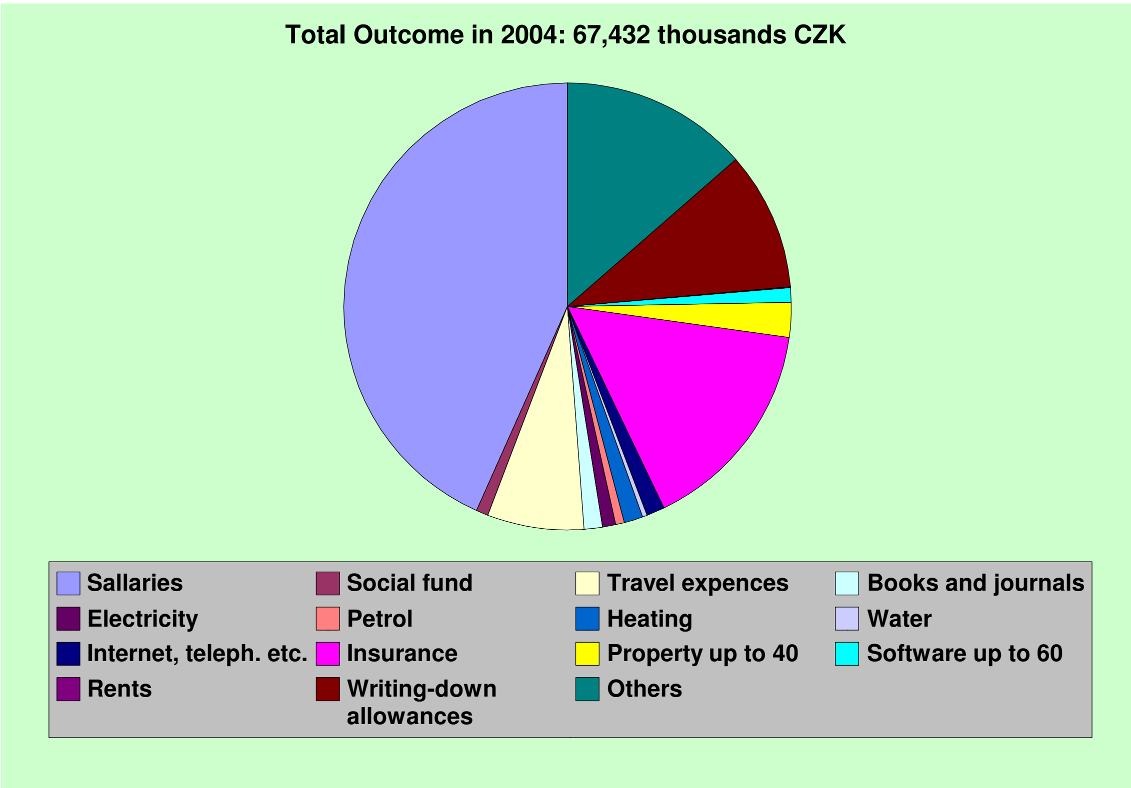
In 2004, issue 1 appeared as a special issue devoted to anisotropy. In 14 contributions, the issue contained most recent results on various aspects of seismic wave propagation in anisotropic media by authors from universities and institutions all over the world. In 2005, the issue 2 appeared as a special issue devoted to the problems of rock magnetism and its applications. Subjects of the papers ranged from basic rock magnetic methods through archeomagnetic dating and paleomagnetic pole reconstruction to modern environmental magnetism.

In 2006, the journal is going to celebrate its 50th aniversary. Two special issues are planned. The first will be devoted to the proceedings of the international workshop "Seismic waves in laterally inhomogeneous media VI", held at the castle of Hrubá Skála on June 20-25, 2005. The main topic of the other one will be the seismicity of Western Bohemia.



Structure of the budget of the Geophysical Institute





List of grant projects solved during 2004-2005

Compiled using the data from CEP (Central Register of Projects, see http://www.vlada.cz/1250/rvv/cep/), updated by August 2005.

Project code	Title	Principal investigator	Funding	Duration
IAA3012105	Study of temporal geomagnetic variation based on observatory and field data	Pavel Hejda	GAASCR	2001 - 2005
GP205/02/D133	Modelling of resistivity distribution in the east margin of the Bohemian Massif and in west Carpathian	Světlana Kováčiková	GACR	2002 - 2005
SB/630/3/02	SLICE	Aleš Špičák	MEnv	2002 - 2005
LA 150	International Continental Drilling Program	Aleš Špičák	MEYS	2002 - 2006
IBS3012353	Updating of tilt monitoring system in the hazardous environment of the ČSA open-pit mine, Most, 2nd stage	Bohumil Chán	GAASCR	2003 - 2005
IBS3012354	Application of the top-soil magnetometry for the pollution mapping in the Czech Republic	Eduard Petrovský	GAASCR	2003 - 2005
GA205/03/1203	Seismotectonics and Deep structure of the Convergent Margin in Middle America	Aleš Špičák	GACR	2003 - 2005
GA205/03/0997	Geothermal research of the Chicxulub impact structure	Jan Šafanda	GACR	2003 - 2005
GA205/03/0999	Velocity model and shallow geologic structure in the Moravo-Silesian Region	Karel Holub and Bohuslav Růžek (common project with the Institute of Geonics Ostrava)	GACR	2003 - 2005
GP205/03/P161	Development of a new method of processing the S wave splitting and the study of the upper mantle anisotropy	Luděk Vecsey	GACR	2003 - 2005
GA205/03/1001	Deep geoelectric model of laterally inhomogeneous Earth, especially in Europe, using time variation of geomagnetic field	Oldřich Praus	GACR	2003 - 2005
GP205/03/P065	Petrophysical properties of upper mantle eclogites, their link to composition and rheology of upper mantle	Stanislav Ulrich	GACR	2003 - 2005
GA205/03/0998	Climate change and global warming	Vladimír Čermák	GACR	2003 - 2005
IAA3012303	Seismic activity distribution as an indicator of volacnic sources in the regions of convergent litospheric plates	Aleš Špičák	GAASCR	2003 - 2006

Project code	Title	Principal investigator	Funding	Duration
IAA3012309	Seismic waves and seismic sources in anisotropic media	Václav Vavryčuk	GAASCR	2003 - 2006
IAA3012308	Kinematic and dynamic phenomena as indicators of seismo-tectonic activity in West Bohemia	Jan Mrlina	GAASCR	2003 - 2007
GP205/04/P182	Modeling the geomagnetic field generation using hydromagnetic geodynamo	Ján Šimkanin	GACR	2004 - 2006
GA205/04/0746	Stochastic iterpretation of geoelectric induction data	Josef Pek	GACR	2004 - 2006
GA205/04/0740	EMTESZ/CEMES: Deep geoelektric model of the Transeuropean suture	Václav Červ	GACR	2004 - 2006
GA205/04/0748	Boundaries of the anisotropic mantle blocks mapped using passive seicmic experiment data and the relation with the core tectonics	Vladislav Babuška	GACR	2004 - 2006
IAA3012401	Elektromagnetic fields in the inhomogeneous and anisotropic Earth	Josef Pek	GAASCR	2004 - 2007
IAA3042401	The influence of solar geomagnetic activity on the tropospheric circulation on the northern hemisphere	Radan Huth and Josef Bochníček (common project with the Institute of Atmoshpere Physics)	GAASCR	2004 - 2007
IAA3012405	Mechanisms of the anisotropic domains generation in the mantle litosphere below continents	Jaroslava Plomerová	GAASCR	2004 - 2008
1P05ME778	Air and soil temperature relation in three different climatic regions	Jan Šafanda	MEYS	2005 - 2005
KJB300120504	Non-shear mechanisms of strong earthquakes from teleseismic records	Zuzana Jechumtálová	GAASCR	2005 - 2007
GA203/05/2256	Magnetic hydrofil-polymer microparticles reacting on outer exciting in bioengineering and medicine	Daniel Horák and Eduard Petrovský (common project with the Institute of Macromolecular Chemistry)	GACR	2005 - 2007
GA205/05/2182	Seismic waves in viscoelastic anisotropic media	Ivan Pšenčík	GACR	2005 - 2007
1P05LA256	Activity inside the IAGA organization (International Association for Geomanetism and Aeronomy)	Eduard Petrovský	MEYS	2005 - 2007
1P05OC031	Daily geomagnetic activity forecasts in middle geomagnetic latitudes	Pavel Hejda	MEYS	2005 - 2007
IAA300120502	Earthquake focus with finite	Jan Šílený	GAASCR	2005 - 2008

Project code	Title	Principal investigator	Funding	Duration
	dimensions determined using seismic moment tensor and inaccurate Earth´s models			
1QS300120506	Development of forecasting the cosmic weather and the influence on the ionosphere/atmosphere system	Josef Bochníček	GAASCR	2005 - 2009
1QS300460551	Definition of geodynamic mobile zones on the Earth's surface and their assesment for applications in land planning and construction designing	Zuzana Jechumtálová	GAASCR	2005 - 2009

In column "Funding": GAASCR = Grant Agency of the ASCR, GACR = Grant Agency of the Czech Republic, MEYS = Ministry of Education Yaouth and Sports, MEnv = Ministry of Environment

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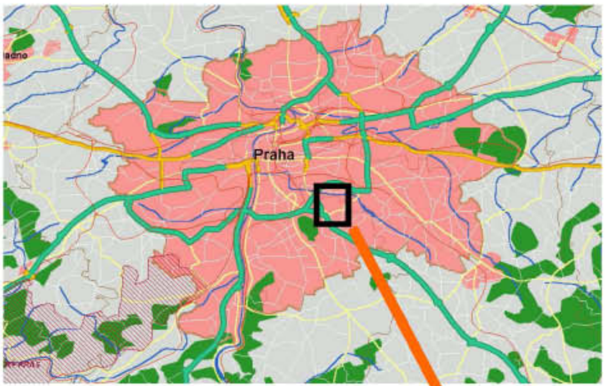
How to get to the Geophysical Institute



- ♦ When arriving by car...
  direction Brno, take Exit Spořilov and immediately another Exit Spořilov. Coming from Brno, take Exit Spořilov.

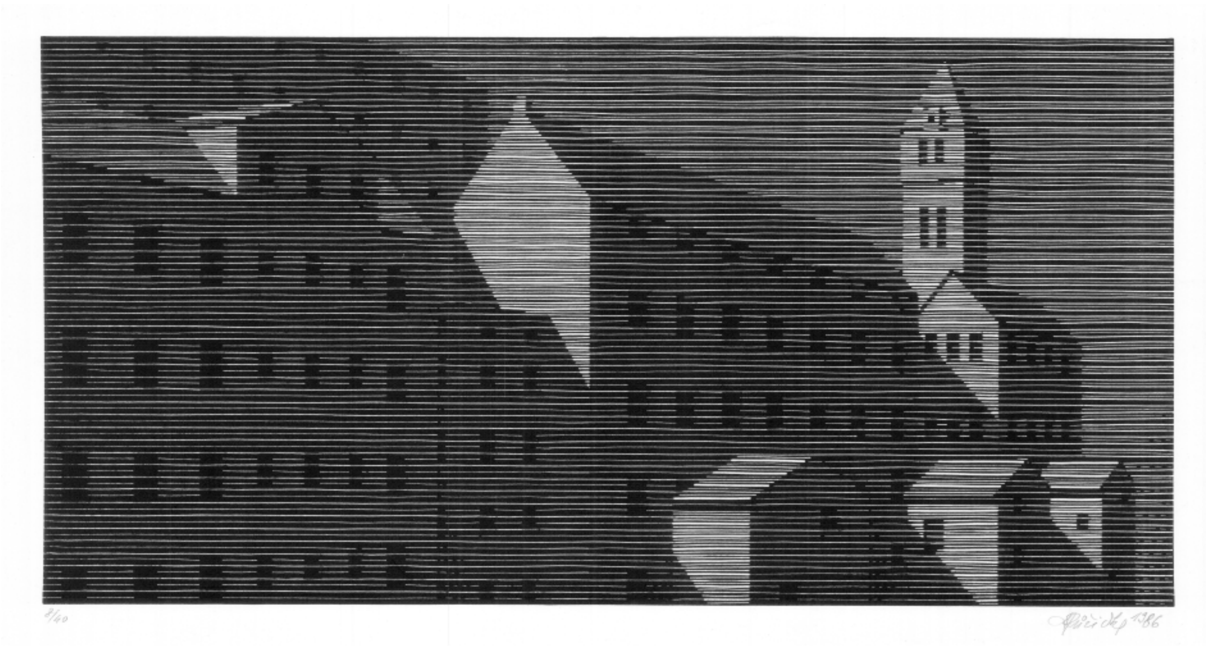
- ♦ When arriving by train…
  Most probably you will arrive at the Main railway station or railway station Holešovice. Take Subway, Line C, direction Háje. Go until station Roztyly. When you get to the surface, you can see the new building of the T-MOBILE Company. The Geophysical Institute is beyond this building and beyond the highway. You can recognize it by the great white parabolic antenna with the label NEXTEL. The final walk will take about 10 minutes.

- ♦ When arriving by plane…
  Take bus No.119 to the bus terminal Dejvická. Take Subway Line A (green color) to station Museum. Change to line C (red color), direction Háje. Get off at station Roztyly. You can see the building of the institute beyond the new building of T-MOBILE Company and beyond the highway. You can recognize it by the great white parabolic antenna with the label NEXTEL.

Art exhibitons at the Geophysical Institute

In 2004 - 2005, eight exhibitions of the following artists took place at the Geophysical Institute: Miroslav Koval (Sobotín, N. Moravia; drawings and photographs), Karel Adamus (Třinec, Silesia; drawings), Pavla Francová (Prague; pastels and touch drawings), Václav Vokolek (Tursko, central Bohemia; drawings, paintings, texts), Ryosuke Cohen (Japan; mailart), Jan Wojnar (Třinec, Silesia; grid poesy), Pavel Mühlbauer (Prague; drawings, paintings, pastels) and Jindřich Růžička (Prague; drawings, linocuts).

The drawing on the opposite page is a photograph by Jindřich Růžička.



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