# Geophysical Doctoral Day, May 31, 2017

*Institute of Geophysics, Czech Academy of Sciences,*
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## Abstracts

## Tidally induced deformation of icy moons

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The data from Cassini and Galileo satellite missions to the systems of Saturn and Jupiter brought convincing evidence of the presence of liquid water on number of their satellites, rising enormous interest of the planetological community in these bodies. A prominent example is Saturn's moon Enceladus thanks to direct observations (and even sampling) of water vapour plumes emanating from its surface. While the existence of liquid water on Enceladus was undoubtedly confirmed, the precise mechanism of how the plumes emerge remains open. Positions of the plumes correlate spatially with four prominent linear features on the south pole of Enceladus, which have been nicknamed Tiger stripes. One of the hypotheses of the origin of the vents relies on an assumption that the tiger stripes are fissures penetrating through the whole thickness of the ice shell in the south polar terrain. Then tidal loading and induced opening of the fissures (and/or possible pressurisation of the underlying ocean) leads to a release of the water in the form of vents, geysers. Recent attempts to numerically simulate the activity of vents on tiger stripes (based on elastic shell models) however exhibit a systematic lag of several hours in the activity with respect to the observations. Recently a 3D viscoelastic model of Enceladus' icy shell was developed in collaboration of Department of Geophysics and Mathematical Institute (Charles University), with the aim to improve the models of tidal deformation of the shell of Enceladus. Besides viscoelasticity this model also includes faults at the position of Tiger stripes modelled as narrow zones of reduced elastic moduli. In our related project, we are currently investigating the possibility of further improvement of the model of Tiger stripes by integrating the seismological rate and state friction model into the framework of continuum mechanics. In the talk, we will provide the basic motivation for the problem, describe the viscoelastic analogue of rate and state friction model and show preliminary results.

## Vp/Vs - estimation from arrival time differences: possibilities and observations

**Martin Bachura**
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Seismic velocities and their ratio Vp/Vs describes the rheological properties of the Earth materials. Knowledge of spatial and temporal changes of Vp/Vs may provide us with useful information about the structure of the material and about dynamical processes occurring during the earthquakes like fluid saturation and fracturing. Vp/Vs value ranges in a very narrow range and therefore it is crucial to pay attention to a careful data processing and methods applied on data. Even small changes in methodology and data processing might cause significant result variations.

In our study we adjusted and developed two methods for Vp/Vs estimation applicable on tightly clustered earthquake groups and applied it on West Bohemian earthquake swarm data and fluid induced hydro-frack data from Rittershoffen geothermal field.
The first method, applied on the earthquake activity in 2014 is a double-difference modification of the standard Wadati method and allowed us to monitor Vp/Vs changes during the activity in time and space. We observed velocity ratios ranging from 1.59 to 1.73. Interpretation of observed values was conducted using Biot-Gassman equations and variations were explained as a result of rupturing during the different stages of the activity. On the contrary, the spatial "tomographical" interpretation as also possible and could not be omitted.
Second method we developed is modification of the standard master-event technique, where we systematically search for the best Vp/Vs ratio using grid search technique. This technique is more suitable for the shallower earthquake clusters with close stations, where the influence of the velocity model plays more significant role. However, the data processing is more pomplicated and is computationally more demanding. We tested this method on a small cluster of induced earthquakes in Rittershoffen geothermal field and observed Vp/Vs of 1.67, what is lower than value predicted by the well-log velocity model.
Both methods require very precise differential times between P and S phase - obtainable only by the means of waveform cross-correlations. Attention also has to be paid to the geometry of the clustered earthquakes and stations distribution. Omitting this aspect produces results not only corrupted with errors, but also systematically biased and leading to misinterpretations."

## Coupled anisotropic and isotropic body-wave tomography of the upper mantle beneath northern Fennoscandia - Application of novel code AniTomo

**Helena Munzarová**
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Seismological investigations of continental mantle lithosphere advance our understanding of plate tectonics and formation of continents. To contribute to studies of large-scale upper-mantle structures, we have developed novel code AniTomo for regional anisotropic tomography. AniTomo allows a simultaneous inversion of relative travel-time residuals of teleseismic P waves both for 3D distribution of isotropic-velocity perturbations and anisotropy in the upper mantle. Weak hexagonal anisotropy with symmetry axes oriented generally in 3D is assumed. The novel code was successfully tested on a large series of synthetic datasets and synthetic structures. The first application of the new code is to data from passive seismic experiment LAPNET (Finland, 2007-2009). The strongest anisotropy and the largest isotropic-velocity perturbations concentrate in the mantle-lithospheric part of the model. We connect the retrieved domain-like anisotropic structure with preserved fossil fabrics of the Archean micro-plates, accreted during the Precambrian orogenic processes.

## Oceanic model LSOMG: Development and applications

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The purpose of this contribution is to present the ocean general circulation model LSOMG. It is a z-coordinate baroclinic ocean model which solves the primitive equations under the Boussinesq and hydrostatic approximations. It originates from the LSG (Maier-Reimer and Mikolajewicz, 1992) ocean model, however, it has been almost completely rewritten during the development. We intend to use the model for various geophysical applications. As an example, we coupled the LSOMG model with the 2D magnetic induction code TLAM. The LSOMG velocities are used to determine the Lorentz force which is plugged into the TLAM as a principal forcing. The TLAM is based on the thin-shell approximation (Vivier et al., 2004; Tyler et al., 1997) which is only suitable for slowly evolving processes. In order to meet the condition, we restrict ourselves to the wind (buoyancy) driven ocean circulation, although the LSOMG model is able to model both the tidally and wind driven circulations

## Inversion of multi-configuration electromagnetic induction data for shallow hydrogeological applications

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In this contribution I present a brief review of the basic principles of electromagnetic induction methods for shallow geophysical investigations and the problems usually found when dealing with the collected data by some well-known branches of equipment. I will present also the current state of development of my doctoral research aiming the quasi 2-D inversion of multi-configuration EMI data. The non-linear inversion problem solution uses as an initial guess model the results of a new quick method for one-dimensional inversion of multi-configuration electromagnetic induction data, obtained by instruments operating at low induction numbers, using new generalized cumulative response curves that may be used for instruments operated at any height from the ground. The quasi-2D inversion procedure starts at the position in which the data is more uniform and a 1-D inversion is performed for this position. The neighbours positions are 1-D inverted using the previous inversion results as model constraints for a regularization term. A preliminary result of the inversion procedure is shown.

## Single Layer Recurrent Neural Network for detection of swarm-like earthquakes in West Bohemia and SW Iceland

**Jana Doubravová**
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We present a new method of local event detection based on neural networks. The proposed algorithm uses a unique neural-network architecture. It combines features used in other neural network concepts like

Real Time Recurrent Network and Nonlinear Autoregressive Neural Network to achieve a good detection performance. We use the recurrence combined with various delays applied to recurrent inputs to make the network remember history of many samples - the Single Layer Recurrent Neural Network (SLRNN). The network was first trained and tested on data from local seismic network in West Bohemia (WEBNET). Then we applied the trained network to different dataset from local seismic network in South-west Iceland (REYKJANET). Both networks monitor earthquake swarm areas, both networks have similar number of stations used for detection and both cover roughly equal areas. We show that the neural network trained on WEBNET data could be used on REYKJANET data with satisfactory results.

## Tides on terrestrial exoplanets

**Michaela Walterová**
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Tidal interaction plays an important role in the internal and orbital dynamics of planetary satellites and close-in exoplanets. Proper assessment of its effects requires, however, an internally consistent tidal model based on realistic rheological assumptions. Here, we will give a brief overview of traditional as well as more recent tidal theories and focus on the effect of the Maxwell or the Andrade viscoelastic rheology on the tidal evolution of Earth-size exoplanets. We will also introduce a numerical model applicable to differentiated planets with possibly heterogeneous viscosity structure of the mantle and present a series of parametric studies of the tidal heating, the tidal torque and the complex Love numbers.

## Byesian inference of centroid moment tensors of the April 2016, Kumamoto (Kyushu, Japan), earthquake sequence

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On 2016 April 16, Kumamoto prefecture in Kyushu region, Japan, was devastated by a shallow M7.3 earthquake. The seismic activity in the region started by foreshocks 28 hours before the main shock. The series of foreshocks have origin in Hinagu fault zone intersecting the main event's Futagawa fault zone Hence, the tectonic background for this earthquake is rather complex.
We computed centroid moment tensors (CMTs) for 11 events with M between 4.8 and 6.5, using the strong motion records of K-NET, KiK-net and F-net networks. We used the innovative Bayesian full-waveform inversion, ISOLA-ObsPy, which takes into account uncertainty of the velocity model structure. Such approach allows us to assess uncertainty of the inverted moment tensors.
The moment tensors show significant spatial variations. Dip-slip events are connected to the N-S extensional tectonic regime and right-lateral strike-slip events are linked to the NE-SW shear zone (Median Tectonic Line). Strike-slip events located close to the intersection of Hinagu and Futagawa fault zone are dipping slightly to east, while those in the southern area (Hinagu fault zone) are dipping to west. Most of events contain only minor CLVD component, which is statistically insignificant and can be related to the velocity model uncertainty. Nevertheless, two of the CMTs involve significantly large CLVD component (~30%), which may reflect complex rupture process. Decomposition of those moment tensors into two pure-shear moment tensors is non-unique. Nevertheless, preserving T-axis of the decomposed moment tensors suggests combined right-lateral strike-slip and dip-slip mechanisms, which are consistent with the tectonic settings of the intersection of the Hinagu and Futagawa fault zones. Finally, the Bayesian full-waveform inversion of CMTs of the Kumamoto earthquake sequence demonstrates the abilities of such a methodology, and suggests complex tectonic background for this earthquake sequence.

## Source-Scanning as a tool for investigating the rupture processes of West Bohemia earthquakes

**Vojtěch Lávička**
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We study earthquake rupture propagation by source-scanning methods. We performed a series of tests on synthetic data in order to assess the capability of these methods for determining rupture parameters of earthquakes *M*L 1.5 — *M*L 4.5 recorded by local networks of seismic stations. The West Bohemia seismoactive region, in the Czech Republic, served as a testing ground. We used two types of synthetic waveforms: seismic records from a finite source computed by means of the DWN method and sine wave pulses with station-dependent pulse duration. We showed that the method is sensitive to rupturing direction for both the types of synthetic data.

## Viscoelastic mantle convection

**Vojtěch Patočka**
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Present thermo-chemical convection models of planetary evolution often assume a purely viscous or visco-plastic rheology. Ignoring elasticity in the cold, outer boundary layer is, however, questionable since elastic effects may play an important role there and affect surface topography as well as the stress distribution within the stiff cold lithosphere. Here we present a modelling study focused on the combined effects of Maxwell viscoelastic rheology and a free surface in the stagnant lid planetary convection. We implemented viscoelastic rheology in the StagYY code using a tracer based stress advection scheme that suppresses subgrid oscillations. We apply this code to perform thermal convection models of the cooling planetary mantles and demonstrate that while the global characteristics of the mantle flow do not change signiffcantly when including viscoelasticity, the stress state of the cold lithosphere may be substantially different. Transient cooling of an initially thin upper thermal boundary layer results in a complex layered stress structure due to the memory effects of viscoelastic rheology. The stress state of the lid may thus contain a record of the planetary thermal evolution.

## Dynamic finite-extent source inversion for physical parameters controlling the 2016 Amatrice, Italy earthquake

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We perform dynamic finite-extent source inversion to study the source processes of the first of the large earthquakes that occurred close to Amatrice, Italy, in August 2016. The events had a moment magnitude of 6.2 and resulted in 299 fatalities. To that end, we utilize a modified version of dynamic inversion code by Twardzik et al. (2014). The direct problem is solved by 3D fourth-order staggered-grid finite difference method in a box assuming linear slip-weakening friction law on a planar fault (Madariaga et al., 1998). The optimal solution is sought using the Neighborhood Algorithm implemented by Sambridge (1999). We invert displacement waveforms from the 20 nearest stations. The distribution and evolution of slip calculated from physical parameters (stress drop, frictional properties) obtained from the dynamic inversion are compared with results of a kinematic inversion.

## Seismic waves in inhomogeneous, weakly dissipative, anisotropic media

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I plan to study combined effects of anisotropy and attenuation. I decided to use the so-called weak-attenuation concept applied to the ray-theory based computations. The concept has several important advantages:
1) It does not require computation of complex rays, which is a complicated task so far realized only to simple types of media. Standard real-valued ray tracing is sufficient for the weak-attenuation computations. Effects of attenuation are calculated as a factor influencing ray amplitudes.
2) The ray-theory based code with the implemented weak-attenuation concept will be fast (comparable to elastic mode) and, thus will allow fast modeling and testing of many situations.
3) I have available the ray-theory base program package ANRAY, which allows computations of seismic wave fields in laterally varying, layered isotropic or anisotropic media. It is thus not necessary to write a new code, it is sufficient to implement the weak-attenuation concept into ANRAY.
In the first part of my study, I am planning to implement the weak-attenuation procedure only to the part enabling computations of wavefields in smooth media. Several tests and applications with the generalized ANRAY package are planned:
1) Tests of correctness of the ANRAY generalization by comparison with available data from other sources.
2) Tests of applicability of the weak-attenuation concept. Seismic wavefields computed by the generalized version of ANRAY package for varying values of Q factor will be compared with similar results obtained by other independent methods, for example, FD. Limits, at which the results become divergent will be sought.
3) Attenuation in anisotropic media varies with direction. Possibilities to use this directivity for distinction of wave propagation in isotropic and anisotropic dissipative media will be studied.
4) Differences in the attenuation directivity and seismic source directivity, and their possible misinterpretation will be studied.
5) The generalized ANRAY package will be used to model realistic situations, which I face in microseismic studies. For example influence of different model of cracks (vertical and horizontal) will be studied.
Preliminary results will be presented.

## Recent magnetotelluric surveys for geological targets

**Radek Klanica**
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The magnetotelluric method is an electromagnetic induction method which uses variations of the natural geoelectromagnetic field as a sufficiently intense, ubiquitous source for the induction in the Earth. Making use of the natural electromagnetic field is the greatest advantage of the method as there is no need of an artificial source signal and the depth range of the method is enormous. But, at the same time, it is also its biggest weakness since strong and practically omnipresent artificial electromagnetic noise corrupts many of the measurements. Despite the cultural noise, magnetotellurics can be an efficient tool for imaging a large variety of geological features, including faults, sedimentary basins, plutonic complexes or water saturated zones. I present interpretations of several recent magnetotelluric measurements from the Czech Republic and Slovakia, specifically a large scale profile across the south-eastern margin of the Bohemian Massif, a

detailed profile aiming at imaging the Mariánské-Lázně fault in West Bohemia and a few kilometres long profile in the Tatra Mountains, which all illustrate the present potential as well as difficulties of practical magnetotelluric investigations.

## Reconstructing temperature conditions associated with past periglacial structures: a case study for sorted patterned ground in the Krkonoše Mountains

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Many regions of the world host a number relict periglacial landforms that have been inherited from colder periods of the Quaternary. So far, these assemblages have been used to reconstruct former environmental conditions particularly in two basic manners. One is to search for a representative analogue in present-day periglacial environments. Second is based on present climatic context of active landforms. Unfortunately, numerous problems arise with both approaches and therefore, the reconstructions are frequently considered as unreliable. Consequently, most periglacial phenomena have been widely accepted only as indicators of seasonally freezing or permafrost conditions and ground-ice presence, but this may also be dubious and rather tentative in some cases.

On the other hand, many theoretical, physically-based studies have emerged in the last few decades that aimed to explain the formation of some periglacial landforms, such as patterned ground. The investigations focused on patterned-ground formation have shown that the length scale of the patterns is more-or-less of the same size as the length scale that initiates the patterns, i.e. the frost depth in seasonally frozen regions and the thaw depth in permafrost areas, respectively. Importantly, the diameter-to-sorting depth ratio of the resulting patterns is constant, of *c*. 3.1 to 3.8 under subaerial conditions, and of the same value regardless of the formation mechanism as well. These findings clearly indicate direct coupling between patterned-ground geometry and both ground and air temperature conditions at the time when the pattern first developed. Hence, if these genetic rules are adopted then the temperature attributes during the pattern initiation can be inferred via the sorting depth, which closely approximates former frost or thaw depth, respectively.

In this contribution, I infer the palaeo-temperature and palaeo-permafrost conditions associated with relict large-scale sorted patterned ground in the Krkonoše Mountains. To achieve this, I employ a multi-disciplinary approach consisting of the Monte Carlo simulation based on a simple equilibrium thermal model, the Stefan equation, in an inverse form, driven by data obtained from remote sensing, geophysical soundings, and modern patterned-ground analogues from elsewhere. The presented approach is a robust, yet straightforward and easy-to-follow procedure to utilize these periglacial phenomena and other structures indicative of the base of palaeo-active layer to reconstruct former climate.

*) *The institute where the PhD-student solved problems of his doctoral thesis*