DEPARTMENT OF GEOPHYSICS
Faculty of Mathematics and Physics
Charles University

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PROGRESS REPORT 1990–93

Praha 1993

Dear reader,

this report summarizes main activities in research and education at the Department of Geophysics, Faculty of Mathematics and Physics, Charles University in Prague, for the period of 1990-93. Its main objective is to present our work in a concise form, to stimulate your exchange of ideas with us, and, perhaps most importantly, to encourage young people from abraod for their studies at our department.

The report starts with a brief explanation of deep historical roots from which the Earth Science research and education at the Charles University has grown. The link between the history and presence is the Seismic Station Prague, with its 70 years of recording, to which a special section is devoted.

The department staff, currently consisting of one professor, four associate professors, one senior assistent, six research associates, a technician and a secretary, is presented with a brief description of our scientific interests. The telephone, fax, and e-mail numbers have been included, for your convenience.

The research at the department concentrates mainly on four disciplines, i.e., Seismology, Geodynamics, Gravity Field, and Geomagnetism. There has been a rather wide range of different topics dealt with within such a framework, and you will find a brief summary of the results herewith. It is followed by a complete list of our nearly one hundred publications for the period of 1990-93, and full abstracts of the recent papers, 1992-93. For completness, the papers submitted for publications have been included, too.

The education in Geophysics, provided by our department, ranges typically from 3 to 6 years, leading to the Mgr. and Dr. degree (equivalent to the M.S. and Ph.D. degree), respectively. Listed in a section are of about thirty lectures currently offered in Czech or English. The students choose the lectures according to their individual plans, with a few obligatory ones. The titles of the lectures, their typical duration, and very short summaries are presented. They are mostly lectured by the staff, but, as for a few subjects not very strongly developed at the departament, some lectures are given by our colleagues from both the Charles University and/or the Czech Academy of Sciences.

Last, but not least, the list of our Mgr. and Dr. students appears, showing the titles of their diploma and doctoral theses defended in 1990-93, or under preparation at present.

For more details, please, don't hesitate to contact us at the following addresses:

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Using any of the two is possible, but the most direct communication is according to the following key:

Address a - O. Čadek, A. Janáčková, Z. Martinec, C. Matyska, J. Moser, O. Novotný, I. Švitorková (Secretary), L. Urban, J. Zahradník. This is our "new" building.

Address b - J. Anděl, J. Brokešová, V. Červený, E. Drahotová, J. Janský. This is our "old" building, formerly referenced as the Institute of Geophysics, Charles University.

Acknowledgements: Thanks go to all who compiled the individual sections (A. Janáčková for History and Geomagnetism, J. Janský for Seismic Station, V. Červený, O. Novotný and J. Zahradník for Seismology, J. Moser for Geodynamics, Z. Martinec for Gravity Field, O. Novotný for Education), as well as to I. Švitorková and E. Drahotová who typed the report.

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HISTORY

First of all let us mention a brief prehistory of geophysics on the territory of the Czech Republic.

In general it is valid all over the world, that the first geophysical measurements were the geomagnetic ones. In Prague the measurements of geomagnetic declination were made at the Astronomical Observatory of Klementinum. They were started in 1839. The time series of declination from Prague belongs to the longest ones in the world. One of the directors of the Klementinum Observatory was professor Carl Kreil. Analysing the Prague measurements, he detected in 1850 the lunar daily variation of the geomagnetic field. He also constructed the first geomagnetic maps of our territory. The name of C. Kreil has been also known in the context with the construction of the first seismograph (C.F. Richter, 1958).

The second geomagnetic mapping of Bohemia and Moravia was made at the end of the 19th century by Josef Liznar. (It was organized in the framework of the Austrian - Hungarian monarchy, but J. Liznar was of Czech nationality.)

In late 19th century pendulum measurements of gravity were started in the mines of Příbram (R. Sterneck in 1882). Later on, in 1911, gravity was measured in Příbram by means of horizontal pendula at a depth of 1009 m (F. Köhler).

Professor Václav Láska

A great personality of the Czech geophysics was Václav Láska (1862 - 1943). He was born in Prague and studied mathematics and physics at the Charles University. His interests and abilities were many-sided. He worked in mathematical statistics, astronomy, geodesy, geomagnetism, meteorology and seismology. He wrote even a little book on philosophy of the exact sciences. Since 1896 he was engaged at the Technical University of Lvov. At that time he started working in seismological research. His main discoveries concerned the interpretation of seismograms. Let us mention Láska's rule for an approximate determination of the epicentral distance: $(S-P)_{min} - 1 =$

$\Delta_{megameters}$. In 1911 Láska moved to Prague where he was named professor of applied mathematics at the Charles University. In spite of his efforts to organize a geophysical workplace in Prague, he was at first compelled to give his time predominantly to the applied mathematics.

Only after World War I, at the beginning of the independent Czechoslovak Republic, conditions became favourable to the ideas of Professor Láska. In 1920 the State Institute of Geophysics was founded at the Charles University in Prague and V. Láska was appointed its first director.

The first and for many years the only scientific co-worker of V. Láska was the geomagnetician J. Liznar, who was also named professor of the Charles University. Besides, the new Institute had some external collaborators, for instance F. Čechura in geomagnetism and applied geophysics, B. Kladivo in gravimetry and B. Šalamon, who was professor of cartography at the Charles University. In 1929, Professor Bedřich Šalamon become Deputy-Director of the Institute.

In 1910 a new building, belonging to the Charles University, was built in Prague in the street Ke Karlovu. It involved a seismic vault. In 1924 Prof. Láska installed a Wiechert horizontal seismograph in this vault. Since 1927 the seismic station of Prague had belonged to the international seismological network. V. Láska retired in 1933. The following director of the Institute of Geophysics became Professor Bedřich Šalamon (1880-1967).

In 1932 R. Běhounek, graduated in mining sciences, became a scientific worker of the Institute. He worked in geomagnetism. (J. Liznar retired in 1925.) R. Běhounek projected a new geomagnetic observatory to be built at Průhonice (at a distance of 13km from Prague), because the measurements in the Klementinum had been very disturbed by the city electrification. The new geomagnetic observatory of Průhonice started to operate and to publish its results only after World War II, in 1946.

Professor Alois Zátopek

Another scientific co-worker became in 1934 Alois Zátopek (1907 - 1985). He graduated at the Charles University in mathematics and physics. In the Institute of Geophysics he concentrated himself on seismological studies. He organized the co-operation of the Prague station with the system of the world seismic stations.

After the earthquake in Northern Moravia in 1935, A. Zátopek began to study the relations between macroseismic phenomena and the regional tectonical structure. Later on, he worked up a monograph on the earthquake observations of Slovakia. In 1936 A. Zátopek enlarged the equipment of Prague seismic station upon the vertical Wiechert seismograph.

At the end of the pre-war period the staff of the Institute was strengthened by J. Bouška, geomagnetician, and B. Bednářová-Nováková, astronomer specialized in solar physics.

The World-War II stopped further development and the Institute was dissolved. After the war it was re-established and its director was again Professor B. Šalamon. The pre-war staff was enlarged by new members; the first new co-workers became J. Pícha (gravity measurements) and J. Šubrt (observations of telluric currents).

In the following time the number of geophysicists grew and their special projects increased, but the conditions at the Charles University were not favourable to further development of the geophysical team. In 1950 the State Institute of Geophysics was incorporated into the newly created Central Institute of Physics.

Therefore, a group of geophysicists endeavoured after establishment of an independent Geophysical Institute in the framework of the planned Czechoslovak Academy of Sciences (ČSAV). This effort was successful and on November 17, 1952, the Geophysical Institute of the ČSAV was established.

Nevertheless, some members of the old Láska's Institute persisted in the staff of University workers. Professor Šalamon returned to the University Department of Cartography, R. Běhounek was nominated Professor of Applies Geophysics at the Faculty of Sciences.

A. Zátopek continuated to work at University Department of Physics as Associated Professor of Geophysics. In 1952 he was nominated Professor of Geophysics at the Faculty of Mathematics and Physics. He continued his seismological and tectonophysical studies, contributed a great deal to the research of microseisms and in his last years concentrated himself on the formation of geophysical syntheses. His work was appreciated in his home country as well as abroad. In 1957 he was awarded the State Prize for elaborating the seismic characteristic of the territory of Czechoslovakia. For two periods, 1962-64 and 1964-66, he was President of the European Seismological Commission.

Perhaps the most important part of Zátopek's work was his pedagogical activity. He gained many students for study of geophysics and in the first years he taught alone all geophysical disciplines. His lectures were excellently prepared and attractive. He educated a whole generation of the Czech geophysicists. It can hardly be understood, how he was able to manage all his work.

Professor Zátopek was Head of the Department of Geophysics of the Charles University till 1972. Since this year be continued in his scientific work at the University till his death in 1985. Professor Karel Pěč, one of Zátopek's students, was Head of the Department of Geophysics since 1972.

For the main part, the data stated in this report were gathered in the paper: A. Zátopek, Sixty years since the foundation of the (State) Institute of Geophysics at the Charles University in Prague. Studia geoph. et geod. 25 (1981), 296 - 312.

SEISMIC STATION

The Department of Geophysics runs as its integral part the seismic station Prague (code PRA).

Established at the Charles University (Prof. V. Láska) in 1924, the station started its regular operation in 1927 and joined the international seismic data exchange. During the years, due to the administrative changes, the station was succesivelly associated to different institutions (e.g. to the independent State Institute of Geophysics, to the Geophysical Institute of the Czechoslovak Academy of Sciences). Since 1958 the station belongs again to the Charles University and is served by its Department of Geophysics, Faculty of Mathematics and Physics.

The station started its work with the Wiechert horizontal seismograph which was soon completed by the Wiechert vertical seismograph and two modified Anderson-Wood seismographs. This instrumental equipment was improved in the sixties by two sets of Kirnos electrodynamic seismographs with galvanometric recording (one set equipped with the 90 s galvanometers). Contemporaneous instrumentation is as follows: 1) Short-period seismograph Vegik, vertical component, anolog recording (heat-sensitive paper). 2) Medium-period seismograph Kirnos SK, vertical component, analog (ink) recording. 3) Long-period seismograph Kirnos SKD, three components, digital recording.

The instruments are located in the seismic vault at the faculty building, see address b) given in Preface.

Mainly due to the work of Prof. A. Zátopek, station PRA contributed substantialy to the development of the European seismology. It was e.g. the second station in Europe (following Strasbourg) that started to use (1949) the quantity of "magnitude" in evaluating earthquake records.

At the present time, the station continues to fulfil three tasks. First, it supplies the interpretation of its records to the "Bulletin of the Czech seismic stations" and to the International Seismological Centre (ISC) in Newbury. According to the U.S. Geological Survey (Open-File Report 91-295) station PRA belonged in the years 1964-1986 to the 15% of the stations that reported to the ISC the largest number of the arrivals. Second, it produces the data to be used in some special investigation, often in international cooperation (e.g., for the studies of the crust and upper mantle structure, that are based on the dispersion of surface waves). Third, the station serves as a training place for the students of geophysics in the seismic record interpretation and methods of data handling and processing.

The request for copy of seismic records, other data or any information about seismic station PRA should be sent to Dr. J. Janský (address b).

STAFF

All the staff has received their degrees from the Charles University in Prague. The meaning of the abbreviations used below, ordered according to the scientific level of the degree, is as follows:

RNDr. = Rerum Naturalium Doctor
CSc. = Candidatus Scienciarum (equivalent to PhD.)
DrSc. = Doctor Scienciarum

It is to mention that the education system introduced recently at the Charles University no more yields to the first two degrees, but introduces a new degree of Dr. (equivalent to PhD.)

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RESEARCH

SEISMOLOGY

Participated by (in the alphabetic order):
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Seismological research at the Department of Geophysics has been concentrated mainly on the following subjects during last five years:

a) Theoretical investigation of propagation of seismic waves in complex structures. b) Inversion of seismic data. c) Earthquake ground motion studies. d) Interpretation of seismic observational data. e) Seismic surface waves.

a) *Theoretical investigation of propagation of seismic waves in complex structures*

The work has concentrated primarily on the numerical modelling of seismic wave fields in complex, laterally varying, isotropic and anisotropic, layered and blocked structures. Asymptotic methods, such as the ray method and its extensions (the paraxial ray method, the method of Gaussian beams, the perturbation ray method, various hybrid methods) and the method of finite differences have been mainly used. Both these methods supplement suitably each other. The theory and numerical implementation of methods developed by our group have been broadly used throughout the seismological community in seismological applications and in seismic prospecting for oil for a long time, both in forward modelling of seismic wave fields and in inversion of seismic data. The computer packages of our group have been distributed, charge free, by World Data Center A For Solid Earth Geophysics, Boulder.

Seismic ray method and its extensions

Two hybrid combinations of the seismic ray method with other methods have been proposed. In the first of them, hybrid ray-reflectivity method was applied to laterally varying models containing a thin high-velocity layer, and to the models, containing a thin, low-velocity surficial layer. The main attention was devoted to the problems of tunneling of seismic body waves through the thin high-velocity layer beyond the critical angle and to the influence and possible suppression of multiples generated within the thin low-velocity near-surface layer. The second hybrid modification combines the ray computations with the Born approximation. The modification can be used to compute seismic wave fields in laterally varying layered macromodels containing small scatterers. The scatterers can be combined to form greater bodies of an irregular shape. These hybrid methods extend considerably the possibilities of the ray method in the numerical modelling of realistic structures.

Algorithms for an efficient Fresnel volume ray tracing were proposed. The Fresnel volumes, representing physical, frequency dependent rays, play an important role in various applications of seismology and seismic prospecting for oil. For example, they can be used to study the resolution of the seismic method and to study the accuracy of the ray method. The proposed algorithms are based on the dynamic ray tracing and on the network ray tracing.

An important role in the recent ray method and in its various extensions is played by the dynamic ray tracing. The dynamic ray tracing can be performed numerically along a known ray in several ways. Some of them are preferable for the numerical efficiency, some others are more useful in theoretical applications. Transformation relations connecting the results of dynamic ray tracing performed by various methods and in different coordinate systems have been proposed.

The method of 2.5-D modelling of high-frequency seismic wave fields has been developed. This approach consists in the solution of the 3-D elastodynamic equation and enables to compute efficiently 3-D rays passing in general directions through 2-D structures being very often used in seismic modelling. 3-D rays are needed whenever a general source-receiver configuration not respecting any symmetries of medium is to be considered. In 2.5-D approach, the number of ray tracing equations is reduced. Thus, in the frame of its applicability, the 2.5-D modelling is more efficient than fully general 3-D approach, giving exactly the same 3-D results. The method has been applied to the modelling of near-source wave field generated by a finite extent fault of arbitrary orientation with respect to receivers as well as to the structure.

A general approach to derive the elastodynamic ray theory Green function for inhomogeneous anisotropic medium has been proposed. The approach is based on the application of paraxial seismic ray methods and on the ray propagator matrices. From the algorithmic point of view, the method requires the dynamic ray tracing. We remind that the knowledge of the elastodynamic Green function is a building brick for the construction od many solutions of the elastodynamic equations and in the solution of seismic inverse problems.

The polarization of high-frequency seismic body waves in complex structures was studied by the ray method. The main attention was devoted to the quasielliptical polarization of S waves. There are five main causes of the quasielliptical polarization of seismic body waves in complex structures: a) The overcritical incidence of the wave on the Earth's surface, b) The overcritical incidence of the wave on an structural interface, c) The source effects, d) The interference of individual waves, e) The presence of anisotropy in the medium.

Seismic rays corresponding to first arrivals may be approximated by the shortest paths through a network that represents the Earth's model. First arrival travel times are defined in the whole model. There are no restrictions of classical ray method: diffracted rays are found correctly, both in illuminated and shadow zones. An efficient algorithm of the network shortest path calculation of rays and travel times of the first arrivals is proposed. The relative travel-time error of such computations is estimated. The error estimate, being the function of the model and of the volume in which the rays are traced, is evaluated prior the network ray tracing, and is minimized by means of a proper choice of the size of a forward star. In this way, the structure of a network is adjusted for a particular model and for a particular computer memory.

Finite-difference method

Our long-term program in the methodical investigations of the finite-difference methods for seismic wave propagation problems has continued. Recent 2nd-order finite-difference schemes for elastic waves were tested for behaviour at discontinuities. Serious problems in the traction continuity were detected and partially solved. A new efficient 2nd order elastic finite-difference scheme was proposed, behaving well at internal discontinuities as well as at the flat free surface. Generalizations of the 2nd-order schemes to the 4th order, saving the computing time, have been investigated, too. A simple method for including the causal absorption into the time domain finite-difference simulations was developed.

b) *Inversion of seismic data*

An inversion of seismic reflection data using the Cohen-Bleistein inversion integrals requires the numerical evaluation of the so-called Beylkin determinant. The procedures for the computation of the Beylkin determinant have been known for 2-D models, but not for 3-D models. A procedure for the computation of the Beylkin determinant in 3-D structures, based on the application of the dynamic ray tracing, has been proposed. The procedure makes even the 3-D inversion numerically feasible.

The perturbation kinematic methods for general anisotropic inhomogeneous media play an important role in recent structural seismological studies. A method of inversion of seismic travel time measurements in inhomogeneous anisotropic media based on the time delay between the split shear waves was proposed. It was shown that the perturbations of the time delay between the split shear waves depend considerably on the perturbation of anisotropy, but only slightly on the perturbations of the inhomogeneity.

When interpreting an observed dispersion of seismic surface waves, it is suitable to know the partial derivatives of the corresponding phase and group velocities with respect to the medium parameters. Numerical differentiation can be used for these purposes, but this method is slow and not very accurate. A more suitable analytical method, based on the implicit function theorem, was proposed and elaborated for computing group velocity and the mentioned partial derivatives and was applied to Love and Rayleigh waves in a layered medium. The waveform inversion for retrieval of parameters of the structure is under development.

c) *Earthquake ground-motion studies*

Swarms of weak earthquakes represent a typical feature of the seismic activity in Czech Republic. The last swarm, which occured in 1985/86, has provided a lot of data significantly improving our understanding of the West-Bohemia region. Studies of these data still continue. To investigate the fault-plane solutions of weak events digitally recorded at a few stations we developed and applied a joint inversion of the polarities and amplitudes. A simple method for mutual interpretations of the macroseismic fields and the fault plane solutions was suggested and applied to improve the source location of the swarm events. The attention was also paid to the pronounced changes of the mineral springs during the swarm, which represent a promissing phenomenon for predicting future events in that region.

We took part in two international experiments the purpose of which was to compare and verify various methods of the computational prediction of the specific site effects upon seismic ground motions. The experiments were organized by the IASPEI Working Group on Effects of Surface Geology. At both studied sites, in California and Japan, we performed a blind predictions of the ground motions based on our 2-D finite-difference program package. The predictions were compared later with those by other participants, and collectively compared with reality. Important implications for further improvements in the seismic ground-motion assessment have been drawn.

d) *Interpretation of seismic observational data*

Theoretical short- and medium-period amplitude-distance curves of different branches of PKP waves or of their interference have been computed using the ray method and by the Gaussian beam approach. The theoretical amplitudes contribute to better interpretation of the observed PKP waves, recorded frequently in Europe from the foci in the Pacific Ocean, and allow the PKP waves to be used for the earthquake magnitude estimation.

A program package for computation of three-component ray-synthetic seismograms in radially inhomogeneous media and their comparison with teleseismic records have been developed. Such a comparison can help in a correct identification of later-arriving phases. The reporting and study of secondary phases represent important goals of the International Seismological Observing Period (ISOP).

To contribute to an improvement of the earthquake body wave magnitude estimations, extensive computations of synthetic seismograms of P waves have been carried out using the WKBJ and ray methods. The PREM and IASP91 Earth models, short and medium signal prevailing periods and different source depths have been used.

A new explanation of the so-called quiet earthquakes has been proposed. It is based on the assumption that great ammounts of fluids can be released from the Earth's interior in some regions. Under specific thermodynamic conditions, the transport of the fluids towards the Earth's surface can probably be accompanied by thermo-mechanical vibrations. Similar phenomena are well-known from laboratory experiments ("singing" flames, etc.). These thermo-mechanical transducers, called "natural machines" , seem to be sufficient to generate quiet earthquakes.

A model of the lithospheric structure along the profile Uppsala-Prague has been derived using the experimental dispersion curves of seismic surface waves.

e) *Seismic surface waves*

Investigations of seismic surface waves have also a long tradition at the department. Late prof. K. Pěč was the first who began the systematic investigations of surface waves in Czechoslovakia. Attention was paid mainly to different aspects of generation and propagation of surface waves in layered media. Many theoretical papers dealt especially with the development of matrix methods (elimination of pure imaginary elements from the Thomson - Haskell matrices, analytical computation of the partial derivatives of phase and group velocities for Love waves, reflection and refraction of body waves at transition zones, etc.). Since the middle of 1970s some investigations of the crust and upper mantle structure along several profiles in Central Europe have been carried out in cooperation with Moscow State University.

The present investigations of surface waves at the department follow these previous directions of investigations. Recent studies have concerned with some problems of Rayleigh wave theory, modal summation method of computing synthetic seismograms in layered media, and modifications of matrix methods using quadratic slownesses.

GEODYNAMICS

Participated by (in the alphabetic order):
O. Čadek, L. Hanyk, Z. Martinec, C. Matyska, J. Moser.

The geodynamics group at the Department of Geophysics has been initiated by Prof. Karel P in the eighties to solve the problems of the global inversion of the gravitational and geomagnetic fields in order to get the distributions of density and conductivity anomalies in the Earth's mantle. The 3-D density models were obtained by taking into account the undulations of the core-mantle boundary, the Moho and the Earth's surface. At the same time the group started work on present-time modelling of mantle convection. The forcing function for this kind of problems is the buoyancy force produced by density anomalies known from seismic tomography and the inverse gravimetric modelling. The approach based on the variational formulation of the momentum equation has been developed and tested for 3-D spherical-shell models. The variational approach has made it possible to include lateral variations of viscosity in Newtonian flows and non-linear rheologies.

The next step in the modelling of global processes in the mantle has been the inclusion of time-dependence in a self-consistent manner. The time-dependent density anomalies have been connected with the evolution of temperature anomalies in the Earth's mantle. Influences of various parameters, such as depth-dependent viscosity and thermal expansivity and radiative heating, on mantle flows and the thermal structure have been carried out. These studies have been performed in two-dimensional cartesian and axisymmetric spherical geometries. Recently, the three-dimensional cartesian convection with constant material properties up to $Ra = 2 \times 10^8$ has been examined.

Interpretation of seismic tomography in terms of the thermal structure of the mantle plays an important role in understanding the present-day state of the mantle. A detailed description of cold and hot thermal anomalies has been obtained by using recent tomography and mineral physics data. These findings have been compared with direct numerical modelling.

There is a clear connection between the Earth's rotation and the processes in the mantle because the redistribution of masses strongly influences the moment of inertia which controlls the rotational behaviour of the planet. The theoretical approach has been developed and partly numerically tested.

Another challenging research has been carried by introducing a new approach in the numerical modelling of postglacial rebound which can take into account lateral variations of viscosity in three-dimensional Maxwell's models.

The group is going to continue in time-dependent modelling of thermal convection in both three- and two-dimensions with temperature-dependent parameters. The lithospheric processes are to be included into the consideration. The rotational-convection problem is to be implemented in three-dimesional spherical-shell geometry. Postglacial rebound studies with lateral viscosity variations are the promissing steps in full understanding the data and the viscosity distribution in the mantle.

GRAVITY FIELD

Participated by (in the alphabetic order):
O. Čadek, Z. Martinec, C. Matyska.

There have been three main trends in studies of the gravity field of the Earth at the department.

a) The first effort was focused on developing the method enabling to find the global solution of the scalar Molodensky boundary-value problems outside the Earth. Spherical harmonic technique allowed to compute the spherical harmonic coefficients of the external gravity potential provided the magnitude of the gravity vector and gravity potential are known on the Earth's surface. To be able to carry out numerical computations, we developed a fast numerical code for computing the associated Legendre functions up to high degrees and orders as well as the code for the spherical harmonic analysis of a function defined in discrete points on a sphere. The preliminary results employing artificial data are tempting for future applications because the covergence of the method was extremely fast.

b) Recently, we started to solve the internal boundary value problem for gravimetric determination of a regional geoid. The problem governed by the Poisson equation with the boundary conditions on the Earth's surface is improperly posed because of the instability of the solution. A simple regularization based on truncation of a high frequency part of the internal gravitational potential was tested on the computation of the geoid over Canada. We showed that this regularization partly removes the instability of the solution. In future, we intend to regularize the problem by constraining it with an additional information, e.g., the deflection of the vertical.

c) We also dealt with the gravimetric inverse problem for determination the mass density inside the Earth. In particular cases, the well-known fact that the solution is non-unique and unstable was overcome by imposing another geophysical information on the density model. For example, taking into account the tomographic models of the seismic wave velocities, we constructed the anomalous density models later used for modelling the present-time mantle convection. We showed that topographic masses are not compensated only by the crustal thickening but that there is a deeper contribution which may be associated with the dynamic topography generated by the mantle convection.

GEOMAGNETISM

Participated by (in the alphabetic order):
A. Janáčková, O. Novotný, L. Urban.

Our interest has been concentrated mainly on the time variations of the surface configuration of geomagnetic field.

Until recently, it has been considered unlikely that the space distribution of the non-dipole geomagnetic field could be in any connection with mantle dynamics. Some isolated opposite opinions such as that of J.A. As did not find much acceptance. J.A. As wrote in 1978 : "A correlation seems to exist between the location of the magnetic belts and tectonic features. The belts are fixed with respect to the earth's mantle, but have their source in the earth's core. The correlation suggests the existence of some processes in the crustal side but also at the core side." J.A. As was led to this idea by a special study of the field geometry. Obviously, that time was not yet suitable for accepting such a hypothesis, above all for a poor knowledge of mantle dynamics.

At present, some palaeomagnetics results attract attention, for instance the records of palaeomagnetic poles during the periods of reversals: it seems that the poles followed always one of two fixed paths, at least in the last 10 million years. (V. Courtillot et al., 1992). This and other features, for example the time coincidence of reversals frequency and strong changes of the rate of the Earth's rotation, (J.A. Jacobs, 1992) provoke speculations on mutual dependences of mantle and core dynamics. The most likely mediating element between the two systems is considered the "D" layer.

In consequence of their enormous complexity, the geodynamo models are to be made in rather general terms, so that they are not very suitable for studying the details. At the same time, the usual description of the instantaneous distribution of the surface geomagnetic field by means of spherical harmonics is probably not convenient for detecting the field features, that could be a result of the above mentioned possible mutual dependences.

Therefore, we are looking for other methods of illustrating the field and its time variations. Our method uses partly the palaeomagnetic terms (virtual poles). Some of our results seem to reveal connections with the plate tectonics.

In some areas (mostly in the Pacific hemisphere) the connection of the geomagnetic with the tectonic features seems to be fixed, in other areas it disappears and again appears in periods of tens of years. At present, we look for an explanation of this diversity; it is possible that the cause of it consists just in the geometry of the problem.

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ABSTRACTS (1992-1993)

O. Čadek, C. Matyska: Variational approach to modeling present-time mantle convection. *Studia geophys. et geod.* **36**, 215-229, 1992

An analogy of the Hellinger-Reissner functional for the Stokes problem is constructed and the way of determining its minimum by means of spherical harmonic vectors and tensors is described. The variational method is applied to a Newtonian mantle in which the body forces were estimated on the basis of global inversion of gravitational and topographic data. The method is then generalized to the case of a realistic rheology (power-law creep), and prospects of the generalised method are briefly discussed.

O. Čadek, Y. Ricard: Toroidal/poloidal energy partitioning and global lithospheric rotation during Cenozoic time. *Earth. Planet. Sci. Lett.* **109**, 621-632, 1992

The motion of surficial plates can be split into two terms: the toroidal field related to shear between plates or to spin around their centres and the poloidal field associated with horizontal divergence at ridges and subductions. Recent papers have suggested that the present-day plate motion minimizes the ratio of poloidal to toroidal energies and that the existence of a global lithospheric rotation results from viscosity variations between oceans and continents. This paper tests and confirms these two hypothesis using plate reconstructions during Cenozoic time. The partion of energy between the two models always favours the poloidal velocities. The global rotation computed using a viscosity one order of magnitude lower below oceans than below continents agrees with observations. The existence of a non-linear rheology in a uniform asthenosphere leads to a satisfactory location of the global lithospheric rotation but with too small an amplitude.

O. Čadek, Z. Martinec, C. Matyska: Spectral variational approach to the non-Newtonian Stokes problem in a spherical shell. *Computer Physics Communications* **71**, 56-70, 1992

The hybrid-variational formulation of the Stokes equation for incompressible non-Newtonian flow is suggested. A spherical harmonic technique is adopted to discretize the problem. In the case of non-Newtonian rheology, the energy functional becomes non-quadratic. To minimize it on the set of admissible stress-functions, the gradient method is used and the convergence of the method is demonstrated.

O. Čadek, Y. Ricard, Z. Martinec, C. Matyska: Comparison between Newtonian and non-Newtonian flow driven by internal loads. *Geophys. J. Int.* **102**, 103-114, 1993

The interpretation of long wavelength geoid and plate motions on the basis of dynamic Earth models has usually been done assuming linear viscous rheologies in the mantle. In this paper, we develop spherical three-dimensional models of mantle circulation using power-law creep rheologies with an exponent $n = 3$. In the steady state limit, the stress-dependent rheologies only modify the amplitude of the topography supported by an internal load by a few percents with respect to the linear predictions. The geoid anomalies induced by internal loads can be affected by around 20%. These changes are also occurring at degrees and orders different from those of the mass anomaly itself. As the geoid spectrum is strongly decreasing with degree, the dynamic topography induced at high degrees can be contaminated in a non-negligible way by the low degree loads. The main contamination occurs at a harmonic triple of that of the most important load. The flow structure is much more dependent on the form of the constitutive law than the dynamic topography and the geoid. On the contrary to linear rheology, a power-law creep is able to sustain a toroidal velocity field. However, this toroidal component only carries a few percents of the kinetic energy and thus, the non linear creep with $n = 3$ cannot by itself explain the observed quasi-equipartition of plate tectonic energy between toroidal and poloidal components.

O. Čadek, D.A. Yuen, V. Steinbach, A. Chopelas, C. Matyska: Lower-mantle thermal structure deduced from seismic tomography, mineral physics and numerical modelling. *Earth Planet. Sci. Lett.*, in press.

The long-wavelength thermal anomalies in the lower mantle have been mapped out, using seismic tomographic models in conjuction with thermodynamic parameters derived from high-pressure mineral physics experiments. These parameters are the depth variations of thermal expansivity and of the proportionality factor between density and seismic velocity. The giant plume-like structures in the lower mantle under the Pacific Ocean and Africa have outer fringes with thermal anomalies around 300 to 400 K, but very high temperatures are found in the center of the plumes near the base of the core-mantle boundary. These extreme values can exceed +1500 degrees and may reflect large hot thermal anomalies in the lower mantle, which are supported by recent measurements of high melting temperatures of perovskite and iron. Extremely cold anomalies, around -1500 degrees, are found for anomalies in the deep mantle around the Pacific rim and under South America. Numerical simulations show that large negative thermal anomalies of this magnitude can be produced in the lower mantle, following a catastrophic flushing event. Cold anomalies in the mid lower mantle have modest magnitudes, around -500 K. A correlation pattern exists between the present-day locations of cold masses and the sites of past subductiun since the Cretaceous. Results from correlation analysis show that the slab mass-flux in the lower mantle did not conform to steady-state nature but exhibited time-dependent behaviour.

V. erven, F.C.M. de Andrade: Influence of a near-surface structure on seismic wave fields recorded at the Earth's surface. *J. Seismic Exploration* **1**, 107-116, 1992

The hybrid ray-reflectivity method is applied to the numerical modelling of seismic wave fields in laterally varying layered models containing a thin near-surface low-velocity layer. The computations within the laterally varying layered models are performed by the ray method, but the thin near-surface layer is attacked locally by the matrix methods. The thin layer need not be homogenous, it may include arbitrary inner layering and it may vary slightly laterally. All multiples within the layer are automatically taken into account. Numerical examples of hybrid ray-reflectivity seismograms for two models of the thin near-surface layer are presented. An inverse algorithm to remove the effects of a thin near-surface layer from seismograms recorded at the Earth's surface is proposed.

V. erven, P. Aranha: Tunneling of seismic body waves through thin high-velocity layers in complex structures. *Studia geoph. et geod.* **36**, 115-138, 1992

The hybrid ray-reflectivity method is applied to the problem of the transmission of the reflected wave field though a thin high-velocity layer (or through a thin stack of high velocity layers), situated in the overburden of the reflector. In the hybrid ray-reflectivity method, the standard ray method is applied in the smooth parts of the models, and the reflectivity method is used locally at the thin high-velocity layer. The reason is that a considerable part of the energy for overcritical angles of incidence may be tunneled though the thin high-velocity layer along complex ray-paths, corresponding to inhomogenous waves. The reflectivity method, applied locally at the thin high-velocity layer, automatically includes all inhomogeneous wave contributions. Thus, the hybrid ray-reflectivity method removes fully the limitations of the standard ray method, but still retains its main advantages, such as its applicability to 2-D and 3-D complex layered structures, flexibility, and low-cost computations. In the numerical examples, the hybrid ray-reflectivity synthetic seismograms are compared with standard ray synthetic seismograms and with full reflectivity computations. The numerical examples show that the hybrid ray-reflectivity method describes the tunneling of seismic energy though a thin high-velocity layer with sufficient accuracy.

V. erven, M.A. de Castro: Application of dynamic ray tracing in the 3-D inversion of seismic-reflection data. *Geophys. J. Int.* **113**, 776-779, 1993

Possible application of dynamic ray tracing to the 3-D Born and Kirchhoff inversion of seismic-reflection data are disccussed. It is shown that the most important quantities in the inversion integrals, such as the Beylkin determinant and the amplitudes of the ray-theory Green functions, can be determined using the dynamic ray-tracing procedure. Dynamic ray tracing can be simply performed along known rays in a very general, laterally varying, layered background medium. The algorithms do not require the determination of the derivatives of traveltimes which play an importent role in some other methods. They will find valuable applications particularly in complex 3-D structures.

V. erven, A. Coppoli D. M.: Ray-Born synthetic seismograms for complex structures containing scatterers. *J. Seismic Exploration* **1**, 191-206, 1992

The hybrid method based on a combination of ray theory with the Born approximation can be used to compute synthetic seismograms in complex, laterally varying layered structures containing small scatterers. The scatterers can be combined to form objects of a complex shape. The wave field in the background, laterally varying layered structure is computed by the ray method and the single scattered wave field by the Born approximation. A computer program package designed for such hybrid ray-Born computations in 2-D models is briefly described and numerical applications are presented. The ray-Born numerical modelling of seismic wave fields extends the possibilities of ray modelling considerably.

V. erven, J.E.P. Soares: Fresnel volume ray tracing. *Geophysics* **57**, 902-915, 1992

The concept of Fresnel volume ray tracing consists of standard ray tracing, supplemented by a computation of parameters defining the first Fresnel zones at each point of the ray. The Fresnel volume represents a 3-D spatial equivalent of Fresnel zone that can also be called a physical ray. The shape of the Fresnel volume depends on the position of the source and the receiver, the structure between them, and the type of body wave under consideration. In addition, the shape also depends on frequency: it is narrow for a high frequency and thick for a low frequency. An efficient algorithm for Fresnel volume ray tracing, based on the paraxial ray method, is proposed. The evaluation of the parameters defining the first Fresnel zone merely consists of a simple algebraic manipulation of the elements of the ray propagator matrix. The proposed algorithm may be applied to any high-frequency seismic body wave propagating in a laterally varying 2-D or 3-D layered structure (P, S, converted, multiply reflected, etc.). Numerical examples of Fresnel volume ray tracing in 2-D inhomogeneous layered structures are presented . Certain interesting properties of Fresnel volumes are discussed (e.g., the double caustic effect). Fresnel volume ray tracing offers numerous applications in seismology and seismic prospecting. Among others, it can be used to study the resolution of the seismic method and the validity conditions of the ray method.

A. Janákov, L. Urban: Geomagnetic field: contribution of higher harmonics to the variations of virtual pole positions. *Studia geoph. et geod.* **34**, 382-387, 1990

On the basis of the 1945 IGRF two sets of virtual geomagnetic poles have been computed and compared. The first set refers to a realistic model of the field; these virtual poles are all located in the north polar area. The second set refers to an artificial field containing higher harmonics only; these virtual poles are distributed over the Earth's surface as a whole. However both sets of virtual poles yield similar distribution of values of their space (and probably also time) variations.

A. Jankov, L. Urban: Magnetic field measurements in India during the last two centuries. *Studia geoph. et geod.* **36**, 151-160, 1992

The direction of the geomagnetic field has changed substatially less in India than in Europe since the end of the 18th century.
Whereas the European geomagnetic time series indicate a tendency of secular variation from which a remarkable westward drift of the non-axial field can'be deduced, in India the field direction seems to have remained more or less fixed over the last two centuries. The drift of the non-axial field seems to be very small, or even eastward.

J. Janský, M. Kvasnička: Theoretical PKIKP magnitude determination. *Studia geoph. et geod.* **36**, 20-25, 1992

The estimation of the theoretical magnitude for deep foci based on the vertical component of medium-period PKIKP waves, Earth model PREM and source spectra is presented. The given graphs are valid for period T ranging from 1.6s to 10s, source depth of 25km to 600km and distance range of 16500km to 19800km. A simplified method of representing calibration curves "sigma" is used.

J. Janský, M. Kvasnička: Interference amplitude curves of short period PKP waves. *Studia geoph. et geod.* **37**, 151-158, 1993

Theoretical short-period amplitude-distance curves of PKP waves are calculated in the range of distances corresponding to the interference zone of the different branches of this waves. The combination of the zero-order approximation of the ray method and the Gaussian beam approach are used for the calculation. The calculated amplitudes are compared with the observed ones. A relatively good coincidence between the theoretical and observational curves has been found.

M. Kvasnička, V. Červený: Fresnel volumes and Fresnel zones in complex laterally varying structures. *J. Seismic Exploration*, submitted

A new method to compute the Fresnel volumes and Fresnel zones of seismic body waves propagating in complex, 2-D and 3-D, laterally varying, layered and blocked structures is proposed. It is based on the network ray tracing. The method is stable and efficient and overcomes limitations of the method based on the paraxial ray approach. Whereas the method based on the paraxial approach can be applied only to regular, zero order seismic body waves (in the terminology of the ray method), the proposed method can be used to compute the Fresnel volumes even for head waves, and for diffracted waves penetrating into shadow zones. The method is also applicable in singular regions of the ray field, and predicts correctly various higher order effect. The limitation of the proposed method is that it is applicable only to waves arriving at the receiver in first arrivals. After some simple modification of the procedure, however, waves reflected from any interface in the model can be treated as first arriving waves. The presented numerical examples show certain interesting properties of Fresnel volumes (splitting of Fresnel volumes, off-ray shift of the interface Fresnel zone, penetration of Fresnel volumes of reflected waves across reflecting interface, penetration of Fresnel volumes of head waves across an interface into a lower velocity medium, etc.).

Z. Martinec: The static, potential free Love numbers for a homogeneous Earth's model bounded by an irregular surface. *Manuscr. Geod.* **17**, 186-200, 1992

The relationship between applied surface stresses and induced displacements depends generally on many factors. Taking into account a materially simple model of the Earth we have investigated the role of the irregularly shaped Earth's topography in this relation. The response function of the model was quantitatively parametrized in terms of the Love numbers. While the Love numbers for a spherically symmetric model are degenerated, i.e. spheroidal /toroidal forces only induce spheroidal/toroidal displacements without any coupling between them, the Earth's topography couples the particular modes and non-zero mixed Love numbers appear. Numerically, the third and higher digits of the Love numbers are influenced by the low-degree harmonics of the Earth's topography surface. This means that if an accuracy of 0.1% or better should be achieved, the Earth's surface ought to be modelled by a more realistic surface than by a sphere or by a rotational ellipsoid.

Z. Martinec: A model of compensation of topographic masses. *Surveys in Geoph.* **14**, 525-535, 1993

The compilation of new global Mohorovičić ('Moho') topographic data enables the density contrast between the crust and mantle to be estimated. Assuming that this contrast is constant, the minimization of the external gravitational potential induced by the Earth's topographic masses and the Moho discontinuity yields the value of 0.28 g/cm^3 for the density jump at the Moho. Moreover, it is shown that the Airy-Heiskanen model of compensation only partly compensates the surface topographic masses. To fit the external gravitational potential, induced by the surface topography, the Pratt-Hayford concept of compensation has to be considered. Employing the dynamical flattening of the Earth, the minimum depth of compensation has been estimated at $100 - 150$ km. This means that the topographic masses are compensated throughout the Earth's lithospere at least.

Z. Martinec: The density contrast at the Mohorovičič discontinuity. *Geophys. J. Int.*, in press

The compilation of new global Mohorovičič ('Moho') topographic data enables us to estimate the density contrast between the crust and mantle. Assuming that this contrast is constant, the minimization of the external gravitational potential induced by the Earth's topographic masses and the Moho discontinuity gives the value of 0.28 g/cm^3 for the density jump at the Moho under the continental areas. For the oceanic areas where the information about the Moho depths is unavailable or poor, the procedure has not been applied.

Z. Martinec: The minimum depth of compensation of topographic masses. *Geophys. J. Int.*, in press

Based on the recently compiled crustal thickness data, it is shown that the Airy-Heiskanen model of compensation only partly compensates the surface topographic masses. To fit the external gravitational potential induced by the surface topography, the Pratt-Hayford concept of compensation has also to be considered. Employing the dynamical flattening of the Earth, the minimum depth of compensation has been estimated to be of the order of $100 - 150$ km. This means that the topographic masses are compensated throughout the Earth's lithosphere at least.

Z. Martinec, P. Vaníček: The indirect effect of topography in the Stokes-Helmert technique for a spherical approximation of the geoid. *Manuscr. Geod.*, in press

It has been customary in Geodesy to evaluate the indirect effect that arises from mathematical removal of the topography in solving the geodetic boundary value problem using Stokes approach, by modelling the geoid as a plate. In this contribution, we show that this planar model gives an incorrect result. Adopting a spherical model for the geoid, we derive new expressions for the indirect topographical effect on potential.

Z. Martinec, P. Vaníček: Direct topographical effect of Helmert's condensation for a spherical approximation of the geoid. *Manuscr. Geod.*, in press

The direct topographical effect that arises when the Stokes problem is treated by means of Helmert's 2nd condensation technique has been a subject of several studies in the recent past. In this paper, we use a spherical rather than planar model of the geoid, to derive more accurate expressions for the effect. Also our expressions are formulated so that the influence of lateral variations of topographical density can be taken into account. As a by-product of our investigation, we show that the integrals figuring in the direct topographical effect are only weakly singular and we proceed to remove the singularities by introducing spherical "Bouguer" shells.

Z. Martinec, P. Vaníček: An improvement of Moritz's procedure for the continuation of external gravity field. *Manuscr. Geod.*, submitted

The continuation of the external gravity field from the earth's surface into the interior by analytical continuation as formulated by Moritz (Moritz, 1980) is represented by a strongly singular integral operator. This makes the problem hard to understand because the continuation can be performed by the Poisson integral which is regular (except one point which can be removed from the integration domain). The strong singularity of the Moritz downward continuation operator appears because of using the Taylor series expansion for expressing the gravity anomaly on the point level surface by means of the gravity anomaly on the telluroid. In this paper, we demonstrate that the Taylor expansion of gravity anomaly can be left from the continuation process. Employing the Poisson integral only, the continuation of the external gravity field is performed by an integral operator which is regular. By this way, the downward continuation of the gravity field is partly stabilized from numerical point of view. It is simply shown that the improvement of Moritz's procedure is significant in a rugged mountains.

Z. Martinec, C. Matyska, O. Čadek, P. Hrdina: The Stokes problem with 3-D Newtonian rheology in a sphericall shell. *Computer Physics Communication* **76**, 63-79, 1993

A variational approach is used to solve the linear Stokes problem with a three-dimensional viscosity in a spherical shell. A semi-spectral method is proposed to discretize the problem. To minimize the energy functional on the set of admissible velocities, the gradient method with a corresponding projection is employed. The numerical behavior is satisfactory and the method can be employed in studies of planetary interiors with complex rheological structures.

Z. Martinec, C. Matyska, E.W. Grafarend, P. Vaníček: On Helmert's 2nd condensation method. *Manuscr. Geod.*, in press

In the past, two different methods were proposed to consider the effect of the terrain in Helmert's 2nd condensation method. In Vaníček and Kleusberg (1987) approach the attraction of the topographical masses is evaluated at a point on the topographical surface. By analogy with the Molodensky's theory, Wang and Rapp (1990) claim that the free-air anomaly should be reduced by the terrain correction. They also state that the attraction of the topographical masses should be referred to a point on the geoid.

This paper shows that key to solve this discrepancy is hidden in the way how the downward continuation of the anomalous gravity is treated in the particular methods. In the Vaníček and Kleusberg approach (1987) the downward continuation of the anomalous gravity from the topographical surface to the geoid is completely neglected, whereas Wang and Rapp (1990) evaluate this term under implicit assumption that there is a linear relationship between free-air gravity anomaly and the elevation of topography. As Moritz (1966) showed such an assumption comes from a simplified view of the compensation of topographical masses; it has not been proved yet that this assumption is acceptable for a precise geoid determination.

In other words it means that both methods, Vaníček and Kleusberg (1987) as well as Wang and Rapp (1990), are for different reasons only approximate. We will not be able to decide which method yields more accurate results until a correct procedure of computing downward continuation of anomalous gravity will be employed. Let us emphasize that this paper does not aspire to provide such an accurate procedure.

Z. Martinec, P. Vaníček, A. Mainville, M. Véronneau: The effect of lake water on geoidal height. *Manuscr. Geod.*, submitted

The complete theory of topographical effects in the Stokes-Helmert technique for geoid determination is developed. New formulae for direct and indirect topographical effects consider lateral density variations of topographical masses. The formulae are further simplified for computing the topographical effect of water in a lake. Numerical values of the particular topographical terms are given for the lake Superior.

C. Matyska: Topographic masses and mass heterogeneities in the upper mantle. *IUGG Monograph Series*, in press

The modified geoid which had been evaluated by incorporating the gravitational effect both of the Earth's surface undulations and the crustal thickening exhibits a high correlation with surface tectonics. It was interpreted by means of mass heterogeneities in the upper mantle. To get the uniqueness of this inversion, Tanimoto's tomographic density anomalies were employed as the a priori reference model. Results were compared with the case when only a spherically symmetric reference model was available. Good correlation between the mass heterogeneities and the surface tectonics as well as relatively low amplitudes were obtained in both cases. This suggests that the part of surface topography, which is not compensated by the crustal thickening, is associated with dynamic processes in the Earth's mantle and could be used to constraint models of dynamic topography resulting from computations of mantle convection.

C. Matyska, O. Čadek: Lateral variations of the mantle density and fluctuation of the core-mantle boundary — Comment. *Phys. Earth Planet. Inter.* **69**, 207-213, 1992

Ye presented a method to find the mantle density heterogeneities and to solve the mantle dynamic problem simultaneously. However, his approach does not guarantee the full consistency with the observed external gravity field. Moreover, Ye's dynamic system is constrained at the Earth's surface only. In this paper it is shown that additional constraints following from the gravity observations and from the seismic tomography should be taken into account and the variational generalization of Ye's approach is suggested.

C. Matyska, J. Moser: Heating in the D$''$-layer and the style of mantle convection. *Studia Geophys. et Geod.*, in press

We have investigated the influence of the heating in the D$''$-layer on the convection dynamics for the Rayleigh number $Ra = 10^6$. A strong heating, which may represent a local small-scale heat transfer in the D$''$-layer, results in an increase of lateral heterogeneities near the upper and lower boundaries, the blob-like structure of upwellings and the stabilization of the convection pattern. The influence of the elmg heating was found to be too weak to produce any substantial effect which is in contrast with the idea of Braginskii and Meitlis (1987).

C. Matyska, J. Moser, D.A. Yuen: The potential influences of radiative heat transfer on the formation of megaplumes in the lower mantle. *Earth Planet. Sci. Lett.*, submitted

Recent seismic tomographic models have revealed broad, low velocity anomalies in the lower mantle beneath Africa and the central Pacific which suggest a break in the symmetry between hot and cold regions in lower-mantle dynamics. We have considered the possible impact from radiative heat-transfer, which can be described by a nonlinear temperature-dependent coefficient in the thermal conductivity, in 2-D numerical simulations. Results for Rayleigh numbers up to 106 show a strong stabilizing influence from radiative heat transfer on mantle upwellings and the production of extremely hot thermal anomalies in the interior. This strong nonlinearity is responsible for producing a strong attractor in the convective system, which greatly simplifies the time-dependent dynamics with polar wander is discussed. The main point here is that slow time-dependence of the huge anomalies in the lower mantle can be the main controlling mechanism of long-time rotational dynamics.

J. Moser, D.A. Yuen, T.B. Larsen: Influences of depth-dependent properties on large-scale upwellings in planetary convection and temporal changes in the moment of inertia. *Phys. Earth Planet. Inter.*, submitted.

The influences of the depth-dependent thermal expansivity and viscosity on mantle flows and temporal variations in the moment of inertia have been studied with an axisymmetric spherical-shell model. Time-dependent numerical simulations in high Rayleigh number regime show that the decrease of thermal expansivity and the increase of mantle viscosity produce a small number of the stable upwellings. Comparison between cartesian and spherical-shell geometries shows that the dynamical behavior, as well as the size of the large thermal plumes, is similar in both geometries, while the downwellings are stronger in cartesian geometry. The average temperature in spherical geometry is about two times lower than the corresponding temperature in cartesian geometry for the same depth-dependent parameters. Spherical models with a small core, as may be the case for Mars, show the existence of the megaplumes with large heads, which can extend several tens of degrees on the planetary surface. We have also investigated the influence of Rayleigh number, internal heating and depth-dependent properties on the time-dependent phase-space trajectories of the moments of inertia and the surface Nusselt number. There are substantial differences in the behavior of the moment of inertia from depth-dependent properties because of the plume-plume collisional dynamics. Large excursions in the phase-space trajectories occur for depth-dependent properties. The time-scales associated with changes of the surface Nusselt number are faster than that associated with changes in the moment of inertia.

J. Moser, D.A. Yuen, C. Matyska: Polar motions excited by a convecting viscous mantle. *Geophys. Res. Lett.* **19**, 2251-2254, 1992

The role played by time-dependent mantle convection on exciting long-term polar motions is examined by means of a viscous model. For sufficiently low effective viscosity, polar wander speeds of O(1 deg/Myr) would require contributions from the off-diagonal elements of the inertia tensor, with magnitudes around 10^5 times smaller than those found in viscoelastic models used for postglacial rebound. Contributions from the large-scale mantle flow to the angular momentum vector can be comparable to those due to changes in moment inertia tensor for non-linear rheology or for young plantes. The relative roles of the two contributions depend on the non-linear rheology of the mantle and its convective vigor.

J. Moser, D.A. Yuen, C. Matyska: Reply to the Comment by Y. Ricard, R. Sabadini and G. Spada. *Geophys. Res. Lett.*, in press

We welcome this opportunity which Drs. Ricard, Sabadini and Spada (RSS) have offered us to elaborate several points on the relationship between convective circulations and rotational dynamics. First of all, mantle convection is a non-linear fluid dynamical phenomenon with some form of non-linear rheology. The usage of linear viscoelastic modes cannot hope to capture many of the complex features in mantle convection, such as the catastrophic flushing events. The relationship of the linear viscoelastic normal-mode theory to other approaches, such as viscous and the non-linear viscoelastic treatments, can be found in Moser et al. (1993). In this reply we will address the issues raised by RSS by first going over the reference system. This will be followed by a discussion concerning long-term polar wander and relative angular momentum. Then we go over the issues concerning the off-diagonal terms in the total moment of inertia and polar wander. Finally, the limitations of the normal-mode approach used by RSS are pointed out within the context of recent developments in geophysics.

J. Moser, C. Matyska, D.A. Yuen, A. Malevsky, H. Harder: Mantle rheology, convection and rotational dynamics. *Phys. Earth Planet. Inter.* **79**, 367-381, 1993

We have examined theoretically the effects from mantle convection on Earth rotational dynamics for both viscoelastic and viscous mantles. Strategies for numerical computations are proposed. A linear Maxwell viscoelastic rheology accounting for finite deformations associated with mantle convection is considered. For both rheologies the two sets of convection and rotational equations can be partitioned into separate systems with the output from convection being used as input for the rotational equations. The differences in this convection-rotational problem between finite-strain and small-amplitude viscoelastic theories are delineated. An algorithm based on the usage of massively parallel processors is proposed in which all of the different processes in the convection-rotational problem are partitioned and the different timescales can be dealt with together. The coupled systems of convective-rotational equations can greatly be simplified by using the hydrostatic approximation for the rotational readjustment process in a viscous Earth model.

This is valid for a young Earth and for non-Newtonian rheology. Larger amounts of contributions to the relative angular momentum can be expected from non-Newtonian rheology. The non-hydrostatic equatorial bulge may also be explained as a consequence of the long-wavelength dynamics associated with the effects of depth-dependent physical properties on mantle convection.

J.S. Sochacki, J. Zahradník, P. O'Leary: Finite-difference schemes for elastic waves based on the integration approach. *Geophysics*, in press

A 2nd order explicit finite-difference scheme for elastic waves in 2-D media, and a 1st order implicit scheme for a horizontal free surface are presented. These are modified versions of Sochacki et al. (1991) and (1987), respectively. The schemes are derived by integrating the equations of motion and the stress-free condition, respectively, before discretizing them on a grid. As an alternative free-surface treatment a practically useful vacuum formalism (an explicit 1st order scheme) is also suggested. It is proved to be a natural consequence of the integrated equations of motion. The consistency study reveals a close link between the vacuum formalism and the integrated/discretized stress-free condition, giving priority to the vacuum formalism when a material discontinuity reaches the free surface. The two presented free-surface treatments coincide in the sense of the limit (grid size approaching 0) for lateral homogeneity at or near the free surface.

P. Vaníček, Z. Martinec: The Stokes-Helmert scheme for the evaluation of a precise geoid. *Manuscr. Geod.*, in press

In this paper, we explore the theoretical properties of Stokes's solution to geodetic boundary value problem in Helmert's modification. We show that the formulation embodied in Helmert's "second condensation method" should remove the widespread objection to Stokes's approach - that the topographical density has to be known very accurately if an accurate geoid is to ensue - by reducing the effect of topographical masses by several orders in magnitude. The study draws heavily on several papers of ours on partial aspects of the Stokes-Helmert scheme that have been recently published.

D.A. Yuen, O. Čadek, R. Boehler, C. Matyska: Large cold anomalies in the deep mantle and mantle instability in the Cretaceous. *Terra Nova*, submitted

Two pools of large cold thermal anomalies in the deep mantle have been delineated and quantified by using long-wavelength seismic tomographic models in conjuction with the experimental parameters derived from high-pressure mineral physics. They are found under the western Pacific and South America with more than 1000 degrees below the ambient mantle temperature. In the middle of the lower mantle cold anomalies are around -500 K. A correlation is found between the current locations of these very cold masses and regions of past subduction since the Cretaceous. Correlation analysis shows that the slab mass-flux into the lower mantle does not behave in a steady-state fashion. These findings support the idea of a strong gravitational instability with origins in the transition zone. This phenomenon has been found in numerical models of mantle convection.

D.A. Yuen, O. Čadek, A. Chopelas, C. Matyska: Geophysical inferences of thermal-chemical structures in the lower mantle. *Geophys. Res. Lett.* **20**, 899-902, 1993

Lateral variations of the temperature field in the lower mantle have been reconstructed using new results in mineral physics and seismic tomographic data. We show that, with the application of high-pressure experimental values of thermal expansivity and of sound velocities, the slow seismic anomalies in the lower mantle under the Pacific and Africa can be converted into realistically looking plume structures with large dimensions of O(10^3 km). The outer fringes of the plumes have an excess temperature of around 400 K. In the core of the plumes are found tongue-like structures with extremely high thermal anomalies. These values can exceed 1200 K and are too high to be explained on the basis of thermal anomalies alone. We suggest that these major plumes in the deep mantle may be driven by both thermal and chemical buoyancies or that enhanced conductive heat-transport may be important there.

J. Zahradník, F. Hron: Robust finite-difference scheme for elastic waves on coarse grids. *Studia geoph. et geod.* **36**, 1-19, 1992

An explicit scheme for 2-D problems of P-SV waves is proposed, 4th order accurate in space and 2nd order accurate in time. The elastodynamic equations are discretized without destroying their self-adjoint nature. Twenty - four effective parameters are introduced at every grid point that make the scheme sensitive enough to spatial variations of the actual Lam parameters. The scheme is of the same form everywhere, including discontinuities. In particular, also the free surface is described without special formulas; the so-called vacuum formalism is developed. These features make the method simple and widely applicable. However, boundary conditions are only approximately satisfied. Nevertheless, comparisons with independent methods indicate satisfactory results. They include, for example, local Rayleigh waves and bidimensional resonances in basin-like models with strongly curved interfaces of a high velocity contrast (1:5), whose principal features were modelled by the present method well.

J. Zahradník, P. Moczo, F. Hron: Testing four elastic finite-difference schemes for behaviour at discontinuities. *Bull. Seism. Soc. Am.* **83**, 107-129, 1993

Three 2nd order and one 4th order finite-difference schemes are theoretically and numerically investigated for their behaviour at elastic discontinuities. One of them is extended with new formulas for a flat free surface. Two of the schemes are consistent with the stress-continuity condition for P-SV waves at discontinuities coinciding with horizontal (or vertical) grid lines, none of them are consistent at diagonal discontinuities. Despite these significant theoretical differences, the numerical results from all four schemes are very similar. Moreover, the results compare well with semianalytic solutions for three different models.

A practical conclusion is that the recent finite-difference schemes are by no means free from the accuracy problems at elastic discontinuities. Nevertheless, the schemes provide synthetic seismograms, whose differences are well below the level normally introduced by structural and focal uncertainties.

J. Zahradník, P. Moczo, F. Hron: Blind prediction of the site effects at Ashigara Valley, Japan, and its comparison with reality. *Nat. Hazards*, in press

Weak and strong ground motions were numerically predicted for three stations of the Ashigara Valley test site. The prediction was based on the records from a rock-outcrop station, one weak-motion record from a surface-sediments station, and the standard geotechnical model. The data were provided by The Japanese Working Group on the Effects of Surface Geology as a part of an international experiment. The finite-difference method for SH waves in a 2-D linear viscoelastic medium (a causal Q model) was employed.

Comparison with the real records shows that at two stations the predictions fit better than at the third one. Strangely, the two better predictions were for stations situated at larger distances from the reference rock station (one station was on the surface, the other in a borehole). The strong ground motion (the peak acceleration of about 200 cm/s/s) was not predicted qualitatively worse than the weak motion (8 cm/s/s). A less sophisticated second prediction (not submitted during the experiment), in which we did not attempt to fit the available weak-motion record at the sedimentary station, agrees with the reality significantly better.

J. Zedník, J. Janský, V. Červený: Synthetic seismograms in radially inhomogeneous media for ISOP applications. *Computers & Geosciences* **19**, 183-187, 1993

A program package for computation of three-component ray-synthetic seismograms in radially inhomogeneous media is presented. Interactive comparison of synthetic seismograms with records of teleseismic earthquakes demonstrates the value of such a display in aiding the seismic analyst in making a correct identification of later-arriving phases. The reporting and study of secondary phases represent important goals of the International Seismological Observing Period (ISOP).

EDUCATION

Geophysics is studied at the Faculty of Mathematics and Physics at two levels: undergraduate study and postgraduate study (doctoral study). Students are admitted to the faculty on a competitive basis by examination.

The *undergraduate study* of geophysics (3 years) is based on a previous thorough basic education in mathematics and physics (2 years). The first two years of study are common for all branches of physics. During these two years students attend lectures on differential and integral calculus, linear algebra, experimental physics, theoretical mechanics, classical electrodynamics, introduction to quantum mechanics and some others. The lectures are accompanied by excercises, seminars and practical training. Most of these subjects are compulsory. The students begin to specialize in the third year of study. The students who have chosen geophysics must attend obligatory lectures dealing with all main branches of solid Earth geophysics, i. e. gravimetry, seismology, geomagnetism and geoelectricity, geothermics, and constitution of the Earth. Also obligatory are lectures on mathematical physics, processing of geophysical data, inverse problems and continuum mechanics. As optional subjects, the students can choose, for example, lectures on potential theory, spectral methods, statistics, numerical methods and programming, Earth rotation, propagation of seismic body and surface waves, ray methods, dynamo theory, physics of ionosphere and magnetosphere, geophysical instruments, applied geophysics, geotectonics, dynamics of the Earth's mantle, and some others. For complete list, see the following section. In the fourth year of study the undergraduates also take up the subjects of their diploma theses. After passing the state examinations, usually at the end of the fifth year of study, the students receive the degree called "magister", abbreviation "Mgr.", which is equivalent to Master's degree.

The organisation of the *post-graduate study* has been changed in the last years. Now it is called the doctoral study and the students having finished this study receive the degree of "doctor" ("Dr."), which is equivalent to PhD. This study usually lasts 3 years for full-time students and about 5 years for part-time students. The individual study plan is in accordance with the previous education and the subject of his/her doctoral theses. The post-graduate students also attend some lectures and seminars of our department, or some of the other departments, too. But the main attention is paid to their independent study and scientific work. A very close cooperation with the Geophysical Institute and the Institute of Rock Structure and Mechanics of the Academy of Sciences of the Czech Republic is organized for these purposes. For foreign post-graduate students the lectures and seminars can be given in English.

Foreign students wishing to submit their application should ask Prof. O. Novotný for more detailed information.

LECTURES

Listed below are the lectures currently offered in Czech or English at our department. The compulsory and voluntary ones are not distinguished here, as the education system is rather flexible. No lectures belonging to the Mgr. and Dr. curricula are distinguished for the same reason. The lecture contents are presented concisely, as they also change according to the individual study plans. Typical durations of the lectures are expressed in teaching hours (45 minutes each), counting with two-three hours a week, as a rule.

Some lecturers listed below don't belong to the department staff directly. Those are our colleagues from Charles University (Prof. RNDr. J. Gruntorád, DrSc., Prof. RNDr. J. Jaroš, DrSc.), and from the Czech Academy of Sciences (RNDr. J. Buben, CSc., Prof. Ing. M. Burša, DrSc., RNDr. V. Fiala, CSc., Ing. P. Holota, DrSc., RNDr. J. Pek, CSc., Ing. A. Plešinger, DrSc., RNDr. V. Rudajev, DrSc. and Doc. RNDr. J. Vaněk, DrSc.).

Fourier spectral analysis, 30 hours
(J. Brokešová)

Fourier series. Fourier integral. Discrete Fourier transform. Alias effect. Hilbert transform. Spectral analysis. Frequency-time analysis. Seismological applications.

Geophysical instruments, 30 hours
(J. Buben)

Geodynamic, seismic and geomagnetic observatories. Instruments for laboratory modelling of geodynamic phenomena. Field instruments for geodetic, seismic and geoelectric measurements.

Satellite method of the gravitational field investigations,

30 hours
(M. Bura)

The motion of a satellite in the gravitational field, pertubation theory. Determination of parameters of the gravitational fields of the Earth, the Moon and planets.

Spectral tensors in geodynamics, 30 hours
(O. Čadek)

Application of generalized spherical harmonics to problems of mantle dynamics. Irreducible representation. Spherical vectors and tensors. Products of spherical tensors. Clebsch-Gordan coefficients. Wigner symbols. Spectral approach to solving the momentum equation. Other applications.

Inverse problem theory, 60 hours
(O. Čadek)

Basic theory of the inverse problem and its application in geophysics. Linear and non-linear problems. Least-squares criterion. L_1 and L_∞ - norms. Analysis of error and resolution. Monte-Carlo method. Gradient methods. Other techniques.

Propagation of seismic waves, 45 hours
(V. erven)

Elastodynamic equations for isotropic and anisotropic inhomogeneous media. Elastodynamic representation theorems. Various methods to solve the elastodynamic equation in 1-D and in laterally varying models (review). Simple solutions of the elastodynamic equations in inhomogeneous media. Plane waves. Reflection and transmission of plane waves at plane interfaces.

Energy considerations. Plane waves in isotropic and anisotropic models: Differences. High-frequency waves in slightly inhomogeneous media. Eikonal equation, transport equation. Point source solutions of the elastodynamic equation and elastodynamic Green functions. Reciprocity of the Green function.

Ray methods in seismology, 30 hours
(V. erven)

Solutions of elastodynamic equations by asymptotic high-frequency methods. Seismic rays and ray tracing in isotropic and anisotropic models. Rays as characteristics of the eikonal equation and as extremals of the Fermat's functional. Other definitions of rays. Shortest path network ray tracing. Fresnel volumes. Ray fields. Initial value and boundary value ray tracing. Ray Jacobian. Dynamic ray tracing. Paraxial ray method. Determinations of ray Jacobian by dynamic ray tracing. Other applications of dynamic ray tracing. Ray synthetic seismograms. Synthetic particle ground motions. Validity conditions of the ray method. Extensions and modifications of the ray method.

Physics of the ionosphere and magnetosphere, 30 hours
(V. Fiala)

Structure of the ionosphere and magnetosphere. Solar wind. Aurora. Experimental methods and results.

Applied geophysics, 60 hours
(J. Gruntorád)

Methods of the geophysical prospection: gravimetry, magnetometry, seismics, radiometry, geotermics, geoelectrics, borehole measurements.

Mathematical theory of the shape and the gravity field of the Earth, 30 hours
(P. Holota)

Methods to solve the boundary value problems of physical geodesy.

Exercise in seismology, 30 hours
(Jaromír Janský)

Application of some basic seismological methods on real data. Information about some more special problems. The extensive work with PC and use of the IASPEI Software Library (Vol. 5, Scherbaum & Johnson) is supposed.

Seismographs, their principle and calibration, recording systems, seismic signal distortion and restitution. Seismic records interpretation and bulletin production. International cooperation and seismological centres. Earthquakes localization (local and global seismic network). Estimation of the velocity-depth distribution and study of the influence of velocity jumps, low velocity zones and velocity gradient changes on the travel times of body waves. Computation of synthetic seismograms and amplitude curves of body waves (PREM Earth model, ray methods). Influence of source depth, radiation pattern and time function.

Geomagnetism and geoelectricity I, 30 hours
(A. Jankov)

Description of the Earth's electromagnetic field. Gauss's analysis of the geomagnetic field. Secular variations of the field, palaeomagnetism and its consequences in the study of global tectonics. Reversals of the geomagnetic field. Westward drift of the non-dipole field. Analysis of the geomagnetic time-series.

Geomagnetism and geoelectricity II, 60 hours
(A. Jankov)

Transient variations and disturbances of the geomagnetic field and their dependence on the solar activity. The electromagnetic induction in the Earth's mantle and the investigation of the electrical conductivity of the Earth. Origin of the Earth's magnetic field.

Dynamo theory of the geomagnetic field, 30 hours
(A. Jankov)

Cosmic magnetic fields. Basic concepts of the dynamo theory of magnetic fields of planets and stars. Mean field electrodynamics. Alpha-effect. Palaeomagnetism and the dynamo-theory.

Geotectonics, 45 hours
(J. Jaroš)

Fundamentals of petrology and structural geology. Plate tectonics. Geology of Czech Republic.

Continuum Mechanics, 45 hours
(Z. Martinec)

Euler and Lagrange description of deformation, deformation tensors. Length-, angle-, area- and volume-changes. Material derivatives of surface and volume integrals. Stress vector, the Cauchy and Piola-Kirchhoff stress tensors. Global and local balance laws, jump and boundary conditions. Constitutive equations, Hook's law, isotropic solids. Small motions in media with large static stresses. Orthogonal curvilinear coordinates.

Spectral analysis of geophysical data, 90 hours
(Z. Martinec)

Fourier transform, the Nyquist frequency, aliasing. Correlation and covariance functions. Power spectrum and its estimates, spectral windows, periodogram, Wiener-Khintchine theorem. Maximum entropy and maximum likehood spectral analysis. Theory of linear filtres, ideal filters, low pass-, band pass- and high pass-filters, Butterworth filter, cosine and binomial filters. Wiener-Hopf optimum filter. Minimum phase signals, z-transformation, minimum delay wavelet, Hilbert transform. Time-spectral analysis of dispersed seismic waves. Polarization analysis.

Boundary-value problems of physical geodesy, 30 hours
(Z. Martinec)

Stokes's and Molodensky's boundary value problem (BVP), Dirichlet's, Neumann's and Stokes's BVP for the Laplace equation. The geoid and the quasigeoid. The orthometric and normal heights. Scalar and vector formulation of BVP's. Free and fixed BVP's. Stokes' integral. Truncation error, Molodensky's truncation coefficients, Paul's coefficients. Ellipsoidal corrections. Continuation of the gravitational field, Poisson's integral. Helmert's condensation and isostatic reductions. Direct and indirect topographical effects.

Rotation of the Earth, 30 hours
(Z. Martinec)

Tidal potential. Rigid-body rotation. Euler's equations. Euler's angles. Chandler wobble. Tilt-over mode. Nutation and polar motion, Woolard's theory. Dynamics of a deformable earth. Euler-Liouville equations. Poisson equations. Secular Love number. Polar motion, precession and nutation for elastic earth. Tisserand figure axis. Poincare equations. SOS theory. Wahr's approach.

Constitution of the Earth, 45 hours
(C. Matyska)

The idea of lectures is to demonstrate historical outline and basic characteristics of various approaches employed for constructing global models of the Earth: seismic waves, free oscillations of the Earth and PREM, hydrostatic Earth, postglacial rebound and viscosities in the mantle, high-pressure mineral physics, global models of seismic tomography, 3-D geodynamic modelling.

Geothermics and radioactivity of the Earth, 45 hours
(C. Matyska)

Transfer of heat — basic equations. Heat sources, radioactive decay and absolute age determination. Green's functions for 1-D heat conduction. Problems of 2-D and 3-D downward heat flow continuation. Cooling of the oceanic lithosphere. Guesses of the horizontally averaged temperature depth-profile in the mantle and the core. Conditions for the onset of convective motions.

Selected chapters from partial differential equations, 30 hours
(C. Matyska)

Classification of the second-order equations. Domains with the Lipschitz boundary. Sobolev spaces. Dirichlet and Neumann problems for elliptic equations — weak formulation and variational approach. Basic ideas of the finite element method. Non-linear equations for strongly monotonous operators.

Geodynamics, 30 hours
(C. Matyska and O. Čadek)

Thermal convection — basic equations. Boussinesq approximation. Dimensionless quantities. 2-D modelling — stream function. Spectral decomposition. Linear theory of convection — critical Rayleigh number. Transition from the stable steady-state solutions to deterministic chaos. Influence of thermal and pressure dependence of viscosity. Models with a non-linear rheology.

Plate motion. Seismic tomography and density structure of the mantle. Infering viscosity from geoid. Spherical harmonic analysis: the fundaments. Post-glacial rebound.

Gravity field and shape of the Earth, 45 hours
(O. Novotný)

Motions of the Earth. Gravimetric and satellite methods of investigating the gravity field and shape of the Earth.

Matrix methods in seismology, 30 hours
(O. Novotný)

The matrix relation between the displacements and stresses at the boundaries of a layer and a system of layers. Thomson-Haskell matrices and their modifications. Applications in the theory of body and surface waves.

Review of geophysics, 30 hours
(O. Novotný)

Shape of the Earth (development of concepts). Foundations of gravimetry, geomagnetism and seismology. A review for students of meteorology and others.

Newtonian potential in physical sciences, 30 hours
(O. Novotný)

Newtonian potential in the form of spherical function series, which appears in electrostatics, magnetostatics, geophysics and astronomy.

Numerical methods, 90 hours
(O. Novotný and J. Zahradník)

Linear and nonlinear equations, applications in the inverse geophysical problems. Ordinary and partial differential equations, applications in the direct geophysical problems. Finite-difference methods for seismic wave propagation problems.

Seismic surface waves, 30 hours
(O. Novotný)

The interference character of surface waves, Rayleigh and Love waves. Waves in layered media, matrix methods. Analysis of dispersed signals.

Potential of regular bodies, 15 hours
(O. Novotný)

Newtonian and logarithmic potential, simple bodies. Elliptic integrals of an ellipsoid. The students will be acquainted with difficult multiple integrals, in the calculation of which many famous mathematicians participated (Lagrange, Gauss and others) and which appear in many applications in physics, geophysics and astronomy.

Magnetotelluric and magnetovariational method, 30 hours
(J. Pek)

Methods of deep geoelectrical study of the Earth. Models of distribution of electric conductivity in the Earth.

Contemporary instrumental seismology, 30 hours
(A. Plešinger)

Fundamentals of the signal theory and of linear dynamic systems, principles of digital seismometry. Analysis of digital seismograms. Selected interpretation procedures of seismic source and structural studies.

Induced seismicity, 30 hours
(V. Rudajev)

Seismic phenomena caused by a technical human activity - water reservoirs, mining for gas, oil and coal. Consequences of rockbursts, their mechanism and prediction. Monitoring polygons.

Selected chapters from programming, 45 hours
(L. Urban)

Personal computers, operational systems, peripheries. FORTRAN, Turbo Pascal. Text and graphic editors.

Seminar on computer graphics, 15 hours
(L. Urban)

Overview of graphical adapters. Basic graphical functions and procedures in Turbo Pascal. EGA, VGA, SVGA. Introduction into computer animation.

Introduction to geophysics, 45 hours
(O. Novotný and J. Zahradník)

The Earth as a planet. Observational data and theoretical principles of gravimetry, geomagnetism and seismology. Physical parameters and processes in the Earth's crust, mantle and core.

Seismology, 45 hours
(J. Zahradník)

Macroseismic and instrumental observations. Seismicity of the Earth. Physical processes in the earthquake foci. Seismic body waves and surface waves in simpler Earth models. Inverse seismic problems. Seismic hazard, zonation and microzonation.

Earthquake foci, 30 hours
(J. Zahradník)

Generation of seismic waves by earthquakes. Retreiving focal parameters from seismic observations (fault-plane solution, seismic moment tensor, source extent, stress drop, seismic energy). Numerical modelling of strong ground motions.

DIPLOMA THESES DEFENDED 1990 - 1993

F. Čermák: Spectral and time-frequency methods for computing surface waves dispersion.
(supervisor: O. Novotný)

L. Hanyk: Normal mode splitting of the Earth due to lateral variations of density.
(supervisor: Z. Martinec)

P. Hrdina: Modelling of the stress field in the lithosphere.
(supervisor: O. Čadek)

M. Chmelař: Computations of the internal gravitational potential.
(supervisor: Z. Martinec)

J. Chroust: Accuracy problems of the elastic waves modelling on curved discontinuities.
(supervisor: J. Zahradník)

P. Kolašín: Potential of a homogeneous three-axial ellipsoid.
(supervisor: O. Novotný)

M. Krejčík: Polarisation analysis.
(supervisor: O. Novotný)

M. Kvasnička: Interaction of a spatial-time ray with a moving interface.
(supervisor: J. Zahradník)

E. Mahdalová: Thermal convection in the Earth's mantle.
(supervisor: C. Matyska)

J. Moser: Influence of topography on the free oscillations of the Earth.
(supervisor: Z. Martinec)

R. Moserová: Symmetries of geophysical fields.
(supervisor: C. Matyska)

P. Nekola: Seismic surface waves in laterally inhomogeneous media.
(supervisor: O. Novotný)

A. Novák: The method of singular value decomposition in inverse problems.
(supervisor: O. Novotný)

T. Semerák: A second-order finite-difference method for P-SV waves.
(supervisor: J. Zahradník)

M. Staša: Computations of seismic energy.
(supervisor: J. Zahradník)

M. Vaicová: Gravity field and the figure of the Earth.
(supervisor: K. Pěč)

R. Zima: Tidal influence of the Moon and the Sun.
(supervisor: C. Matyska)

DIPLOMA THESES UNDER PREPARATION

E. Apostolopoulos: Characteristics of earthquake occurence at western coast of Greece.
(supervisor: V. Schenk, Geophysical Institute, Czech Academy of Sciences)

J. Blaek: Sudden changes in the secular acceleration of the geomagnetic field.
(supervisor: A. Jankov)

M. Brajanovsk: Robust estimation of the magnetotelluric tensor-Q-W- algorithm.
(supervisor: J. Pek, Geophysical Institute, Czech Academy of Sciences)

P. Bulant: Two-point boundary problem for rays in 3-D structures.
(supervisor: L. Klime)

B. Bystrzyck: Density structure of Venus.
(supervisor: O. Čadek)

D. Bystrzycki: Basic characteristics of the Saltzman equations.
(supervisor: C. Matyska)

R. : Seismic tomography with applications in mining.

(supervisor: O. Novotn)

L. Eisner: Higher order ray-theory approximations for seismic waves.
(supervisor: I. Penk, Geophysical Institute, Czech Academy of Sciences)

L. Ivanova: Secular variation jerk about the year 1910.
(supervisor: A. Jankov)

P. Jlek: Influence of local structures in vicinity of source and receivers upon seismic wave fields.
(supervisor: I. Penk, Geophysical Institute, Czech Academy of Sciences)

J. Jindra: Surface wave dispersion along selected Euroasiatic paths.
(supervisor: O. Novotn)

M. Klika: Modelling flow in the mantle with a 3-dimensional viscosity structure.
(supervisor: O. Čadek)

P. Knov: Influence of the electric-field anomalies on the distribution of the particles in the external ionosphere.
(supervisor: J. Bokov, Geophysical Institute, Czech Academy of Sciences)

J. Kua: Dispersion curves for leaking modes of Love waves.
(supervisor: O. Novotn)

H. Kvalov: Phase transitions and the dynamics of the mantle.
(supervisor: O. Čadek)

J. Matas: Infering density and viscosity structure of the mantle from seismic tomography and geoid.
(supervisor: O. adek)

E. Ondroukov: Investigation of the space distribution of the rate and acceleration of the geomagnetic secular variation.
(supervisor: A. Jankov)

A. Pavlov: 2-D study of the westward drift.
(supervisor: A. Jankov)

V. Plicka: Modelling earthquakes with empirical Green functions.

(supervisor: J. Zahradník)

J. Prochzka: Secular variation of the geomagnetic field on the teritory of Bohemia and Moravia.
(supervisor: I. Cupal, Geophysical Institute, Czech Academy of Sciences)

Z. Schenkov: An attempt to interpret the seismic-noise spectra at sites in Southern Spain.
(supervisor: J. Zahradnk)

P. Trefn: Comparison of computer methods for K-index determination and suitability of their application to geomagnetic data of the Budkov Observatory.
(supervisor: J. Bochnek, Geophysical Institute, Czech Academy of Sciences)

L. Vecsey: Variational approaches to the solution of the free oscilations of the Earth's general model.
(supervisor: Z. Martinec)

DOCTORAL THESES DEFENDED 1990 - 1993

O. Čadek: Modelling of three-dimensional convection in the Earth's mantle.
(supervisor: K. Pěč)

DOCTORAL THESES UNDER PREPARATION

J. Brokešová: High-frequency ground motions due to extended seismic sources in complex structures. *Submitted 1993.*
(supervisor: V. Červený)

R. Bystrick: Finite-difference studies of seismic waves at liquid-solid interfaces.
(supervisor: J. Zahradník)

L. Hanyk: Post–glacial rebound in a real Earth.
(supervisor: O. Čadek)

J. Chroust: Modelling of seismic waves by combined numerical methods.
(supervisor: J. Zahradník)

M. Kvasnička: Computing Fresnel volumes and Fresnel zones in 2-D and 3-D inhomogeneous media.
(supervisor: V. Červený)

J. Málek: Interpretation of seismograms of the Kladno coal-mine network.
(supervisor: O. Novotný)

J. Moser: Dynamics of the mantle and the rotation of the Earth. *Submitted.*
(supervisor: Z. Martinec)

J. Pospíšil: Investigations of the lithosphere in Europe by means of broad-band seismic observations.
(supervisor: O. Novotný)