Rolf-Meissner-Symposium:

From Crustal Seismology to Geodynamics

Abstract Volume

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FRIDAY 05 June 2015		Speaker	Theme	Chairperson
11:30	...		Registration	
12:30	5 min	W. Rabbel	Welcome	W. Rabbel
12:35	10 min	W. Duschl	Opening address of the Dean of th MNF	
12:45	15 min	J. Zschau	Rolf Meissner	
13:00	30 min	L. Brown	COCORP, INDEPTH and the Legacy of Rolf Meissner (Keynote)	
13:30	30 min	J. Mechie	Imaging the Himalayas and Tibet with seismic methods (Keynote)	
14:00	20 min	X. Yuan	Depth-variant azimuthal anisotropy in Tibet	
14:20	30 min		**Coffee & Posters**	
14:50	30 min	W. Mooney	Deep Structure of Mountain Belts and the Tectonics of the 2015 M7.8 Nepal Earthquake (Keynote)	H. Kopp
15:20	30 min	H. Thybo	The lithosphere in cratonic margins (Keynote)	
15:50	20 min	R. Kind	Structure of the upper mantle in the north-western and central United States from USArray S-receiver functions	
16:10	20 min	C. Schiffer	The geophysical and isostatic expression of the East Greenland Caledonides	
16:30	50 min		**Poster-Session**	
17:20	20 min	B. Luehr	The ascent and storage of fluids and melts at subduction zones	J. Ebbing
17:40	20 min	I. Wölbern	Crustal thickness beneath Central Java obtained from H-k stacking	
18:00	20 min	J. Bialas	Variable spreading cycles at a MAR segment end	
18:20	20 min	C. Berndt	Tectonic controls on gas hydrate distribution off Taiwan	
18:40	20 min	H. Kopp	Going offshore: First deployments of the GeoSEA Array	
19:00	...		**Dinner**	

SATURDAY 06 June 2015		Speaker	Theme	Chairperson
9:00	30 min	I. Artemieva	Crustal and upper mantle structure beneath Eurasia (Keynote)	T. Meier
9:30	20 min	R. England	The Moho in and around Europe	
9:50	20 min	R. Carbonell	Deep Seismic Sounding Exploration in Iberia Peninsula	
10:10	20 min	J. Díaz	The seismic component of Topo-Iberia: an example of a new generation of crustal seismology experiments	
10:30	30 min		**Coffee & Posters**	
11:00	20 min	T. Meier	Evolution of the continental lithosphere in central Europe	S. Krastel
11:20	20 min	N. Balling	The lithosphere around the Northern Tornquist Zone	
11:40	20 min	B. Almqvist	Seismic properties of orogenic middle crust in the central Scandinavian Caledonides	
12:00	20 min	M. Malinowski	Results of the deep reflection seismic imaging in SE Poland using extended correlation method applied to PolandSPAN data	
12:20	60 min		**Lunch Break**	
13:20	20 min	D. Snyder	Tectonic wedges, seismic crocodiles & grey noise	M. Thorwart
13:40	20 min	B. Milkereit	Seismic reflections: how forgetful are seismic waves?	
14:00	20 min	D. Gajewski	Diffractions: Are we using the imaging potential?	
14:20	20 min	D. Wehner	A combined elastic waveform and gravity inversion	
14:40	20 min	L. Vinnik	Crustal models from joint inversion of P- and S-wave receiver functions	
15:00	15:20		**Closing remarks**	

	Author(s)	Poster Presentations
1	L. Cristiano, A. Minakov, T. Meier, H. Keers	Observation and modelling of P-wave polarization for teleseismic events
2	R. A. Soomro, C. Weidle, L. Cristiano, S. Lebedev, T. Meier	Phase velocities of Rayleigh and Love waves in central and northern Europe from automated, broadband, inter-station measurements
3	J. Ebbing	The Blue Norma experiment revisited
4	F. Pappa	Lithospheric thickness at the Sorgenfrei-Tornquist Zone
5	M. Malinowski	Crustal structure of the East European Platform margin and its foreland based on the POLCRUST-01 deep reflection seismic profile
6	M. Thorwart , W. Rabbel	The crustal structure of Avalonia beneath Schleswig-Holstein as seen by surface waves of the Mw=9.0 2011 Tohoku Earthquakes
7	Eckhardt, Thorwart, W. Rabbel	Regional domains of crustal seismic anisotropy in the central European Variszides
8	J. Strehlau	Earthquakes and metamorphism in the lower continental crust
9	J. Díaz, J. Gallart, R. Carbonell, D. Córdoba	Crustal structure beneath the Iberian Peninsula and surrounding waters from active seismic experiments; a case example
10	M. Sobiesiak, T. Schaller, B. Gutknecht	Batholitic structures influence seismogenic processes in the North Chilean Seismic Gap
11	J. Geersen and J. Behrmann	Mass-balancing the accretionary prism of Central Chile
12	L. Dzieran, M. Thorwart, O. Ritter, W. Rabbel	Seismo-electromagnetic signals of earthquakes in South and Central America
13	D. Lange and 6 co-authors	The velocity structure of the Central Sumatran forearc
14	Eken, T., Tilmann F., Yuan X., Kufner, S. et al.	Contrasting SKS and local shear wave observations in the Pamir-Hindukush continental collision zone
15	C. Weidle, P. Agard, C. Ducassou, I. El-Hussain, C. Prigent, T. Meier	COOL: Crust of the Oman Ophiolite and its Lithosphere – a passive seismic experiment
16	P. Haas	Geoid-anomalies of passive margins from satellite data and interpretation by isostatic models
17	W. Szwillus	Depth sensitivity of satellite gravity gradients
18	N. Holzrichter	Improved lithospheric density model and heat flow estimation
19	M. Thorwart and 9 co-authors	Geothermal assessment based on seismic, magnetotelluric and potential field analysis and hydrothermal forward modeling -an example from Southern Tuscany (Italy)
20	W. Rabbel, E. Szalaiová	Seismic assessment of geothermal potential of crystalline crust
21	H. Wiederhold	Glacial tectonics and erosion - effects on groundwater pathways
22	D. Köhn, D. Wilken, C. Mohr, W. Rabbel	Disaggregation of marine sediments monitored offshore by waveform inversion of Stoneley waves
23	F. Gross et al.	Continental margin instability and its relation to volcano buildup offshore the edifice of Mt Etna, Italy

Participants

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Oral Presentations

Friday, 05 June 2015, 13:00 – 13:30

COCORP, INDEPTH and the Legacy of Rolf Meissner

Larry D. Brown

Earth and Atmospheric Sciences, Cornell University, USA

In 1975 a relatively small group of U.S. scientists carried out a small seismic survey in a remote part of the state of Texas. The goal was to demonstrate whether the multichannel seismic reflection method as developed by the oil and gas industry could be systematically used to explore the deep continental crust. The success of this test was largely assured by prior knowledge of oil exploration data that had found prominent layering in the Precambrian basement beneath the test site. But the experiment itself was inspired by pioneering experiments using this method in other parts of the world, especially Australia, Canada and most notably Germany. Of the latter, it was the work of Rolf Meissner in the 1970's that perhaps best foretold the nature of this new technology and its potential for transforming our understanding of continental structure and evolution. The Texas experiment became known as the first field foray of a group known as COCORP, and from that relatively modest beginning there arose a series of large-scale national programs around the world to systematically map the details of the deep continental lithosphere. Among the most direct offspring of COCORP were the BIRPS program in England, the ECORS program in France, the LithoProbe program in Canada and, of course, the DEKORP program in Germany, which Rolf was so instrumental in establishing. Rolf was also influential in what could be considered the first truly global consortium for deep reflection profiling, Project INDEPTH, which was launched in 1992 to begin is two decade long effort to transect the Himalayas and Tibetan Plateau. In this talk I review some of the highlights of the deep seismic reflection-profiling era that Rolf helped launch, identify some remaining challenges, and reflect on the role of reflection profiling in the modern landscape of lithospheric seismology. Lastly I will describe some fresh opportunities in deep reflection profiling enabled by recent technological advances.

Friday, 05 June 2015, 13:30 – 14:00

Imaging the Himalayas and Tibet with seismic methods

James Mechie

Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences, Potsdam, Germany

The involvement of German institutions in the INDEPTH (INternational DEep Profiling of Tibet and the Himalaya) project comprised the participation in the reconnaissance survey in the late eighties and in phases II to IV of the main project from 1994 until the present-day. In all these efforts Rolf Meissner was one of the principal investigators from the German side. Based on the INDEPTH II data, R. Meissner proposed a temperature profile through the Tibetan crust – one of the few people to do so. From the INDEPTH III data, R. Meissner derived the detailed structure of the Moho beneath central Tibet. In this contribution a 700 km deep seismic velocity cross-section beneath the Lhasa to Golmud transect across the Tibetan plateau will be presented, based to a large extent on the results of the INDEPTH project. Beneath the cover layer, felsic rocks rich in alphaαquartz exist down to 15-25 km depth. Beneath these depths, temperatures are probably high enough for ductile flow and partial melting to occur. The velocity increase across the boundary at 30-40 km depth marks the interface between felsic upper crust and more mafic lower crust. Crustal thickness is greatest (~74 km) south of ~31.5°N, where Indian lower crust forms the basal layer. Northwards, crustal thickness decreases to ~64 km around 33°N, before increasing to ~70 km beneath northern Tibet. About 100 km north of the Kunlun Fault, the crust thins to ~50 km beneath the Qaidam basin. Beneath the crust, high-velocity, dense, cold Indian lithospheric mantle extends northwards until about the Banggong-Nujiang suture. Northwards, Asian lithospheric mantle is overlain by a low-velocity, less dense, warm Tibetan plate consisting of an upper lithospheric and a lower asthenospheric part. The apparent northwards deepening of the 410 and 660 km discontinuities by about 20 km implies that the upper mantle beneath north Tibet is slower, less dense and warmer than under south Tibet, in agreement with the observed uppermost mantle velocities. This, in turn, could provide some of the isostatic support for the high elevations in the north where the crust is somewhat thinner than in the southern plateau.

Friday, 05 June 2015, 14:00 – 14:20

Depth-variant azimuthal anisotropy in Tibet

Xiaohui Yuan

Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences, Potsdam, Germany

Azimuthal anisotropy derived from a multi-mode Rayleigh wave tomography in China exhibits depth-dependent variations in Tibet, which can be explained as induced by the Cenozoic India-Eurasian collision. In west Tibet, the E-W fast polarization direction at depths <100 km is consistent with the accumulated shear strain in the Tibetan lithosphere, whereas the N-S fast direction at greater depths is aligned with the Indian plate motion. In northeast Tibet, depth-consistent NW-SE directions imply coupled deformation throughout the whole lithosphere. Significant anisotropy at depths of 225 km in southeast Tibet reflects the sublithospheric deformation induced by the northward and eastward lithospheric subduction beneath the Himalaya and Burma, respectively. The multi-layer anisotropic surface wave model can explain some features of SKS splitting measurements in Tibet, with differences probably attributable to the limited backazimuthal coverage of most SKS studies in Tibet and the limited horizontal resolution of the surface wave results.

Friday, 05 June 2015, 14:20 – 14:50

COFFEE & POSTER

Friday, 05 June 2015, 14:50 – 15:20

Deep Structure of Mountain Belts and the Tectonics of the 2015 M7.8 Nepal Earthquake

Walter D. Mooney

Earthquake Science Center, Menlo Park, USA

Rolf Meissner made many fundamental contributions to studies of the structure and evolution of mountain belts, ranging from the Andes of South America to the Tibetan Plateau. The 2015 M7.8 earthquake in Nepal highlights the importance of these studies, not only for their basic scientific value, but for their application to the reduction of earthquake hazards. Knowledge of crustal structure in seismically active regions is needed to accurately locate hypocenters, model of strong motion data, and constrain rheological models. In this talk I examine the contributions of geophysical studies, especially crustal imaging, to understanding the tectonic setting of the 2015 Nepal earthquake. The systematic investigation of the Himalayas begin in 1851 with the appointment of T. Oldham as Director of the Geological Survey of India. The first geophysical inferences regarding the Himalayas were made in 1985 by Pratt and Airy based on topographic and geodetic data. Middlemiss (1910) published a classic study of the 1905 M7.8 Kangra earthquake. Earthquake relocation studies (e.g., Ni and Barazangi, 1984) defined the geometry of the Indian plate beneath the high Himalayas. Seismic reflection imaging was first provided by the INDEPT I profile (Zhao et al., 1993). This profile succeeded in providing a spectacular image of the main detachment fault and Moho beneath southern Tibet. Detailed passive-source imaging of the lithospheric structure of Nepal and Tibet is presented by Nabelek et al (2009). Caldwell et al. (2013) reprocessed these data to image the structure of the shallow-dipping detachment surface corresponding to the 2015 Nepal earthquake. Teleseismic earthquake modeling by the USGS provides a finite fault model for the 2015 event that has a dimension of 160 km along strike and about 100 km along dip. Slip is confined to a depth of 5-25 km, in agreement with some thermal models of this collisional orogen. I present a multi-disciplinary comparison of geologic and geophysical results that highlight the progress made in the past several decades in the study of mountain belts and their seismic hazards. It also points out the gaps in out present knowledge. Newly developed, highly portable seismic nodes now make it possible to efficiently record seismic reflection profiles in the Himalayas. Such data would provide a significant advance in understanding the tectonics of this region that has a high seismic hazard.

Friday, 05 June 2015, 15:20 – 15:50

The lithosphere in cratonic margins

Hans Thybo

University of Copenhagen, Copenhagen, Denmark

Tectonic structure and geophysical characteristics of palaeo-collisional belts was one of Rolf Meissner's many scientific interests. Craton margins show large variability from active or former orogens to continental shelves and passive margins. Generally, craton edges are characterised by an abrupt change in crustal thickness, average seismic velocity, and lithosphere thickness as well as in seismic reflectivity of the mantle lithosphere. The crustal tectonic style in collisional settings often includes "crocodile tectonics" as proposed by R. Meissner based on his extensive seismic studies. Cratonic margins include transitions from craton to younger provinces, where parts of the former cratonic margins often have been subject to substantial tectono-magmatic activity and crustal/lithospheric thinning. The continental "passive" margins of cratons mainly show substantial thinning of the crust and lithosphere caused by the rifting and break-up processes. Remarkably, many cratonic margins have been uplifted close to the coastline while the shelves have subsided. This observation remains enigmatic and explanation requires extensive new geophysical data acquisition linked with numerical modelling of tectonic and geodynamic processes.
Examples of the geological-tectonic-geophysical changes across the TransEuropean Suture Zone (TESZ), North America, Siberia and the North Atlantic region will be presented. The TESZ transition will receive special attention, as it was one of the main study areas for Rolf Meissner's geophysical-tectonic studies. It forms the highly variable transition from craton to younger provinces in Europe, spanning from the transition into oceanic crust in the Black Sea, into deep sedimentary basins in Romania, Poland and Denmark and into the Carpathian mountains in Poland-Slovakia. This suture zone has been subject to several collision events since Proterozoic times. The latest occurred when the Caledonian/Variscan orogenies shaped present day central Europe, and has been succeeded by rifting, lithosphere thinning and formation of deep basins.

Friday, 05 June 2015, 15:50 – 16:10

Structure of the upper mantle in the north-western and central United States from USArray S-receiver functions

Rainer Kind

Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences, Potsdam, Germany

We used more than 40,000 S-receiver functions recorded by the USArray project to study the structure of the upper mantle between Moho and the 410-km discontinuity from the Phanerozoic western United States to the cratonic central US. We obtained clear observations of downward velocity reductions in the uppermost mantle which are commonly interpreted as lithosphere-asthenosphere boundary (LAB) in the western US and as mid-lithospheric discontinuity (MLD) in the cratonic US. We observe the western LAB reaching partly to the mid-continental rift system underneath the cratonic crust. The MLD is surprisingly plunging steeply towards the west from the Rocky Mountains Front to about 200 km depth near the Sevier Thrust Belt. There is a significant break in the lithosphere at the Sevier Thrust Belt. We also observe a velocity reduction about 30 km above the 410-km discontinuity in the same region where in the western US the LAB is observed, but not in the cratonic US.

Friday, 05 June 2015, 16:10 – 16:30

The geophysical and isostatic expression of the East Greenland Caledonides

Christian Schiffer

Department of Geoscience, Aarhus University, Denmark

The detailed tectonic evolution and the present-day geodynamic state of the Palaeozoic Caledonian Orogen in East Greenland is generally poorly understood. The isostatic state of the East Greenland Caledonides is matter of discussion and deep structural information related to the general tectonic development during the collision of Baltica, Laurentia and Avalonia and numerous microcontinents is sparse.

Constraints on timing, location and polarity of most likely several subduction and collision events are diffuse. The ages of metamorphic rocks and orogenic magmatics for instance show a large variability along the passive margins of East Greenland and Norway. The surface geological expression indicates a bivergent orogen. Previously no deep geophysical image of a possible subduction or suture zone was obtained in the Caledonian Orogen.

A teleseismic receiver function signature of a recently imaged eastward dipping sub-Moho structure in the East Greenland Caledonides indicates high velocities, possibly associated with subducted and eclogitized crust. Thus the structure is interpreted as a fossil Caledonian subduction complex which is corroborated by its strong spatial correlation to the Caledonian Deformation Front.

Previous wide angle seismic images and gravity modelling in East Greenland indicate a crustal root beneath high topography. The receiver function image supports this tendency, however shows some considerable differences to previous data.

Further investigation of the structure by receiver function inversion and gravity modelling gives insight into the crustal structure and isostatic state of the East Greenland Caledonides and the nature and origin of the eastward dipping upper mantle structure. Preliminary results confirm the existence of a crustal root underlain by a complex upper mantle including high velocities and densities in the dipping upper mantle structure.

Friday, 05 June 2015, 16:30 – 17:20

COFFEE & POSTER

Friday, 05 June 2015, 17:20 – 17:40

The ascent and storage of fluids and melts at subduction zones

Birger-G. Luehr (1), Ivan Koulakov (2), Zulfakriza Zulhan (3), Heidrun Kopp (4), Wolfgang Rabbel (5), Kirbani Sri Brotopuspito (6), Ir. Surono (7), P. J. Prih Harjadi Suhardjono (8), Jochen Zschau (9)

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9) Institute of Earth and Enviromental Science, University of Potsdam, Potsdam, Germany

During the last decades active continental margins were investigated to understand the link between the subduction of fluid saturated oceanic plates and the process of ascent of these fluids and partial melts forming magmatic system that leads to volcanism at the earth surface. For this purpose the geophysical structure of the mantle and crustal range above the down going slap has to be resolved, Furthermore, information are required about slap, the ascent paths as well as the storage of fluids and partial melts in the mantle and the crust up to the volcanoes at the surface. Statistically the distance between the volcanoes of volcanic arcs down to their Wadati Benioff zone results of approximately 100 kilometers in mean value. Surprisingly, this depth range shows pronounced seismicity at most of all subduction zones. Additionally, mineralogical investigations in the lab have shown that the diving plate is maximal dehydrated at around 100 km depth because of temperature and pressure conditions at this depth range. However, assuming a vertical fluid ascent there are exceptions. For instance at the Sunda Arc beneath Central Java the vertical distance results in approximately 150 km. But, in this case seismic investigations have shown that the fluids do not ascend vertically, but inclined even from a source area at around the 100 km depth. The ascent of the fluids and the appearance of partial melts as well as the distribution of these materials in the crust can be proved by seismic and seismological methods. With the seismic tomography these areas are imaged by lowered seismic velocities, high Vp/Vs ratios, as well as increased attenuation of seismic shear waves. But, to explore plate boundaries large and complex amphibious experiments are required, in which active and passive seismic investigations should be combined. They have to recover a range from before the trench to far behind the volcanic chain, to provide under favorable conditions information down to a depth of 150 km. In particular the record of the natural seismicity and its distribution allows the three-dimensional imaging of the entire crust and lithosphere structure above the Wadati Benioff zone with the help of tomographic procedures, and, therewith the exposure of the entire ascent path region of fluids and melts, which are responsible for volcanism. The seismic velocity anomalies detected so far are within a range of a few per cent to more than 30% reduction. In the lecture findings of different subduction zones will be compared and discussed.

Friday, 05 June 2015, 17:40 – 18:00

Crustal thickness beneath Central Java obtained from H-k stacking

Ingo Woelbern, Georg Ruempker

Institut of Geoscience, Goethe University Frankfurt, Frankfurt, Germany

It is generally accepted that Southeast Asia comprises a complex assemblage of continental terranes, volcanic arcs and suture zones. The formation of SE Asia is assumed to have started in the Early Devonian with the opening of the Palaeo-Tethys ocean accompanied by the rifting of continental fragments from the NE margin of Gondwana. Two other episodes of rifting followed during the Early Permian and the Late Triassic to Jurassic and were connected with the opening of the Meso-Tethys and the Ceno-Tethys ocean, respectively. The continental fragments have subsequently moved northward and amalgamated to form the continental core of SE Asia. However, there is still a lack of detailed information about the boundaries between the individual blocks or the thickness of the crust leading. Indonesia is situated today at the southern continental margin of South East Asia being part of the volcanic Sunda arc. The formation of Java has likely started with the collision of the Southwest Borneo block in the Early Cretaceous and was completed with the accretion of East Java–West Sulawesi during the Late Cretaceous. These Gondwana-derived fragments are divided by the Meratus suture complex representing the remnants of the subducted Meso-Tethys ocean. However, its width and exact location zone are not well constrained and differ in previous publications. We use teleseismic receiver functions extracted from data of the MERapi AMphibious EXperiment (MERAMEX) to address these questions. For this purpose we determine the thickness beneath Central/East Java utilizing the H-k stacking approach in order to verify the extent of the continental fragments and the suture zone between them. Our results indicate continental crust of uniform thickness in the southern and northern parts of the study area. In between, the crust is thinner by at least 3-4 km which we suggest to represent the Meratus suture zone. Anomalously thick crustal bodies are observed to line up west and north of the thinned area which we interpret as a result of overthrusting and compressional deformation within the former collision zone between two continental fragments.

Friday, 05 June 2015, 18:00 – 18:20

Variable spreading cycles at a MAR segment end

Joerg Bialas (1), Anke Dannowski (1), Timothy J. Reston (2)

1) GEOMAR, Helmholtz Centre for Ocean Research Kiel, Germany
2) University of Birmingham, Birmingham, UK

A wide-angle seismic section across the Mid-Atlantic Ridge just south of the Ascension transform system reveals laterally varying crustal thickness, and to the east a strongly distorted Moho that appears to result from slip along a large-offset normal fault, termed an oceanic detachment fault. Gravity modelling supports the basic crustal structure. We investigate the interplay between magmatism, detachment faulting and the changing asymmetry of crustal accretion, and consider several possible scenarios. The one that appears most likely is remarkably simple: episodes of detachment faulting which accommodate all plate divergence and result in the westward migration of the ridge axis, are interspersed with dominantly magmatic and moderately asymmetric (most on the western side) spreading which moves the spreading axis back towards the east. We also infer that although the crustal thickness varies considerably, the magma production may have been relatively constant, only to be unevenly distributed during detachment faulting. Following the runaway weakening of a normal fault and its development into an oceanic detachment fault, magma both intrudes the footwall to the fault, producing a layer of gabbro (subsequently partially exhumed), and also intrudes and "underplates" the hanging wall crust immediately west of the root zone, resulting in the local increase in the thickness of the magmatic crust.

Friday, 05 June 2015, 18:20 – 18:40

Tectonic controls on gas hydrate distribution off Taiwan

Christian Berndt, W.-C. Chi, M. Jegen, S. Muff, S. Hoelz, E. Lebas, M. Sommer, S. Lin, S.-C- Liu, A.T. Lin, D. Klaeschen, I. Klauke, L. Chen, P., Kunath, K. McIntosh, T. Feseker

GEOMAR, Helmholtz Centre for Ocean Research Kiel, Germany

The northern part of the South China Sea is characterized by wide-spread occurrence of bottom simulating reflectors (BSR) indicating the presence of marine gas hydrate. Because the area covers both the tectonically inactive passive margin and the northern termination of the Manila Trench subduction zone while sediment input is broadly similar, this area provides an excellent opportunity to study the influence of tectonism on the dynamics of gas hydrate systems. Long-offset multi-channel seismic data show that movement along thrust faults and blind thrusts caused anticlinal ridges on the active margin while much fewer faults are imaged on the passive margin. This coincides with high hydrate saturation derived from ocean bottom seismometer data and controlled source electromagnetic data and conspicuous high-amplitude reflections in P-Cable 3D seismic data above the BSR in the anticlinal ridges of the active margin. On the contrary all geophysical evidence for the passive margin points to normal to low hydrate saturations. Geochemical analysis of gas samples collected at seep sites on the active margin show methane with heavy δ13C isotope composition, while gas collected at the passive margin shows highly depleted (light) carbon isotope composition. Thus, we interpret the passive margin as a typical gas hydrate province fuelled by biogenic production of methane and the active margin gas hydrate system as a system that is fuelled not only by biogenic gas production but also by additional advection of thermogenic methane from the subduction system. The location of the highest gas hydrate saturations in the hanging wall next to the thrust faults suggests that the thrust faults and permeable strata represent pathways for the migration of methane. Our findings suggest that the most promising gas hydrate occurrences for exploitation of gas hydrate as an energy source may be found in the core of the active margin anticlines immediately above the BSR and that high-amplitude reflections in the reflection seismic data may be a good proxy for these targets.

Friday, 05 June 2015, 18:40 – 19:00

Going offshore: First deployments of the GeoSEA Array

Heidrun Kopp, Dietrich Lange, Joerg Bialas, Florian Petersen

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Seafloor geodesy has been identified as one of the central tools in marine geosciences to monitor seafloor deformation at high resolution. To quantify strain accumulation and assess the resultant hazard potential we urgently need systems to resolve seafloor crustal deformation. Against this backdrop, we developed the GeoSEA (Geodetic Earthquake Observatory on the Seafloor) array. The array consists of a seafloor transponder network comprising a total of 35 units and a wave glider acting as a surface unit (GeoSURF) to ensure satellite correspondence, data transfer and monitor system health.

For horizontal direct path measurements, the system utilizes acoustic ranging techniques with a ranging precision better than 15 mm and long term stability over 2 km distance. Vertical motion is obtained from pressure gauges. Integrated inclinometers monitor station settlement in two horizontal directions. Travel time between instruments and the local water sound velocity will be recorded autonomously subsea without system or human intervention for up to 3.5 years. Data from the autonomous network on the seafloor can be retrieved via the integrated high-speed acoustic telemetry link without recovering the seafloor units.

The GeoSEA array is currently deployed in the Sea of Marmara to monitor crustal deformation along the marine segment of the North Anatolian Fault Zone. In late 2015, the array will additionally be installed offshore northern Chile in the Iquique seismic gap, which experienced the 2014 Mw 8.1 Pisagua earthquake that apparently occurred within a local locking minimum. It is thus crucial to better resolve resolve strain in the forearc between the mainland and the trench in order to improve our understanding of forearc deformation required for hazard assessment. Mobile autonomous seafloor arrays for continuous measurement of active seafloor deformation in hazard zones have the potential to lead to transformative discoveries of plate boundary/fault zone tectonic processes and address a novel element of marine geophysical research.

Friday, 05 June 2015, 19:00 - ….

Dinner

Saturday, 06 June 2015, 09:00 – 09:30

Crustal and upper mantle structure beneath Eurasia

Irena Artemiva

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Rolf Meissner is among pioneers in seismic studies of the crust, and one of the first maps of depth to the Moho in Europe was published by him in 1987. This map based on a limited seismic data shows all major features of the Moho topography that are recognized in later regional crustal studies of Europe. Here, we present a recent (2013) regional compilation of seismic structure of the crust in Europe and the North Atlantics, EUNAseis, which together with the new (2013) regional seismic model of the crust for Siberia, SibCrust, is used for correlating crustal structure with tectonic provinces and regional geodynamic evolution.
High-resolution seismic models of the crust provide crucial information for studies of the upper mantle heterogeneity. We take advantage of the regional seismic models EUNAseis and SibCrust to construct a continent-scale model of density variations in the upper mantle of Europe and Siberia based on free-board and satellite gravity data. A comparison of density structure of the Eurasian lithosphere with crustal structure and surface tectonics indicates a significant correlation between the deep, shallow, and near-surface structure of the lithosphere. The latter observation is illustrated by examples from the East European and the Siberian cratons, where Proterozoic sutures and intracratonic basins are manifested by an increase in mantle density as compared to light and strongly depleted lithospheric mantle of the Archean nuclei. The presence of high-density anomalies beneath the major rifts of the West Siberian basin is interpreted in terms of basin subsidence history.
Since we cannot identify the depth distribution of density anomalies, we complement the approach by seismic data in order to understand better geodynamic causes of mantle density heterogeneity. An analysis of temperature-corrected seismic velocity structure based on surface-wave and body-wave tomography models indicates strong vertical and lateral heterogeneity of the continental lithospheric mantle, with a pronounced stratification in many Precambrian terranes. We discuss lateral and vertical heterogeneity of the cratonic lithosphere in connection to regional tectono-thermal evolution, and compare our regional upper mantle density model with non-thermal part of upper mantle seismic velocity anomalies and with petrological studies of mantle-derived xenoliths from the Baltic shield, the Arkhangelsk region, and the Siberian kimberlite provinces.

Saturday, 06 June 2015, 09:30 – 09:50

The Moho in and around Europe

Richard England

Department of Geology, University of Leicester, UK

In 1986 Rolf Meissner, who had done much to lead and promote deep seismic reflection profiling in Europe joined with his friend and colleague Drum Matthews to write a paper on 'The “Moho” in and around Great Britain'. This contribution revisits that paper, looks at its influence on subsequent work and how our knowledge might have advanced in the last 30 years.
Prior to the early 1980's our knowledge of the Moho, particularly its depth was derived from refraction data. This all changed with the first deep reflection profiling experiment, pioneered in Europe in the Black Forest region by Meissner and others. Early work, typified by Meissner et al., considered the relationship between the Moho as observed in reflection data with that observed in refraction data and there was considerable debate as to whether they were the same thing. The refraction Moho being a distinct velocity increase whereas the reflection Moho is an, often complex, impedence contrast. By 1985 deep reflection profiling had been completed along the western coast of England, Wales and Scotland which allowed, in combination with onshore refraction data, the first map of the depth to the Moho beneath the UK to be produced. While simplified compared with the present models the essential features of the map remain the same. It showed a thickening of the crust from west to east, with the thickest crust beneath southern England. Critically, the paper noted that 'There are no signs of the great tectonic processes like the formation of the Iapetus suture or other compressional features in the Caledonian area', although there was abundance evidence of reflections that were considered to be thrusts in the reflection data. This is an observation that that is still being made e.g. beneath the Scandinavian Caledonides but our understanding of the processes of orogenic collapse and crustal extension have advanced to the point at which they can explain such observations. The paper was also forward looking in comparing the results of reflection experiments with those of refraction and wide angle studies. This contribution will develop this theme by considering the problem of Moho topography and its relation to surface topography and structure.

Meissner, R., Matthews, D. & Weaver, Th. 1986. The “Moho” in and around Great Britain. Annales Geophysicae, 4, B, 6, 659-664.

Saturday, 06 June 2015, 09:50 – 10:10

Deep Seismic Sounding Exploration in Iberia Peninsula

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3) Dept. of Geodynamics, University of Granada, Spain

Since late 80's a large amount of Deep Seismic Sounding (DSS) transects have been acquired within the microcontinent of Iberia and it margins. This data infrastructure has provided a wealth of knowledge on the strucrure of the crust and lithosphere of the Iberia peninsula, new information on the crustal parameters (Vp, Vs, Poisson's ratio), topography of the Moho discontinuity, the detailed internal architecture of tectonic terranes and orogenic belts, and settled very strong constraints on its geodynamic evolution. The normal incidence seismic imaging effort was initiated by the ESCI program mainly in two key areas. One in the northwestern Iberian to study the crustal structure of the external Variscides, which delineated the geometry of the foreland thrust and fold belt (Cantabrian Zone) and the transition to the hinterland areas (Narcea Antiform area). It revealed high amplitude dipping reflections within the Paleozoic rocks sequences and the flat and ramp geometries of the Cantabrian Zone detachment. The second ESCI Initiative targeted the Betic orogen in order to image the crust belonging to two different crustal domains. The terrane to the north, the crust of the Variscan Iberian Massif and the terrane to the south that corresponded to the Alpine metamorphic complexes of the Betics. These data unveiled the differences between both crustal terranes. In early 2000's and under EUROPROBE's umbrela the most complete transect of the Variscan Orogen was acquired across the SW Ibreria, revealing the anatomy of a transpresive orogen affected by mantle plume during the Carboniferous. The seismic profile samples three major tectonic terranes: the South Portuguese Zone, the Ossa-Morena Zone, and the Central Iberian Zone, which were accreted in Late Paleozoic times. These terranes show a distinctive seismic signature, as do the sutures separating them. The geometry of the sutures appear to be modified by strike slip movements. The upper crust appears to be decoupled from the lower crust suggesting a differences in the distribution of the stress. An unexpected finding was a 1-2 s thick 175 km long high-amplitude conspicuous reflective band a sill-like structure. This was interpreted as an intrusion of mafic magmas in a mid-crustal decollement, a result of the interaction of a mantle plume with an oblique collision/transpression tectonic setting. The data acquired in its margins as part of numerous projects has enrich the knowledge on the ocean continent transition, the lithospheric transition from the Variscan Iberian Massif to the Jurassic oceanic crust, has contained the development of the Valencia trough, has aimed to unravel the complex geodynamics of the Alboran basin. The aim of this work is to revisit the scientific contribution of the high resolution deep seismic sounding to the knowledge of the Iberian Microcontinent and it surroundings.

Saturday, 06 June 2015, 10:10 – 10:30

The seismic component of Topo-Iberia: an example of a new generation of crustal seismology experiments.

J. Gallart, J. Díaz, R. Carbonell, A. Villaseñor, M. Schimmel, TOPOIBERIA Seismic working group

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With the wide availability of broad-band sensors and dataloggers equipped with large storage capabilities, a new approach in crustal and lithospheric seismology has become possible. One of the best examples in Europe of such kind of new generation experiments is provided by the Iberarray observatory platform designed in the framework of the TopoIberia. The IberArray seismic pool was composed by 70+ BB stations, covering the study area in 3 deployments with a site-density of 60km x 60km. The data base holds ~300 sites, including the permanent networks in the area. Hence it forms a unique seismic database in Europe that allows for multiple analyses to constrain the complex geodinamics of the Western Mediterranean. The scientific explotation of this large database is still on progress, but the main results are already available and have lead to the publication of an Special Issue devoted to the Iberian Geodynamics in Tectonophysics. We will highlight here some of the results coming from different techniques.
The SKS splitting analysis has provided a spectacular image of the rotation of the fast velocity direction along the Gibraltar Arc. In central and northern Iberia, the fast polarization directions are close to EW, consistently with global mantle flow models considering contributions of surface plate motion, density variations and net lithosphere rotation. Those results suggest an asthenospheric origin of the observed anisotropy related to present-day mantle flow.
Receiver functions have revealed the crustal thickness variations beneath the Atlas, Rif and southern Iberia, evidencing a relevant crustal root beneath the Rif, in agreement with recent, high-density active seismic experiments. The Variscan Iberian massif shows a flat Moho discontinuity, while the areas reworked in the Alpine orogeny show a slightly thicker crust. Beneath N Iberia, the imbrication of the Iberian and Eurasian crusts results in complex receiver functions. Depths exceeding 45 km are observed along the Pyrenean range, while the crust thins to values of 26-28 km close to the Atlantic coasts. It is interesting to note that this Moho topography can be compared to the Moho map derived from active seismic profiling, as many deep profile are available on the area.
The geometry of the 410-km and 660-km discontinuities has been investigated using novel cross-correlation/stacking techniques, which have revealed significant changes in the transition zone thickness which needs to be explained geodynamically.
Ambient noise tomography has allowed to identify the main sedimentary basins and to discriminate between the Variscan and the Alpine reworked areas. Local body-wave tomography in North Morocco has improved the location of the small magnitude events on the area and the details of the crustal structure. Finally, teleseismic tomography has confirmed, using an independent data set, the presence of a high-velocity slab beneath the Gibraltar Arc.
It is worthy to note that only the fruitfully collaboration of different research teams from Europe, Africa and North America has made possible to get those results

Saturday, 06 June 2015, 10:30 – 11:00

COFFEE & POSTER

Saturday, 06 June 2015, 11:00 – 11:20

Evolution of the continental lithosphere in central Europe

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Several intraplate volcanic fields between the Eifel (Germany) and Silesia (Poland) form the northern E - W oriented zone of the Central European Cenozoic Igneous Province (CECIP). The mafic magmas show systematic regional trends in geochemistry and mineralogy that require variations in the pT conditions during melt formation in the upper mantle. From the Eifel to NW Bohemia the magmas exhibit increasing Si-saturation and decreasing (La/Yb) ratios approaching the volcanic field of the Vogelsberg from both sides. The chemical variations correlate with decreasing depths of melt segregation and/or increasing degrees of partial melting. These findings are compared to results of surface tomography. Broad-band Rayleigh wave dispersion curves have been determined consistently using available seismic data for more than 25000 inter-station paths in Europe and phase velocity maps have been obtained for periods from 10 s to 200 s representing depths between about 15 km and 300 km. These maps reveal the shape of the asthenospheric reservoir beneath the CECIP. A shallow asthenosphere is found beneath the Vogelsberg region and beneath the Egergraben. The thickness of the mantle lithosphere is increasing with increasing distance to the Vogelsberg region and the volume of the shallow asthenosphere is decreasing towards the East in agreement with the geochemical evidence. The volcanic fields in the Eger graben are found above a transition from larger LAB depth beneath the Bohemian Massive to shallower LAB depths beneath the Saxothuringicum.

Saturday, 06 June 2015, 11:20 – 11:40

The lithosphere around the Northern Tornquist Zone

Niels Balling

Department of Geoscience, Aarhus University, Denmark

The Tornquist Zone defines a major tectonic lineament across Europe. It extends from the Black Sea to the North Sea and separates old Precambrian cratonic units to the east and northeast from the younger Phanerozoic accreted terranes in Central and Western Europe. This tectonic boundary, and in particular its northern part, was one of Rolf Meissner's many areas of interest.
In the north, the tectonic lineament splits into two main parts, the Sorgenfrei-Tornquist Zone (STZ) and the Thor Suture (TS). The STZ, trending NW extends from the island of Bornholm across the northeaster part of Denmark to the Skagerrak, with Precambrian Baltic Shield to the northeast and mainly deep basins to the southwest. The TS runs WNW close to the border areas between Germany and Denmark and continues into the North Sea. It separates the two palaeo-continents Baltica and Avalonia.
Marked contrasts in crustal and upper-mantle structure are observed around the Northern Tornquist Zone and in particular around and across the STZ. From Baltic Shield areas in southern Sweden to deep basins in the Danish and adjacent areas, we observe marked crustal and lithospheric thinning, increase in heat flow and differences in the characteristics of gravity field anomalies. Recent teleseismic tomography studies outline a marked Upper-Mantle Velocity Boundary (UMVB) which, from being close to the STZ in Danish area, extends northward into and across southern Norway. It defines a narrow zone between shield areas with high upper-mantle seismic velocity and basins, as well as most of southern Norway, with significantly lower velocity. This main boundary, extending to a depth of 200-300 km or more, with P- and S- velocity contrasts of up to ± 2-3%. It is also clearly reflected in the V_P/V_S ratio, with generally low values in shield areas to the east and relatively higher values in basin areas to the southwest and in southern Norway.
For the depth interval of about 100-300 km, thick, depleted, relatively cold shield lithosphere is indicated in southern Sweden, contrasting with more fertile, warm mantle asthenosphere beneath most of the basins in Denmark and northern Germany. Both compositional and temperature differences seem to play a significant role in explaining the UMVB between southern Norway and southern Sweden. The UMVB follows closely along the eastern boundary of marked Late Carboniferous-Permian magmatic and tectonic activity. These results clearly emphasizes the importance of the northern Tornquist Zone, as a very deep structural boundary, separating old, thick, cratonic Baltica lithosphere in southern Sweden from reworked and attenuated Baltica lithosphere in Denmark, and in southern Norway as well.

Saturday, 06 June 2015, 11:40 – 12:00

Seismic properties of orogenic middle crust in the central Scandinavian Caledonides

Bjarne S. G. Almqvist (1), Daria Czaplinska (2), Quinn Wenning (3), Peter Hedin (1), Théo Berthet (1), Sandra Piazolo (2), Alba Zappone (3), Christopher Juhlin (1)

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3) Department of Earth Sciences, ETH Zurich, Zurich, Switzerland

A number of geophysical and petrophysical data sets have been acquired in conjunction with deep drilling investigations in the Collisional Orogeny in the Scandinavian Caledonides (COSC) project. These include data from seismic field experiments, petrophysical laboratory measurements, and electron backscatter diffraction (EBSD)-based modeling of seismic properties from mineral composition and texture. We now integrate the multiple data sets in order to understand the seismic properties of a middle crustal section in the central Scandinavian Caledonides (Jämtland, central eastern Sweden). Combined analysis of the scale-dependent data sets allows us to test hypotheses and derive plausible interpretations of the composition and state of deformation in the orogenic mid and lower crust.
The target of the first borehole in COSC, known as COSC-1, was to penetrate a succession of allochthonous lithologies, consisting of mainly amphibolite grade meta-sediments and meta-igneous rocks, in order to understand the mechanisms of their emplacement. The lithologies include felsic gneisses, calc-silicates, amphibolites, meta-gabbros and minor marble. In general, the rocks are highly deformed, occurring in outcrops and drillcore as intermittent layers ranging in thickness from <1 cm to greater than 10 m. The seismic properties obtained from modeling, are governed on the grain scale by the composition and texture of the minerals. In contrast, on intermediate scales the laboratory core measurements and borehole geophysics, indicates that lithological layering, occurring on centimeter to decimeter scale, and texture has considerable effect on the seismic properties. On the scale of reflection seismic experiments, it is mainly lithological boundaries and layering that occur over 10=E2=80=99s of meters or more that determine the seismic response. In order to combine the different data sets it is necessary to consider how the data may be best integrated. Scaling issues, as well as the representativeness of results from laboratory measurements and modeling need to be taken into account.
Seismic waves with wavelengths ranging from 10 to 100 meters will average the intrinsic seismic properties that exist on the mm to cm scale, as well as thin layering (i.e., <10 m). However, the rheological properties in the orogenic middle crust depend on processes that have occurred on a vast range of scales, from microns up to kilometers. Therefore, the multiscale approach adopted in this study has distinct advantages to understand seismic properties of the middle crust. Deformation mechanisms and processes that operate across the entire spectrum of scales can be incorporated into geological interpretations. Furthermore, the integrated scheme applied to data from the COSC-1 borehole will also be relevant for the upcoming second part of the COSC drilling project (COSC-2), where the aim is to drill through the basal contact of the allochthonous meta-sediments, through the main thrust zone and into the Precambrian basement of the Baltic shield.

Saturday, 06 June 2015, 12:00 – 12:20

Results of the deep reflection seismic imaging in SE Poland using extended correlation method applied to PolandSPAN data

M. Malinowski

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In the effort to provide constraints on the deep crustal structure we have applied extended correlation technique
to the ION GXTechnology PolandSPAN seismic reflection data. It allows to extend nominal record length of the survey (12 s in this case) to much longer times (18 s and 22 s tested here), given that raw uncorrelated data are stored and the up-sweep is used. The technique is not novel and has been successfully used, e.g. in Canada, during the LITHOPROBE project to save the time spend on single VP. For the times greater than the nominal record length, data are correlated using self-truncating sweep resulting in the original sweep spectrum kept for the nominal record length and the higher frequencies cut off for the greater times. Given the broad sweep spectrum (2-140 Hz) used in the survey, the high-end frequency at 22 s is 55 Hz (88 Hz at 18 s), which is way below the expected frequency of deep crustal arrivals (usually below 30 Hz). The correlation was performed both using the pilot sweep signal and the mean of the measured ground force recorded for each separate vibrator and VP. Processing of the ground-force correlated data produced clearer reflectivity in the deeper section, which can be attributed to the lower-frequency characteristics of the ground-force signal. Initial results of processing applied to one of the PolandSPAN lines in SE Poland (line 5100) revealed highly reflective lower crust and clear Moho discontinuity signature at around 15-16 s, being in agreement with coincident deep-refraction profile and the recently acquired deep reflection line.

Saturday, 06 June 2015, 12:20 – 13:20

Lunch Break

Saturday, 06 June 2015, 13:20 – 13:40

Tectonic wedges, seismic crocodiles & grey noise

David Snyder

University of Ottawa, Canada

The interpretation of seismic sections as geological cross sections is often deceptively simple. The increasing availability of 3-D seismic cubes makes this deception clearer. Prof. Rolf Meissner recognised this need for interpretative care many decades ago when he urged general seismic patterns or signatures should be emphasized, rather than specific structural interpretations of seismic reflections. He is most famous for his seismic “lamellae” and “crocodiles” signatures. The former he associated with pervasive near-horizontal reflectors within the lower crust of areas where the last tectonic event was horizontal extension. BIRPS had some of the best examples. A number of modelling studies have now shown that out-of-the-plane reflections from corrugated reflector surfaces probably contribute greatly to this apparent complex pattern on seismic sections. His fundamental tectonic interpretation of “lamellae” proved sound, but comprehensive understanding remains open. The latter signatures Meissner associated with tectonic wedges in regions that experienced horizontal shortening. Caledonian and Variscan structures observed on DEKORP sections were prime examples, but similar observations were global. As acquisition and processing techniques used in deep reflection profiling improved with time, so did the clarity and number of “crocodile” sightings throughout the entire crust. Tectonic wedging provides a ready explanation as the cause of these signatures and also the resolution of the enigma of predominately vertical surface structures but sub-horizontal reflectors at mid-crustal depths. Large-scale “crocodiles” are now also found in the uppermost mantle on sections that use transmitted P-to-S converted waves instead of reflected waves in what is now often termed structural seismology. Finally, ambient or environmental noise was not considered a good thing in the early days of deep seismic reflection profiling by COCORP, DEKORP and BIRPS --- it was the “mist” through which seismologists peered to interpret structures. Today this grey noise is instead considered a useful bandwidth for less expensive and more environmentally friendly seismic exploration because it still lies below the threshold of strong seismic wave scattering. Whether passive seismic surveys can out-perform controlled-source surveys is a current challenge.

Saturday, 06 June 2015, 13:40 – 14:00

Seismic reflections: how forgetful are seismic waves?

Bernd Milkereit

Department of Earth Sciences, University of Toronto, Canada

Seismic imaging is an important geophysical tool for delineating and monitoring the earths subsurface structure and its oil, gas and mineral resources. Owing to the earths heterogeneity, such subsurface structures exist at different scales (sizes) with lateral and vertical variations in physical properties such as contrasts in bulk and shear moduli, and densities.

Seismic methods illuminate subsurface structures using compressional and shear waves. Recorded signal at surface and borehole seismic sensor locations arise from reflection, refraction, transmission, scattering and attenuation of elastic waves at lithological contacts, structural boundaries and the earth's free surface, where abrupt and gradual changes in physical rock properties occur. The effects of heterogeneities on seismic wave propagation can be described in terms of different propagation regimes and physical rock property contrasts: quasi-homogeneous for heterogeneities too small to be seen by seismic waves, Rayleigh scattering, Mie scattering and small-angle scattering. These scattering regimes cause characteristic amplitude, phase and travel time fluctuations, thus limiting the resolving power of seismic imaging. Examples of reflections with strong contrasts in physical rock properties include the lower crustal reflection, the crust-mantle boundary, mafic sills as well as shallow permafrost layers, gas and gas hydrate accumulations, and massive sulfide mineral deposits. Consequently, the presence of strong contrast in the earth's crust provides an interesting challenge for a wide range of controlled source seismic imaging and passive source seismic monitoring studies.

Saturday, 06 June 2015, 14:00 – 14:20

Diffractions: Are we using the imaging potential?

Dirk Gajewski

Institute of Geophysics, University of Hamburg, Hamburg, Germany

Diffractions are the key to superresolution. They provide insight in complex regions, where the conventional reflection processing does not deliver sufficient detail. Moreover, the kinematic diffraction response can be decomposed into two zero-offset rays, which allows to establish a finite offset (FO) tomographic approach entirely based on so called Normal Incident Point (NIP) rays. Whereas conventional FO reflection tomography (also called stereo-tomography) demands computationally expensive processing on the whole prestack data volume, the diffraction decomposition based FO tomography is solely based on stable and efficient zero-offset processing, thus substantially reducing the demands for picking and quality control. For the successful application of a FO tomographic model building process, diffraction separation, data enhancement and conflicting dip processing are essential steps. These processes can be formulated in a consistent system applying kinematic wavefield attributes. This allows to set up a diffraction FO tomographic model building approach based on a multi-parameter stacking procedure using the Common Reflection Surface (CRS) method. Because of the local character of the diffractor the FO diffraction tomographic model building has the potential for an improved lateral resolution compared to conventional tomographic approaches.

Saturday, 06 June 2015, 14:20 – 14:40

A combined elastic waveform and gravity inversion

Daniel Wehner, Daniel Köhn, Denise De Nil, Sabine Schmidt, Said Attia al Hagrey, Wolfgang Rabbel (1)

Institute of Geoscience, University of Kiel, Germany

In recent years the elastic full waveform inversion (FWI) was successfully applied to synthetic and field data to compute high resolution velocity models. While seismic velocities are derived from recorded phase information, density models can be estimated from the amplitudes. However, due to the complexity of the inverse problem a long wavelength initial model is required for a good reconstruction of the density. The inclusion of gravity data into the FWI concept can solve this problem.

In this study a two-step hierarchic joint inversion of seismic waveforms and gravity data is tested using the Marmousi-II model. In step 1 FWI is performed for all elastic parameters. Gaussian filtered velocity models of the true model and a constant halfspace density model (CHD) are used as initial models. While the velocities can be reconstructed well, the density shows large deviations from the true model. In step 2 joint inversion is applied to optimize only the density model, while the velocity inversion results of the first step and the CHD are used as initial models. The results of this combined approach show a significant improvement of the density model compared to the results of a pure FWI.

Saturday, 06 June 2015, 14:40 – 15:00

Crustal models from joint inversion of P- and S-wave receiver functions.

Lev Vinnik

Institute of Physics of the Earth, Moscow, Russia

In the last years crustal models for several regions were obtained by joint inversion of P- and S-wave receiver functions. These techniques provide robust estimates of the S –wave velocities and useful constraints on the P –wave velocities and the Vp/Vs ratio as functions of depth. I review the principles and summarize the results. The crustal models to be discussed are obtained for (1) the Indian Shield, Himalaya and Tibet, (2) the Azores and Cape Verde hotspots, (3) the Fennoscandian Shield and (4) the Siberian Shield. These models differ in substantial details from those obtained by other means and include clear evidence of magmatic underplating in the hotspots, explanation of the "double Moho" in the Himalaya and Tibet, possible evidence of ultramafic cumulates in the lowermost crust of Fennoscandia and a pronounced low S-wave velocity layer in the lower crust of the Siberian craton.

Saturday, 06 June 2015, 14:40 – 15:20

Closing remarks

Poster Presentations

P1

Observation and modelling of P-wave polarization for teleseismic events

Luigia Cristiano (1), Alexander Minakov (2), Thomas Meier (1), Henk Keers (3)

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2) University of Oslo, Oslo, Norway
3) University of Bergen, Bergen, Norway

P-wave polarization may yield valuable information on lateral heterogeneity and anisotropy of the crust and uppermost mantle. Using 20 years of the Gräfenberg (GRF) array data we show that stable measurements of P-wave polarization attributes - azimuthal deviation and incidence angle - may be obtained by automated data processing. The P-wave polarization at the GRF array is frequency dependent and a function of backazimuth. By applying harmonic analysis, properties of the 180° and 360° periodicities of azimuthal deviation and incidence angle as a function of backazimuth are quantified. The observations point to the presence of azimuthal anisotropy and lateral heterogenetiy in the crust and uppermost mantle in the vicinity of the stations. The fast propagation direction of P-waves and lateral velocity gradients of P-wave velocity may be estimated based on results of the harmonic analysis. For the GRF array the fast direction of P-wave propagation is found to be about 20° in the frequency range from 0.03 to 0.1Hz that is mainly sensitive to the lower crust and the uppermost mantle. At higher frequencies from 0.1 to 0.5 Hz, mainly related to the upper crust, the variability is larger with a predominant direction of fast P-wave propagation of about 100°.
In order to investigate the sensitivity of P-wave polarization to azimuthal anisotropy quantitatively, full waveform forward modellings are performed using 3D Elastic Ray-Born Modelling. Ray and ray-Born techniques have proven their importance in seismology as all travel time tomography is based on ray tracing and all finite frequency travel time and amplitude kernels are based on ray-Born theory. Moreover ray and ray-Born methods are relatively fast and specifically valid at high frequencies. Thus these methods complement the finite-difference and spectral-element full waveform modelling methods. The actual implementation is done using an isotropic background medium with an anisotropic medium perturbation characterized by the 3 Thomsen parameters (which were originally developed for use in hydrocarbon exploration). The ray tracing through the background model is done using 4th order Runge-Kutta and the background model maybe 1D or 3D. Kinematic ray tracing is used for the computation of the travel times and dynamic ray tracing is used for the computation of the amplitudes. In our numerical examples we use a velocity model with a horizontal size 2000 km and depth 1000 km. The background model is a smoothed version of PREM. The 3D anisotropic perturbation has a Gaussian shape and is placed 30 km below the receiver. The modelling is done for earthquakes located within an annulus around the receiver. The inner radius of the annulus is 1400 km and its outer radius is 1900 km. All three components of the seismograms have been computed and are shown. These seismograms are used to perform a synthetic polarization analysis of the P-phase. The effects of the strength, depth and horizontal location of the anisotropic perturbation are investigated. Finally, we compute and show sensitivity attributes for the polarization parameters.

P2

Phase velocities of Rayleigh and Love waves in central and northern Europe from automated, broadband, inter-station measurements

Riaz A. Soomro (1), Christian Weidle (1), Luigia Cristiano (1), Sergei Lebedev (2), Thomas Meier (1)

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2) Dublin Institute for Advanced Studies, Dublin, Ireland

We process all freely available data in Europe, from January 1990 to October 2013, obtained through the European Integrated data archive (EIDA) in order to calculate surface wave phase velocity maps. We develop an automated technique for the measurement of inter-station phase velocities of the fundamental-mode surface waves in very broad period ranges (10 s ->200 s). We then apply the method to all available broad-band data from more than 1000 permanent and temporary stations across the Europe. In total, around 63000 Rayleigh- and 27500 Love-wave dispersion curves have been determined, with standard deviations lower than 2 % and standard errors lower than 0.5 %.

Using our large new dataset, we construct phase-velocity maps for central and northern Europe. According to checkerboard tests, the lateral resolution in central Europe is <150 km.

Comparison of regional surface-wave tomography with independent data on sediment thickness in North-German Basin and Polish Trough (from a compilation of deep seismic sounding (DSS) results) confirms the accuracy of the imaging using our short-period, phase-velocity measurements. At longer periods, the structure of the lithosphere and asthenosphere around the Trans-European Suture Zone (TESZ) is seen clearly. The region of the Tornquist-Teisseyre Zone (TTZ) is associated with a stronger lateral contrast in the lithospheric thickness from the East European Platform (EEP) towards the southwest compared to the region across the Sorgenfrei-Tornquist Zone (STZ). The new, broad-band, phase-velocity dataset offers abundant, valuable information on the structure of the crust and upper mantle beneath Europe.

P3

The Blue Norma experiment revisited

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Almost 40 years after the initial seismic experiment along the Blue Norma experiment in Northern Norway, we revisited the area and acquired receiver function data both along a profile from Norway's coast to the Finish border. Already, the early studies by Rolf Meissner and co-workers observed a moderate increase of crustal thickness from the coast beneath the mountains and stated that seismic velocity has to increase eastward in the mantle.

While the mountain belt is best known for preserving the core of the Scandinavian Caledonides, the crust forming the root of that orogen was involved in earlier Fennoscandian and Sveco-Norwegian mountain building, which affected its current structure.

Current concepts emphasize the role of the upper mantle structure in the isostatic state of the lithosphere. The upper mantle beneath the Scandinavian mountains reflects both the tectonothermal age of the lithosphere and the transitional position between the North Atlantic margin and the Fennoscandian shield.

We present a new Moho map based on the recent receiver functions experiments Scanlips -2 and Scanlips-3D and present integrated lithospheric-scale models of crust and upper mantle structure.

P4

Lithospheric thickness at the Sorgenfrei-Tornquist Zone

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Results from the teleseismic tomography project TOR indicate sharp, stepwise differences in lithospheric thickness across the Sorgenfrei-Tornquist Zone (STZ): thick beneath southern Sweden, thin beneath northern Germany. However, changes in topography are virtually absent in this region. This study examines these discrepancies from an isostatic point of view, using the modeling software LitMod3D, which provides combined geophysical-petrological modeling of the lithosphere and the sublithospheric upper mantle. Effects of mantle compositions and temperatures on seismic velocities are analyzed. Basic models with a step-like lithosphere-asthenosphere boundary (LAB) already exhibit velocity patterns similar to the Tor results. Considering isostatic compensation and the strong impact of compositions on density distribution within the lithospheric mantle, a transition from Phanerozoic (fertile) to Proterozoic (moderately depleted) composition may be expected. Regional models are set up and matched to topography, gravity and seismological data sets. Explaining both the observed upper mantle velocities, topography and isostasy by changes in mantle properties only turned out to be difficult. Increased values for thermal conductivities of the sediments and the crust of the Phanerozoic platform (SW of the STZ) solve this problem. The final model with a LAB in depths of 100 km in SW and 200-350 km in NE correlates well with the observed P-wave anomalies and is isostatically consistent with the observed topography and surface heat flow data.

P5

Crustal structure of the East European Platform margin and its foreland based on the POLCRUST-01 deep reflection seismic profile

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A new 240-km long, deep seismic reflection profile (POLCRUST-01) was recently acquired in SE Poland crossing the East European Platform (EEP) margin south-east of the North-German-Polish Caledonides (NGPC). Here we document geophysical field work and subsequent data processing and modelling. Results obtained from reflection seismic data are augmented by results of the first-arrival tomography applied to co-located extended-offset refraction data, as well as potential field modelling and comparison with the available wide-angle reflection/refraction data. Our preferred model of the crustal structure, derived by integrating seismic, potential field and geological data, is composed of crustal blocks (terranes) separated by nearly-vertical faults. These are: (I) intact part of the EEP; (II) Łysogóry Terrane; (III) Małopolska Terrane; (IV) Carpathian Mts. with their basement. Reflective lower crust of the EEP can be an inherited feature of crustal extension (rifting) or compressional tectonics acting at the cratonic margin. The Teisseyre-Tornquist Zone (TTZ) is depicted as a Caledonian transcurrent accretion zone corresponding with the near-vertical Tomaszów Fault, bounding the Łysogóry Terrane to the east. The crust of the Łysogóry Terrane suggests EEP affinity, although its middle/lower crust thickness is highly reduced. The Małopolska Terrane seems to be internally subdivided into blocks of different magnetic properties of the lower crust. The Carpathian frontal thrust is associated with a change in the rock properties in the deep basement (an unknown crustal block?) which is not visible in seismic data alone. The interpreted structure of the Caledonian terranes and their tectonic boundaries favours a transcurrent style of a crustal accretion along the central and SE Polish segments of the TTZ, implying a very complex nature of the Caledonian accretionary belt of Central Europe: from an array of terranes displaced along the TTZ to an accretionary wedge of the collisional NGPC orogen between NW Poland and southern North Sea area.

P6

The crustal structure of Avalonia beneath Schleswig-Holstein as seen by surface waves of the Mw=9.0 2011 Tohoku Earthquake

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In 2011 sea mines of the world war II were detonated in the baltic sea offshore Heidkate (east off Kiel). A 100 km long seismic profile was installed on 11./12.03. to record the detonations. It consisted of 100 4.5 Hz vertical geophones with an averaged spacing of 1 km.

59 geophones recorded the Mw9.0 Tohoku earthquake on 11.03.2011, 05:46 UTC. The waveform could be restitute to ground velocity between 0.02 Hz and 0.2 Hz. The dispersion of the Rayleigh wave could be determined between 0.03 and 0.2 Hz by slant stack analysis. We find a change in the dispersion between 0.07 Hz and 0.15 Hz along the profile suggesting a change in the lower crust.

The seismic section of the detonations show an early arrival of the Pg-wave by 0.3s due to the salt dome of Bad Segeberg. A strong phase with an apparent velocity of 7 km/s is seen for distances over 60 km as seen in the EUGEMI-Profile (1988).

P7

Regional domains of crustal seismic anisotropy in the central Europe

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We investigated if the tectonic processes that formed the central European Variscides have left regionally coherent imprints in terms of seismic anisotropy. The study is based on P-receiver functions (RFs) of the stations of the German Regional Seismic Network (GRSN) and on spatial cluster analysis. It turned out that almost all GRSN sites have azimuthally variable RFs and show strong coherent energy on the transverse seismometer components. Most of the azimuthal RF patterns are too complicated to be explained by simple subsurface models of anisotropy or layer dip. Despite their complicated appearance the crustal RFs show geographical coherence that can be understood as regional anisotropic domains. Major anisotropic domains are found along the suture zone of the Saxothuringian and Moldanubian terranes and around the metamorphic core complex of the Saxonian Granulite Massif. The anisotropic domains generally do not agree with the areas of the Variscan terranes of which the central European lithosphere is composed but seem to be associated with specific tectonic processes such as complex oblique folding or the formation of laminated lower crust during the Variscan post-orogenic collapse.

P8

Earthquakes and metamorphism in the lower continental crust

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One of Rolf Meissner's major research goals was to explain the seismic refraction and reflection structures observed in the lower continental crust. In his early publications (e.g., "The 'Moho' as a transition zone", 1973), he already considered, among several ideas, vertical and lateral tectonic movements in the deep crust. He generally assumed that "the lower crust is a region of weakness compared with the colder upper crust" (Meissner 1973, p. 210). A few years later, he and Ute Vetter calculated steady-state extrapolations of new experimental friction and flow laws; they suggested that a quartz-rich lower crust may indeed be weaker than a brittle upper crust and a strong olivine-rich upper mantle. Despite the uncertainties involved, this layered strength model appeared to be consistent with observations of earthquake hypocentral depth distributions available at the time, showing a rough correspondence between the calculated brittle-plastic transition and the maximum depth of microseismicity (about 20 km; Meissner & Strehlau 1982, Strehlau & Meissner 1987, among other authors including Brace & Kohlstedt, Sibson, Chen & Molnar). Faulting in continental earthquakes has thus been regarded as a low-temperature process, with the thickness of the seismogenic layer believed to be limited by a specific seismic-aseismic transition temperature (about 250-500 °C). The concept of parts of the lower crust deforming by high-temperature ductile flow was confirmed by geologic studies of exposed metamorphic rocks. Consequently, the "jelly sandwich" model was widely accepted by the geoscience community and has since been applied in many studies of lithospheric deformation processes.

Recent results, however, have called this simple model into question. For example, lower-crustal seismicity, deep low-frequency earthquakes and nonvolcanic tremors have been located, using dense seismic networks, in a broad variety of tectonic regions with moderate to high heat flow (e.g., transcurrent faults, rift zones, continental margins, forelands of mountain ranges). Numerical simulations of earthquake scaling relations indicate that coseismic slip in large earthquakes may propagate deeply below a shallow frictional-viscous transition, thus implying that crustal-scale faults may undergo large seismogenic slip in the lower crust. This inference is supported by field observations of pseudotachylytes (preserved in high-grade shear zones) that were generated by frictional melting at lower-crustal depths under ambient temperatures of about 650-700 °C.

Conventional strength models can accommodate deep crustal earthquakes at elevated temperatures by assuming mafic composition, high strain rates, high fluid pressures, or any combination thereof. These assumptions (including an extension of Byerlee's law to the deep crust, isochemical crustal composition, and dichotomy of deformation mode: either friction or flow) may not be sufficiently adequate, however. For example, deep crustal seismicity may be associated with active metamorphism. Localized metamorphic phase changes involving hydration and/or dehydration reactions may cause fluid transport in fractures that are in turn generated by transient changes in rock properties and rheology due to the compositional changes during metamorphism. This inference is consistent with evidence of reaction-induced flow instabilities, ductile fracturing, and embrittlement recently found in exposed metamorphic terrains. Coupled chemo-hydro-thermo-mechanical processes may therefore play an important role in deep crustal deformation. It is yet to be determined how time- and composition-dependent deformation processes can generate earthquakes and tremor. In this contribution, I discuss key questions to be resolved if one hopes to improve our understanding of deep crustal processes.

P9

Crustal structure beneath the Iberian Peninsula and surrounding waters from active seismic experiments; a case example

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Since the 1970s, the lithospheric structure beneath the Iberian Peninsula and its continental margins has been extensively investigated using deep multichannel seismic reflection and refraction / wide-angle reflection profiling by different international research teams. The revision of the acquisition experiments and the interpretation methods used along those decades allows to get a beautiful insight on the evolution of active seismic methodologies, from the use of a limited number of analog dataloggers interpreted using 1D reflectivity methods, to the deployment of hundreds to thousands of digital equipments along a single profile inverted using ray theory.

On the other hand, the compilation of all the available models reveals the seismic properties of the different tectonic domains sampled, which have a great geodynamical diversity. The investigated areas include crustal imbrication in the Pyrenean range, a large and relatively undisturbed Variscan Massif in the center of Iberia and areas of complex and still not completely understood geodynamics in the Alboran crust domain. This results in Moho depths ranging from around 10 km beneath the Atlantic to values exceeding 50 km in some parts of the Pyrenees or the Rif Cordillera. The compilation of the inferred Moho depths along the interpreted profiles has allowed to obtain a Moho depth model which has been extensively used to contrain numerical modeling studies at crustal and lithospheric scales in a key area of the Western Mediterranean.

P10

Batholitic structures influence seismogenic processes in the North Chilean Seismic Gap

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In former studies we have been able to co-interpret seismologically determined asperity structures on the seismogenic interface between the Nazca and South American plates in the Antofagasta region in the North Chilean subduction zone and anomalies of the gravity field. This link enabled us to assign material properties to the identified asperities and showed that geological structures obviously play a role in seismogenesis. However, recent years have shown that asperities and barriere or seismic activity alone are not enough to describe seismogenic behavior on a fault: phenomena like silent slip events and creep are co-existing and also interact with geological structures. They have to be studied to get a complete picture of the processes which lead to the next large earthquake. We show some results on these aspects from investigating the Iquique region, the central part of the North Chilean Seismic Gap, by using the data from the Iquique Local Network (ILN) and gravity data analysis as well as respective density modeling and demonstrate, that the slip distribution of the recent Mw 8.2, 2014, Iquique earthquake seemed to be influenced by batholitic structures.

P11

Mass-balancing the accretionary prism of Central Chile

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ABSTRACT:
The growth and structural development of an accretionary prism is primarily a function of variations in input sediment flux over time. Input sediment volume in turn is controlled by changing sediment sources and pathways, climate variations, oceanic basement topography, and erosion and reworking of material from the forearc. Constraining the present shape and size of an accretionary prism and comparison of the derived values with calculations of input sediment flux can help to reconstruct the history of accretion, erosion, and sediment subduction at the margin. We conduct mass-balance calculations for seven transects along the Central Chilean continental margin (34°S - 45°S) by comparing the estimating sediment flux into the subduction zone with the present volume of the accretionary prism. The prism volume is calculated from swath bathymetric data, seismic reflection and refraction data as well as a regional model of slab geometry. We consider a time interval starting in the late Miocene, which is seen as the starting point of the Southern Andes glaciation and related pulse of terrestrial sediment flux to the trench, forming the prerequisite for prism formation. Several specific factors that affect prism evolution are considered, including: décollement position above the oceanic basement; underthrusting and subduction of sediment, compaction during accretion; re-accretion of sediment eroded from the prism into the trench; prism age; variations in input sediment thickness over time. First results considering a 4 Ma history of accretion suggest that at two latitudes, south of the Juan Fernandez Ridge and south of the Mocha Fracture Zone the present prism volume exceeds the calculated flux of input sediment. This could point to an earlier onset of prism formation and/or a thicker input sediment section over the past. In contrast, for all other transects, the calculated flux of sediment exceeds the present prism volumes, indicating a later onset of prism formation and/or less input sediment over the past. These latitudinal variations suggest that the change in the tectonic mode of the Central Chilean continental margin (i.e the switch from subduction erosion to sediment accretion) did not occur uniformly in time. A possible explanation is provided by northward-directed sediment transport within the Chile Trench that follows the bathymetric gradient. Bathymetric features on the incoming Nazca Plate such as the Juan Fernandez Ridge and the fracture zones appear to have acted as barriers to sediment transport over certain periods of time, thus creating sedimentary sub-basins within their neighborhood. Although the flux of terrestrial sediments to the Chile trench started and was likely highest in the South of the study area, where the glaciation of the Andes started, the trench appears to have filled in opposite direction from North to South.

P12

Seismo-electromagnetic signals of earthquakes in South and Central America

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It has been observed that magnetotelluric stations can record seismic events, the graphs of which are similar to seismograms. One possible explanation for these signals is the seismo-electric (SE) effect. The SE-effect is caused by the movement of ions in the porefluid relative to the surrounding mineral grains. The passing of a compressional P-wave leads to a disturbance of the zeta-potential, which affects the electric (E) field measured by ground electrode pairs. The E-field change is proportional to the ground acceleration caused by the passing P-wave. The shear deformation of S-waves creates a local seismo-magnetic (SM) field which is expected to be proportional to the ground velocity.

We used magnetotelluric field data from Costa Rica and Chile to investigate the characteristics of SE-signals. In Costa Rica 25 earthquakes could be identified on the MT-stations within 16 month. The dataset of Chile comprises the Iquique Mw8.1 Earthquake of April 1st, 2014 and its aftershocks.
The analysis of some selected events shows that the seismic and electromagnetic data is correlated. Against theoretical expectations P- and S-waves could be observed on all components. The amplitudes of the co-seismic electric fields observed in Chile are smaller than in Costa Rica (Chile: 0.05 μV/m, Costa Rica: 10 μV/m) although the seismic amplitudes are larger. The electric signals lack the higher frequencies (>5 Hz). In Costa Rica the frequency spectra show a pronounced resonance at 2.5 Hz. The frequency content of the magnetic field seems to be similar to the ground acceleration.

We estimated the magnitude of different physical effects to find an explanation for the observed waveform of the data. The co-seismic SE-effect of the incoming seismic wave produces an electric field which is in the same order of magnitude as the observed electric field. The difference in the amplitude between Costa Rica and Chile can be explained by the fluid saturation of the uppermost crust. The co-seismic SM-effect is too small to produce a measurable signal. The change of the magnetic flux through the tilting of the measuring coils during wave passage induces a voltage which is large enough to explain the signal of the magnetic components and their frequency behavior. A tilt of 10-5° produces a voltage of 5 mV. Other effects such as a lateral movement of the measurement equipment can be neglected for the magnetic as well as the electric field.

P13

The velocity structure of the Central Sumatran forearc

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The Sumatran subduction zone exhibits strong seismic and tsunamogenic potential with the prominent examples of the 2004, 2005, 2007 and 2012 earthquakes. Here, we invert travel time data of local earthquakes for a three-dimensional Vp and Vs/Vs velocity model of the Sumatran forearc using data from an amphibious network located on a segment of the Sumatran subduction zone, where the megathrust did not rupture in a great earthquake since 1797 but witnessed recent ruptures to the north in 2005 (Nias earthquake, Mw=8.7) and south in 2007. (Bengkulu earthquake, Mw=8.5). 2D and 3D vp and vp/vs anomalies reveal the downgoing slab and the sedimentary basins. Although the region is characterized by the subducted Investigator fracture zone which influences seismicity down to depths of 200 km the 3D velocity model shows prevailing trench parallel structures. Beneath the Sumatran Fault zones velocities of 5 km/s and slightly reduced vp/vs values of 1.65 are found down to depths of ~20 km. The tomography suggests a thinned crust adjacent east of the Batu Islands at approx. 180 km distance to the trench. We find moderately elevated Vp/Vs of 1.85 values at distances 150 km to the trench in the region of the Mentawai fault.

P14

Contrasting SKS and local shear wave observations in the Pamir-Hindukush continental collision zone

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The Pamir-Hindukush region, located north of the western Himalayan syntaxis, is considered to be the site of active southward subduction of Eurasian continental lithosphere in a highly arcuate geometry, accompanied by seismicity reaching intermediate depths (up to 250 km). Our main motivation in the current study is to map lateral variations of seismic anisotropy parameters for a better understanding of a possible link between surface and internal deformation in the context of crust and mantle structure. Using data recorded by several temporary (TIPAGE, FERGANA, TIPTIMON) and permanent passive seismic networks in the region, we performed shear wave splitting analysis of SKS phases of teleseismic earthquakes as well as S-wave signals of mostly deep-focus local earthquakes. We have measured splitting parameters from 932 high-quality SKS waveforms extracted from 193 teleseismic events (Mw>5.5) recorded at 104 broadband stations and obtained time delays ranging from 1.0 to 1.5 s. A coherent dominant pattern of ENE-WSW oriented fast polarization directions (FPD) is observed at most of the stations, which corresponds to the general strike direction of sutures within the Pamir as well as to the curvature of the underlying slab. Analysis of local shear wave splitting yields much smaller delay times (~0.025-0.5s) with a complicated pattern of anisotropic directions. Considering that our local event database mostly contains deep focus (>120 km) events in the subducting slab, small time delays imply that the crust and shallow part of the mantle only have a minor contribution to the observed SKS splitting. The coherent pattern of rather large SKS splitting parameters thus most likely represents sub-lithospheric anisotropy, which could be diagnostic of asthenospheric return flow in response to the ongoing indentation of Indian lithosphere into Eurasia.

P15

COOL: Crust of the Oman Ophiolite and its Lithosphere – a passive seismic experiment

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Plate tectonics has established a framework for geoscientists to understand most geologic/tectonic processes that shaped our present-day Earth. 'Obduction', the emplacement of young, dense oceanic lithosphere (ophiolites) on top of older lighter continental lithosphere remains, however, a rather odd phenomenon. Some ophiolites are fundamentally similar to young oceanic crust and it is hence assumed that they were obducted as thrust sheets at the onset of continental subduction in a previously intra-oceanic subduction setting.

The Peri-Arabic obduction corresponded to a spectacular, almost synchronous thrust movement along thousands of km from Turkey to Oman. At the eastern margin of the Arabian plate, the world's largest and best preserved ophiolite was emplaced in only a few My during Upper Cretaceous and is exposed today atop the Oman Mountain range. Although being the best studied ophiolite in the world, rather little is still known about the internal structure of the ophiolite and the Oman Mountains. The dimension of the ophiolite is large enough (~700 km) to be studied with seismological methods, providing thus a rare setting to investigate oceanic crust on land without ocean bottom installations.

The origin and emplacement of the ophiolites, as well as the shaping of topography in the Oman Mountains is closely linked to the southeast prograding continental collision between Arabia and Eurasia along the Main Zagros thrust front. Just North of the Oman Mountains, the collisional front is offset southwards by a major transpressional fault zone and continues eastwards as oceanic subduction along the Makran trench. The Makran subduction is fastly converging but, particularly its western part, anomalously aseismic. Detailed images of the crust-upper mantle below the eastern Arabian plate and the transitional zone from collision to subduction do not exist in this sparsely instrumented region.

We have deployed a network of 40 broadband seismometers across the Oman Mountains in Oct/Nov 2013 for passive seismic registration for a duration of ca. 26 months. The network is complemented by 10 permanent stations in the area operated by the Earthquake Monitoring Center in Oman.
Aims of the project include:

- Seismological imaging of the geometry and internal properties of obducted oceanic, and its underlying continental lithosphere.
- Regional tomographic velocity models will provide constraints on geodynamic processes that led to large scale obduction.
- Investigating the “quiet” Makran subduction zone for local seismicity will improve understanding of seismic hazard on the eastern Arabian plate.

P16

Geoid-anomalies of passive margins from satellite data and interpretation by isostatic models

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Satellite data of GOCE is used to measure the geoid on passive margins. By filtering the coefficients of spherical harmonics it is apparent that the height of the geoid on passive margins varies between 4-8 m. The Argentinian and western South African coast are located on oceanic lithosphere which has an age between 130-140 Ma. The drop of the geoid within the transformation from oceanic to continental lithosphere is about 7-8 m and exhibits only low errors. As a result the measurements in this region derived by satellite data can be interpreted by isostasy.

The isostatic model combines vertical and horizontal variations of density and contains the effect of the asthenosphere. By varying the four parameters thickness of oceanic and continental mantle lithosphere together with oceanic and continental crust an isostatic model is generated. It is fitted to the Argentinian and South African passive margin. It is visible that small changes in the thickness of oceanic and continental crust have big effects on the thickness of the mantle lithosphere. Comparing both lithospheres it becomes apparent that the lithosphere of South Africa is thicker than the lithosphere of Argentina.

P17

Depth sensitivity of satellite gravity gradients

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For lithospheric scale modeling the vertical gravity acceleration or the geoid are often used to complement seismological and electromagnetic data. For such investigations, the gravity field is divided into a lithospheric and a sub-lithospheric part. Often spherical harmonics degrees 2-9 are identified as the sub-lithospheric gravity field. However, this separation is unreliable, because the lithosphere contains significant density anomalies at these degrees. This "contaminates" the filtered gravity field with a considerable lithospheric effect.

An alternative approach is to strip the total field of the contribution of lithospheric sources by forward calculation, making use of gravity gradient data as available from the GOCE satellite mission. Gravity gradients have a depth sensitivity that is different from conventional gravity. We have determined and compared the relative proportion of signal coming from different depths for all gravity and gravity gradient components. These proportions can be interpreted as an estimate of depth sensitivity. Our first results show that the density contrast at the crust-mantle boundary causes the strongest signal in both the gravity field and the gravity gradients. Gravity gradients have an increased sensitivity to inner-crustal density anomalies, whereas the normal, vertical gravity field better reflects sub-lithospheric anomalies. Furthermore, the non-vertical gradient components show a different depth sensitivity than the vertical gradient components. These characteristics can be used (a) to improve the quality of crustal density models and (b) to better separate the lithospheric and sub-lithospheric parts of the gravity field.

We demonstrate this approach for the North American continent. The starting model is based mainly on the seismological model of the North American Crust NACr 14. Additionally, we include travel time tomography for the velocity distribution in the upper mantle. This approach gives a sub-lithospheric contribution to gravity of several 100 mGal. It is likely that a significant part of this (supposed) contribution results from errors in the lithospheric models that are projected into the sub-lithosphere. The different sensitivities of gravity and gravity gradients allow distinguishing genuine sub-lithospheric contributions from projected errors of the lithospheric models.

P 18

Improved lithospheric density model and heat flow estimation

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We show a forward model approach of the Arabian peninsula to derive the denstiy structure of the lithosphere constrained by GOCE gravity gradients=2E Pre-existing information about the crustal structure, Moho and LAB depth are very sparse. Conventional crustal thickness models are based on inversion of near-surface gravity constrained by few seismic data. These models do not explain the gravity gradients observed by the GOCE satellite mission. To overcome this misfit, we optimized initial models for isostasy, gravity and the full gravity gradient tensor in orbit height (225 and 255 km) by forward modelling and inversion. Results show that the gravity gradients in orbit height provide additional information about the area which result in a refined model with lateral density variations in the crust and significant LAB and Moho depth variations over the area. In addition, for a satisfying fit vertical density gradients and separation between upper and lower crust has to be introduced. The final structures are compared to global crustal model Crust 1.0 and misfits are discussed.
The goal of explaining the full gravity tensor in one model constraints the model procedure much more than only using gravity or the vertical gravity gradient alone. Thus, the density modelling benefits from the use of the full gravity gradient tensor and should be used for large scale models. Finally, the new model is used to calculate an improved heat flow model of the whole area to derive better maturity maps for hydrocarbon exploration.

P 19

Geothermal Assessment Based on Seismic and Potential Field Analysis and Hydrothermal Forward Modeling - an Example from Tuscany (Italy)

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We present an approach for estimating geothermal and hydraulic properties in a medium-enthalpy geothermal reservoir Southern Tuscany (Italy) on a regional scale. The focus of the presentation lies on the analysis of seismic reflection data as the backbone of an integrative approach of geothermal prospecting, complemented by magnetotelluric and gravimetric data.

The geophysical field data comprise a network of 2D profiles of seismic reflection, areal gravity and electromagnetic data and thermal data from boreholes. A 3D geological model is based on these data as well as on fault and fracture patterns, and petrophysical and hydro-geothermal properties are assigned to the various domains of this model. Deriving a most comprehensive and consistent 3D model from a combination of seismic information gathered along a widely meshed net of profiles with 2D potential field data recorded on the earth's surface is a particular challenge. We approach this by forward modeling and iteratively adjusting residual field data at subsequent depth intervals. Magnetotelluric forward modeling constrained by seismic data is applied in order to discriminate between alternative model versions and to identify possible fluid enrichment in the upper crust.

Special attention is paid to quantifying the uncertainties of the derived 3D model. For estimating model uncertainties, distribution functions are derived or estimated for all geophysical properties involved based on borehole measurements, careful seismic velocity analysis and forward modeling.

Attributing (crack) porosities and permeabilities to the 3D geophysical model yields a thermo-hydraulic model down to 8 km depth. This model is evaluated and calibrated by geothermal modeling.

P20

Seismic assessment of geothermal potential of crystalline crust

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On the basis of seismic and petrophysical data collected at the 9.1 km deep Continental Deep Drillhole (KTB) we are presenting a stochastic approach to estimate geothermal and hydraulic properties of deeply fractured crystalline crust. The work is an approach to realistically estimating the geothermal potential of faulted crystalline crust. Its seismic part consists of applying new techniques of data analysis to 3D seismic reflection data in order to identify and statistically quantify complex networks of fractures and their relation to major fault planes. Concentrating on a 10x10x10 km crustal cube this analysis is combined with vertical seismic profiling, geophysical logging, petrophysical laboratory and mineralogical data in order to estimate crack porosity values in situ. In order to determine model uncertainties distribution functions are derived for all geophysical properties involved on the basis of borehole measurements and seismic modeling. Attributing the resulting crack porosities and permeabilities to the 3D seismic fracture patterns leads to a hydraulic model of the brittle upper crust which is evaluated and calibrated in two ways: (1) by the outcome of the hydraulic injection experiments performed previously at the KTB site, and (2) by geothermal modelling. To calculate the thermal and hydraulic field, coupled steady-state hydrothermal simulations were performed for a large scale model of the whole area. The resulting boundary conditions could then be used as input into more detailed models of doublet systems simulating the actual heat extraction. Resulting changes of production temperature and pressure in time show the potential of the KTB site to accommodate a successful geothermal installation. The work concept followed during the geothermal potential assessment of the KTB site is applicable also for other reservoirs located in a similar environment.

P21

Glacial tectonics and erosion - effects on groundwater pathways

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The glaciations in Northern Europe formed a gently rolling landscape but also the sedimentary cover down to several hundred meters depth is affected by the ice sheet.
The tectonic effect of advancing glaciers is thrust faulting of aquifers (sand, gravel) and groundwater dividing layers (till, clay) by ice push. After faulting these layers are steeply dipping and the dividing layers no longer act as groundwater protecting barriers. At airborne electromagnetic surveys the thrusted sediments can be detected by elongated structures of alternating resistivities. Reflection seismic surveys at these locations show the disturbances in form of steeply dipping horizons. In combination with resistivity methods (airborne or ground based) clayey and sandy layers can be separated.

In a late stage of glaciation the ice mass can be fractured leading to pathways of meltwater. Meltwater flow driven by hydrostatic pressure can lead to subglacial erosion and form deep valleys. Filled again with moraine material and without indications at the surface, they are called buried valleys. Buried valleys can be investigated with reflections seismic and gravity measurements. If a resistivity contrast between valley fill and surrounding material exist, resistivity methods can be applied for buried valley mapping.

Both, glacial tectonic and glacial erosion have strong effects on the groundwater dynamic. Methods and strategies for the mapping of these structures were developed and applied in the EU projects BurVal and CLIWAT. Results are discussed in the poster.

P 22

Disaggregation of marine sediments monitored offshore by Stoneley-waveform inversion

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Marine sediments react with changes in their shear strength and density when stressed by dynamic/cyclic loads. These loads can have natural or man-made origin. In the latter case offshore buildings with cyclic, horizontal movement due to wind and wave load can cause sediment changes. Shear strength is furthermore connected to the elastic properties of the sediment, especially the shear modulus and can thus be investigated by seismic methods. We present an investigation done at the FINO3 offshore research platform in the North Sea. Possible changes of the shear modulus and density of the sediments in the vicinity of the FINO3 monopile are determined from seismic field measurements by a Stoneley-waveform inversion. The Stoneley waves are excited by a hammer blow at the internal wall of the FINO3 monopile foundation above the water line. The seismic wavefield propagates through the water column and sediments and is measured in situ by hydrophones at the external wall of the monopile below the seafloor. Homogenous long wavelength initial models for the waveform inversion are estimated by simple 2D finite difference forward modeling. The resolution of the Stoneley-waveform inversion is estimated by simple checkerboard tests. The tomographic results of the field data show severe shear-wave velocity changes of the sediments near the FINO3 platform in comparison to studies performed before the foundation of the pile. Qualitatively the seismic results agree well with finite-element based geomechanical forward modeling of the disaggregation of marine sediment under wind and wave stress near an idealized pile.

P23

Continental margin instability and its relation to volcano buildup offshore the edifice of Mt Etna, Italy

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Mount Etna is the largest active volcano in Europe. Its volcano edifice is located on top of continental crust close to the Ionian shore in east Sicily. Instability of the eastern flank of the volcano edifice is well documented onshore, and is monitored by a series of geodetic and InSAR measurements. In addition to the volcano edifice, the continental margin is supposed to reveal an instability, too. Little is known, however, about the offshore extension of the eastern volcano flank and its adjacent continental margin, defining a serious shortcoming in stability models.
In order to better constrain the active tectonics of the continental margin offshore the eastern flank of the volcano, we acquired and processed a new marine hydro-acoustic dataset, including high-resolution 2D reflection seismics and multi-beam swath bathymetry. The data provide new detailed insights into the heterogeneous geology and tectonics at the uppermost ~750 m of the continental margin offshore Mt Etna. In the same manner as observed onshore and at the volcano edifice, the submarine realm can be characterized by different blocks, which are controlled by local- and regional tectonics. We are able to image a compressional regime at the toe of the continental margin, which is bound to an asymmetric basin system confining the eastward movement of the flank. In addition, we constrain the proposed southern boundary of the moving flank, which is identified as a right lateral oblique fault movement north of Catania Canyon. From our findings, we consider a major coupled volcano edifice instability and continental margin gravitational collapse and spreading to be present at Mt Etna, as we can see a clear link between on- and offshore tectonic structures across the entire eastern flank. The new
findings will help to evaluate hazards and risks accompanied by Mt Etna’s slope- and continental margin instability and will be used as a base for future investigations in this region.