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Contents

ORAL PRESENTATIONS

Session: The continental lithosphere I

M.I.1 In search of a fossil plate boundary of Baltica in Poland – the Teisseyre-Tornquist Zone revisited (KEYNOTE)

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The Teisseyre-Tornquist Zone (TTZ) is the longest European tectonic and geophysical lineament extending from the Baltic Sea in the NW to the Black Sea in the SE. This transcontinental feature is clearly visible in seismic refraction data as a transition zone form the thick Precambrian crust of the East European Craton (EEC) to the thinner crust of the Palaeozoic Platform of Western Europe. The TTZ is evident from the seismic data as a perturbation of the Moho depth as well as from magnetic and gravity anomaly maps and heat flow distribution. For over a century, the TTZ has been considered a fossil plate boundary of the EEC corresponding to the limit of early Palaeozoic palaeocontinent Baltica. The nature of the TTZ has remained unresolved for a long time due to the lack of adequate data on its in-depth architecture. This situation has changed with the emergence of the first high-resolution reflective seismic profiles imaging the structure of the SW slope of the EEC.

We present the results of quantitative interpretation of gravimetric and magnetic data, integrated with the interpretation of seismic reflection profiles from PolandSPAN™ survey to explain whether the TTZ is a tectonic boundary of the EEC. Our data indicate the continuation of the Precambrian basement of the EEC and its lower Palaeozoic cover toward the SW underneath the Palaeozoic Platform. Potential field modelling also suggests the occurrence of a crustal keel underneath the TTZ. These results imply the location of a Caledonian tectonic suture (Thor Suture), marking the site of the collision between Avalonia and Baltica, not along the TTZ, but farther SW, in NE Germany and SW Poland. Consequently, the extensive Permo-Mesozoic sedimentary basin of western Poland is established above the attenuated margin of the Baltica palaeocontinent. New geophysical evidence suggests which the TTZ was formed in the latest Precambrian as a crustal necking zone during Ediacaran rifting and break-up of the Tornquist Ocean. The study highlights the value and importance of regional deep reflection profiles, such as the PolandSPAN™ survey and the POLCRUST-01 line, since they revived the debate on the nature of the TTZ.

M.I.2 RomUkrSeis: the deep structure of the TESZ where it is obscured by the Eastern Carpathians

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RomUkrSeis is a controlled source wide-angle reflection and refraction (WARR) profile acquired in August 2014. It is 675 km long, running roughly SW-NE from the Apuseni Mountains in Romania and the Transylvanian Basin (Tisza-Dacia) behind the arc of the eastern Carpathian orogeny, crossing this and terminating in the East European Craton (EEC) in central Ukraine. A well-constrained velocity model has been constructed along the RomUkrSeis profile from 350 single component seismic recorders and eleven shot points in a single deployment. The Eastern Carpathian arc and the complex tectonic processes that formed it in the Cenozoic have obscured the pre-existing Trans-European Suture Zone (TESZ), which is the transition zone between the EEC and terranes accreted to its southwest in pre-Cenozoic (especially Palaeozoic) times.

Relatively low velocities are determined throughout the whole crust along the RomUkrSeis profile. The velocities in the southwestern part of the model are comparable with those from the Pannonian Basin (Vp <6.6 km/s) observed elsewhere but the crustal thickness is higher, >30 km. There is a high velocity body (Vp ~6.36 km/s) at depths of 3-12 km at a location corresponding to the surface expression of the ophiolite formation of Apuseni Mts. Immediately below this body, lower velocities are found. In the central part of the model, there is a large sedimentary wedge that comprises the Cenozoic Carpathian foreland itself as well as older sedimentary units. The wedge consists of two thick layers of Vp ~4.7 and 5.35 km/s with a width of ~30 km, asymmetrically dipping to the SW and reaching a depth of ~15 km. Below it, up to a depth of 45 km, Vp of ~6.3 km/s is determined. On the EEC side of the model, the velocities near the base of the crust (to depths 33-43 km) reach Vp ~6.6 km/s. Strongly differentiated Moho depths are observed along the profile as a whole. Four segments can be identified from the southwest to the northeast, with depth variations from 32 to 50 km. Velocities below the Moho boundary are: 8.15-8.2 km/s and ~8.3-8.35 km/s below a sub-Moho discontinuity in the uppermost mantle (at depths ~52 km in the central part of the profile and ~47 km in its northeastern part).

A comparative study of the RomUkrSeis profile and two other WARR profiles that cross the Eastern Carpathians, PANCAKE to the northwest and VRANCEA 2001 to the southeast, could illuminate important aspects of the relationship between the emplacement of the Carpathian arc and the earlier crustal architecture of this fundamental tectonic transition zone.

M.I.3 Late Archean continental spreading inferred from seismic reflection images of the Australian Yilgarn craton

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On the early Earth, oceanic plateaux similar to present-day Iceland are thought to have evolved into less dense micro-continents as they thickened by continued melt intrusion and crustal fractionation. These earliest continents may have been so weak on a hotter Earth that they collapsed laterally in response to thickening by further magmatic growth or tectonic imbrication. This continental spreading is likely to have resulted in the development of pervasive ductile strain fabrics in the deeper crust, which, if preserved, could generate seismic reflections. Deep seismic reflection images from the Youanmi Terrane, which represents the ancient core of the Yilgarn Craton of Australia, reveal pervasive shallowly dipping to subhorizontal reflections in the middle and lower crust. Although imbricate structures related to thrusting are identified in some parts of the middle crust, the normal offset of upper crustal reflections and listric reflections in the middle and lower crust indicate that much of the crust has been affected by extension. The resulting structural basins in the upper crust, which include half-grabens and symmetric synforms, appear to be filled by high temperature crustal melts dated at 2.65-2.61 Ga, implying that this extension occurred late in the evolution of the craton and was key to cratonsation of the Archean crust here. Seismic reflection data from the northeastern part of the Yilgarn craton show that the Eastern Goldfields Superterrane, immediately east of the Youanmi Terrane, was also affected by widespread extension, but in this area extension was accommodated in the upper and middle crust along discrete shear zones that flatten out into the top of a relatively transparent lower crust. Laterally continuous, short duration, subhorizontal lower crustal reflections may also represent discrete shear zones that accommodated collapse of the cratonic crust. These deep seismic reflection surveys indicate that, though structural styles differ somewhat between the Youanmi Terrane and Eastern Goldfields Superterrane, crustal collapse occurred over >500 km of the northern Yilgarn craton. Some reflections that project to the surface within greenstone belts, extend beneath adjacent younger granites, leading us to also conclude that large regions of the upper crust in the hanging walls of listric shear zones subsided beneath the late granitic melts rising towards the surface, and did not involve Rayleigh-Taylor instabilities within a mostly mobile crust.

M.I.4 *Crustal Structure of Sulu Orogenic Belt: from an Active Source Onshore-Offshore Wide-angle Seismic Profile*

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Most of the northern part of China is formed by the collision between the Sino-Korean (North China) Block and the Yangtze Block, these two blocks collided and merged together to form the famous Sulu-Dabie orogenic belt in the world. Coesite and diamond particle inclusions found in the Sulu orogenic belt area indicate that the orogenic belt has undergone ultra-high pressure (UHP) metamorphism. The exposed UHP metamorphic belt in this area has been proved to be one of the world's largest UHP metamorphic structural units, which made this area a natural laboratory for the study of the continent-continent collision, subduction, and reentry dynamic processes. This area has attracted the attention and research of global earth scientists and has successively achieved important advances. Here we can found that all of the deep seismic sounding works were carried out on the land, and there are only little potential field data like gravity and magnetic studies in the sea area or some regional seismic tomography results around the sea area. But the Sulu orogenic belt is extending to the South Yellow Sea area, where there is no seismic sounding profile exist yet, and there is yet no exactly answer to where the boundary of Sulu orogenic belt is, and how Sino-Korean block and Yangtze block merged together.

In order to get the deep structure characteristics and find out the boundary of Sino-Korean Block and Yangtze Block in the south Yellow Sea, to reveal the collision process of these two blocks, we deployed an active source onshore-offshore wide-angle seismic survey line across the Sulu orogenic belt in 2013. The line (Line2013) started from the Bohai Sea in the NW and ended in the south Yellow Sea in the SE, By using first arrival tomography and ray-tracing modeling method, we finally got the Vp structure of Sino-Korean block and Yangtze block. The result shows that the block boundary is marked by great deep fault zone, the Vp structure is very different from each other on the two sides of the fault zones. The Muping-Jimo fault zone is the boundary between Sino-Korean block and the conjunction zone, and the Qianliyan fault zone is the boundary between Yangtze block and the conjunction zone. Both of these two blocks have no large-scale undulance of Moho, but the crust thickness of Sino-Korean block (30 km) is a little less than the Yangtze block (32km). The thinnest crust locates at the Central Bohai Depression (CBD) (25km) which indicates that the CBD is the crust thinning center of North China Craton (NCC). The structure of the Sulu orogenic belt is much more complicated, a large scale high velocity zone in the upper crust beneath the Qianliyan uplift can be found, and there is a large scale low velocity zone in the middle crust beneath the Sulu orogenic belt. At the same time, our result shows that the Moho interface is very different in different tectonic units, the Moho of Yangtze is the smoothest, followed by North China (except for an uplift in the CBD), and the moho of orogenic belt is the roughest, which indicate that some complicated deep processes have taken place during the collision of these two blocks.

M.II.1 *Seismic imaging of a Variscan suture in SW Iberia and its role in seismicity control*

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The crustal structure in Western Iberia, is the result of a complex geodynamic history. The majority of lithological units outcropping in Western Iberia are of Paleozoic age (480-290 Ma) and compose the Iberian Massif or Iberian Autochthonous Terrane, the major outcrop of the SW European Variscides. The Mesozoic-Cenozoic extension associated with the Atlantic rifting stages are mostly limited to coastal ranges, with Mesocenozoic basins only partially extending into the mainland. The current slow oblique convergence between Iberia and Nubia is accommodated along a broad region of diffuse deformation, influenced inland by the variscan structures which control the observed seismicity.

The temporary seismic network deployment of the WILAS project in 2010-2012, coupled with the TOPOIBERIA experiment in Spain, allowed a significant quality increase of the seismicity recorded in Western Iberia. This, adding additional carefully selected events from the period 2000-2014, allowed to obtain a local earthquake tomographic model of the crust. In this work we will present the results of a zooming into the structure of SW Iberia, and across the variscan suture zone from the South-Portuguese Zone (SPZ), through the Ossa-Morena Zone (OMZ) and up to the Centro-Iberian Zone (CIZ).

In the OMZ and CIZ the obtained tomograms present a good correlation with the surface geology, whereas in the SPZ a greater heterogeneity is observed than the suggested by the shallow structures. The SPZ presents an east-west velocity variation, with decreasing Vp and also Vp/Vs values instead of the apparent surface homogeneity, suggesting a deep north-south contact of pre-variscan nature which may explain an observed SSW-NNE seismicity alignment with no apparent associated surface fault.

A complex transition SPZ-OMZ is visible in both Vp and Vp/Vs models, associated with the Beja-Acebuches Ophiolite and extending farther west. The vertical profiles present anomalies consistent with the subduction of the SPZ beneath the OMZ. The inner OMZ presents the greater heterogeneity, as expected, with the general orientation of the structures defining blocks of persistent seismicity. While the OMZ-CIZ limit is usually considered along the Tomar-Cordoba Shear Zone, the transition OMZ-CIZ is relatively smooth, the greater discontinuity being marked well inside the OMZ along the well-defined WNW-ESE seismicity Ciborro alignment. The CIZ is well defined by higher Vp values, with the Vp/Vs showing some similar tendency.

Of the Mesocenozoic basins, the one corresponding to the Lower Tagus Valley presents a strong low Vp and high Vp/Vs anomalies, consistent with a 4-5 km thick saturated sediments. The margin basins are also associated with low Vp values, but being located on the outer layers of the model do not have a clear spatial definition.

M.II.2 *Seismic imaging of the Eastern Pyrenean belt*

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The presence of a crustal root beneath the central part of the Pyrenees has been extensively documented by seismic and gravity data and is related to the building of the Pyrenees Chain during the Alpine orogeny. The Eastern termination of the chain is affected by a second major orogenic process, the Neogene extension associated to the rotation of the Sardinia-Corsica block and the opening of the Valencia Trough. This extensional feature has resulted in a rather abrupt thinning of the crust, from 40-45 km about 80 km to the west of the Mediterranean coastline to less than 25 km beneath the eastern termination of the chain. The details of the transition between the central and eastern Pyrenees domains needs still to be fixed into detail.

With this objective in mind, two passive seismic profiles have been acquired from mid 2015 to late 2016 within the OROGEN and Pyrope projects. Up to 38 broad-band stations were deployed along two orthogonal lines, with an interstation spacing close to 10 km. The NNE-SSW profile, oriented orthogonally to the Pyrenees trend, shows a well defined Moho beneath Iberia, slightly deepening from 32 to 35 km northwards. Beneath the Axial zone the Moho is located between 30 and 35 km and appears to be segmented in a couple of convertors. Further North, underneath the North Pyrenean Front Thrust , the Moho appears again as a clear and continuous convertor located at 28-30 km. This image clearly differs from the sections obtained in Central and Western Pyrenees, where the imbrication between the Iberian and Eurasian crusts is more conspicuous.

Results of receiver function migration on the E-W profile suggest a smooth Moho thinning from a 40 km depth beneath the western termination of the line to 23 km close to the coastline, confirming the picture retrieved from previous, lower resolution experiments and evidencing the crustal thinning due to the Neogene extensional processes.

Moderate magnitude earthquakes with epicenters located in the Gulf of Roses and near the intersecting point of the profiles have been recorded along the seismic lines during the experiment, hence providing additional constraints on the geometry of the crust/mantle boundary in the Eastern Pyrenees. In particular, the recordings of the Gulf of Roses event along the NNE-SSW line resulted in a fan profile proving than minor crustal thickness differences between Iberian and Eurasian crusts can still be recognized at longitudes around 2.7ºE, about 30 km away from the Mediterranean coast.

We are now progressing in the integration of these results with the available geologic transects in order to provide a more accurate geodynamical interpretation of this region.

M.II.3 *Understanding the origins of intraplate volcanism: A geophysical perspective*

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Evidence of intraplate volcanism can be found throughout the globe, yet it remains a relatively poorly understood phenomenon, with many different mechanisms proposed to explain its provenance. In Australia, the origin of widespread Cenozoic intraplate volcanism, which traverses almost the entire length of the eastern seaboard, is a subject of considerable uncertainty and debate. One of the key challenges in trying to pinpoint the mechanisms which lead to melting and emplacement is to explain the overlapping presence, in time and space, of both age-progressive and non age-progressive volcanism. Recent results from seismic tomography in eastern Australia demonstrate a clear link between lithospheric thickness and the occurrence, composition and volume of volcanic outcrop. Furthermore, non age-progressive lava-fields overlie significant cavities in the base of the lithosphere. Numerical simulations of mantle flow show that these cavities generate vigorous mantle upwellings, which promote decompression melting. However, due to the intermittent nature of the lava-field volcanics over the last 50 Ma, it is likely that transient mechanisms must also operate to induce or enhance melting. In the case of the Newer Volcanics Province in Victoria, the passage of a nearby plume appears to be a likely candidate. These results demonstrate why detailed 3-D variations in lithospheric thickness, plate motion and transient sources of mantle heterogeneity need to be considered when studying the origin of volcanism in continental interiors.

M.II.4 *Influence of a megathrust earthquake on crustal properties and seismicity in regional distances*

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Megathrust earthquakes accompany large permanent lithospheric displacements as well as strong transient ground shaking up to regional distances. The lateral permanent displacements construct stress shadows in a wide backarc region. The Korean Peninsula is placed in the far-eastern Eurasian plate that belongs to a stable intraplate region with a low earthquake occurrence rate and diffused seismicity, and is located in the backarc at ~1300 km in the west from the epicenter of the 11 March 2011 M9.0 Tohoku-Oki earthquake. The seismicity around the Korean Peninsula was increased significantly after the 2011 M9.0 Tohoku-Oki earthquake. Strong seismic waves cause large dynamic stress changes, incurring fluid migration and increasing pore fluid pressure in the media. The lithospheric displacements directing to the epicenter on the convergent plate boundary develop transient radial tension field over the backarc lithospheres. The seismic velocities in the crust were decreased after the megathrust earthquake, which recovered gradually with time for several years. A series of moderate-sized earthquakes and earthquake swarms occur as a consequence of medium response to the temporal evolution of stress field. The long-term evolution of seismicity is expected to continue until the ambient stress field is fully recovered.

Session: Passive continental margins

M.III.1 *Continental breakup mechanisms and their controlling factors in magma-poor and magma-rich settings; evidence from deep reflections seismic imagery?* (KEYNOTE)

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Two end-member types of passive margins are discussed. The first, most commonly magma-poor type, results from a crust first/mantle second breakup scenario. The second, usually magma-rich type, results from a mantle first/crust second scenario. The crustal architecture of both margins can be roughly divided into stretched proximal margin and thinned distal margin. The main differences between the two scenarios include oceanward-dipping listric normal faults accommodating thinning in the distal margin with a zone of the exhumed mantle separating continental and oceanic crusts in the first case, versus landward-dipping listric faults accommodating magma-assisted thinning in the distal margin and no exhumed mantle in the second case. The final breakup affects the lithospheric mantle layer in the first case and the crustal layer in the second case. Although the temperature-dependent rheologies of these two last unbroken layers are rather different, deep seismic images indicate that they are both broken by upward-convex normal faults, which succeed the development of listric faults. They appear to be the first spontaneously formed faults in the breakup-delivering process, although their nucleation may be magma-assisted. They develop with increasing heat flow and extension rate as the last thinning layer reaches critical thickness. Assisting magma type varies from case to case. The aforementioned end members are accompanied by a whole spectrum of margin types representing various stages of their transition.

M.III.2 *Crustal structure of the Natal Valley from combined wide-angle and reflection seismic data (MOZ3/5 cruise), South Mozambique Margin*

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The study of South Mozambique passive margin is essential to constrain the kinematic of the SW Indian Ocean opening since the Gondwana break-up at the transition between divergent and strike-slip segments. As one part of the PAMELA project (PAssive Margins Exploration Laboratories), conducted by TOTAL, IFREMER, in collaboration with Université de Bretagne Occidentale, Université Rennes 1, Université Pierre and Marie Curie, CNRS et IFPEN, the Natal Valley, Mozambique coastal plains, and the East Limpopo margin have been explored during the MOZ3/5 cruise (2016), conducted onboard the R/V Pourquoi Pas?, through the acquisition of 7 onshore-offshore wide-angle profiles and coincident marine multichannel (720 traces) seismic as well as multibeam bathymetry and potential field data. This study focuses on 2 perpendicular wide-angle profiles: MZ6 oriented NNW-SSE 625 km in length, and MZ2 oriented E-W 300 km in length, composed of 25 and 23 OBS (Ocean Bottom Seismometers) and 20 and 19 LSS (Land Seismic Station) spaced by about 12 km and 4-5 km, respectively.

Forward modeling through combined interpretation of the multichannel seismic, the main reflected and refracted phases of the wide-angle, and gravity data reveals: 1) a sedimentary cover poorly compacted up to 3 km thick, separated by magmatic diked and volcanoes, and inter-bedded with high-velocity volcanic seals; 2) Between 2 to 7 km thick magma-intruded or volcano-clastic deposit characterized by a velocity ranging from 4 to 6 km/s; 3) At the onshore portion of MZ6 and MZ2 profile, the crust reaches 42 km thickness gradually thinning to 25 km at the southern end of MZ6 and stepwise thinning to 21 km at the eastern end of MZ2. The crust presents 3 to 4 distinct layers, the velocity exceeding 7.15 km/s in the deepest layer and reaching at its base 7.8 km/s on the western end of MZ2. 4) The Moho is marked by a strong reflection on the wide-angle data, and the upper-mantle appears homogeneous in the study area with a velocity of 7.9 km/s at the Moho increasing to 8 km/s around 50 km depth.

The analysis of MZ2 and MZ6 profile does not reveal oceanic crust in the Mozambique coastal plains and the Natal Valley, but rather suggests that the basement in the study area is composed of thinned and altered continental crust, most likely intruded by intense magmatism.

[1] Moulin, M., Aslanian, D., 2016. *PAMELA-MOZ03 cruise*, RV Pourquoi pas ?, dx.doi.org/10.17600/16001600

[2] Moulin, M., Evain, M., 2016. *PAMELA-MOZ05 cruise*, RV Pourquoi pas ?, dx.doi.org/10.17600/16009500

M.III.3 *Fossil margin of Baltica in Poland – how does it compare with the Atlantic passive margins?*

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High velocity and density middle/lower crustal bodies are a common feature at passive continental margins, especially underneath the present-day Atlantic shelf that was formed in the course of Mesozoic or Cenozoic continental break-up. Nevertheless, similar bodies have never been identified within relic passive margins mostly because of their subsequent involvement in collisional processes. Our study provides evidence indicating the occurrence of crustal bodies in an intraplate tectonic setting along a fossil continental margin. Although high velocity bodies along the Teisseyre-Tornquist Zone (TTZ) in SE Poland have been already known for the last three decades from seismic refraction and reflection studies the uncertainty concerning the character of the TTZ hindered the full understanding of their geological implications. Thus, only after the acquisition of new high-resolution reflection seismic and a comprehensive integration of seismic, gravity and magnetic data new prospects became available to better understand the origin and tectonic setting of high velocity/density bodies associated with the TTZ. Based on two- and three-dimensional modelling of gravity and magnetic data combined with seismic interpretation of reflection and refraction profiles, we determined the distribution, geometry and physical properties of the high velocity/density bodies as well as the geometry of a fossil passive margin. The results of our study suggest that the crustal bodies associated with the Ediacaran Baltica passive margin represent an ancient analogue for those occurring along the modern margins of the Atlantic Ocean. The high-density bodies from SE Poland were emplaced along a magma-rich section of the Baltica rifted margin near a triple point where three arms of Ediacaran continental rift, i.e. the Teisseyre-Tornquist and Volyn-Orsza Rifts, were connected.

M.IV.1 *Eastern Gondwana breakup: Rifting and breakup as viewed from northern Zealandia*

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The Late Cretaceous continental rifting and breakup of eastern Gondwana formed northern Zealandia, a ribbon of continental crust in the southwest Pacific that is 94% submerged and provides the main record of the processes that isolated it from eastern Australia. To examine this poorly-studied region, we use wide-angle seismic velocity constraints and pre-stack depth-migrated multi-channel seismic reflection data to determine how the continental rifting and breakup occurred. These results provide evidence for oceanic crust beneath the Middleton Basin that separates two known blocks of continental crust, the Dampier Ridge and Lord Howe Rise. This configuration indicates a two-stage breakup of eastern Gondwana, starting first at the Middleton Basin and later switching to open the Tasman Basin to the west. The Dampier Ridge, located between these two oceanic domains, has experienced breakup on both its eastern and western margins. Recently-acquired bathymetry data show a range of seafloor features that contrast the largely featureless seafloor of the Lord Howe Rise. Seismic data on the Dampier Ridge indicate the presence of dominantly NW–SE striking basement ridges that reach the seafloor. These ridges are approximately perpendicular to the inferred opening direction of the Tasman Basin, but another set of N–S-striking ridges is also evident. This ridge geometry is similar to what has been shown from previous work on the Lord Howe Rise and suggests a regional stress change linked to the two-stage breakup of eastern Gondwana. This breakup first involved E–W extension in the Middleton Basin and on the Lord Howe Rise, followed by NE–SW extension during formation of the Tasman Basin. To better understand the rifting events evident on the Lord Howe Rise, we have acquired pre-drilling seismic data at sites that are under consideration for riser drilling as part of an approved, but yet-to-be-funded, International Ocean Discovery Program proposal. The drill site seismic data reveal previously poorly-imaged pre-rift strata beneath well-imaged syn- and post-rift sediments, thereby allowing the full history of this rifted margin to be unlocked.

M.IV.2 *A key of understanding the earliest separation of New Zealand from Gondwana - The crustal structure of the Chatham Rise and Chatham Terrace*

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The submarine continental Chatham Rise extends up 1500 km east of New Zealand's South Island as part of the continent Zealandia. During the Cretaceous it underwent a two-fold tectonic history:

1) At ~100 Ma, the long ongoing subduction of the Proto-Pacific plate at the eastern Gondwana margin abruptly ceased as the Hikurangi Plateau collided with the subduction trench.
2) At least since ~94 Ma after cessation of the subduction, the compressional regime was replaced by continental rifting as evident by the oldest known terrestrial graben sandstones on the Chatham Islands, development of metamorphic core complexes on the South Island and changing geochemical constraints (I-type to A-type granites) in western Marie Byrd Land, Antarctica.

Little is known about the geodynamic processes that accompany the rifting as well as the nature, characteristics and extent of continental thinning at the southern margin of the Chatham Rise. We examine two deep crustal seismic refraction/wide-angle reflection lines crossing the southern margin of the Chatham Rise and adjacent Chatham Terrace, and a third deep crustal seismic profile at the southeasternmost part of the Chatham Rise. Modelling of P-wave velocities indicate variable thicknesses for the part of the Chatham Rise close to Chatham Island (~24 km), west of Wishbone Ridge (< 22 km), east of Wishbone Ridge (18 – 12 km), and the easternmost part (only up to ~13 km). While thicker parts of Chatham Rise are probably underlain by the subducted Hikurangi Plateau, the thinner parts of the crust are strongly affected by normal faulting. As part of the southern Chatham Rise margin, the elevated Chatham Terrace shows a crustal thickness between 10 and 7 km. On the Chatham Terrace, P-wave velocities exceeding 7 km/s at the crustal base probably related to magmatic underplating.

Our results indicate that the Chatham Terrace has continental affinities as evident from graben structures obvious in the seismic reflection data and from continental-affinity rocks dredged from the Stuttgart Seamount. We suggest that magma-poor continental rifting led to the formation of the Chatham Terrace, Bounty Trough, Canterbury Basin as well as the metamorphic core complex exhumation in the Dunstin Range onshore New Zealand's South Island until ~84 Ma. Highly asymmetric westward propagation of the Pacific-Bellingshausen spreading ridge led to a magmatic overprint and formation of the Chatham Terrace seamounts, separation of the Bollons Seamount from the Bounty Platform and the breakup of the Chatham Rise and Campbell Plateau from Antarctica proceeded.

M.IV.3 *Crustal structure of the Arabian passive margin from seismic and gravity data*

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The UAE-Oman mountains constitute a 700 km long, 50 km wide compressional orogenic belt that developed during the Cenozoic on an underlying extensional Tethyan rifted margin. The mountains are associated with significant topographic relief, large-amplitude isostatic gravity anomalies and an unusually deep flanking foreland basin. Perhaps most significantly, this orogenic belt contains the world's largest and best-exposed thrust sheet of oceanic crust and upper mantle (Semail Ophiolite), which was obducted onto the Arabian rifted continental margin during the Late Cretaceous. Although the shallow structure of the UAE-Oman mountain belt is reasonably well known through the exploitation of a diverse range of techniques, information on deeper structure remains little. Moreover, the mechanisms by which dense oceanic crustal and mantle rocks are emplaced onto less dense and more buoyant continental crust are still controversial and remain a great challenge for the Earth Science community.

In an attempt to provide new constraints on the nature of continental and oceanic crust beneath both the Semail Ophiolite and underlying crust of the UAE-Oman orogenic belt, we have carried out the first integrated seismic reflection and refraction experiment in the UAE-Oman region in July 2014. The experiment combines passive and active seismic techniques, corroborated by potential field data.

The focus here is on two active-source seismic E-W transect extending from the UAE-mountain belt to the offshore, running broadly orthogonal to the mountain range. Seismic refraction data were acquired using the survey ship M/V Hawk Explorer, which was equipped with a large-volume airgun array (7060 cubic inches, 116 litres). In addition, reflection data were acquired at 20 seconds interval and recorded by a 5-km-long multichannel streamer. Results presented here include two P-wave velocity crustal profiles (stretching both onshore and offshore) derived by a combination of forward modelling and inversion of both diving and reflected wave traveltimes using RAYINVR software. We find ophiolite seismic velocities of about 5.5 km/s, which is underlain by a thick layer of faster material, where velocities vary between 6.0 and 6.4 km/s. The velocity and gravity models reveal a highly stretched crust with the Moho discontinuity lying at about 20 km in the eastern offshore, which abruptly decreases to about 40 km in the foreland area.

A number of prestack depth-migrated profiles (totalling 925 km) from the Gulf of Oman clearly show the contact between the ophiolite and overlying sediments and evidence for thick seaward dipping sedimentation, tilted fault blocks and a number of listric (normal) faults, some of which intersect the seabed and so reflect recent tectonic activity. We interpret the NE margin of the ophiolite to be a low-angle normal fault with up to 8 km of Cenozoic sediments in localised depocenters.

M.IV.4 *New tectonostratigraphic model of the Interior Basin, onshore Gabon, based on reinterpreted seismic data, or how the Central Atlantic was opened*

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The Lower Cretaceous (Berriasian – Barremian) Interior Basin in Gabon is located between two exposed Precambrian units: the Larmbarene Horst and Cristal Mountains. It has been traditionally interpreted as a typical rift basin that developed during the first stages of breakup of Gondwana that eventually led to the opening of the Atlantic (cf. e.g. Heine et al., 2013). A classic model of the Interior Basin assumes that it is bordered by a deeply rooted master normal fault that separates it from the Larmbarene Horst located farther west, towards the Atlantic (Mounguengui & Guiraud, 2009). This normal fault was interpreted as developed during the first stages of Atlantic opening and formation of incipient rifting axis that was in the Barremian – Aptian shifted towards the west, into the present-day Atlantic domain.

Recently reinterpreted seismic data suggest very different kinematics of this master fault separating the Lambarene High and Interior Basin. It was reinterpreted as a regional reverse fault along which a large crustal block i.e. the Lambarene High, was uplifted in relation to the Interior Basin. Additionally, the seismic data acquired in the eastern part of the Interior Basin clearly show that its Lower Cretaceous sedimentary cover must have extended much farther towards the E-NE, i.e. towards the present-day African interior. Analysis of thermal history of the Interior Basin revealed very low paleo-heat flow, incompatible with typical rift basin characteristics. Also, this basin seems to be missing post-rift thermal sag deposits, typical for extensional rift basins. All these findings suggest that the Interior Basin did not evolve as a focused, relatively narrow rift basin, located within the hanging wall of the master normal fault (fault zone) developed along the NE edge of the Lambarene Horst but it might have extended much farther both towards the E-NE and W-SW, and was narrowed by uplift of the Lambarene High and Cristal Mountains. Comparison of tectonic models of the Interior Basin and its companion depocentre from Brasil i.e. the Recôncavo Basin, often regarded as an almost exact mirror image of the Interior Basin (e.g. Magnavita & da Silva., 1995) suggests that prior to uplift of the Lambarene High and its equivalent block from E Brasil i.e. the Salvador High, both basins might have been connected. Under such a still speculative model the future axis of Atlantic opening would have developed within the uplifted Salvador – Lambarene crustal block. All these findings would have a significant impact on regional paleogeographic and plate tectonic reconstructions.

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M.IV.5 *A detailed look at diapir piercement onto the ocean floor: New evidence from Santos Basin, offshore Brazil*

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Diapir piercement through the ocean floor marks the final stages of a dynamic migration path. Once exhumed, a diapir extrudes from the seafloor, placing an obstacle for the flow of ocean bottom currents. While the hydrodynamic response of the flow has been previously studied, the detailed depositional and weathering modifications involved in the piercement process are less understood. To bridge this gap, we gathered already available multibeam bathymetric data and multichannel 2D seismic reflection profiles and collected new single-channel CHIRP profiles, Acoustic Doppler Current Profiler data and sediment samples across Santos Basin, offshore Brazil. In this region, the processes connecting the uppermost subsurface with the lowermost section of the water column are unknown. Data show three main stages of diapir exhumation: pre-, syn- and post-piercement into the seafloor. During the pre and syn stages, elongated depressions forming over extensional faults crowning a non-exposed diapir are reworked by bottom currents to shape broad and shallow concave topographic lows. In cases of diapir exposure, bottom currents tightly detour the emerging obstacle caused by the irregular relief of the diapir head (syn-piercement). In some cases, a typical drift and moat contourite morphology is formed. These contourites continue to develop in the uppermost strata in later stages of the exposure while the diapir head undergoes chemical and physical erosion (syn and post piercement). Our high-resolution data allow relating these morphologies to seafloor processes, and distinguishing them from other reflector geometries related to diapir flank deformation, such as outward dipping of reflections. We further use this geometrical distinction to suggest a key for interpreting the exposure versus burial history of other diapirs worldwide.

Session: Active continental margins

T.I.1 *Seismic Image of the Japan Trench Seismogenic Zone and its Implications for Earthquake Processes* (KEYNOTE)

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A rapid response cruise soon after the 2011 Tohoku-oki earthquake acquired bathymetry and seismic reflection data across the trench axis at the coseismic slip zone. These data enable us to obtain differential bathymetry and seismic images before and after the earthquake, which show crucial evidences indicating a trench breaching coseismic slip. A characteristic structure at the trench axis in the rupture zone is a fold-and-thrust structure limited in the trench axis. This structure is proposed to be a structural proxy to identify a coseismic slip to the trench.

Remaining questions to be addressed are: how far does the large trench breaching coseismic fault slip extend laterally along the trench, and what is a structural factor to control a lateral propagation of the slip to the trench? To answer those questions, JAMSTEC has been acquiring additional differential bathymetry data and high-resolution seismic reflection data around the trench axis. High-resolution seismic data and differential bathymetry data at 50 km north and south of the epicenter show no significant coseismic structural deformation at the trench axis. These data indicate that trench breaching slip is only restricted at ~50 km around the epicenter within ~ 500 km wide of the coseismic slip fault. Regarding a structural factor controlling a slip behavior of a megathrust earthquake, a global compilation indicates that large megathrust earthquakes tend to occur in subduction zones where the oceanic crust is covered with thick sediment. Seismic data acquired from the outer rise to the trench axis show localized thin sediment patches in a part of the outer rise and the trench axis. Comparing the seismic section and core samples from deep sea drilling at the outer rise and the fault zone shows that the pelagic clay layer, which observed along the plate boundary fault in the large slip region during the 2011 Tohoku-oki earthquake, is likely missing in the thin sediment area. The thin sediment patch in the trench axis seems to be well correlated with the northern end of the large slip zone along the trench axis.

T.I.2 *New findings on structures of the subducted Philippine Sea plate and the overriding SW Japan arc by reinterpretation of previous seismic data in Kii Peninsula*

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In the last two decades, a number of seismic data with use of controlled seismic sources have been accumulated in and around the Japan. In the present paper, we intended to derive new structural information directly related with the plate subduction beneath the Kii peninsula, SW Japan, by applying recent modern processing and interpretation methods to relatively old seismic data collected in 2004 and 2006.

An offshore region south of the SW Japan arc is one of the well-known seismogenic zone associated with the subduction of the Philippine Sea (PHS) plate along the Suruga-Nankai trough. An area off the Kii peninsula corresponds to the eastern part of this seismogenic zone, where the Tonankai earthquake (M7.9) occurred in 1944. The Kii peninsula well recorded deformation and evolution processes dominated by the plate subduction, and is geologically divided into two part by the E-W trending Median Tectonic Line (MTL). South of the MTL (the Outer zone), Cretaceous-Jurassic accretionary complexes are exposed, whose northernmost unit consists of high P-T metamorphic rocks (the Sanbagawa metamorphic belt (SMB)). The region north of the MTL (the Inner zone), on the other hand, is occupied by older accretionary complexes, partly suffered from the Cretaceous magmatic intrusions. The plate boundary beneath this peninsula is in the stable or conditionally stable regime except for its southernmost tip (the northwestern end of the rupture area at the 1944 event).

The reflection/wide-angle reflection data we used were acquired in 2004 and 2006. We applied modern processing and interpretation techniques including CRS (Common Reflection Surface)/MDRS (Multi-Dip Reflection Surfaces) stacking and seismic interferometry (SI) to get more reliable structural image to deeper parts including subducted plate. For the 2006 data, careful wide-angle reflection analysis was also undertaken to estimate heterogeneous velocity structure around the subducted plate boundary.

The present reflection processing with aid of SI was quite effective to image the subducted PHS plate and the overriding SW Japan arc crust. Beneath the 2006 profile line, running in the eastern part of the Kii peninsula, the intensive wide-angle reflection analysis revealed significant lateral change in reflectivity along the downgoing plate interface. Around the northwestern end of rupture zone of the Tonankai earthquake, reflection occurs in a very thin (<1 km) low velocity (Vp=3.5-5 km/s) layer at the top of the PHS plate. In the region with stable/conditionally stable regime landward of the rupture zone, on the other hand, reflectors are distributed in diffused manner with a thickness of 3-5 km, around which low frequency earthquakes are occurring. Such structural difference is probably dominated by dehydrated fluid from the subducted oceanic crust/mantle.

For the overriding SW Japan arc, very clear image of the MTL was obtained from the 2006 seismic data. It extends almost to the plate boundary with a 5-10 km thick reflection band. Amplitude analysis indicates that the top of the MTL has a velocity contrast of 0.5-1 km/s to a depth of 15-20 km. According to the preliminary processing for the 2004 seismic data, similar structural feature of the reflection band was found along the MTL in the middle part of the Kii Peninsula.

T.I.3 *The amplitude variation of the reflected wave from the subducting Philippine Sea plate around the source region of non-volcanic tremor in southwestern Japan*

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The Philippine Sea plate is subducting beneath the southwestern Japan. Many large earthquakes have occurred periodically at the Nankai Trough. The non-volcanic tremor is one of the important phenomena at the subduction zone of the Philippine Sea plate (Obara, 2002). Seismic structure at the plate boundary is one of the important information to know the mechanism of the non-volcanic tremor. Several seismic explorations using active sources have been done to know the structure at the plate boundary in southwestern Japan. The configuration and seismic wave velocity structure of the Philippine Sea plate have been studied (e.g., Kodaira et al., 2002; Iidaka et al., 2004; Iwasaki et al., 2016). It is a remarkable characteristic of the seismic experiments in this region that a clear reflected waves from the subducting Philippine Sea plate have been observed. The reflected wave from the subducting plate is very important data to know the physical property at the plate boundary. The presence of the extremely low-velocity layer at the top of the Philippine Sea slab has been suggested (e.g., Kodaira et al., 2002; Iidaka et al., 2004). A seismic experiment with artificial sources at the southwestern Japan was done in 2004 by a program of the Headquarters for Earthquake Research Promotion Japan. In this study, we used the data of the profile line which was termed Shingu-Maizuru profile line. The profile line traversed at the central part of Japan from Pacific Ocean side to Japan Sea side. The clear reflected wave from the subducting Philippine Sea plate was detected on the record sections of the profile line. A large amplitude variation of the reflected wave was observed along the depth direction. To explain the observed amplitude of the reflected wave from the Philippine Sea slab, a low velocity layer is required at the top of the subducting plate. The depth range of the low velocity layer is estimated to be 25 km – 30 km.

The existences of the strong reflector and low velocity layer have been reported at other regions along the Nankai Trough. In the Tokai region, which is in the eastern part of the Nankai Trough, the extremely low velocity layer was detected at the depth range of 25 km - 35 km (Iidaka et al., 2004). Iwasaki et al., (2016) studied the crustal structure using active sources at the eastern part of Kii Peninsula, which is in the central part of Nankai Trough. They also detected a strong reflector at the depth range of 25 km - 35 km. In the Shikoku region, which is in the western part of the Nankai Trough, the low velocity layer and its depth variation were reported by Kodaira et al. (2002) and Kurashimo et al. (2003), respectively. The depth ranges of the low velocity layer at the areas are consistent with source area of non-volcanic tremor.

The results, which were obtained from the analysis of Shingu-Maizuru profile line, are consistent with those of other profile lines along the Nankai Trough. The low velocity layer seems to be related to the non-volcanic tremor.

T.I.4 *Structural controls on slip behaviours in the Ryukyu subduction zone*

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Slip behaviors along subduction megathrust faults range from aseismic creep to fast rupture leading to destructive earthquakes. However, physical and structural characteristics controlling the slip speed and rupture extent are still major subjects of debate.

Recent seismic investigations in the Ryukyu subduction zone provide new insights on this issue. Seismic reflection data in the southern Ryukyu Trench where a huge tsunami earthquake is thought to have occurred in 1771 reveal that it shares common subduction features with other tsunamigenic regions, such as a small-scale low-velocity sedimentary wedge at the toe of the overriding plate and landward-dipping branching faults that stem from the plate interface and breach the seafloor (Arai et al., 2016). On the seaward side of the trench, the incoming plate hosts linear fracture zones and thus may be highly faulted, which is likely to facilitate seawater penetration prior to subduction. As evidenced by negative polarity of seismic reflections, the plate interface is enriched in fluids down to a depth of at least ~25 km, suggesting that the regionally extensional stress regime, as exemplified by the slab roll-back at the trench and the back-arc rifting, contributes to increasing the permeability along the plate interface. As such, slow earthquakes including low-frequency earthquake, very-low-frequency earthquake and slow slip event occur at these depths. The passive observations confirmed that these slow earthquakes are located close to but do not overlap regular earthquakes (Yamamoto et al., 2018). This spatial pattern suggests that the frictional properties along the plate boundary may vary rapidly not only in the dip direction but also along the strike direction.

Another important control on subduction earthquakes is the roughness of the plate interface. We find in northern Ryukyu that the plate interface is vertically displaced and forms an obvious step of over 1 km at the downdip of the subducting seamount (Arai et al., 2017). This slab-intersecting faults are active, as demonstrated by large normal-fault earthquakes with a magnitude of 7.1 in 1995, and suggest that internal heterogeneities of the slab, especially significant buoyancy acting on the incoming plateau, can produce sufficient differential stress leading to high-angle normal-fault earthquakes within the slab. On the other hand, the upper surface of the seamount (plate interface) is likely to overlap the source region of slow slip events (Nishimura, 2014), indicating that weak coupling is a predominant mode along the rugged plate interface.

These marine observations have greatly improved our understanding of the seismogenic processes in subduction zones by revealing the high-resolution structures and increasing the accuracy of earthquake locations, but we are still in lack of knowledge on the coupling condition at the shallow plate interface and its along-trench variation. In order to step into a next stage, we may need to focus on extensive three-dimensional seismic imaging and seafloor seismic/geodetic observations at subduction trenches.

T.II.1 *Deep to shallow structures and active tectonics of frontal fold-and-thrust belts in arc-arc collision system: the Kuril-Northeastern Japan arc collision Zone, Northern Japan*

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Collision of neighboring arc systems commonly displays complex structural styles depending on geodynamic interactions between crustal blocks with different mechanical properties under subduction processes, which in turn may complicate full understanding of present styles of strain accommodation, their relation to modern subduction processes, and regional earthquake scenarios. To clarify structural characters of the shallow to deep subsurface geometry of underlying blind thrust fault systems, we newly collected deep (Sato et al., 2018) and shallow, onshore high-resolution two dimensional (2D) seismic reflection and refraction data across the leading edge of the Hidaka fold-and-thrust belt (HFTB), Hokkaido, northern Japan. The HFTB has been built as a result of collision processes between the Northeast Japan and Kuril arcs and are now emplaced within the hanging wall block above the subducting Pacific plate along the Kuril trench. Modern westerly oblique subduction and strong coupling has posed a possibility of a future M>9 interplate earthquake and preceding intraplate earthquakes as analogue with the Nankai and Tohokuoki events. Processed deep seismic profile and its preliminary interpretation illuminated up to 10 km depth of structures of the frontal part of the fold-and-thrust belt, including active blind thrust-related folds at shallower structural levels beneath the Ishikari plain and Umaoi Hills. Blind thrust-related folds in our new shallow seismic reflection profiles tied with Neogene stratigraphy are also useful to define shallowly to moderately east-dipping blind thrust faults and pairs of overlying fault-related anticlines that deform Pleistocene to Pliocene sedimentary units. In addition, coupled with middle to late Pleistocene geomorphic and geologic signatures of their structural growth and fault activity, we also estimate recent rates of fault slips and associated crustal shortening on the frontal blind thrust systems. Our results illuminate that active folds within western part of the foreland basin are underlain by moderately to steeply dipping blind thrusts, suggesting origin of reactivated normal faults formed within the NE Japan arc. These structural characters are in contrast to thin-skinned nature of the west-verging HFTB and presumably generate independent earthquakes. We will also mainly discuss (1) present fault slip rates on the frontal part of the HFTB and its northern extension by linking shallow to deep thrust trajectories with active folding, (2) comparison between the present and millennial, longer-term fault slip rates across the HFTB, and its implications for (3) tectonic history of its structural growth and (4) styles of strain accommodation of the HFTB.

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T.II.2 *Configuration of Moho discontinuity beneath Japanese Islands characterized by failed rift system with shallow Moho derived from the standard three-dimensional seismic velocity structure obtained by seismic tomography*

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The Mohorovicic discontinuity (Moho) is defined on the basis of an abrupt increase in seismic velocity in the lithosphere that has been observed using seismic refraction and receiver function analysis methods worldwide. Moho depth varies regionally and remains a fundamental parameter of crustal structure. We present a new method of mapping the Moho using a 3D seismic tomography model.

We treat the Moho as a zone of high velocity gradient since the tomographic method cannot locate discontinuities. Maximum lower crust/minimum upper mantle P-wave velocities in Japan are known to be 7.0 km/s and 7.5 km/s, respectively. We map the residual between iso-velocity surfaces of 7.0 km/s and 7.5 km/s to find areas where the residual is small, the separation between the surfaces is narrow, and the velocity gradient is high. The Moho is best constrained where the iso-velocity surfaces are close together, and under much of Japan, they are <6 km and rarely >10 km apart. We chose an iso-velocity surface of 7.2 km/s as a representative Moho 'proxy' in these areas.

Our resulting 'Moho' map under Japan compares favorably with existing regional Moho models that were obtained from controlled-source seismic investigations. The 'Moho' varies from shallow (25-30 km) to deep (>30 km), and this variability relates to the structural evolution of the Japanese islands: the opening of the Sea of Japan back-arc, ongoing arc-arc collisions at the Hidaka and Izu collision zones, ongoing back-arc extension in Kyushu, and a possible failed back-arc extensional event of Mesozoic age. It is apparent that the Moho is less well-constrained in area where the crustal structure has been modified by magmatic activity or thickened due to arc-arc collision.

The Moho along the failed rifts on the Japan Sea side beneath the central Honshu Island is shallow since the high-V lower crust exists there. These zones are consistent with the steep gradient of gravity anomaly. This reflects that the mafic rock were attached at the base of lower crust at the opening of the Sea of Japan and that the low-V sediments accumulated at the surface after the opening of the Sea of Japan.

This Moho structure is open to public in the NIED Hi-net web site and everyone can download the structure. Software to get the image of the map views and cross-sections of the standard seismic velocity structure beneath Japanese Islands is also open at the NIED Hi-net web site

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T.II.3 *Seismic images of the North Chilean subduction zone prior to the 2014 Iquique earthquake*

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On April 1, 2014, a Mw 8.1 megathrust earthquake occurred within a previously locked section of the North Chilean subduction zone. In order to understand the pre-rupture conditions, we have reprocessed an offshore seismic reflection line from the CINCA'95 experiment using advanced seismic depth imaging methods with the aim of obtaining a high resolution image of the structures within the locked zone. This seismic profile crosses the rupture zone and provides an image of that area prior to the megathrust rupture.

The reprocessed CINCA'95 profile line 22 crosses the North Chilean subduction zone at 19°40'S, extending 180 km over the oceanic Nazca plate, the trench, and the continental margin. Following the data pre-processing, velocity model building, and focusing prestack depth migration, we provide an image of the oceanic and the continental crust including the subduction interface down to a depth of approximately 16 km.

The oceanic plate shows a significant horst-and-graben structure caused by the downward bending of the plate. Several of the bending-related faults reach depths of about 2 km below the seafloor and more. The generally little sediment accumulates predominantly in the grabens with maximum sediment thicknesses of about 400 m. Due to little sediments this subduction zone has no accretionary wedge and subduction erosion is prominent in this part of the North-Chilean subduction zone.

The resulting high resolution seismic depth image reveals the plate interface as a boundary with strongly varying reflectivity. We interpret these variations as lenses with enhanced fluid pressure, possibly caused by subducted sediment-filled grabens and half-grabens. This interpretation is in contrast to previous explanations of this varying reflectivity to be caused by e.g. a subducted seamount which is also supposed to control the interplate coupling and seismic rupture of the Iquique earthquake.

Within the continental crust, the seismic depth image clearly shows complex structures with several large splay faults in the frontal prism and crystalline forearc basement that do not crosscut the thin overlying sediments. At a shallower part of the continental seafloor a sedimentary basin can be interpreted with a rough basement and maximum thickness of about 500 m. Stationary onlap structures are interrupted by plume like areas with little reflectivity.

We compare our imaging results with data from other investigations like the fore- and aftershock series from the Iquique 2014 megathrust earthquake and with reflection boundaries derived from wide angle measurements along this seismic line.

T.II.4 *The seismic structure of the Calabrian subduction system (Central Mediterranean): new insights into crustal construction and mantle hydration from wide-angle seismic data*

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Subduction zones are known to be key in shaping the lithospheric structure of the Earth, and consequently its surface. The dehydration of ultramafic products from the subducted oceanic lithosphere triggers the hydration of the overlying mantle wedge, resulting in the production of hydrous flush melting, and the consequent formation of new crustal material at the volcanic arc. However, the evolution of processes such as crustal construction and mantle hydration are still poorly constrained mainly because of the lack of observations from young subduction settings. In this study, we focus on the Plio-Quaternary Calabrian subduction system, located in the Central Mediterranean. This subduction zone is the result of the same slab rollback process that shaped back-arc basins in the Western Mediterranean and is characterized by the subduction of the Ionian Lithosphere under Calabria. To date, there is limited understanding of its shallow crustal structure and the transition between lithospheric domains (e.g. Arc – back-arc) due to the lack of dedicated active-source experiments.

Here, we present the 2D P-wave velocity structure of the entire subduction system from travel-time tomography of wide-angle seismic data. The data were recorded during the CHIANTI amphibious experiment in 2015 along a ~600 km-long transect that extends from the Tyrrhenian back-arc domain to the fore-arc in the Ionian Sea, across Calabria.

In the back-arc system, OBS sections lack PmP-like arrivals and the velocity structure of the model shows a continuous and strong vertical velocity gradient of ~1 s-1. These results together with previous tomographic models, analysis of Vp/Vs and basement rock sampling strongly supports the exhumation of the mantle along ~300 km long section in the back-arc region. The back-arc region is also characterized by large volcanic edifices that were emplaced soon after the exhumation of the mantle.

The transition between back-arc and Calabria is marked by a steep Moho geometry that shallows from SE to NW, revealing a dramatic crustal thinning along the N Calabrian margin. The lower crust of the margin has localized Vp of ~7 km/s under the submarine volcanic arc. The vertical velocity structure of this young arc (< 2Ma) reveals a thin and mafic crust, suggesting that crustal growth by magmatic addition is still at an early stage in the Calabrian volcanic arc, and that little crustal felsic-to-mafic differentiation has occurred as opposed to older well-established volcanic arcs in the Pacific.

SE Calabria, the model shows a strong horizontal velocity gradient that is interpreted as the backstop of the subduction. In the Ionian, a 3-5 km thick sedimentary wedge thickens towards the NW. The frontal part of the wedge shows sub-vertical low-velocity anomalies indicating the presence of fluid-saturated large thrusts faults.

T.II.5 *Constraining the structural style and earthquake geology of the Himalayan foreland fold and thrust belt in central and eastern Nepal with active source seismic data*

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The Himalaya represents one of the few regions on Earth where great, surface-rupturing thrust earthquakes occur on land. The Main Frontal Thrust (MFT) in Nepal is the youngest and southernmost structure in the Himalayan Fold and Thrust belt (Gansser, 1964). This thrust roots into a regional décollement known as the Main Himalayan Thrust (MHT) that underlies the entire Himalaya and represents the contact between the Indian and Asian plates (Seeber and Armbruster, 1981; Zhao et al., 1993).

We acquired 21 seismic profiles throughout the Siwalik range (over 130 km of data), between January 2014 and March of 2015 using a 264-channel iSeis system. Each string of 24 geophones was physically connected to a (24-bit) digitizer (DAQ-III) with wireless communications to a central "doghouse" (i.e., data collection center). The geophone response was continuously recorded during acquisition, and timing was synchronized with a GPS unit in each digitizer. Shot records were extracted using trigger times obtained from a source-based GPS unit. Single element, five-m spaced 10-Hz geophones were deployed. The source was a 7,400 kg Industrial Vehicles International Envirovibe2, with shot points spaced at five meters, providing nominal 132 fold data. We ran 6-12 source sweeps per location and vertically stacked each sweep to attenuate noise. We used 10-180 Hz linear eight second sweeps with a four second listening time. Pre-processing of the data included surface wave attenuation, spiking deconvolution, and elevation static corrections. Following these steps, iterative velocity analyses, dip move-out, and residual statics were all applied (Yilmaz, 2001). Final velocity model and images were produced using a Kirchhoff pre-stack depth migration (PSDM) from topography approach (e.g., Bradford et al., 2006). Prior to data stacking, amplitude gains were applied to attenuate remaining surface waves and to boost scattered and attenuated signal loss. Post PSDM step included frequency-distance (F-X) deconvolution.

In one of our lines, the 13-km Ratu profile we can observe several key characteristics of the MFT:

1) In central Nepal the décollement is shallow and has a ramp below the Siwalik foothills: Our imaging shows that the MFT at this location flattens at 2-2.5 km. Exposed stratigraphy implies that this thrust must sole into a deeper stratigraphic level to the north. 2) The Bardibas thrust is blind: We observe that the Bardibas thrust does not reach the surface. In contrast, the Patu thrust has been trenched and is imaged here as surface emergent. 3) Direct measurements of fault dip: We directly measure the dips of the Patu (27-39°) and Bardibas (15°) thrusts from our seismic sections.

Based on our new data we also present new interpretations of total shortening recorded by the MFT system in central vs. eastern Nepal (200 km apart), Our structural interpretations demonstrate that the geological shortening recorded on the MFT ranges from >11 km in central Nepal to <1 km in far eastern Nepal. If these shortening measurements are correct, and the shortening rates in the past were the same present, one option is that the MFT must have broken forward at different times along strike. We propose an alternative model that does not require a dramatic difference in the age of the MFT. It is possible that older MFT thrust sheets have formed, and then been consumed as the MBT passively slid south in the hanging wall of the MFT. The amount of total shortening would depend on the number of thrust sheets that have been consumed.

Session: Innovative seismic acquisition and processing techniques

T.III.1 *Fibre-optic strain sensing: new developments for seismic surveying*

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Since natural hazard prediction and efficient crust exploration benefit from densely designed surveys, the improvement of resolution in time and space is sought for. Seismological techniques provide ground-motion data, while active seismics aims at structural imaging and increasingly on physical properties, too. Dense networks are generally deployed on volcanoes and in sedimentary areas to image and monitor the crust.

Fibre optic cable technology is able to record strain, useful for both industry-related exploration and may be useful for seismic/seismological applications. In this study, we demonstrate that direct strain determination is now possible with conventional fibre-optic cables deployed for telecommunication. This is a new tool for earthquake location, for crustal exploration using unexpected sources, and it provides key records for understanding earthquake and fault structure and behaviour.

On Reykjanes Peninsula, SW Iceland, we recorded seismic signals from natural and man-made sources with 4-m spacing along a 15-km-long fibre-optic cable layout. Extending recently distributed acoustic sensing (DAS) studies, we provide spatially un-aliased broadband nano-strain data. With unprecedented resolution structural features like normal faults and dykes are identified in the Reykjanes oblique rift system, allowing to infer new fault dynamic processes. Comparison with conventional seismometer recordings corroborates dynamic and stable spectral amplitudes between 0.1-100 Hz bandwidth.

If the data analyses just started proved stable, the use of fibre-optic telecommunication line networks worldwide as seismometers would open a new window for Earth hazard monitoring and exploration.

T.III.2 *Seismic exploration of the Kylylahti sulphide deposit using underground conventional and DAS VSP data*

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Exploration of mineral resources using seismic methods still remains a challenging subject. Within the scope of the COGITO-MIN (COst-effective Geophysical Imaging Techniques for supporting Ongoing MINeral exploration in Europe) project, a collaboration of Finnish and Polish research institutions and companies, a spectrum of passive and active-source seismic surface and borehole methods are assessed and integrated with the goal to create an efficient workflow from regional-scale mineral exploration to high-resolution resource delineation and mine planning.

As part of this project, the presented work utilizes Vertical Seismic Profiling (VSP) reflection seismic data that were acquired in the Kylylahti Cu-Au-Zn mine, belonging to the famous Outokumpu mining district in Eastern Finland. The measurements were carried out using two different VSP systems; a conventional three-component geophone system and a novel fibre-optic Distributed Acoustic Sensing (DAS) system, both using the same seismic source.

In comparison to conventional VSP systems, DAS technology combines rapid data acquisition with increased spatial resolution, and thus offers a method of high potential value for cost-effective mineral exploration and resource delineation. However, up to the present day, the applications of DAS systems have largely been confined to the hydrocarbon industry. To our knowledge, the Kylylahti experiment represents the first application of a DAS system for exploration in a hard-rock environment. The combination of the DAS experiment with conventional systems, as well as the extensive geological data available at the Kylylahti site, makes this survey an ideal showcase for the actual applicability of DAS methodology in a hard-rock setting.

The VSP data were acquired in four boreholes located in vicinity of the Kylylahti massive to semi-massive sulphide deposit. Using a VIBSIST-200 time-distributed impact source, a total of 31 shots were fired within the mine tunnels. The DAS and conventional data were processed using a target-specific processing flow, providing high-resolution (dominant P-wavelength of about 30-35 m) reflectivity images of the target area from both acquisition systems. Interpretation of these data was supported by three-dimensional elastic forward modeling, that was based on a detailed model of the known geology, providing synthetic VSP seismograms. Processing and comparison of the synthetic data alongside with the acquired VSP shots led to successful correlation of the seismic images with known geological contrasts. Seismic reflections originating directly from the sulphide deposit and various other contrasts within its hosting formation were successfully identified. Additionally, several new reflective features beyond the previously explored area were also imaged.

The results of this study demonstrate the value of in-mine VSP acquisition for precise delineation of mineral resources in general. The DAS system was proven to provide images of similar quality as the conventional systems, but at a much faster acquisition rate. Thus, the possibility of efficiently acquiring larger data volumes in order to optimize the illumination of a target area, makes DAS an attractive method for the delineation of new prospects.

T.III.3 *How useful is DAS in hard rock environments of Australia?*

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Modern, high density 3D reflection seismic data can resolve complex structures of hard rock environments. However the process of transforming seismic “wiggles” into geological information is more involved. The essential step along this process is calibration of seismic images with borehole measurements. Full waveform sonic (FWI) is often measured in boreholes but the results may be disappointing in some cases. In fact the measurement often fails when borehole intercepts highly structured region and this is typically related to mineralized zones. Another approach is to deploy seismic receivers in a borehole which is so-called vertical seismic profiling (VSP). Traditionally three-component geophones are used for that purpose. In hard rocks unfortunately these measurements are risky due to narrow diameter, uncased and potentially unstable boreholes and inefficient because long geophone arrays cannot be deployed due to insurance limitations and too high cost. Consequently VSP measurements are rarely utilized my mineral industry. The end result is that seismic images are poorly calibrated by other means such as pre-existing workings, “known” geological models, core sample tests, etc. This no-win situation could be resolved by introducing new technologies and changing the seismic exploration practice. One way might be to deploy Distributed Acoustic Sensing (DAS) technology. DAS provides a nearly continuous receiver space (0.2-0.5 m sampling) along entire length of a borehole that in principle will allow for accurate calibration of 3D seismic images. Moreover a quiet borehole environment is favorable for implementation of novel technologies such is the full waveform inversion (FWS) that could provide high-resolution reconstruction of velocity and, more importantly for mineral exploration density fields.

DAS surveys are flexible and may incorporate simultaneous recording in multiple boreholes. However implementation of DAS in hard rock environments is not straightforward. In its simplistic implementation that is desirable due to very low cost, DAS measurements may suffer from low signal to noise due to generation of high energy borehole fluid modes (tube waves). Other unwanted cases include dry boreholes and loosely PVC cased boreholes. Ideal situations include DAS cemented behind casing or cementation within entire borehole space. In this presentation we show and discuss some challenges related to implementation of DAS measurements in difficult borehole settings. Case studies include VSP experiment with DAS was conducted in Western and South Australia.

T.III.4 *4D Seismic Imaging using Permanent Fibre-Optic and Geophone Systems: Experience from the Aquistore CO2 Storage Site, Saskatchewan, Canada*

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Time-lapse seismic monitoring of subsurface processes is often required over the lifetime of a project which may extend for years or decades. Under these circumstances, permanent installation of seismic imaging systems can be beneficial both economically and in terms of 4D seismic imaging capabilities. This strategy has been employed at the Aquistore CO2 storage site in Saskatchewan, Canada, where large-scale injection of CO2 is occurring for the purposes of long-term storage. The storage reservoir is a 220-m thick brine-filled sandstone formation at ~3200 m depth lying unconformably on Precambrian basement rocks. CO2 injection began in May-2015 with a total of ~140 ktonnes of CO2 having been injected by the end of March, 2018.

4D seismic imaging has been adopted as the primary means of tracking CO2 within the subsurface at the Aquistore site. The depth of the reservoir and the relatively small quantities of CO2 injected to date pose a serious challenge for seismic imaging of the CO2 plume. Permanent seismic installations have been made at the site to provide 4D surface seismic and 4D vertical seismic profiling. A sparse permanent areal array of buried vertical-component geophones was deployed to maximize time-lapse repeatability by providing constant receiver coupling, positioning, and improved signal-to-noise ratio. Buried geophones and shots minimize the effects of near-surface seasonal variability. Fibre-optic cables have been deployed at the site to allow seismic imaging using distributed acoustic sensing (DAS). A fibre-optic cable was permanently cemented outside of the observation well casing to ~2800 m depth as well as in various configurations (straight and helically wound) within a shallow surface trench. Data from the DAS system have been calibrated against data recorded simultaneously on geophone systems. The good-to-excellent repeatability of the data acquired using permanently installed sensors (both surface geophones and well-based fibre cable) and buried dynamite sources provides the sensitivity to map CO2-related amplitude differences for depths of >3200 m depth.

A total of six 3D seismic surveys have now been conducted at the Aquistore site; 3 prior to the start of injection and 3 following. 4D seismic images corresponding to injection quantities of 36 and 102 ktonnes of CO2 show clear time-lapse amplitude anomalies associated with the CO2 plume. They delineate a stratified CO2 plume within the lower part of the reservoir. Based on the partitioning of injected CO2 amongst the perforated injection zones the initial seismic amplitude anomaly likely corresponds to <18 ktonnes of CO2 . Minimum CO2 thickness/saturation estimates for this zone are 4-10 m thick for saturations of 50%-100%.

T.IV.1 *Field comparison of direct and array-derived rotation measurements*

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Six-component (6C) sensors recording three components of translational and three components of rotational motion are a novel seismic instrument type with a vast potential application range in both active-source seismic exploration and passive-source observational seismology. For example, rotational motion sensors allow us carrying our array-type processing with a single station (e.g., local slowness estimation). Conventional sensor arrays need to be large, regular, and dense for, for example, f-k beamforming analysis. Alternatively, estimating the spatial gradients of the wavefield and deriving related rotational motion estimates at the free-surface by finite-difference approximation enables using substantially smaller arrays of closely-spaced 3C sensors. However, all arrays can suffer from limitations such as size requirements, sensor coupling variations and subsurface inhomogeneity across an array that negatively affect the array-processing results. Rotational motion and 6C stations provide point measurements to overcome these limitations of instrument arrays as well as enable carrying out array-type processing in situations where placing instrument arrays is hardly possible or not feasible (e.g., in boreholes, for planetary seismology).

With the motivation to validate a prototype rotational seismometer and to compare direct measurements and array-derived rotational motion estimates, we carried out a field validation experiment. We compared three prototype units of the blueSeis3A rotational seismometer with arrays of conventional 3C 4.5-Hz geophones placed approximately in the centre of a commercial 3D seismic-exploration survey. A total number of 86 3C geophones were laid out in four patches around 30 m apart. Three patches consisted of a hexagonal sensor pattern to optimally estimate the spatial gradients with different inter-sensor spacing in the meter range. Additionally, four broadband 3C seismometers and groups and lines of conventional 1C (vertical-component) geophones were installed. During around three weeks, signals from several thousand vibroseis sweeps and explosions with up to 2-km distance to the sensor layout as well as ambient noise were continuously recorded. Even though synchronizing a total of 10 independently operating recording units, snow and low temperatures as well as technical issues with the prototype instruments made this field campaign challenging, the recorded data allow, for example, comparing conventional slowness and dispersion-curve analyses with single 6C station processing.

T.IV.2 *Imaging of crooked-line seismic data: The cross-dip correction revisited*

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Imaging the Earth's crust with reflection seismology is always a challenging task. A special challenge arises for crooked line land seismic profiles where reflector dip in the cross-profile direction leads to non-hyperbolic time shifts that can significantly reduce imaging quality. In their fundamental paper in 2003, Nedimović and West introduced a cross-dip moveout (CDMO) correction term that they derive automatically from the data. In spite of their method's promising results, it has rarely been used by other authors – probably because it is a rather complex and computationally costly method. Instead, the CDMO correction is often applied as a static shift to the whole trace. This approach has the problem that it distorts other reflections without cross-dip. Another currently unresolved issue is whether to incorporate the CDMO correction before or after the dip moveout (DMO) correction.

We have developed a processing module that builds upon the method of Nedimović and West, but where the cross-dip term is determined manually and applied locally around straight reflector segments. The major advantages of this approach are that it can be used for noisy datasets with complicated geometries and that the processor can ensure that the results are geologically reasonable.

To test the interaction between CDMO and DMO corrections, we created a series of synthetic datasets with different combinations of inline and crossline reflector dip. Finally, we applied our method to a noisy dataset acquired over a post-glacial fault in Burträsk, northern Sweden.

In our tests, we successfully retrieved cross-dip angles from the synthetic data for reflectors dipping in the crossline direction only as well as for reflectors dipping in arbitrary direction. In the case of arbitrary dip, it is important to pick only dip values that lead to a consistent improvement of the reflection image since interactions of the CDMO and DMO corrections can locally result in false stack optima. As expected, we do not obtain any conclusive cross-dip values for reflectors dipping merely in the inline direction. On the other hand, applying DMO correction to reflections dipping in the crossline direction introduced artifacts into the final stack. Therefore, we recommend to place the cross-dip correction before the DMO correction in the processing flow.

Determining consistent dip angles for the field data was more challenging due to the high noise level, but including the CDMO correction into the processing enhanced the coherency and continuity of some reflections considerably. The influence of reflection cross-dip on the stacking velocities was also clear in the data analysis.

Our results demonstrate that the CDMO correction can significantly improve reflection images of crooked line profiles, but is also susceptible to interactions with other types of moveout. Therefore, it is essential to only apply the cross-dip correction where it leads to a consistent improvement of a whole reflection segment.

[1] Nedimović, M. R. and West, G. F., *2003 Crooked-line 2D seismic reflection imaging in crystalline terrains: Part 1, data processing*. Geophysics, 68, 274-285

T.IV.3 *Australian Ocean Bottom Seismography: Earth imaging and beyond*

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The Australian Ocean Bottom Seismographs (OBSs) fleet has broadband frequency range, and is one of few fleets globally, with this capability. The OBSs have been used to (a) determine the velocity profile of the subsurface to better characterise the geology, and (b) monitor anthropogenic and biological noise to better understand the distribution and behaviour of noise in the marine environment.

In terms of velocity modelling the OBS data collected during commercial seismic surveys in Australian waters demonstrate that it is possible to image the velocity distribution of the whole crust and upper mantle from analysis of both reflected and refracted phases generated by an industry-standard airgun array. Comparison of seismic velocities estimated from travel time inversion of OBS data to those derived through the isotropic PreSDM of marine reflection data along coincident lines, shows significant differences between the two. In the non-crystalline crust OBS-derived velocities appear to be consistently faster. This could be an indication of anisotropy with the OBS-derived velocities representing velocities sampled by sub-horizontally travelling rays. Combination of the OBS and PreSDM velocity models can be used to build an anisotropy model that may lead to improvement in crustal imaging from the reflection data. In the lower crust the OBS-derived velocity model is slower than the isotropic PreSDM velocity model and this has significant implications for the petrological interpretation of the lower crust.

In terms of noise in the marine environment, recording of airgun signal by highly sensitive hydrophones incorporated into the OBSs allows the measurement of Sound Pressure Levels (SPL) and Sound Exposure Levels (SEL) to very large offsets exceeding 200 km. These values can be benchmarked against those predicted by seismic source modelling, and against marine mammal injury criteria. Peak SPL values registered on the seafloor from a 4630 cubic inch gun array exceeded 173 dB re 1µPa at near offsets, dropping to ~167 dB re 1µPa at 10 km offset, and to ~153 dB re 1µPa at 50 km offset. These values appear to be lower than those predicted by the airgun source modelling for the particular seismic survey. In many countries source modelling is required by environmental regulators as part of the seismic survey approval process. Our results suggest that credibility of seismic source modelling would benefit from calibration against experimental measurements by OBSs. Further value can be derived from deploying OBSs during other seismic surveys in order to estimate SPL and SEL values for broad offset ranges, in varying water depths, and from airgun arrays of varying configurations and volumes.

The OBSs have proven their capability beyond earth imaging and are also useful to measure noise in the marine environment.

Session: Seismic imaging for earth hazards, resources and near-surface

W.I.1 *Enhanced bandwidth in Seismic and Magnetotelluric Exploration for Minerals*

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Innovative technology for conducting seismic and magnetotelluric exploration historically derives from petroleum exploration in soft rock environments. Mineral exploration in hard rock environments requires different emphasis so that simple porting of methods from soft to hard-rock settings seldom works well. Completed seismic data acquisition and planned magnetotelluric acquisition for the Metal Earth project will benefit greatly from recent advances in the petroleum sector. Vibroseis® methods used had both sources and receivers rated down to 5 Hz frequencies and generated records with clear 2-60 Hz signal. Not only will this enhance reflections from deep in the crust, it also enables the use of full waveform inversion and related techniques at depths of a few kilometers. Regional-scale transects target mineralizing fluid pathways throughout the crust, whereas higher spatial-resolution reflection and full-waveform surveys target structures at mine camp scales in order to determine the linkage between early Archean faults, successor basins, and Paleoproterozoic basins and fault systems. These geologic controls can then be related to the distribution of varied metal deposits including Au-base metals in Archean greenstones, Ni-Cu-PGE in Paleoproterozoic deposits at Sudbury, and Ag-Co-Ni-Bi-As at Cobalt, Ontario. Regional scale profiles show intersecting reflectors comparable in quality to the best Lithoprobe sections located in similar settings. A second phase of acquisition will work in remote areas and attempt passive (source-less) surveys at relatively high resolution. Because Metal Earth was proposed to map entire Archean mineral systems, teleseismic methods that use sparse, 3-component broadband sensors will also be analyzed to map major seismic discontinuities within the lithospheric mantle, but with resolution of a few kilometers. Such studies have been used for decades in diamond exploration and mapping structures controlling deep carbon concentration appears increasingly relevant to both diamond and metals exploration.

W.I.2 *New Seismic Reflection Profiling Surveys in the Context of the Exploring for the Future Program in Australia, 2017-2020*

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The Australian Government has provided funding to Geoscience Australia to manage the Exploring for the Future Programme designed to increase investment in minerals, energy and groundwater resources. This Program will concentrate activities in Northern Australia and South Australia. Over the next four years, Geoscience Australia, in collaboration with the State and Territory Geological Surveys, is planning to acquire deep seismic reflection data in Northern Australia, where the resource potential is limited or unknown. Two new large precompetitive seismic transects and associated data will boost exploration investment by assisting industry to better target areas likely to contain the next major oil, gas and mineral deposits, South Nicholson and Kidson Sub-basin.

The South Nicholson 2D seismic vibroseis survey was undertaken in the region between the southern McArthur Basin to the Mt Isa Western Succession, crossing the South Nicholson Basin and Murphy Province as part of this program in collaboration between Geoscience Australia, the Northern Territory Geological Survey, the Geological Survey of Queensland (GSQ) and AuScope.

The data along 1100 km long transect comprising five deep crustal reflection lines were acquired in June-August 2017 and are currently being processed. The data are of excellent quality and image a variety of previously unknown features.

The 900 km Kidson Sub-basin 2D deep crustal seismic survey is due to commence in June 2018 and will cover an area within the Kidson Sub-basin of the Canning Basin extending across the Paterson Orogen and on to the eastern margin of the Pilbara Craton. The collected data will help to image basin and basement structure, and geological interpretation to determine the stratigraphy, lateral extent and stratigraphic and structural relationships.

W.I.3 *Towards a new model for assessing seismic risk from crustal earthquakes in the overriding plate: source fault geometry, stress field changes, and crustal deformation in the Japan arc*

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At present, long-term evaluation of seismic risk for active faults relies on paleo-seismological data. However, this data cannot resolve decade-scale stress changes and can be difficult to obtain for blind source faults that exhibit no surface expression. The 2011 Tohoku oki earthquake (M9) provided a clear demonstration of how seismicity in the overriding plate before and after a large megathrust event could be strongly controlled by conditions at the plate boundary. In order to quantify the effect of plate boundary conditions on crustal seismicity, we constructed a numerical model to calculate temporal stress changes and crustal deformation in the overriding plate at the Japan Trench/Nankai Trough subduction zones. Dense GPS and seismic networks in Japan provided the data necessary to estimate appropriate boundary conditions. We then evaluated the effect of the modeled stress rate changes on Coulomb stress for known source faults, given their location and geometry.

Source faults models are critical to our evaluation of seismic risk. Deep seismic profiling has been a powerful tool in Japan over the past two decades for direct imaging of seismogenic source faults, including the megathrust. Addition of geological information has improved the resulting source fault models. In Japan, the location, geometry, and dimensions of these source faults is often determined by the geological structures that evolved during the opening of the Sea of Japan back-arc. In particular, a failed rift zone that developed in the marginal back-arc now acts as a weak zone characterized by active folding and faulting. Rheological changes introduced during back-arc rifting appear to influence fault behavior: the boundary between pre-rift arc crust and an intruded mafic body in the failed rift now functions as a seismogenic fault. Along with geophysical and geological data, we incorporated gravity data into our source fault models.

We constructed a 3D visco-elastic finite element model (FEM) for Japan in which we constrained the viscosity profile with the results of a previous numerical simulation for post-Tohoku oki (M9) crustal deformation (Freed et al., 2017). Through inversion of plate boundary conditions, our model successfully reconstructs crustal deformation observed by GPS during the years 2000-2010. It also reproduces the pattern, over the 100 years preceding the M9 event, of M6 to M7 class earthquakes in northern Honshu, which are distributed in zones of calculated high stress accumulation. Likewise, our 3D FEM model successfully reconstructs crustal deformation in southwest Japan, where ongoing deformation is governed by strong coupling at the Nankai Trough subduction zone and trench retreat along the Ryukyu Trench. We calculated the Coulomb stress rate change on source faults in SW Japan and found that the distribution of M7-class earthquakes correlates with areas of positive accumulation rate of Coulomb stress.

We believe that numerical modeling of stress regime changes in the overriding plate, and quantification of the resulting stress changes on seismogenic source faults, can aid in the effective evaluation of decade-scale earthquake risk. Future improvements to the model may come from better source fault models that incorporate parameters beyond fault geometry, such as slip rate and timing of last event.

W.I.4 Reprocessing *of a vintage 2D reflection seismic line across the Norcia-Mt. Vettore faults, Area of the Mw = 6.5 earthquake (2016-2017 sequence, Central Italy)*

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The Central Italian region is among the most seismically active areas of the Mediterranean region, and it is often struck by earthquakes of Mw > 6.0. The recent strong seismic sequence (9 main earthquakes of Mw > 5) started during the August 2016 at Amatrice and it reached its peak the 30th October 2016 with the Mw =6.5 mainshock . The epicenter was located about 7 km depth between Norcia and Mt. Castelluccio di Norcia basins (Monti Sibillini chain), producing impressive surface ruptures at the Mt. Vettore. But despite the large amount of datasets and studies made available so far, uncertainties still remain about the complex subsurface geology of the area. The presentation addresses the seismic processing and interpretation effort carried out on seismic line NOR2 (ENI, S.p.a.) that goes across the Norcia and Castelluccio di Norcia basins. The resulting seismic section reveals new details that contribute to better constrain the subsurface structure of the study area. The two basins (Norcia and Castelluccio di Norcia) are clearly visible and it is possible to detect the contact between the Quaternary deposits and the underlying bedrock. Some alignments and offsets of reflectors enhance the visualization of the main faults: the Castelluccio di Norcia Basin is clearly limited on its west side by a steep W-dipping normal fault visible down to about 3.0 s. Here, some sub-horizontal or gently E-dipping high amplitude reflectors are clearly visible down to 8.0 s, making it possible to extend the previous interpretation . This work confirms that a targeted reprocessing of a vintage industrial seismic line provides new and clear images of the subsurface geology of the epicentral area between Norcia and Castelluccio di Norcia basins. The work carried out enhances the value of new processing of vintage seismic reflection data. Such data is relatively expensive to acquire, however it is unique as it reveals high resolution details of the subsurface not achievable otherwise.

W.I.5 *Reflection seismic imaging of the causative geological structure of the M5.5 earthquake (2014) in South Africa*

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An unusual M5.5 earthquake took place near the Moab Khotsong gold mine in South Africa on 5 August 2014. A series of aftershocks were then recorded using two strainmeters at the bottom of the mine at a depth of about 3 km, 46 in-mine 4.5-Hz 3C seismometers at depths of 2-3 km within a hypocentral radius of 2-3 km, and 17 surface strong motion stations within an epicentral radius of 25 km. These aftershocks helped to delineate the seismogenic zone and characterize the variation of seismicity in time and space. The aftershocks are distributed on a nearly vertical plane striking NNW-SSE and are considered to define the "M5.5 fault zone". On mining horizons at 2-3 km below surface, the mining-induced earthquakes and seismicity that immediately followed the M5.5 earthquake had normal-faulting mechanisms (which is expected for mining related events), with larger events on normal faults with NE-SW strikes. On the other hand, the 2014 M5.5 event and its aftershocks were located between 3.5 and 7 km depth with a left-lateral strike-slip faulting mechanism (which is not expected for mining related events) on an unknown geological structure.

To understand how earthquakes nucleate and propagate, a Japanese-South African consortium (DSeis) through the support from the International Continental Scientific Drilling Program (ICDP) aimed at drilling the fault zone. The first 817-m-long hole was drilled from a chamber excavated at a depth of 2.9 km, however this hole deviated and did not intersect the fault zone. The second 750-m-long hole is being drilled from the same location but in a slightly different direction. To locate and re-direct drilling targets more accurately and identify the responsible geological structure, we have recovered, processed and interpreted 2D reflection seismic data acquired for gold exploration by the mining company in the 1990s. We have used the geological information from exploration boreholes and borehole sonic logs to improve our velocity model for velocity analysis, migration and time-to-depth conversion. Processing results provide great insight into the complex geologic structural architecture around the M5.5 earthquake source zone. In particular, seismically imaged geological structures in the mining area are extremely complex, discontinuous with numerous faults and dykes of various ages. One of the dykes, possibly collocated with the fault zone, is particularly speculated to have been the cause of the M5.5 rupture.

W.II.1 *A MEMS-based 3C seismic landstreamer for various urban infrastructure and mining applications*

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Geophysical surveys in urban and mining environments are by far more challenging than those in other places. Given the logistical challenges, space limitation, various types of noise, source and receiver coupling, and underground complexities, new and refined ways to better tackle these issues are necessary. With the idea of overcoming some of these, particularly in urban environment, we developed a digital, MEMS-based (microelectro-mechanical system) three component (3C) seismic landstreamer system. A number of tests were first conducted to check the reliability of the data gathered on all the three components. Apart from the reliability tests, we illustrated the potential of the system to address a wide range of applications in more than 15 case studies across Scandinavia. The applications ranged from urban underground infrastructures, groundwater exploration, post-glacial fault mapping, delineation of pathways for contaminants and tunnel-surface-tunnel survey for fracture mapping and delineation, to mineral exploration and mine planning. Among others, in the examples chosen, we illustrate that the seismic streamer is free of electromagnetic-electric noise; it allows high-resolution broadband data recording and it is superior to its geophone-type predecessors offering various data handling strategies and applications.

In one of the examples, at the Äspö Hard Rock Laboratory test site in Sweden, we targeted a fracture system using a tunnel-surface-tunnel seismic data acquisition approach. Low-velocity zones related to steeply dipping fracture systems were delineated and their dynamic mechanical properties such as Poisson's ratio and P- and S-wave seismic quality factors estimated. Changes in these parameters for different fracture subsets were then attributed to the degree of fluid conductivity, fracture aperture and orientations. In particular, wave-mode conversions (P-S and S-P) were observed in the streamer data originating from the fracture sets.

The streamer was also tested for its deep imaging potential targeting an iron-oxide mineralization in Sweden known to extend down to 850 m depth. Within 3 days, approximately 3.5 km of high-resolution seismic data, 2-4 m source and receiver spacing, were acquired. The mineralization was clearly imaged in the streamer data down to about 1000 m depth, proving its potential for such purposes as well. At a site in Finland, the streamer was used for open-pit mine planning where zones of weaknesses and a number of steeply dipping dykes were imaged. Such a seismic survey would be extremely difficult and cost-ineffective if done conventionally using plant-type sensors.

The streamer system currently contains 120 MEMS-based 3C sensors and it uses GPS time signal for data sampling and stamping. The GPS time base allows overcoming a number of logistically challenging situations by combining it with wireless recorders operating in an autonomous mode.

W.II.2 *Random array seismic data acquisition for 3D subsurface characterization in urban and near-surface environments*

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As a part of a field campaign to map bedrock morphology and zones of weaknesses within it at a contaminated site in south Sweden, a seismic survey was conducted. A multi-lane tunnel and an underground train station is planned at the site; hence a risk the excavation process may cause contaminant mobilization. The seismic survey consisted of 12 active-source landstreamer seismic profiles, 90 randomly distributed wireless seismic recorders along an area of 350x300 m and 50 wireless seismic recorders deployed along the train tracks crossing the site. The main goal was to identify potential contamination pathways using the 12 active-source profiles so that detailed remediation could be planned. Parallel to this goal, we wanted to test the potential of the randomly distributed array for the same purpose. Within 5 days of data acquisition, two datasets were produced from all 140 wireless recorders. One dataset where shots recorded on the 12 active-source profiles were used as common GPS time to extract corresponding data segments from the wireless recorders operating in an autonomous mode. The second dataset consisted of 5 days of passive recording, but also having the active shots registered during the same period, on all 140 wireless recorders.

We first evaluate the random array characteristics with respect to the azimuthal-offset distribution, potential for 3D seismic imaging, aerial fold distributions and improvement required for random array acquisition methodologies. Bedrock characterization using 3D P-wave first arrival tomography, acquisition footprint and uncertainties in bedrock depth estimation from tomography versus borehole data on a combined random array and recorders on the train tracks is also evaluated. Lastly, we analyze the potential of both random array and a combined random-train track array for passive seismic purposes. Preliminary results indicate that the random array shows good azimuthal source and aerial fold distribution, offering potential for 3D seismic processing and a relatively minor acquisition footprint on the 3D tomography results of both random array and a combined random-train track array. From the passive seismic perspective, the random array shows promising results both for the ambient noise interferometry and passive surface-wave studies by combining different receivers to obtain an optimal array response. Although preliminary, the results obtained have met both the primary and secondary survey goals and demonstrate possibility for other applications, such as for mining and other near-surface studies.

W.II.3 *High-resolution seismic imaging of dyke swarms within the Tornquist Zone (Sweden) and their implications for thermal energy storage*

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There is a large interest and demand for green-type energy storage in Sweden for both short- and long-terms (hours, days, weeks and seasons). While there are a number of approaches proposed (e.g., compressed air, geothermal and thermal), none have yet been commercially demonstrated through up-scaling projects. Among these, the thermal energy storage (TES) that uses the same mechanism as for the thermos is quite appealing particularly when there is access to excess heat energy (can also be cold). The excess energy then can be stored underground and used for large district heating and cooling purposes. A suitable site for such a plant then should be known geologically and hydrologically, and suitable in terms of rock quality for underground construction purposes. Seismic studies are therefore important since they can provide both the required resolution at depth (<500 m) and information required for such a project.

For an up-scaling underground thermal-energy-storage project within the Tornquist suture zone of Scania in southwest of Sweden three high-resolution, 1 km long each, 5 m receiver and source spacing, refraction and reflection seismic profiles were acquired during August 2015.

Geologically the site sits within the southern margin of the Romeleåsen Fault Zone in the Sorgenfrei Tornquist Zone (STZ) where dolerite dyke swarms of Carboniferous-Permian (Paleozoic) age are inferred and occasionally even observed striking in SE-NW direction for over 100s of kilometers both on land and in offshore seismic and magnetic data. These dykes, 20-100 m thick, in nearby quarries (both within Precambrian gneiss and quartzite) express themselves remarkably sub-vertical. They can therefore act as a good water barrier, which can be an important geological factor for any storage site.

Combined cabled- and wireless recorders were used to provide continuity on both sides of a major road running in the middle of the study area. First arrivals are clear in most shot gathers allowing them to be used for traditional refraction seismic data analysis and also for more advanced traveltime tomography. Bedrock depressions are clearly observed in the tomograms suggesting the possibility of weakness zones, highly fractured and/or weathered, in the bedrock and confirmed at several places by followed-up boreholes. Signs of reflections in raw shot gathers were encouraging and motivated to process the reflection component of the data. Several steeply-dipping reflections were imaged down to 400 m depth. The origins of the reflections are unclear right now ranging from amphibolite sheets to dolerite dykes as well as faults within the gneissic rocks, and each of this implies a different geological scenario at where the site will be developed. To provide further insight into the origin of the reflections even the historical offshore BABEL lines (A-AA-AB) were revisited. We favor that the reflections are of dolerite origin and that their dip component (i.e., not sub-vertical) may imply a local fault (for example at one of the regions of extreme low-velocity associated with a bedrock depression and topographic change) that led to a block-rotation south of the main road hence the tilting of the dykes. Dipping reverse faults have also been suggested south of the Romeleåsen Fault Zone and can also be a candidate for the origin of the reflections.

W.II.4 *High-resolution shear-wave reflection seismics and borehole seismics as tools for the imaging and the characterization of near-surface sinkhole areas*

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Subrosion and the resulting structures, such as sinkholes and depressions, pose a great hazard risk. They can cause damage to buildings and infrastructure, and lead to life-threatening situations. Germany suffers from a widespread sinkhole problem, because soluble deposits, such as gypsum and anhydrite, are close to the surface in many areas. One such area is the federal state of Thuringia, where the two investigation areas of this study, Bad Frankenhausen and Schmalkalden, are located. This study is concerned with high-resolution imaging and characterization of near-surface subrosion structures using shear-wave reflection- and borehole seismics. The possibilities and limitations of the seismic methods are outlined. Furthermore, the impact of faults on sinkhole occurrence is shown, and unstable zones are identified using geotechnical parameters derived from seismic.

The main structural characteristics of depressions and sinkholes, and the development of a multiple collapse event, using SH-wave reflection seismic imaging were investigated. A strongly heterogeneous, fractured strata with small-scale intraformational faults was identified as the subrosion horizon. The displaced reflectors at the fractured sinkhole margins dip towards the focal point of collapse structures, and consecutive collapse events are triggered more easily at the margins due to enhanced fluid flow.

The role of faults in sinkhole development was also investigated using structural S-wave analysis. The results show that if an area is tectonically divided into fault blocks this enables groundwater flow and therefore leaching of soluble rocks. Steep-dipping faults can act as a barrier for horizontal groundwater flow, but can allow water to flow parallel to the fault strike. As a result, areas affected by tectonic deformation are prone to enhanced dissolution and sinkhole formation.

Electrical resistivity tomography, transient electromagnetics and gravimetry were used to support the reflection seismic results. The former two methods helped to correlate buried and near-surface subrosion structures, and faults and fractures that were observed in P-wave and SH-wave reflection seismic sections with low resistivity zones, and therefore show the vertical and horizontal water flow. Local minima of the Bouguer anomaly helped to identify subrosion-induced mass-movement.

An analysis of elastic parameters and seismic attributes derived from VSP and 2D SH-wave reflection seismic delivered information about subrosion-induced unstable zones that are important for engineering and construction. Low shear wave velocities and a reduced shear strength were identified for the subrosion horizon and the disturbed overlying deposits. Low shear strength values indicate unstable zones, which show in part high Poisson's ratios. Conversion of S-to-P-wave within the subrosion horizon was also observed, and is probably caused by dipping layers and fractures.

In summary, this work demonstrates the suitability of 2D SH-wave reflection seismic and VSP to investigate subrosion areas and to identify unstable zones.

W.II.5 *Reliable determination of the reflector azimuth from borehole acoustic cross-dipole data*

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Borehole acoustic imaging methods aim at creating a high-resolution image of the geological structures in the vicinity of boreholes. They are usually based on measurements where the sources and receivers are placed along a single drilling path. Due to the axial symmetry of this acquisition geometry, diffraction or reflection points are imaged on circles around the borehole. This ambiguity can be resolved if information about the azimuth of the recorded incident waves is available.

One possibility to obtain the azimuth angle from borehole acoustic data is a cross-dipole measurement. It combines measurements of two dipole sources that are aligned perpendicular to each other. The directivity of these sources follows the cosine and the sine of the azimuth. The wavefield is recorded by cross-dipole receivers, such as receivers for the two horizontal components of the particle velocity.

The azimuth for both dipole measurements can be calculated independently as the arctangent of the ratio of the recorded components. If a reflector is aligned nearly parallel to the orientation of a dipole source, only a small amount of wave energy is emitted towards the reflector. In this case, the computed azimuth angle is very likely distorted by noise. This can be avoided by using all four components of the cross-dipole measurement at once. They can be regarded as components of a tensor of rank two, which is symmetric apart from the noise. The reflector azimuth can be derived from this tensor by a principal axis transformation. The eigenvector of the tensor that pertains to the greatest eigenvalue represents the incidence angle of the reflection. However, the performance of this method is still unsatisfactory in the presence of noise. The noise might even dominate reflection signals with high amplitudes near their zero points and cause significant deviations from the true azimuth.

Since the reflection signals have a certain duration, neighboring time samples can be included into the calculation in order to improve the reliability of the method. The determination of the azimuth angle for a given time window can be formulated as a minimisation problem. Rotating the tensor by an optimum angle minimises the appropriate tensor components for all time samples. The resulting mathematical term for the azimuth comprises the variance and covariance of the four time series of the cross-dipole measurement in the time window. The advantages of the presented method are its insensitivity to random noise and the compensation of different receiver sensitivities due to the subtraction of the arithmetic means of the time series, which is inherent to the variance and covariance functions. However, the solution for the azimuth is pi-periodic, and one of the two possible directions has to be selected based on additional information. If an incident wave does not propagate within the plane perpendicular to the borehole, the shifts in traveltime between dipole receivers at different borehole depths can help to resolve this ambiguity and to obtain a unique solution.

Session: Advanced seismic imaging and inversion methods including FWI and interferometry

TH.I.1 *Next leap forward in seismic crustal imaging: Full Waveform Inversion of 3D 4C OBS data* (KEYNOTE)

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To make a step change in our understanding of the geodynamical processes that shape the earth's crust, it is crucial to design new seismic experiments allowing to retrieve 3-D visco-elastic models of the crust at a wavelength-scale resolution (typically, few hundred meters). Along with the design of new acquisitions, the quest for high-resolution multi-parameter reconstructions requires new developments in leading-edge seismic imaging methods such as Full Waveform Inversion (FWI) to manage large-scale numerical problems and complex datasets recorded by ultra-long offset surveys.

The aim of this presentation is to discuss the feasibility of next generation of 3-D multi-component (4-C) OBS (Ocean Bottom Seismometer) surveys amenable to high-resolution multi-parameter crustal imaging by FWI. In this context, there are three main issues to be tackled. The first is related to the acquisition design in terms of geometry, sampling and spread for deep crustal imaging by FWI. We first need to understand how the acquisition design controls the sampling of the spectral components of the subsurface model reconstructed by FWI, any subsampling of these components leading to aliasing artefacts in the spatial domain. The conclusions of this analysis will control which area and depths can be covered by the survey for a given number of instruments. Then, we need to validate these conclusions with relevant numerical experiments, which require to build realistic benchmark synthetic crustal model. The second is related to the computational burden associated with large-scale inversions involving at least 500 million of unknowns. Seismic modeling can be performed either in the time-space or frequency-space domain, whose pros and cons should be discussed in the specific context of crustal-scale imaging (very large computational domains with a limited number of reciprocal multi-component sources). The specifications of massively-parallel FWI code in terms of parallelism, optimal management of memory and disk traffic and optimal management of reciprocal sources by blending and encoding should be defined to be able to tackle such frontier high-performance computing problems. The third issue is to mitigate the nonlinearity of FWI. One source of nonlinearity is cycle skipping, which is quite pregnant in crustal scale imaging due to the large number of propagated wavelengths in ultra-long offset surveys. Other source of nonlinearities are noise, approximate physics, parameter trade-off and uneven illumination, which require efficient regularization techniques. Four methodological focus will be evoked: the first is to improve the resolution of tomographic methods beyond first-arrival to build more accurate initial velocity model for FWI. To achieve this goal, we will show the superior resolution power of slopes picked in common-OBS gathers relative to travel times. The second is to design more convex distance than the usual l2 difference-based misfit function. The third one is to extend the search space to bypass more efficiently local minima, for example by alternating wave field reconstruction with a feedback term to the observables and parameter updating. A fourth one is to develop new edge-preserving regularization methods amenable to boost the resolution power of FWI at low frequencies (< 10Hz), while preserving the smooth components of the crust. Some possible methods to address these methodological challenges will be introduced during this presentation and will be discussed with an unprecedented synthetic crustal model of the eastern Nankai trough.

TH.I.2 *Synthetic study on the crustal-scale imaging via FWI of the 3D OBS data – building a realistic benchmark model of a subduction zone*

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Ray-based tomographic methods still remain the most common techniques for seismic imaging of deep lithosphere targets. Indeed, they are able to provide smooth velocity models illustrating the main structural units while maintaining reasonable costs of data-acquisition and processing. However, along with the benefits coming from this compromise for academic regional imaging there is also one particular drawback. Namely, relatively slow development of high resolution imaging frameworks in the scale of whole crust such as full-waveform inversion (FWI) schemes.

Although the ability of the academic community to perform OBS acquisitions is increasing, the gathering of large OBS pools remains challenging. This in turn limits the amount of real 3D data-sets which could potentially serve as a benchmark for different imaging schemes proving their robustness and stimulating their expansion in the community. As a byproduct we get limited interest in development of the massively parallel FWI implementations, allowing to tackle not only 2D but also large 3D inversion problems and providing efficient exploitation of the available computer resources. Therefore, in order to broaden our knowledge about the geodynamical contexts in various environments we must first scrutinize our abilities in terms of crustal-scale imaging via FWI and improve our understanding of the factors controlling FWI results like optimal acquisition design, 2D/3D geometries, acoustic/elastic approximations, frequency/time domain implementations, misfit functions, parallelism etc.

Here we make first step trying to mitigate the mentioned issues. We build a realistic 3D marine crustal-scale model amenable to benchmark different acquisition geometries and processing techniques suitable for deep crustal imaging. The model has been inspired by the geologically complex structure of the Nankai Trough combined with the results of previous geophysical investigations of this area. It contains wide range of realistic features like strong bathymetry variations, oceanic ridges, subducted topography highs, low-velocity zones, velocity gradients, complex accretionary prism, large faults and thrusts with local damage-zones as well as shallow sedimentary basins. Additionally we incorporate different stochastic components to mimic more realistic wave propagation. We further obtain S-wave velocity and density models using polynomial functions derived from empirical relations between P-wave velocity and other physical parameters. These basic elastic models are consequently modified according to our assumptions about local heterogeneities caused for example by the fluid saturation.

We cast all these structural and physical features into the 3D cube of the dimension 30 x 170 x 105 km and 25 m grid interval. Such parameterization leads to more than 34 billion degrees of freedom imposing additional challenge for computational resources and the high performance computing implementations.

We demonstrate the procedure that has been designed to generate this structural model, provide the insight into obtained structure and aim on the acoustic and elastic wavefield and ray tracing modeling as well as the first acoustic FWI tests. We believe that through the development of this synthetic model and the following visco-elastic data-set we have chance to: (i) better understand determinants of the crustal-scale imaging via FWI, (ii) stimulate its popularization in the communities aiming on regional data acquisition and imaging, (iii) mitigate the gap between industrial and academic state-of-art FWI.

TH.I.3 *Detailed crustal imaging in the Nankai Trough subduction zone using OBS-airgun data*

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The Nankai Trough is one of the best studies seismogenic subduction zones in the world, where the Philippine Sea plate is subducting beneath the Southwestern Japan. A long historical record of megathrust earthquakes in this subduction zone shows that rupture zones of M8-class events are divided into 4 segments, and recurrence intervals of megathrust event in each segment are typically 100-200 years, but two or more segments sometimes rupture in synchronization, resulting in M9-class earthquakes. For better understanding of these megathrust activities, many crustal scale seismic surveys have been conducted. In particular, the Kumano forearc basin is the most investigated area of this subduction zone and a great number of 2-D MCS surveys, 3-D MCS survey, and 1-km-spacing 2D-OBS seismic survey have been conducted. Besides, an ocean drilling project which aims to drill through the megathrust fault interface in the Kumano basin is now on going. Thus, this is a good place to test the state-of-the-art seismic imaging techniques for crustal scale structure studies.

OBS-airgun seismic survey data have been traditionally processed by using traveltime data alone. Recently, Full-waveform inversion (FWI) technique, which utilizes waveform itself to model seismic structure and have a potential to image seismic structure in much higher resolution than the traveltime inversion, has begun to come into practical use in the actual OBS-airgun data analysis. For example, Kamei et al. (2012) succeeded in imaging detailed Vp structure by applying acoustic FWI to the 1-km-spacing OBS data obtained in the Kumano forearc basin. Gorszczyk et al. (2017) also succeeded in imaging detailed Vp model in the Tokai segment of the Nankai subduction zone with use of another 1-km-spacing OBS data set. These successful former studies have shown that the FWI of dense OBS data set can model thin layers that cannot be detected traveltime inversion. However, it is not straightforward to investigate reliability and uncertainty of the obtained model and to interpret geological meanings of the detailed structure, such as thin layers.

In this study, we model seismic velocity structure by applying FWI to the 1-km-spacing OBS-airgun data in the Kumano basin, which is the same data set as Kamei et al. (2012). We adopted the TOY2DAC, which is a frequency-domain acoustic FWI code developed under the framework of the SEISCOPE consortium. The effectiveness of the TOY2DAC code for crustal scale imaging has been confirmed by Gorszczyk et al. (2017), and we referred to the robust workflow proposed by Gorszczyk et al. (2017). The obtained seismic velocity model shows variety of features, including a strong bottom-simulating reflector (BSR) and both of a thin high velocity layer and low velocity layer just above the plate interface. We will compare the result of FWI with the 2-D, 3-D seismic reflection images and OBS interferometric images and discuss the reliability of the results of FWI.

TH.I.4 *Slope tomography, stereotomography, double-difference tomography, diffraction tomography and so on*

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Building a subsurface model directly from seismic waves is quite challenging. First-arrival time tomography, velocity analysis or reflection time tomography are widely used for such purpose. New acquisition design allows a drastic improvement of wavefront estimation which requires new tomographic tools. Thanks to the increasing density of seismic sensors and sources, slopes which are the horizontal component of the slowness vector are efficiently extracted from seismic traces while time curvatures are considered in diffraction tomography (Bauer et al, 2017).

Such approach with times and slopes, namely stereotomography reviewed by Lambaré (2008), have incorporated advanced picking strategies of seismic events in the image domain (Chauris et al., 2002). Improved signal-to-noise ratio comes from the stacking procedure with more continuous events inducing less ambiguous picks. This slope information could be related to double-difference approaches for locating earthquakes (Waldhauser & Ellsworth, 2000) or for passive tomography.

Stereotomography is based on efficient ray tracing tools requiring specific definitions of data and model spaces. For example, stereotomography performs raytracing from a scattering point inside the medium towards source/receiver positions. Consequently, related shooting angles are integrated into the model space for restarting the ray tracing at each update of the velocity and scatterers positions. Moreover, previous one-way traveltimes allows to end the ray tracing nearby source or receiver positions and, therefore, these positions to be reached have to be added to the data space, while one-way traveltimes should be integrated into the model space.

Recently, Tavakoli F et al. (2017) have revisited this tomography through a so-called adjoint slope tomography (AST), where an eikonal solver is used for computing traveltimes and horizontal slopes, starting from either the source or the receiver, reducing drastically quantities to be integrated into data and model spaces. The model space is now composed only of velocity parameters and scatterer positions, while both times and slopes at sources and receivers have to be locally minimized through an adjoint formulation. Moreover, the forward modeling task has a complexity related to the acquisition and no more to the data density related to scattering positions.

A further reduction of the model space could be considered where only velocity parameters are involved as proposed by Sambolian et al. (2018), promoted as the parsimonious adjoint slope tomography (PAST). The selected data is only the horizontal slope at the source while two-way traveltimes and horizontal slope at the receiver are used for locating scatterers through the so-called focusing equations (Chauris et al, 2002). The complexity of the different forward problems is still related to the acquisition density, while locating scatterers is dependent of the number of picks as previous formulations. The main advantage of this approach is the single class of model parameters, providing a different trade-off impact between velocity and scatterer positions as shown in the Marmousi example investigated by Tavakoli F et al. (2017). This parsimonious approach, which does not require systematically scatterers, can be extended to first-arrival time tomography with a direct link to double-difference passive tomography.

TH.II.1 *Appraisal of Instantaneous Phase-Based Functions in Adjoint Waveform Inversion*

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Complex signal analysis allows separation of instantaneous envelope and phase of seismic waveforms. Seismic attributes have long routinely been used in geological interpretation and signal processing of seismic data as robust tools to highlight relevant characteristics of seismic waveforms. In the context of adjoint waveform inversion (AWI), it is crucial choosing an efficient parameter to describe the seismic data. The most straightforward option is using whole waveforms but the mixing of amplitude and phase parameters increases the nonlinearity inherent to the methodology. Several studies support the good functioning of the instantaneous phase (IP), a more linear parameter to measure the misfit between synthetic and recorded data. The IP is calculated using the inverse of the tangent function, where its principal value can be defined either wrapped in between different limits or also unwrapped. The wrapped phase presents phase jumps that reflect as noise in the inversion results. The conditioning of these discontinuities solves the problem partially and the continuous unwrapped IP is not a good descriptor of the waveform. For this reason, it is worth to explore beyond the traditional description of the IP parameter. Two alternative functions have been studied: 1) a revision of the triangular IP and 2) the first implementation of the normalized signal. The main objective of this paper is therefore, to review the fundamentals of the IP attribute in order to design robust IP-based objective functions which allow mitigating the inherent nonlinearity in the AWI method.

TH.II.2 *2D adjoint-state full-waveform inversion of band-limited multichannel seismic data in the Alboran basin (SE Iberia)*

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Here we present a high-resolution P-wave velocity model of the sedimentary cover and the uppermost basement until ~3 km depth obtained by applying adjoint-waveform inversion (AWI) to a Multichannel Seismic (MCS) data set acquired with a 6 km-long streamer of 480 channels. The MCS profile was acquired in the Alboran Sea (SE Iberia), in the framework of the TOPOMED-2011 experiment. The inherent non-linearity of AWI for short-offset, band-limited seismic data as this one, was circumvented by using a reference velocity model obtained by travel-time tomography. Given the water depth in excess of ~2 km and the short acquisition offset, refractions are not visible as first arrivals in the original shot gathers. To solve this issue, we applied a data processing/modeling sequence consisting of three steps: (1) data re-datuming (i.e. downward continuation, DC) by back-propagation of the recorded seismograms to the seafloor using a numerical solver of the wave equation; (2) joint refraction (first arrival of the DC shot gathers) and reflection (top of basement) travel-time tomography; and (3) AWI of the original shot gathers using the model obtained by travel-time tomography as initial reference.

AWI is performed using specific data and gradient preconditioning techniques to concentrate model updates in the regions where the gradient is more reliable. A multi-scale strategy adding low to high frequencies sequentially is followed to reduce the risk of converging to a local minimum and add details progressively to the model. The source wavelet is also inverted and updated in each inversion step. We show that AWI provides reliable and accurate results starting at frequencies as high as ~6 Hz, because the initial model has the low wavenumber information needed to avoid cycle-skipping.

The final velocity model shows a number of geologically meaningful details that cannot be identified in the initial model. For instance, a volcano-like structure is observed in the central part of the profile, also a strong velocity contrast that accurately follows the shape and geometry of the top of the basement, and steeply dipping anomalies that correspond to normal faults can be seen at the flanks of the basin. In addition, a 200-300 m thick, high-velocity layer embedded within the sediments that likely correspond to salt deposited during the Messinian crises is clearly imaged. The two-way-time transformed velocity model has an excellent match with time-migrated MCS image: velocity changes nicely follow major reflectivity contrasts and fault locations, which further validates the inversion result. The results confirm that the combination of DC and joint refraction and reflection travel-time inversion provides models that are accurate enough to apply AWI to relatively short offset streamer data starting at realistic field data frequencies.

TH.II.3 *Seismic imaging of the Alpine Fault at the DFDP-2 drill site in Whataroa, New Zealand using 3D VSP data*

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The Alpine Fault in New Zealand is an 850 km-long transpressive continental fault zone that is late in its typical earthquake cycle. The Deep Fault Drilling Project (DFDP) is designed to elucidate the geological structure of this fault zone and its evolution by drilling and sampling the Alpine Fault at depth. To link geological results from the drilling with local fault zone structures in the Whataroa river valley, we acquired, processed and interpreted various 2D and 3D seismic data sets.

The 2D seismic reflection data image the main Alpine Fault reflector at a depth of 1.5–2.2 km with a dip of approximately 45-50° southeast below the DFDP-2B borehole. Indication of a more complex 3D fault structure consisting of several fault branches cannot sufficiently be explained by the 2D data.

Consequently, we conducted a 3D VSP survey including surface receivers to study seismic reflections from the main Alpine Fault zone over a broad depth range. Within the borehole, a permanently installed "Distributed Acoustic Fibre Optic Cable" and a three-component borehole tool were used to record the seismic wavefield generated by an Envirovibe source. A total of ~450 one-component receivers were deployed at the surface in addition to 160 three-component receivers positioned in a roll-along scheme at more than 1900 different locations.

Using this multifaceted data set, a detailed 3D velocity model was derived by first arrival tomographic inversion. Tests of various inversion parameters, subsets of the whole data set and varying starting models, emphasize the reliability of the observed features in the final P-wave velocity model. Notably, the old glacial valley structures in this area are revealed for the first time in three dimensions. As suggested already by the 2D analysis, a sedimentary layer overlies the basement, but the 3D results show that the central sedimentary infill is a few hundreds of meters thick and thins out significantly towards the valley sides. In particular, a high P-wave anomaly within the 3D velocity model can be linked to the western flank of the glacially scoured valley.

The large contrast in seismic wave speeds for the dipping bedrock complicates all of the travel paths including the zero-offset VSP. Hence, a more sophisticated approach is required to processing of the VSP data.

Within the seismic reflection data recorded by the densely spaced three-component receivers, single reflection events can be identified on both inline and crossline profiles. Hence, the 3D character is revealed and the origin of the reflections can be identified. Single-shot seismic gathers give strong evidence for reflections coming from the steeply dipping valley flanks. Applying advanced seismic imaging methods is a key step in analysing the valley structures in more detail. The resulting images resolve the valley flanks at both the eastern and western side. Additionally, internal sedimentary structures are resolved that have not been previously detectable with the original 2D data set.

The 3D seismic data are crucial for imaging the highly complex 3D structures around the Alpine Fault within the Whataroa valley. Only by applying advanced seismic imaging techniques, are we able to image the geometry of the underlying glacial valley. Thus, the remaining structures belonging to the Alpine Fault can be resolved and understood in more detail. Our results provide a basis for ongoing seismic site characterisation at the DFDP-2 drill site, which will be crucial to understanding the structural and geological architecture of the Alpine Fault zone in this area.

TH.II.4 *Seismic imaging in an anisotropic crystalline environment at the COSC-1 borehole, central Sweden*

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The Scandinavian Caledonides represent a well preserved deeply eroded Palaeozoic orogen, formed by the collision of the two palaeocontinents Baltica and Laurentia. Today, after four hundred million years of erosion along with uplift and extension during the opening of the North Atlantic Ocean, the geological structure in central western Sweden consists of allochthons units, the underlying precambrian crystalline basement, and a shallow 1-2° west-dipping décollement that separates the two and is associated with a thin layer of Cambrian black shales. The project COSC (Collisional Orogeny in the Scandinavian Caledonides) aims to investigate these structures and their physical conditions, in particular the Seve Nappe Complex (as part of the Middle Allochthons), the Lower Allochthons and the underlying basement with two approximately 2.5 km deep fully cored scientific boreholes in central Sweden. Thus, a continuous 5 km tectonostratigraphic profile through the Caledonian nappes into Baltica's basement will be recovered. The first borehole COSC-1 was successfully drilled in 2014 near the town of Åre. Thus, a continuous section through the seismically highly reflective Lower Seve Nappe and a underlying mylonite zone was obtained. The Seve Nappe Complex, mainly consisting of felsic (gneisses) and mafic (amphibolites) rocks, has been deformed ductilely and emplaced hot onto the Lower Allochthons during the collisional orogeny that formed the Scandinavian Caledonides.

In order to allow the extrapolation from core analysis and downhole logging to the structures around the borehole, several surface and borehole based seismic experiments were conducted right after drilling completed. In this study, the data from a multi-azimuthal walkaway VSP in combination with three long offset surface lines was used to image the structures in the vicinity of the borehole. Clear differences in vertical and horizontal P-wave velocities, observed by comparing tomographic results with interval velocities derived from a zero-offset VSP, made it necessary to also account for anisotropy during velocity modelling. With the resulting VTI velocity model, consisting of the vertical P-wave velocities and two homogeneous Thomsen parameters, the first arrivals for both, surface and VSP data, could be explained very well. Subsequently, seismic imaging approaches, like Kirchhoff prestack depth migration were applied, including the calculation of Green's functions with an anisotropic eikonal solver. The resulting images were compared to the corresponding migration results based on an isotropic velocity model. Both images are dominated by strong and clear reflections, which appear more continuous and better focused in the anisotropic result. Most of the dominant reflections originate below the bottom of the borehole and therefore are probably situated within the Precambrian basement or at the transition zones between Middle and Lower Allochthons and the basement. The deeper reflections might also represent dolerite intrusions or deformation zones of Caledonian or pre-Caledonian age. Their origin remains enigmatic and might only be revealed by drilling the proposed borehole COSC-2, which is supposed to penetrate at least one of the basement reflectors.

TH.II.5 *Imaging of near-vertical faults with converted waves*

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Surface seismic surveys are efficient at imaging sub-horizontal or gently-dipping layered structures. Vertical and near-vertical elements of geological structures (like faults, overturned folds or salt diapir necks) scatter downgoing energy from seismic sources further down and away from the receivers. This deflected energy can still be recorded at the surface if it is scattered upwards by an underlying reflective interface. Modern imaging algorithms accounting for multi-pathing or relying on full wave field propagation can be used to properly migrate the multiply-scattered and mode-converted waves in these challenging cases. The information on the presence and configuration of these near-vertical elements is often crucial in complex geological setting.

In this work we explored the illumination capabilities of different ray paths and wave modalities (multi-views) for better imaging of vertical faults. We used synthetic and experimental ultrasound datasets of the geological models containing vertical blind faults to illustrate the concept. We used only the vertical component of the data to be consistent with conventional exploration seismic surveys that mostly use vertical geophones.

First, we calculated the travel times along the multi-legged ray paths between sources, vertical fault interface, underlying reflector and receivers at the surface considering both P- and S-waves as well as their conversions at each interface. Second, we used these travel times in the pre-stack Kirchhoff depth migration to generate multiple images (multi-views) of the same geological structure.

The vertical faults were not favorably illuminated and, as expected, were hardly visible in the P-P and P-S views. The views with the ray paths reflected from the underlying interface (PP-P, PP-S and even SS-S) improved illumination of the faults significantly and enhanced their presence in the images. This case study shows that the converted waves that are often disregarded in the conventional seismic surveys with vertical geophones can bring important additional information on geological structures. This information may be readily available in some previously acquired surveys and thus can be extracted by advanced imaging algorithms decreasing the interpretation uncertainties in challenging geological settings.

TH.III.1 *Crustal Seismic Reflection Imaging using Uncontrolled Sources and Large N Arrays*

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Reflection seismology with controlled sources often provides the highest resolution of any seismic technique. However, the application of the reflection method to probe all but the shallowest of structures is often inhibited by the substantial cost of artificial sources as well as logistical barriers to their deployment. Here we describe how reflection processing can be applied to recordings of ambient energy sources, natural and artificial, to produce reflection imagery that approaches the quality of conventional controlled source (CMP) surveys. Such "passive" seismic reflection imaging has only recently become practical with the advent of large N nodal technology that can simultaneously record spatially dense arrays for substantial lengths of time. Three diverse approaches are considered: seismic interferometry of ambient "noise" (natural or artificial), redatuming of microearthquake subsets via interferometry (a subset of the previous methods), and VSP imaging of microearthquakes with known locations. Examples from Iceland, the eastern US and Alaska suggest that these methods represent a transformative approach to studying, and monitoring, deep structure in areas illuminated by ongoing microseismicity.

TH.III.2 *Using large N arrays in mineral exploration: the passive seismic experiment in the Kylylahti Cu-Au-Zn mine area, Finland*

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Over the past twenty years, reflection seismology has been progressively used for mineral-exploration purposes. However, acquisition of active-source seismic data in the mining camps is challenging and costly. Recently, passive seismic imagery, using noise sources and utilizing seismic interferometry (SI), has developed as a promising tool to image the Earth's interiors without the requirement of having active sources. It is especially attractive as the recent advances in the wireless acquisition technology allow to deploy and record large N arrays (~thousand receivers and more) for a long time.

Here, we propose to use SI as a cost-effective method to support mineral exploration at a mining-camp scale. To investigate the feasibility of SI to image hard-rock environments hosting mineralizations, a 3D passive seismic experiment was conducted over the Kylylahti Cu-Au-Zn mining area, eastern Finland, as a part of the ERA-MIN funded COGITO-MIN project. A dense seismic array consisting of 1000 receivers placed with 200-m line spacing and 50-m inline receiver interval were continuously recording for 30 days during August 2016. The terrain conditions of the receiver places were varying and included both boreal forest and fields as well as inhabited areas and mine site.

We present a methodology to retrieve body-wave reflections in the setting dominated by ambient noise generated by underground mine activities and urban sources. First, we investigate the spectral content of our data and show the results of array-processing techniques to understand the spatio-temporal distribution of the dominant noise sources. Power spectral-density plots and beamforming analysis indicate broad frequency content (5-150 Hz) and diverse spatial distribution of the recorded noise sources. Surface waves constitute the bulk part of our recordings; however, by the means of visual inspection we found some noise panels containing high-velocity (>5 km/s) seismic events likely related to routine underground mine activity. To employ seismic energy generated below Kylylahti array, we propose a robust workflow for processing of mineral-exploration seismic interferometry (MESI) data.

The key steps of MESI method involve detection of body-wave sources, evaluation of their locations, and selective stacking over stationary-phase areas. We create virtual-shot gathers following two approaches – by summing all noise and by using approximately 1000 body-wave sources detected and processed with MESI workflow. We further test different selective-stacking schemes for captured body-wave events. We demonstrate comprehensive comparison of the stacked seismic sections retrieved using SI and 3D active seismic survey. Sections retrieved with SI exhibit high reflectivity, consistent with some geological features and correlating to some extent with reflectors observed in the active seismic study. We show that discrepancies in reflectivity patterns between the passive and active seismic results might be attributed to using sources that illuminate the target bodies from different angles. Our results are supported with extensive numerical-modelling study which confirms the fidelity of reflections obtained using SI.

COGITO-MIN has been funded through ERA-MIN, which is a network of European organisations owning and/or managing research programs on raw materials. The funding for the Finnish COGITO-MIN project partners comes from TEKES (the Finnish Funding Agency for Innovation) and for the Polish project partners from the NCBR (the National Centre for Research and Development).

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TH.III.3 *Seismic while drilling imaging: can it replace active seismic surveys?*

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Interferometry principles allow us to bring distant sources of seismic energy to the surface of the earth and use them as virtual shots to image subsurface geological features. Theoretically, a virtual shot can be generated from the recorded energy of an underground or surface source by cross correlating transmission responses measured by a reference geophone and those measured by other geophones along a seismic line. In controlled source interferometry where the source excitations are isolated temporally, correlograms of several individual sources are summed in order to reconstruct the reflection response of the earth at the location of the virtual shot. In ambient noise interferometry sources are mainly linked to human activity or microseismic energy caused by natural phenomenon such as oceanic disturbances. Ambient noise is usually recorded for many days or weeks in order to effectively reconstruct the reflection response at the location of virtual shots. Either way, each geophone is transformed into a seismic source on the surface that can be used in imaging the subsurface.

In June 2017, Curtin University and BHP Minerals Australia, acquired two sets of active and passive 3D seismic surveys at the site of an iron ore prospect in northern Western Australia. Passive survey was acquired immediately after active survey using the same array of geophones on the surface and simultaneous with drilling operations in the survey area. In passive survey, recorded noise from a total number of 19 drilling wells was stored in 7359 segd files (400 Gb) with each file containing 30s of data. The initial objectives of acquiring such dataset was twofold:

1. To investigate if seismic while drilling (SWD) data can provide subsurface image comparable in quality to the one derived from active source measurements.
2. To provide the opportunity for studying complex seismic wavefield associated with drilling into the iron ore bearing strata.

Our approach in processing such dataset with the objective of subsurface imaging was to reconstruct virtual shots on the surface and process these shots into a subsurface image as we did with active source recordings. Several wells in the survey area were positioned along each receiver line so that they could all contribute in construction of virtual 3D shots with larger fold leading to improved image quality. In data processing, we first removed the noise (e.g. surface waves, airwave, etc.) so that geophone recordings can be regarded as an approximation to transmission response of the medium between the bit location and geophone position on the surface. We then built virtual shots for each field recording (30s window) over a given receiver line and stacked the results to improve the reflected event coherency as described by controlled source interferometry method. We approximated drill bit source function with the trace recorded by the geophone nearest to drill rig as drilling was carried out with no pilot sensor mounted on the drill string. We then removed the source function effect from cross correlated data by deconvolving the autocorrelation of the nearest (to the rig) geophone trace from correlograms. Despite the fact that we only used a rough approximation of the bit source function in our deconvolution, we produced an image of the subsurface along one of the receiver lines that showed more details about the subsurface geology than image created by active source data. We conclude that recording while drilling can provide a low cost alternative to active source methods.

Session: The continental lithosphere II

TH.IV.1 *BASIC: A high-density crustal-scale refraction seismic profile across the Bergslagen ore district, Sweden*

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The Bergslagen ore district forms part of a major lithotectonic terrane in the Fennoscandian Shield bounded to the south and north by shear belts. This terrane is affected by variable metamorphic conditions, the ore district occurring in the lower grade central part. Different tectonic models for the development of the ore-bearing terrane, such as accretionary processes along an active continental margin or collision of separate microcontinents, have been proposed. However, deep onshore crustal-scale seismic data are missing to shed light on this question where surface geological data can support and complement. To better understand the contact relationships between the terrane containing the ore district and its northern boundary we have acquired, for the first time since the Fennolora project in 1979, a deep refraction seismic profile (650 km long) to study the seismic velocity structure of the crust and variation in Moho-depth onshore Sweden.

The profile was acquired during one week in May-June 2017 in a joint experiment involving several organizations. The profile employed 580 mixed 1C-3C receivers between 35 km south of Linköping and 65 km northeast of Sundsvall. Three different types of recorders were mainly used: DATA-CUBE3, Reftek Texans and Sercel RAU. Sensors were mainly 4.5 Hz 1C geophones supplemented by 20-4.5 Hz 3C geophones and 23 MEMS-based 3C sensors. In the middle of the profile the geophone recorders were distributed with a spacing of approximately 800 m for about 300 km distance. Towards the two ends an average spacing of 1.4 km was used. Additionally, 18 Güralp 3C broadband seismometers were deployed along the profile with an average spacing of 29 km. Seven explosive shots in quarries along the profile were recorded. Total charge size at each shot point was 360-500 kg distributed in 3-5 boreholes drilled down to 30 m depth in bedrock; at one location 11 boreholes were used. Shots were recorded in the early morning and early afternoon to avoid high cultural noise due to peak traffic periods and human activities. Midnight shooting was not permitted. GPS times of the active shots were recorded and used to extract the data from the wireless recorders operated in an autonomous mode. Data from the Swedish National Seismic Network (SNSN) with high sensitivity (20,000 V/m/s) were also obtained through the active-source GPS times, showing clear first arrivals on some shots up to 1200 km offset. Generally, first arrivals are distinct up to an offset of more than 300 km on the mobile stations. Key seismic phases such as Pg, PmP and Pn have been identified to constrain the velocity-depth structures along the whole profile. We will present our results and discuss their interpretations and potentials for future work given the unique nature of the data.

TH.IV.2 *Russian Program «Network of Geotransects & Deep Wells» (current stage & progress)*

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Russian Program «Network of Geotransects and Deep Wells» is the third stage of deep structure studies of Russia, which has been started nearly 25 years ago. Its main task is studying of deep structure of Russian Federation by field experiments with wide range of geophysical methods and parameterization of geophysical data by deep drilling.

Now, within the framework of this Program more than 31 000 km of geotransects, including nearly of 12 500 km of onshore, 7 deep wells with more than 3.5-4.0 km depth each were carried out. At the last decade, the main direction of Program was shifted to the east of Russia, including the adjacent seas of the Arctic and Pacific Oceans. For the last 4 years 2 geotransects were ended. The first (3-DV (2900 km) was crossed the southern part of Siberian Craton and two adjacent Fold Systems - Central Asian Fold Belt and Verkhoyansk-Kolyma Fold Region. Other geotransect (1-SB (1700 km) is characterizes deep structure of Trans-Baikal region, joining the Chinese Deep profile «Sinoprobe IV» with its southern end. In 2016 new geotransect (8-DV (2000 km) has been started. It has been run from southeastern part of Siberian Craton to Pacific Ocean shore across eastern part of the Central Asian orogenic belt including Mongol-Okhotsk fold area, Bureya continental massif and Sikhote-Alin fold area. In 2017 drilling of the Zabaikalskaya Deep Well laid on 1-SB has been started too.

Large amount of reprocessing and reinterpretation was done in addition to field experiments in recent years. New direction of Program is Superlong geological and geophysical geotransects created from separate geological and geophysical support profiles and their fragments. Now, we construct such superlong geotransect from Amerisian Basin of Arctic Ocean to South Kuril across Chukotka and Koryak with total amount more than 5000 km.

Besides geological and geophysical data received on geotransects are an important basis for the deep component of different tectonic maps of great blocks of Earth crust. Usually, a set of typical maps includes: Earth's Crust Thickness map, Sediments Thickness map, Consolidated Crust Thickness map, Earth's Crust Zoning map and as result – Map of Earth's Crust Types. In fact, such sets of maps represent 3D models of the Earth's crust throughout its thickness. For the last years such sets were created for 2 International projects: «Deep processes and Metallogeny of the North Central and East Asia» and «Tectonic map of the Circumpolar Arctic».

In 2018 -2020 years, 8-DV geotransect and drilling of the Zabaikalskaya Deep Well (target depth - 4000 m) will be completed. Further plans are also related to the study of the deep structure of the east of Russia.

TH.IV.3 *Towards a pan-European Deep Seismic Sounding (DSS) European database: Promoting the impact, preservation, and accessibility of the existing wealth of controlled source seismic data*

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Since the 70's European Earth scientists have devoted extensive efforts to acquiring Deep Seismic Sounding (DSS) data. These projects, mostly supported by national and international agencies and research institutions are undoubtedly the base that supports all the current existing knowledge on the structure of the crust and lithosphere. These seismic experiments that resulted in unique and critical data sets are practically and logistically demanding and expensive, and many geographical areas are relatively poorly covered. Because of this, both new and old data is of great scientific importance, especially as modern analysis tools allow increasingly refined interpretations. Currently, there is no fully organized pan-European structure for ensuring that this valuable data is properly preserved for future use and is accessible in a homogeneous and robust manner to all researchers, and furthermore in manner which will assure that the efforts of the research teams involved in their acquisition are properly acknowledged. These data alone have contributed greatly to our current understanding of the continental lithosphere of Eurasia and new analysis methods and scientific questions mean that the data continues to be used actively. Many of these projects were nationally funded within specific research programs. The list of acronyms related to key experiments and datasets is extensive, it includes: ECORS, BIRPS, DEKORP, ESCI, FIRE, HIRE, URSEIS, ESRU, EUROBRIDGE, ECORS-CROP, TRANSALP, POLAR, NFP20, EUGENO, BABEL and several others. These data sets, and new ones of the same class, are irreplaceable, and will continue to be highly relevant for studies of the deep Earth and tectonic evolution. The inclusion of DSS data and research infrastructures in the large portfolio of the EPOS initiative is being assessed through SERA project with a few specific goals that include: To identify and gather the relevant institutions currently holding and/or collecting such data; map and establish a first comprehensive inventory of available raw and processed data, formats, metadata, products of various levels obtained from the raw data, reports and technical documentation of past experiments; investigate access mechanisms and ownership issues where relevant; aim to join the active and passive seismology data collections. (This activity is supported by the SERA project, supported under project 730900, INFRAIA-01-2016-2017).

Session: Mid-ocean ridges and ocean lithosphere

F.I.1 *Imaging upper crustal structure at the 9°50´N East Pacific Rise using elastic 3-D full-waveform inversion: Implications for crustal accretion* (KEYNOTE)

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The East Pacific Rise (EPR) is one of the magmatically most dynamic ocean spreading center along which ~6 km thick oceanic crust has been accreting over the last 180 Ma forming the vast expanse of the Pacific Ocean. Until now, it has been accepted that the most of the upper oceanic crust at the EPR is formed from an axial magma lens (AML) at its base. While the large portion of mobilized melt from the AML is intruded into preexisting crust forming ~1.3 km thick dike section, a part of the melt erupts on the seafloor forming a porous layer of pillow basalts. Available 2D seismic images suggest that the thickness of this basaltic layer varies rapidly from ~200 m at the ridge axis ~600 m within only few kilometers from the ridge axis. Due to limited information on the upper crustal velocities this observation has been attributed to the thickening of the pillow basalts, or to downward propagating, hydrothermally driven, cracking front. Furthermore, it is rather difficult to clearly delimit the contact between pillow basalts and dikes due to the presence of high velocity gradient, the origin of which is not clear. To address these scientific issues, we have applied a 3D elastic full waveform inversion technique to 3D seismic dataset collected at the EPR in 2008, covering an area of ~32x40 km2 centered at the ridge axis. A number of tests were carried out to develop an adequate and efficient strategy for the inversion. We simultaneously inverted P-wave velocity (Vp), Vp/Vs ratio and impedance contrast (Ip). To stabilize the inversion weighting of the Vs/Vp parameter needed to be introduced. We inverted data in 2-3-5-7 Hz frequency band and performed 15 iterations. We also carried out acoustic inversion of Vp and Ip within the same frequency band. Our results show that the effect of shear wave must be taken into account to avoid erroneous geological representation of the subsurface. The resulting 3D elastic velocity image reveals the presence of a high velocity gradient zone marked by an ~4.2 km/s velocity contour at its base that can be followed throughout the entire area. The consistency in the character of this gradient zone and distinct velocity anomalies near active hydrothermal discharge zones (where the most of the alteration is expected to take place) suggest that this boundary is predominantly lithological and that the basalt thickening is due to the emplacement of lava outside of the innermost axial zone. Interestingly, the zone of thin basalt layer is present within a very limited zone (~1 km) centered at the ridge axis, same as the width of the AML underneath, suggesting that the diking is predominantly vertical. The transition from thin (~200 m) to thick (300-550 m) basaltic layer occurs within an ~4 km wide zone around the ridge axis. Our results allow to image the 3D shape of this transition, which seems to be controlled by the width of the AML, the rate of basalts thickening and/or presence of numerous active faults in the vicinity of the ridge axis. By combining the available observables and results of our analyses we suggest that the emplacement of basaltic lavas, variation in their thickness, and rate of dike subsidence are predominantly controlled by tectono-magmatic features and processes operating at the ridge axis.

F.I.2 *OSCAR – Oceanographic and Seismic Characterisation of heat dissipation and alteration by hydrothermal fluids at an Axial Ridge*

R. Hobbs[1] & OSCAR Science Party

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The interdisciplinary OSCAR project is examining the heat and mass fluxes in the solid Earth and overlying ocean at the Costa Rica mid-ocean Ridge (CRR) in the Panama Basin. The 3500 m-deep Panama basin is isolated from the wider Pacific Ocean below ~2000 m by the Cocos and Carnegie Ridges except for a deep water channel along the Ecuador Trench. This channel supplies cold abyssal water into the basin at a rate of 0.35 Sv (106 m3 s-1) at a temperature of 1.75°C. Within the basin this water is heated to ~2°C. The energy for this heating is dominated by geothermal effects with a smaller contribution mainly from tidal induced mixing over the ridges.

The main geophysical transect for the OSCAR survey links the CRR with the ODP 504B borehole which was drilled 2111 m into 6.9 Ma oceanic crust. Changes in the solid Earth properties from the CRR to 504B are mapped using a combination of active and passive seismic data (including 2D- and 3D-refraction and synthetic aperture reflection), together with magnetic, gravity, magnetotelluric, swath bathymetry and heat-flow data. Results show that the properties of layer 2 are variable and dominated by episodic change in magma flux at the ridge axis rather than simply by the effects of ageing. Of particular note is the abrupt change at about 6 Ma, where older crust has a higher velocity and lower basement topography when compared with younger crust. At this age the lower topography becomes sealed by pelagic sediments resulting in heat-flow through the older crust being largely through conduction whereas in the younger crust it is still dominated by advection.

The physical oceanography data include conductivity temperature depth (CTD) casts, micro-structure casts, helium and other isotope data, together with seabed and moored temperature, pressure and Doppler current measurements. The inflowing water along the Ecuador Trench initially mixes with the warmer water as it enters the basin. Vigorous mixing and heating continues as the water circulates into the western part of the basin generating a bottom boundary layer with no vertical density gradient that is over 1000 m thick. Evidence of a hydrothermally-driven plume was also detected along the CRR but the exact location of its source was not found.

Our best estimate from the OSCAR data is that the geothermal heating contributes over 60% to the abyssal water upwelling. This is the largest contribution yet observed in abyssal basins and is in line with a growing number of studies that argue that geothermal heating plays a significant role in driving the abyssal and global circulation.

The NERC OSCAR project was supported by grants to project PIs: Hobbs & Peirce (Durham), Maqueda (NOC and Newcastle), Tong (UCL) & Morgan (Imperial College). The research was also supported in part by NSF grants to Lowell (Virginia Tech) and Harris (Oregon State) and the project involves scientists from Germany, China, Colombia, Costa Rica and Ecuador. The authors would like to thank the officers, crew, technicians and science party on board the RRS James Cook during cruises JC112/113 and JC114, and FS Sonne SO238.

F.I.3 *Exploring the lithosphere-asthenosphere boundary (LAB) with active-source seismic methods*

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A traditional view of the LAB is that it is a gradual rheological boundary defined by the temperature of the mantle adiabat. A smooth shear-wave decrease across the LAB, often reported from surface-wave inversion studies in oceanic areas, has reinforced that view. But more recent work with converted and reflected seismic waves now show that the LAB can be characterised by a sharp change in P and S wave speeds. P-wave reflections with frequencies as high as 14 Hz have been generated with explosive sources from what is interpreted to be the oceanic LAB of the subducted Pacific plate, at about 100 km deep beneath eastern New Zealand. A 14 Hz frequency implies that the "sharpness" of the interface can be defined by a boundary layer ~ 500 m thick. Moreover, active source studies, both on land and offshore, report a 10-15 km thick channel at the LAB, and there is evidence that this channel thins and deepens with age. Amplitude analysis suggest a ~ 8 % drop in P-wave speed within the channel which is consistent with a layer with about 2% partial melt.

Mid-lithospheric boundaries have recently been reported at a variety of oceanic locations. These are shallower (~ 50 km deep), less continuous, and do not show the 10 -15 km thick channels that are discussed here.

The land-based study in New Zealand used ~ 850 seismographs spread over ~ 82 km, with a spacing between them of ~ 100 m. Explosive charges of 500 kg in 50 m deep bore holes were used. Very large shot sizes like this generate a much broader range of frequencies than smaller air-gun shots and this is one of the key advantages of land -based studies for imaging deep targets like the LAB. On the other-hand a marine source is repeated multiple times so a more continuous image can be obtained.

We also recorded strong reflectivity from the LAB beneath eastern New Zealand with receiver gathers from onshore seismographs that record airgun shots from offshore. This method allows us to record at wider angles (incidence angles > 50 deg) where higher levels of reflection energy are generated. In the wide-angle data we see the 10 km channel of the Pacific plate at depth of about 90-100 km, with the bottom reflector having reflection amplitude than the top. Polarity analysis of these two reflectors is consistent with a melt channel interpretation, although there is a significant level of uncertainty in picking polarity from a 100 km deep reflector.

Both our wide-angle onshore-offshore and on-land data define, once the crustal thickness of the overlying plate is taken into account, a plate that is about 75 km thick. This is about 20% thinner than plate or half-space cooling models for the lithosphere. But these thicknesses are also seen by studies that use receiver functions and SS precursors. We interpret these unusually shallow values of the LAB as being due to the accumulation and focusing of melt in a channel by the dynamics of plate motion. We suggest that this so-called "LAB channel" may be a key feature of the earth that allows plate tectonics to work.

F.I.4 *Preliminary results of the Logachev Seamount seismic modeling*

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To better understand the lithospheric structure beneath the ultra-slow spreading ridges the active seismic survey within the Knipovich Ridge Passive Seismic Experiment (KNIPAS) was carried out. The aim of this work is to provide a segment-scale image of lithosphere structure, velocity field and its boundary beneath the small part of the Knipovich Ridge in the area of Logachev Seamount. It is believed that this type of ultra-slow spreading ridges is characterized by pronounced supply of melt along axis. Our intention is to provide evidence of crustal thickness variation beneath the Logachev Seamount area which may substantially contribute to an understanding of this type of ridges.

The active seismic profiles were acquired during cruise no. MSM67 in September 2017 with an array of 16 G-guns of a total volume of 51 l and shot interval of 60 s. On the ocean floor at depths from 2.3 to 3.3 km seismic energy was recorded by 8 ocean bottom seismometers (OBS). In total 320 km of seismic data was acquired along 6 profiles of length from 30 to 60 km covering the area of around 2200 km2. The profiles were crossing each other over the Logachev Seamount. Most of the deployed OBSs are slightly off the profile. High resolution bathymetric data acquired during the cruise combined with previous bathymetry datasets was utilized as an ocean bottom layer within the seismic model.

For the 2D seismic modeling process data from OBSs near the profiles were used. Available offline information will be used for 3D modeling. The crustal structure was determined only from P-waves. Water wave and its multiples allowed for the possibility to estimate velocity in the sea water. We will present our preliminary result in the form of velocity models of the Logachev Seamount area and discuss their interpretations and potential for future work.

Session: Continental rifts and sedimentary basins
+ Intra-continental deformation, collision and accretion

F.II.1 *Western Eger Rift in Central Europe: active magmatic emplacement from combined seismic and isotope study*

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Seismicity at lithospheric plate boundaries can be accompanied by magmatic processes, which play fundamental role in formation and differentiation of the Earth's crust. These processes are connected with magmatic emplacement as a result of an ongoing magmatic activity at the lower crustal level. Though they are usually confined to lithospheric plate boundaries, they can also occur in an intraplate setting. However there, they are rare phenomena not commonly observed or discussed. The western edge of the Eger Rift in central Europe as a part of the European Cenozoic Rift System is a geodynamic region abundant of repeated seismic swarms and mantle derived fluids emanating at surface, Cenozoic volcanism, and neotectonic crustal movements at the intersections of major intraplate faults. As such, it represents unique European intracontinental setting. Active and passive seismic data in this area show increased seismic velocities at the lower-crustal level, which points to a magmatic addition at the base of the crust and to a concept of magmatic underplating. Moreover, character of the seismic image differs laterally. This enables to differentiate two types of the magmatic underplating and relate them to two episodes with different times of origin. High-velocity lower crust with increase seismic reflectivity evidences the first type of magmatic underplating related to Variscan or pre-Variscan age westward of the Eger Rift. The other type is evidenced by high-velocity reflection-free lower crust which together with a strong reflector at its top at depths of ~28-30 km forms a lower-crustal magma body. Lateral extent of this body correlates with the distribution of mantle-derived fluid emanations at the surface. Increased helium isotope ratios in CO2-rich gases suggest active magmatic processes in the intracontinental setting in this area. Xenoliths from corresponding depths document the origin of the magma at the lower crust/upper mantle transition. As a result, spatial and temporal relations of this magma emplacement to recent geodynamic processes with Cenozoic/Quaternary volcanism point to the ongoing magmatic activity within a broader late Cenozoic body and its possible reactivation in the last 0.3 Ma during mid-Pleistocene to Holocene.

F.II.2 *Combining of alternative versions of wide-angle reflection/refraction and near-vertical reflection data processing in the area of folded belts of the Southern Siberia, Russia*

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Usually reliability of geophysical studies is estimated internally within a single experimental approach. Wide-angle reflection and refraction data at the 1200 km long eastern segment of the “1-SB” profile in the area of folded belts of the Southern Siberia were processed by three different research groups. In addition, the near-vertical reflection data from the same profile were processed by other three different research groups. This allowed comparing the results of independent techniques and approaches, estimate their reliability and spot artifacts. Each research group utilized forward ray-tracing modeling of refracted and wide-angle reflected phases for developing final velocity-interface models of the crust and uppermost mantle. At the same time, these groups used different ways of constructing initial models, such as either first arrivals tomographic inversion or inversion of equal-offset time field of wide-angle reflections. The difference in the Moho depth of the different “ray-traced” models does not exceed 2 km. The difference in the depth of the intra-crustal wide-angle reflector reaches 5 km. “Internal” refraction velocity uncertainty (i.e. for the single models) does not exceed ±0.15 km/s for the Moho. “External” uncertainty (difference for different models) reaches 0.3 km/s. Near-vertical reflection sections were time to depth converted using the model of average velocities obtained from wide-angle data. For the most of the profile, misfit between depths of “near-vertical” and “wide-angle” reflection Moho is less than 1 km. Only in some local zones that misfit reaches 3 km. The normal incidence data were processed with and without automatic gain control (AGC), with more strict and less strict signal coherency enhancement. Combined results of the three different versions of the processing provided the structural framework and regional reflectivity zoning of the section. Noticeable changes in signal/noise ratio along the profile are manifested as anomalous sub-vertical reflective bands in the deep seismic image. The zones of lower signal/noise ratio in many cases are tied with shallow Mesozoic-Cenozoic depressions, but not with deep structures. In general, zoning of the upper crust corresponds to the major tectonic units. However, for example, the wide suture zone (the Mongol-Okhotsk fault zone) between two major tectonic units is practically not pronounced in the normal incidence reflection image. Combination of the sections obtained with different gain control helped to detect intra-crustal listric faults and detachments. Unexpectedly, “detachment-like” reflections were observed at three different depth levels down to the lower crust. Some detachments can be traced as far as 500 km along the profile. Near-vertical reflection Moho is fairly sharp and is marked by abrupt die out of reflectivity at the most extent of the profile. At the same time, the base of the crust under the Baikal rift zone is barely visible in the section with preserved amplitude relationship. This peculiarity may be caused by an influence of recent movements (Cenozoic extension and rifting) on the state of the crust-mantle transition zone. It may explain why the sharp reflective bottom of the crust has been blurred here. One hypothesis is that the medium here has not reached yet physical and chemical compositional equilibrium for the new P/T conditions at a new depth of occurrence.

F.II.3 *On Mesozoic regional uplifts in SE and N Poland – insight from regional seismic data*

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The inversion of a sedimentary basin could be associated with compressional reactivation of basin-forming normal faults, upward movement of the basement blocks, and partial or complete erosion of its sedimentary infill. Basin inversion might be however also related to whole-basin uplift that might not be linked to the reactivation of basement faults and results in the development of regional stratigraphic gaps and unconformities. This second type of regional, basin-scale movements have been recently documented in SE and N Poland using regional, almost 800 km long seismic profile, belonging to the PolandSPAN regional seismic survey, stretching from the Baltic coast to the Polish-Ukrainian border and calibrated by numerous deep wells. This profile is located within the NE flank of the Mid-Polish Swell that was formed as a result of Late Cretaceous – Paleogene inversion of the Mid-Polish Trough i.e. axial part of the epicontinental Polish Basin that formed the easternmost part of the Permian–Mesozoic epicontinental basins of Western and Central Europe. It illustrated earliest Late Jurassic (earliest Oxfordian) and earliest Late Cretaceous (Cenomanian) regional unconformities related to the regional, basin-scale uplifts in the SE segment of the Polish Basin. Latter unconformity is also present in N Poland where it truncates Triassic and Jurassic deposits. In this part of the basin Upper Cretaceous succession is characterized by sigmoidal and oblique seismic reflection pattern, numerous unconformities and discontinuity surfaces highlighted by downlap, onlap and toplap seismic terminations. This hitherto unknown progradational pattern strongly suggest regional Late Cretaceous progradation directed from the North towards the South. Source area that might have been uplifted during the Late Cretaceous and undergone regional erosion could have been located within the present-day Baltic Sea and/or the South Swedish Dome. Development of syn-tectonic progradational Upper Cretaceous succession can be explained using a model developed for the Bornholm – Darłowo Fault Zone (SW Baltic Sea) and SE Poland.

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F.II.4 *A tale of weak crust in northern England: multiple extension and multiple inversion*

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The Môn-Deemster-Ribblesdale Fold-Thrust Belt (FTB), exposed in northern England and concealed beneath the Irish Sea, represents the Variscan inversion of the Bowland Basin. It represents a strain discontinuity between granite-underpinned basement highs e.g. the Lake District Massif, in the north, and the Anglo-Brabant Massif, in the south. Four parallel anticlinal fold-thrust pairs affect strata of Mississippian to late Pennsylvanian age. The predominantly southward-vergent Variscan thrusts extend downward into the Caledonian basement and apparently terminate above a gently northward-dipping zone of reflectivity, interpreted as an intra-crustal shear zone. The latter is correlated with the exposed Lŷn Shear Zone, the terrane boundary between crust of Avalonian and Ganderian affinity in southern Britain. In the absence of modern, broadband, deep seismic reflection data in this area, it is not possible to say much about the composition and structure of the crustal substrate. However, analogies can be made with the exposed Caledonian basement of Anglesey to the SW, and the Ingleton Inlier of the northern Pennines, to the NE. The former comprises lenses of late Neoproterozoic metamorphic and meta-igneous crust and exotic Cambrian metamorphosed deepwater sedimentary sequences of Ganderian affinity, accreted onto the then NE-facing margin of Gondwana during the Penobscotian Phase (late Tremadocian). This complex and a mid Ordovician – Silurian terrane-linking sequence were cleaved and thrust during the Acadian Phase (mid Devonian). Evidence is growing that the Ingleton Group, a thick sequence of poorly dated deepwater turbiditic strata, isoclinally folded prior to deposition of a late Ordovician terrane-stitching sequence (Windermere Supergroup), may also have suffered Penobscotian deformation. The compressional structures in the weak crust of this multiply deformed Caledonide substrate were readily reactivated by Mississippian extension during the formation of the Bowland Basin and its offshore continuation, prospective for conventional and non-conventional hydrocarbons. Variscan compression in late Pennsylvanian time led to further reactivation, formation of the SW-NE trending Môn-Deemster-Ribblesdale FTB, and a later generation of compressional structures on a NNW Uralian trend. It was the extensional reactivation of these latter structures, in Triassic to Jurassic time, which allowed the development of the East Irish Sea Basin with up to 7 km of subsidence. During Cenozoic time, the region was further impacted by thermal doming associated with the opening of the Atlantic Ocean, and the far-field effects of Alpine compression, manifested in widespread inversion and the modification of the major hydrocarbon traps. The complex structural history of this weak crust is in strong contrast to that of the surrounding crustal blocks, which have remained largely undeformed and buoyant since their stabilisation at the end of the Caledonian Orogeny.

POSTER PRESENTATIONS

P01 *Failed rift system in northern Honshu, Japan, imaged by the improved standard seismic velocity structure beneath the Japanese Islands using offshore earthquake events*

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We investigate the three-dimensional (3D) seismic velocity structure beneath the ocean as well as beneath the Japanese Islands, using offshore events as well as events beneath the Japanese Islands. Offshore events have a large uncertainty for focal depth determined by the high-sensitivity seismograph observation network (Hi-net) operated by the National Research Institute for Earth Science and Disaster Resilience (NIED), however, broadband seismograph network (F-net) operated by NIED determined the focal depth with moment tensor inversion. NIED also determined the centroid depth with accelerometers of NIED Hi-net with moment tensor inversion. Matsubara and Obara (2011) analyzed the seismic velocity structure beneath and around Japanese Islands using offshore events with the combination of Hi-net picked data and F-net focal depths from 2000 to 2009. In this study we added the data after 2010 including the aftershocks of the 2011 Tohoku-oki event.

The target region, 20-48°N and 120-148°E, covers the Japanese Islands from Hokkaido to Okinawa. A total of manually picked 5795093 P-wave and 3076047 S-wave arrival times for 223081 earthquakes recorded at approximately 1769 stations from October 2000 to December 2014 is available for use in the tomographic method. The inversion reduces the root mean square of the P-wave traveltime residual from 0.682 s to 0.196 s and that of the S-wave data from 0.798 s to 0.241 s after ten iterations.

Our new analysis revealed the failed rift structures, marked by higher Vp at lower crust and lower Vp at the upper crust, along the Japan Sea cost of central Honshu. Judging the age of the rift fill, they were produced during the formation of the Japan Sea. Similar, rifting structure also detected along the Pacific coast of Northern Honshu. It is marked by uplifted Moho surface, trending NS to NNW-SSE direction (Matsubara et al., 2017a). Geologically, it is interpreted as a rift structure formed in the late Mesozoic. However, the tectonic meaning of this structure is still poorly understood. NIED deployed the Seafloor observation network for earthquake and tsunami along the Japan Trench (S-net). The new tomographic result using S-net data, makes us possible to understand the tectonic framework of the Mesozoic rifting off Tohoku.

This structure is open to public in the NIED Hi-net web site and everyone can download the structure. Software to get the image of the map views and cross-sections is also open at the NIED Hi-net web site.

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P02 *2017 Deep seismic reflection profiling across the western part of the Hidaka collision zone and the Ishikari foreland basin, Hokkaido, Japan*

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The Hidaka collision zone (HCZ) in south central Hokkaido was formed by collision of the NE Japan and Kuril arcs. The HCZ is marked by west-vergent thrusting, and the frontal thrust has continued to be active through the late Quaternary. In the Ishikari foreland basin west of the HCZ, thick-Cenozoic sediments form gentle active folds. The city of Sapporo, with a population of 2 million, is located in the Ishikari basin, and faces the threat of damaging earthquakes due to blind thrusts covered by sedimentary fill. To identify seismogenic source faults in the frontal part of the HCZ and in the Ishikari foreland basin, we performed deep seismic reflection profiling as a part of the "Integrated research project on tsunami and earthquakes in the Sea of Japan".

We collected deep seismic reflection data in late June - mid July 2017 along a 68.5-km seismic line across the western part of the Hidaka collision zone and along the Ishikari River. Four vibroseis trucks provided the seismic source, at shots intervals of 50 m in the western half of the seismic line and 100 m in the eastern half. Sweep frequency was 3 to 40 Hz, while the number of sweeps was 3 in the west and 8 sweeps in the east. Seismic signals were collected by off-line recorders (GSX and GSR, Geospace Inc.) with a receiver interval of 50 m, a sampling rate of 4 msec, and a total of 1358 fixed channels. For deeper imaging, we made a standard 50 sweeps at 4 km intervals along the seismic line, and employed a dynamite shot (100 kg) at the eastern end and 850 sweeps at the western end of the seismic line. The acquired seismic data were processed using CMP and MDRS methods. A P-wave velocity profile was obtained by refraction tomography.

The processed seismic section portrays a structural image to 4.5 sec (TWT). In the western part of the Hidaka collision zone, a pattern of crustal reflectors shows poor coherence due to significant crustal shortening and a complicated structure. The frontal thrust of the HCZ forms a wedge-thrust at 2 km depth and can be traced to 10 km along reflectors that dip eastwards at 20-30 degrees.

Thick basin fill (~4 km) in the Ishikari foreland basin shows gentle folds associated with eastward-dipping reverse faults. Syn-rift strata (Paleogene?) on the hanging wall of these reverse faults indicate that the folds were produced by basin inversion of older normal faults. The crustal seismic reflection section shows thin-skinned deformation in the western HCZ and thick-skinned deformation beneath the Ishikari fore-land. The geometry of seismogenic source faults was clearly identified in our deep seismic profiling.

P03 *Tomography model of the outer fore arc of the Ecuador-Colombia subduction zone using TOMO3D: 3D velocity distribution and 2-D geometry of the interplate boundary*

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We present preliminary results from the application of TOMO3D [Meléndez et al., 2015] to the modelling of wide-angle seismic data set acquired at the convergent margin of Ecuador and Colombia in 2005, in the framework the ESMERALDAS project. The offshore data were recorded on 23 OBS with the oceanographic R/V L'Atalante in a cruise leaded by IRD-Géosciences Azur and funded by French agencies. These data were complemented by onshore recordings of the airgun shots in a network of 31 landstations. The aim of this survey was gathering 3-D information on the nature and structure of the margin at the rupture area of the 1906 and 1958 seismic events in order to increase the present geological knowledge derived from existing 2-D experiments, and to extract possible seismological implications. The results prove useful for the on-going study of this subduction zone, the characterisation of the North Andean margin, and the associated seismic activity.

Refraction traveltime picks from this data set were previously modelled by García-Cano et al. [2014] using FAST. For the new tomographic inversion with TOMO3D we added ~20,000 reflection picks, corresponding to the interplate boundary, to the ~200,000 refraction picks already available. In a first step, we limited the model to the marine area containing all OBS, which has the best ray coverage and resolution of the experiment. Comparison between the resulting 3D velocity models shows that the general structures and the major geological features defined by the isovelocity contours are rather similar, indicating that TOMO3D is capable of producing sound results for the velocity distributions of the overriding and underthrusting plates, and thus that it is a valuable tool for crustal-scale investigation.

The main geological features interpreted from the 3-D velocity model are a low vertical velocity gradient that characterises the weak, highly fractured outer margin wedge, which is related to the trenchward limit of the rupture area and the tsunami excitation, and the low-velocity zone in the overriding plate just above the interplate boundary and below the continental slope. Furthermore, the sedimentary thickness both on the oceanic crust and on the continental shelf can be estimated, and two high velocity anomalies are observed: one in the continental crust and another in the subducting plate, which seems to indicate a thin oceanic crust. The thickness of the oceanic crust and its dip angle are discussed assuming that it is limited between the 4 km/s and 7.5 km/s isovelocity contours. Our inversion of reflected data associated to the interplate boundary allows us to define a 2-D geometry model of this reflective discontinuity as well as the physical properties just above it, and to correlate them with characteristics of the seismogenic zone. This new information contributes to the general understanding of the margin, in particular regarding its seismological behaviour and the characterization of the oceanic plate.

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P04 *Anisotropic P-wave traveltime tomography implementing Thomsen's weak approximation in TOMO3D*

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We present the implementation of Thomsen's weak anisotropy approximation for TTI media within TOMO3D, our code for 2D and 3D joint refraction and reflection traveltime tomographic inversion. In addition to the inversion of seismic P-wave velocity and reflector depth, the code can now retrieve models of the Thomsen's parameters δ and ε. Here we test this new implementation following four different strategies on a canonical synthetic experiment. First, we study the sensitivity of traveltimes to the presence of a 20% anomaly in each of the parameters. Next, we invert for two combinations of parameters, ($v_{||}$, δ, ε) and ($v_{||}$, δ, $v_{|||}$), following two inversion strategies, simultaneous and sequential, and compare the results to study their performances and discuss their advantages and disadvantages. Simultaneously inverting the parameter combination ($v_{||}$, δ, ε) produces the best overall results, but the most accurate $v_{||}$ model is obtained with the combination ($v_{||}$, δ, $v_{|||}$), also with a simultaneous inversion. In each case we derive the fourth parameter from the relationship between ε, $v_{||}$ and $v_{|||}$. Recovery of $v_{||}$, ε and $v_{|||}$ is satisfactory whereas δ proves to be impossible to recover even in the most favorable scenario. However, this does not hinder the recovery of the other parameters, and we show that it is still possible to obtain a rough approximation of δ distribution in the medium by sampling a reasonable range of homogeneous initial δ models and averaging the final δ models that are satisfactory in terms of data fit.

We apply this new anisotropic code to a real case study that we already modelled with its 2-D isotropic version. The 2-D wide-angle seismic data set was acquired parallel to the subduction trench offshore Nicaragua. The resulting isotropic model of the overriding plate displays small lateral velocity variations and a nearly flat interplate reflector. We detected a certain degree of anisotropy by comparing the location of the interplate reflector obtained from traveltime tomographic inversion to that in a coincident seismic reflection image. A 15% increase in the subhorizontal velocities obtained from the tomographic inversion was able to cancel the misfit between reflectors. The anisotropic inversion of the original refraction and wide-angle reflection data along with newly-added reflection picks from streamer data yields a model of anisotropy for the overriding plate, and a more reliable location of the interplate reflector.

P05 *Adjoint-state FWI of streamer data in the upper plate of the Nicaragua subduction zone*

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Adjoint-state FWI is in terms of resolution the most powerful existing tomographic method. It has become a well-established inversion method thanks to the efforts made by both industry and academy (Virieux and Operto, 2009). The main strength of the technique is that it allows obtaining unprecedented high resolution images of the subsurface of the Earth. In the last years we have developed our own FWI code called 2D3DA-FWI as a reference to the 2D and 3D acoustic FWI (Dagnino et al. 2014, Jimenez et al. 2015, Dagnino et al. 2016). Now, we applied this code to invert a 66 km-wide and 3 km-deep Vp model. This shallow part displays the deep Sandino basin, filled by a sediment pile of variable thickness, which is folded and bent by the tectonic activity associated to the convergence between the subducting Cocos plate and the continent. Below the sediments, the basement is located at a variable depth between 200m and 2.5km depth. The details of its inner structure, the lithology of the geological domains, and the geometry and location of the main faults, which reflect the coupling between the subducting and overriding plates, are unknown. To better define all this details we have applied an adjoint-state FWI using the streamer data acquired in this region to obtain a higher resolution Vp model. To achieve this goal we have processed the multi-channel seismic data, applying data processing sequences designed by our group (Dagnino et al. 2017), and we have generated an initial model using a first arrival travel time tomography code based on a previously obtained one (Sallares et al., 2013).

P06 *Estimation of the uncertainty in seismic tomography*

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Like any method in the science the traveltime tomography required estimation of the uncertainty. Knowledge about the dependence of the result on a starting model of velocity field, grid and inversion parameterization is common. However, often the influence of the picking precision is omitted. We show the application of our method to the industrial data from survey near city of Koło, Central Poland. This survey was realized with industrial standards with vibroseis sources and standalone seismic stations distributed in full-spread geometry. The data were processed with cross correlation resulting in clear refraction arrivals to maximum offset of 14 km. In our research we are trying to show that the influence of the picking precision is as relevant as others factors. To explore it even better we take into account two types of statistically changed distributions of P wave first-arrival traveltimes – the symmetric and the asymmetric one. We consider a number of the starting model using the grid search attempt to determine their effect on obtained velocity field. Whereas Monte Carlo approach was used to check the impact of picking precision. For assumed parameters we recognize that two mentioned factors have almost the same influence on the result. Both of them differs about 1.5% from the best model. During our investigation we have also considered the rays density in each block of the model. We have affirmed that taking the rays coverage into account is necessary to get proper uncertainty estimator, because it drastically changes the obtained distribution. In previous step some artefacts may appear, that are difficult to explain. This procedure significantly improves the result eliminating all artefacts, thus making the results more useful for scientific interpretations.

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P07 *The large-N and large-T Maupasacq experiment – A very dense seismic network to image the deep architecture of the western Pyrenees*

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A dense seismic network of about 450 three-component (3C) sensors recording continuously for 6 months, from March to October 2017, was deployed in the Mauleon basin which is located in the northern foothills of the western Pyrenees. Three different types of sensors were used: 191 SG-10 3C SERCEL nodes, 197 3C 5 Hz Seismotech short period stations, and 54 broadband stations (Guralp CMG40, Trillium Compact, and Trillium 120 seismometers). The experiment was designed to sample the wavefield with a regular grid of sensors spaced by 1 km along E-W and N-S profiles and covering an area of 30x50 km. This network was complemented by additional outer-rings of stations in order to increase the spatial aperture of the acquisition, a key point for a better resolution of deep structures. These outer-ring stations will also provide virtual sources for ambient noise tomography with a very good azimuthal coverage. During the experiment, we performed 3 shots of 50 kg of dynamite that will be used to calibrate the crustal velocity models. The main scientific objective of this experiment is to image the remnants of the hyper-extended European distal rift margin buried beneath the Mauleon basin with passive imaging approaches. Another major goal is to get a better picture of the local seismicity and its relationship with geological structures. In this presentation, we will give an overview of the deployment and the signals that were collected, and present some preliminary results obtained with different types of classical imaging techniques such as receiver functions, travel time tomography, and ambient noise tomography.

P08 *The structure of the Spanish Central System and surrounding basins from ambient noise autocorrelations and controlled source data*

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The Spanish Central System is an intraplate mountain range characterized by a thick-skin pop-up and pop-down configuration formed by the reactivation of Variscan structures during the Alpine Orogeny. The Central System and surrounding basins, the Duero Basin to the North, and the Tajo Basin to the South, present an anomalous high elevation. Peaks above 2000 m exist and average height of the Duero Basin is above 700 m. The high topography is, most probably, the response of the crustal thickness, geometry of the Moho discontinuity, crustal architecture and rheological properties. These are the main target of the current investigation developed in the area.

As part of a multi-seismic project, limited controlled source data has been acquired, jointly with ambient noise seismic records along a ~300 km long, NNW-SSE trending profile. The seismic noise records are being acquired in a three-stages deployment pattern by short period (2 Hz) seismic stations with a 4.8 km average station spacing. Here, we present results from the two first stages, which account for the central and southern part of the profile, i.e. the southern branch of the Central System and part of the Tajo Basin. Stations have recorded the ambient seismic field continuously for a month and a half. Processing consisted on: phase autocorrelation of the seismic noise to retrieve the zero-offset reflection response at the receivers and, time-frequency domain phase-weighted stack used to stack the auto correlations. For calibration and, along the same transect, over 500 TEXANS, with a station spacing of 400 m were deployed to record a wide-angle shot gather. The preliminary results provide relatively strong constraints on the deep structure of the Spanish Central System. The lower crust and the crust-mantle transition are constrained by both data sets. Furthermore, small crustal discontinuities and structures are interpreted and correlated with surface geology features. The results of the processing are compared to synthetic models to certify the validity of our interpretations. (Research support, Ref: CGL2016-81964-REDE, CGL2014-56548-P, EU grant 730900).

P09 *Retrieving Moho reflections from high-frequency autocorrelations of ambient noise*

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Autocorrelations of the seismic noise are becoming a useful technique to resolve crustal features through retrieving the zero-offset reflection response at a receiver. Here, we explore the autocorrelations of the ambient seismic wavefield at different frequency bands in order to evaluate the feasibility to recover body wave reflections from the Moho. We emphasize on the high-frequency content of the ambient field since we are interested in performing higher resolution studies. We use two years of data from broadband stations of the TopoIberia network and additional temporal short period stations, all deployed in Spain. The frequency-dependent visibility of the Moho reflections depends on structural complexity (along the path and of the discontinuity itself) and of the ambient noise energy spectrum. The frequencies analysed go from 0.7 Hz up to 11 Hz and are scaled in octaves in different bands of interest. The reflectivity response has been calculated using the phase autocorrelation and the classical auto-correlation, and are stacked using the linear stack and the time-frequency domain phase weighted stack. Consistency and robustness of autocorrelograms is explored by comparing stacks from different recording periods. Low-frequency Moho reflections are robust and easy to detect. Higher-frequency reflections, nevertheless, are difficult to single out and show a high spatial variability when they are detected. (Research support, Ref: CGL2016-81964-REDE, CGL2014-56548-P, EU grant 730900).

P10 *Characterization of sinkhole areas using elastic parameters and seismic attributes derived from reflection seismic*

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Elastic moduli derived from vertical seismic profiles (VSPs) and 2D SH-wave reflection seismic profiles were used to characterize mechanical properties of rocks in sinkhole areas. VP and VS were used to calculate the Poisson's ratio and the dynamic shear modulus. The study shows that 2D shear-wave reflection seismics is ideally suited to depict the lateral changes due to heterogeneities of the subsurface induced by subrosion. Low shear wave velocities of ca. 120 m/s to 350 m/s and low shear strength values between 25 MPa and 250 MPa are identified for the subrosion horizon and the disturbed overlying deposits, which are a result of cavities and fractures induced by dissolution creating unstable zones. In compliance with the shear modulus the Poisson's ratio from the VSPs shows high values of 0.38 to 0.48 for both, the presumed subrosion horizon and the deposits above. This is a further indicator of reduced ground stability. In the VSPs, anomalies of the shear modulus and the Poisson's ratio correlate with low electrical resistivities of less than 10 Ωm from borehole logs, indicating high conductivity due to fluid flow. Further investigation reveals a conversion of S-to-P-wave for the subrosion horizon, which is probably the result of dipping layers and an oriented fracture network. Seismic attribute analysis of the 2D sections shows strong attenuation of high frequencies and low similarity of adjacent traces, which correlate with the degree of subrosion-induced disturbance of the underground.

P11 *Shear-wave, very shallow seismic reflection profiling across the Kamishiro fault, Itoigawa-Shizuoka tectonic Line active fault system, central Japan*

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For assessing seismic risk from crustal earthquakes in the overriding plate, to obtain slip rates of active faults is essential. High-resolution imaging by seismic reflection profiling provides a powerful tool. We investigated shallow subsurface structure using Shear-wave, Electrodynamic Vibrator System and a land streamer across the active reverse faults to evaluate the effectivity of imaging methods. The target fault was the Kamishiro fault, in the northern part of the Itoigawa-Shizuoka tectonic line (ISTL) active fault system, central Japan. This fault was formed as a basin bounding fault, which separates the NE and SW Japan in the Miocene. Along the Kamishiro fault, surface ruptures appeared with the 2014 Nagano-ken-hokubu earthquake (Mw = 6.2). We performed shear-wave seismic reflection surveys along three seismic lines across the surface ruptures in November 2017. Surface ruptures were NNE-SSW trending thrusts. Shallow subsurface geology consists of Quaternary fluvial deposits. We acquired CMP-seismic reflection data using a seismic acquisition system combined with Electrodynamic Vibrator System and a land streamer. The seismic source ELVIS (Electrodynamic Vibrator System) manufactured by GEOSYM, was used in Shear-wave mode to generate horizontally polarized shear waves (SH-waves). The sweep length was 10 seconds, and its frequency was 20-80 Hz. Seismic signals were recorded by a land streamer equipped with 96 SH geophones. The source intervals were 1 m (2 m only in the Wing 21 seismic line), and the receiver intervals were 0.5 m. We selected the recording system GEODE (GeoMetrics), and its sampling rate was 1 msec. The Shiojima seismic line to the north of the Matsu River had 60 shot points, 168 receiver points, and a length of 83.5 m. The Oide seismic line to the north of the Onara River had 239 shot points, 476 receiver points, and a length of 237.5 m. The Wing 21 seismic line to the south of the Onara River had 108 shot points, 236 receiver points, and a length of 117.5 m. In this seismic line, we performed hammer-impacts at intervals of 2 m to compare the performance with ELVIS.

In the Oide seismic line, CMP stacking after NMO corrections using 0.3 km/s for S-wave velocity reveals the geometry of a fault. The obtained seismic section demonstrates the eastward dipping seismic event, which corresponds to the subsurface extension of surface rupture up to a depth of approximately 50 m. Shear-wave seismic reflection surveys using Electrodynamic Vibrator System and a land streamer were very effective to obtain great detailed subsurface images of active faults.

P12 *Near-surface structure of the Carpathian Foredeep marginal zone in the Roztocze Hills area*

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Shallow seismic survey was made along 1280 m profile in the marginal zone of the Carpathian Foredeep. Measurements performed with standalone wireless stations and especially designed accelerated weight drop system resulted in high fold (up to 60), long offset seismic data. The acquisition has been designed to gather both high-resolution reflection and wide-angle refraction data at long offsets. Seismic processing has been realised separately in two paths with focus on the shallow and deep structures. Data processing for the shallow part combines the travel time tomography and the wide angle reflection imaging. This difficult analysis shows that a careful manual front mute combined with correct statics leads to detailed recognition of structures between 30 and 200 m. For those depths, we recognised several SW dipping tectonic displacements and a main fault zone that probably is the main fault limiting the Roztocze Hills area, and at the same time constitutes the border of the Carpathian Forebulge. The deep interpretation clearly shows a NE dipping evaporate layer at a depth of about 500–700 m. We also show limitations of our survey that leads to unclear recognition of the first 30 m, concluding with the need of joint interpretation with other geophysical methods. Additionally, we present initial results of seismic analysis of recorded horizontal components resulting in additional information about the structure.

P13 *Seismic signature of massive sulfide ore body: A case study from Pyhäsalmi, Finland*

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Significant percentage of the world's Zn, Cu, Pb, Au and Ag reserves are in the form of volcanogenic massive sulfide (VMS) deposits. Polymetallic VMS are stratabound mineral deposits that are formed by the precipitation of sulfide minerals on and near the seafloor during submarine volcanic activity. Petrophysical studies of density and seismic velocity in VMS ores and its host rocks have shown that, in a typical geological setting, VMS ores have a high impedance contrast where in contact with any of the typical host rocks. This provides the means to use reflection seismic surveys for exploring VMS type ores. However, the capability of a seismic survey to image an ore body at depth is not only influenced by the acoustic impedance but also the geometry and orientation of the body.

In this work, we study the seismic signature of the Pyhäsalmi massive sulfide ore body, located in Central Finland. The ore deposit belongs to the Raahe-Ladoga belt, hosting 90% of the known massive sulfide deposits of Finland. The Pyhäsalmi deposit is a polymetallic Zn-Cu VMS ore body with total reserve of 58.3 Mt @ Cu 0.9 %, Zn 2.4 %, S 37.8 %, Au 0.4 g/t and Ag 14 g/t. The ore body has two parts: The upper part is a sub-vertical folded sheet that has an elongated conical shape extending to approximately 1100 m depth. The lower part of the Pyhäsalmi ore body extends from 1100 m to 1420 m. This deeper part is a roundish massive sulfide with approximate dimensions of 350 x 200 x 300 m3. A detailed model of the ore has been made, based on the exploration and production drilling.

In 2007, The Geological Survey of Finland acquired high resolution reflection seismic data over the Pyhäsalmi deposit as a part of the project HIRE (High Resolution Reflection Seismics for Ore Exploration). Although the particular seismic profile of interest, E1, was acquired directly on top of the Pyhäsalmi ore deposit, the signature of the ore deposit is not easily recognizable from the seismic data. Therefore, in order to better understand the data, we conduct both 2D and 3D seismic forward modeling of the target area.

In this study, the 2D reflection seismic signature of the Pyhäsalmi ore body – both synthetic and real – is analyzed and compared. As a starting model, we use a simple, smoothed 2D cross section of the E1 line with the ore body and surrounding rock underneath. Step by step, the complexity of the model is increased, starting with the alteration zone surrounding the ore deposit and finally to the full geological model. To fully understand the seismic response of the Pyhäsalmi massive sulfide ore body, the final step in the modeling is to use a 3D model with the actual shot and receiver locations. With 3D forward modeling we are able to compare these synthetic data with the data acquired from the actual seismic reflection profile, E1.

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P14 *Seismic reflections from Northern Finland: Experiment of Sodankylä Deep Exploration*

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Geological Survey of Finland (GTK), Technische Universität Bergakademie Freiberg (TUBAF) and Oulu University (OU) are working together in the project XSoDEx (Experiment of Sodankylä Deep Exploration) to study bedrock structures in the Sodankylä area located in Northern Finland. The project studies structural and lithological framework of different mineral deposit types by using seismic reflection and refraction methods, gravity and audio magnetotelluric measurements.

The Sodankylä region in Northern Finland is currently one of the most active mineral exploration areas in Fennoscandia. The Kevitsa Ni-Cu-Au-PGE mine has been operating in the northeastern part of the area since 2012, and the largest primar gold producing mine of Europe is located in the eastern edge of the area. Exploration in Sodankylä region has been further boosted by the discovery of Sakatti Cu-Ni-PGE sulfide deposit in 2009. It is located some 20 km south of the Kevitsa mine. The XSoDEx survey is studying the linkage of the major mineral deposits of the Sodankylä area in depth and aims to achieve a better understanding of the mineral system.

The main task of the XSoDEx experiment was to acquire almost 100 km of seismic reflection and refraction data in Sodankylä region during July and August 2017. The seismic surveys utilized a 32 ton vibroseis truck owned by TUBAF as a source. In reflection seismic survey, 8-15 Geode recorders each with 24 geophones spaced at 10 m interval were used in a split-spread geometry. In the refraction survey, maximum 100 Sercel RauX Unite wireless sensors were placed along the line. The wireless units were constantly recording from morning to late evening, providing data for both refraction seismic analysis as well as passive seismic interferometry studies.

Data acquisition was done along accessible roads within the research area and surrounding terrain conditions were varying from woodland to wet swamps. In general, data is of good quality and first arrival energy is clearly visible on maximum offsets of reflection data (3.6 km) and refraction data (~10 km). There is also clear reflectors visible in the raw shot gathers and XSoDEx data acquired is expected to provide new insight to the deep geology of the Sodankylä region after careful processing of the data.

While the seismic reflection data is used to extract information about geological interfaces of the subsurface, seismic refraction data provides independent information about velocity structures of the subsurface. The velocity field derived from the refraction data will provide constraints to the seismic reflection data processing. Data interpretation of the XSoDEx project is aided by the results of petrophysical measurements of density and P-wave velocity from the samples collected in the vicinity of the survey area.

P15 *Characterization of the Lower Paleozoic Shales in Northern Poland from the Analysis of Wide Azimuth Seismic Data*

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Here we present a case study of characterization of Lower Paleozoic shales in Northern Poland based on analysis of a seismic data. This study consist of two parts, where in both the same wide-azimuth full-azimuth angle-domain pre-stack depth migration (PSDM) seismic data has been used. First part is the amplitude versus angle and azimuth analysis (AVAZ) applied to quantify the amount of the azimuthal anisotropy. Second part is the brittleness prediction by integrating well and 3D seismic data using machine learning technique (proximal support vector machine (PSVM) algorithm).

The challenges encountered here are related to thin (up to 25 m), deeply buried (approximately 3 km) targets, characterized by a weak average azimuthal anisotropy (1-2% from cross-dipole sonic data). Another obstacle is related to small number of the available wells what makes the brittleness prediction's statistics not satisfactory.

For AVAz analysis data has been converted into Common Angle Common Azimuth (CACAz) gathers and used as an input for analysis using both Near Offsets Ruger and Fourier Coefficients methods. Additionally, in-house sectored pre-stack time migration (PSTM) has been run to examine the impact of a processing on AVAz analysis results. Application of AVAZ on full-azimuth PSDM data provided results that were further corroborated by the available calibration data. Anisotropy azimuths from AVAZ correlates with natural fracture direction from image logs (XRMI) interpretation, especially at the wells with only one dominant fracture system present. Fracture strikes inferred from AVAZ correspond also with fracture strikes inverted from the microseismic shear-wave splitting analysis. Hudson's crack densities calculated from the AVAZ anisotropic gradients matched crack densities from cross-dipole sonic as well as followed the same trend as the fracture intensities from XRMI (X-tended Range Micro Imager) data.

For brittleness prediction full-azimuth PSDM data has been used as an input for simultaneous AVO inversion. Volumes resulted from inversion has been then integrated with brittleness index (BI) logs using PSVM algorithm resulting in the relatively high resolution 3D brittleness volume. The workflow allowed for differentiation of the brittle and ductile zones of the thin shale layers, as well as mapping of the marly formation (fracture barrier). The important part of the success was the appropriate definition of the mineralogical brittleness index (BI) tailored to the local geological conditions.

The results from AVAz analysis and brittleness prediction compared together are consistent to some extent where the areas of a high value of the azimuthal anisotropy have also high values of BI.

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P16 *Reprocessing of a vintage 2D reflection seismic line across the Norcia-Mt. Vettore faults, Area of the Mw = 6.5 earthquake (2016-2017 sequence, Central Italy)*

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The Central Italian region is among the most seismically active areas of the Mediterranean region, and it is often struck by earthquakes of Mw > 6.0. The recent strong seismic sequence (9 main earthquakes of Mw > 5) started during the August 2016 at Amatrice and it reached its peak the 30th October 2016 with the Mw =6.5 mainshock . The epicenter was located about 7 km depth between Norcia and Mt. Castelluccio di Norcia basins (Monti Sibillini chain), producing impressive surface ruptures at the Mt. Vettore. But despite the large amount of datasets and studies made available so far, uncertainties still remain about the complex subsurface geology of the area. The presentation addresses the seismic processing and interpretation effort carried out on seismic line NOR2 (ENI, S.p.a.) that goes across the Norcia and Castelluccio di Norcia basins. The resulting seismic section reveals new details that contribute to better constrain the subsurface structure of the study area. The two basins (Norcia and Castelluccio di Norcia) are clearly visible and it is possible to detect the contact between the Quaternary deposits and the underlying bedrock. Some alignments and offsets of reflectors enhance the visualization of the main faults: the Castelluccio di Norcia Basin is clearly limited on its west side by a steep W-dipping normal fault visible down to about 3.0 s. Here, some sub-horizontal or gently E-dipping high amplitude reflectors are clearly visible down to 8.0 s, making it possible to extend the previous interpretation . This work confirms that a targeted reprocessing of a vintage industrial seismic line provides new and clear images of the subsurface geology of the epicentral area between Norcia and Castelluccio di Norcia basins. The work carried out enhances the value of new processing of vintage seismic reflection data. Such data is relatively expensive to acquire, however it is unique as it reveals high resolution details of the subsurface not achievable otherwise.

P17 *Imaging of near-vertical faults with converted waves*

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Surface seismic surveys are efficient at imaging sub-horizontal or gently-dipping layered structures. Vertical and near-vertical elements of geological structures (like faults, overturned folds or salt diapir necks) scatter downgoing energy from seismic sources further down and away from the receivers. This deflected energy can still be recorded at the surface if it is scattered upwards by an underlying reflective interface. Modern imaging algorithms accounting for multi-pathing or relying on full wave field propagation can be used to properly migrate the multiply-scattered and mode-converted waves in these challenging cases. The information on the presence and configuration of these near-vertical elements is often crucial in complex geological setting.

In this work we explored the illumination capabilities of different ray paths and wave modalities (multi-views) for better imaging of vertical faults. We used synthetic and experimental ultrasound datasets of the geological models containing vertical blind faults to illustrate the concept. We used only the vertical component of the data to be consistent with conventional exploration seismic surveys that mostly use vertical geophones.

First, we calculated the travel times along the multi-legged ray paths between sources, vertical fault interface, underlying reflector and receivers at the surface considering both P- and S-waves as well as their conversions at each interface. Second, we used these travel times in the pre-stack Kirchhoff depth migration to generate multiple images (multi-views) of the same geological structure.

The vertical faults were not favorably illuminated and, as expected, were hardly visible in the P-P and P-S views. The views with the ray paths reflected from the underlying interface (PP-P, PP-S and even SS-S) improved illumination of the faults significantly and enhanced their presence in the images. This case study shows that the converted waves that are often disregarded in the conventional seismic surveys with vertical geophones can bring important additional information on geological structures. This information may be readily available in some previously acquired surveys and thus can be extracted by advanced imaging algorithms decreasing the interpretation uncertainties in challenging geological settings.

P18 *Mapping depth-to-basement using joint inversion of gravity, seismic and borehole data – a case study from eastern and central Poland*

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Our approach to inverting of gravity data is based on the spatial method published by Barnes and Barraud (2012). This method combats nonuniqueness problem that occurs when inverting potential field data through a joint inversion of gravity data with independent data sets, incorporating depth information and regularizing the solution. This approach is particularly useful when combining gravity data with depth horizons estimated from interpreted 2D seismic profiles to create a high-resolution three-dimensional (3D) inversion for imaging subsurface geological bodies. The depth estimates (well tops, seismic horizons) are treated as representing a set of measurements of the geological surface and are incorporated in the same way as potential field data.

Results of a depth-to-basement study are presented for the East European Craton and the Teisseyre-Tornquist Zone (TTZ) in Poland. The terrestrial gravity data are inverted for the top of crystalline basement and, separately, for the top of Ediacaran jointly with 2D seismic horizons from the Poland-SPAN™ seismic reflection survey and well tops. The depth to Ediacaran modelling was additionally extended to cover the Łysogóry Block and the northern part of the Małopolska Block. The results are visualised as isobath maps for the top of crystalline basement and top of Ediacaran, and a isopachyte map for the Ediacaran. The maps are supplemented with the results of quantitative structural interpretation based on gravity and magnetic anomaly maps and their derivatives. The modelled horizons show a smooth crystalline basement slope above the TTZ with the top basement uniformly descending south-westwards by 10-14 km. The thickness of Ediacaran in SE Poland is increasing in the same direction presumably to more than 10 km within the TTZ. The top of crystalline basement shows no signs of thick-skinned deformation during the Phanerozoic. The results obtained reveal significant thinning of Precambrian crust within the TTZ probably due to an Ediacaran rifting event related to the break-up of Rodinia.

[1] Barnes, G., Barraud, J., 2012. *Imaging geologic surfaces by inverting gravity gradient data with depth horizons*. Geophysics, 77, G1–11.

P19 *Imaging East European Craton margin in Northern Poland using extended-correlation processing applied to regional seismic profiles*

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Detailed image of the entire crust and Moho discontinuity in the area of the Baltic basin, N Poland, were derived from reprocessing several 2D Vibroseis industry seismic reflection profiles with the use of the extended-correlation technique. We apply this method to a subset (5 profiles of 950 km total length) of ION Geophysical PolandSPAN™ regional seismic program covering the marginal region of the East European Craton (EEC) and originally aimed at imagining Lower Palaeozoic shale play over entire country.

Given the raw, uncorrelated seismic data, acquired with a 28-s listening time and 16-s long sweep, we were able to extend the nominal record length up to 22 s two-way-time (TWT) (60 km depth). For the recorrelated dataset, we designed a special processing workflow including denoising, cascade deconvolution, signal enhancement, frequency filtering and post-stack migration. In order to boost signal coherency, the novel form of stacking seismic traces along common-reflection surface (CRS) was also tested here and compared with well-known common-midpoint stacking. The CRS method is based on summing traces that are collected not only along offsets but also in a midpoint direction. In that way, the multidimensional stacking tends to output image with improved signal-to-noise ratio and more stable continuity of reflections, especially in low fold zones. In order to support interpretation of the final results, we performed a time-depth conversion of the post-stack migrated sections using velocity model compiled from the available pre-stack depth migration velocity models for the section above the basement and the velocity field based on a recent compilation of the wide-angle reflection/refraction (WARR) profiles for the deeper section below the basement.

Processing of the strike lines (i.e. perpendicular to the Teisseyre-Tornquist Zone, TTZ) revealed a very reflective lower crustal domain. Previously, reflective lower crust was noted in the legacy deep reflection seismic data from the Pomerania region, as well as in the new reflection seismic profiles further south along the TTZ in Poland (profiles from the same PolandSPAN™ family as well as the POLCRUST profile). We tentatively link this reflectivity with the passive-margin stage of Baltica. Moho reflectivity varies in strength and quality, but is observed across the profiles at a consistent depth level of ca. 35-40 km, which is compatible with the observations from-WARR data. Our extended-correlation processing of the PolandSPAN™ data provides a new source of information that will undoubtedly shed some light on the evolution of the EEC in the upcoming tectonic model creation.

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P20 *Late Archean continental spreading inferred from seismic reflection images of the Australian Yilgarn craton*

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On the early Earth, oceanic plateaux similar to present-day Iceland are thought to have evolved into less dense micro-continents as they thickened by continued melt intrusion and crustal fractionation. These earliest continents may have been so weak on a hotter Earth that they collapsed laterally in response to thickening by further magmatic growth or tectonic imbrication. This continental spreading is likely to have resulted in the development of pervasive ductile strain fabrics in the deeper crust, which, if preserved, could generate seismic reflections. Deep seismic reflection images from the Youanmi Terrane, which represents the ancient core of the Yilgarn Craton of Australia, reveal pervasive shallowly dipping to subhorizontal reflections in the middle and lower crust. Although imbricate structures related to thrusting are identified in some parts of the middle crust, the normal offset of upper crustal reflections and listric reflections in the middle and lower crust indicate that much of the crust has been affected by extension. The resulting structural basins in the upper crust, which include half-grabens and symmetric synforms, appear to be filled by high temperature crustal melts dated at 2.65-2.61 Ga, implying that this extension occurred late in the evolution of the craton and was key to cratonsation of the Archean crust here. Seismic reflection data from the northeastern part of the Yilgarn craton show that the Eastern Goldfields Superterrane, immediately east of the Youanmi Terrane, was also affected by widespread extension, but in this area extension was accommodated in the upper and middle crust along discrete shear zones that flatten out into the top of a relatively transparent lower crust. Laterally continuous, short duration, subhorizontal lower crustal reflections may also represent discrete shear zones that accommodated collapse of the cratonic crust. These deep seismic reflection surveys indicate that, though structural styles differ somewhat between the Youanmi Terrane and Eastern Goldfields Superterrane, crustal collapse occurred over >500 km of the northern Yilgarn craton. Some reflections that project to the surface within greenstone belts, extend beneath adjacent younger granites, leading us to also conclude that large regions of the upper crust in the hanging walls of listric shear zones subsided beneath the late granitic melts rising towards the surface, and did not involve Rayleigh-Taylor instabilities within a mostly mobile crust.

P21 *High-resolution seismic survey at a planned PIER-ICDP fluid-monitoring site in the Eger Rift zone, Czech Republic*

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The Eger Rift zone (Czech Republic) is an intra-continental non-volcanic region and is characterized by outstanding geodynamic activities, which result in periodically occurring earthquake swarms and significant CO_2 emanations. The epicentres of the earthquake swarms cluster at the northern part of the Cheb Basin. Although the location of the cluster coincides with the major Mariánské-Lázně Fault Zone (MLFZ) the strike of the focal plane indicates another fault zone, the N-S trending Počátky-Plesná Zone (PPZ). Isotopic analysis of the CO_2-rich fluids revealed a significant portion of upper mantle derived components, hence a magmatic fluid source in the upper mantle was postulated. Because of these phenomena, the Eger Rift area is a unique site for interdisciplinary drilling programs to study the fluid-earthquake interaction. The ICDP project PIER (Drilling the Eger Rift: Magmatic fluids driving the earthquake swarms and the deep biosphere) will set up an observatory consisting of five shallow monitoring boreholes.

In preparation for the drilling, the seismic survey aims at the characterization of the projected fluid-monitoring drill site at the CO_2 degassing mofette field near Hartoušov. In October 2017, a 6 km long profile with dense source and receiver spacing was accomplished. The W-E trending profile crosses the proposed drill site and the surface traces of the MLFZ and the PPZ. Up to 1200 Vibroseis shots were recorded with 312 single-component geophones deployed in two spreads along the profile, resulting in maximum offsets of 4 km. The TUBAF Vibroseis truck (32 tons, 250 kN peak force) was used as the seismic source and generated 3-5 sweeps at each source position with a length of 16 s and a frequency bandwidth of 10-120 Hz. The data quality is generally good, although bad coupling of the geophones (due to soft ground) and strong noise from traffic and a nearby factory had a strong impact on the data acquisition. Nevertheless, in most cases the first breaks can be identified for the entire offset range and some near surface reflections are visible even in the raw data. Processing of these recently acquired new data is now ongoing and includes first arrival tomography and the application of focusing pre-stack depth migration methods. The outcome of this work will be a detailed near-surface velocity model, high-resolution structural images of potential reflectors (within the Cheb Basin and related to the fault systems of MLFZ and PPZ) and will provide crucial constraints on the petrophysical properties of the prevailing rock formations. During interpretation of the seismic data, a resistivity model derived from a geoelectrical survey acquired along the same profile line will provide important constraints, especially with respect to the suspected fluid pathways related to the earthquake swarms and the CO_2 emanations.

P22 *High-resolution 3D seismic reflection and VSP survey at the deep geothermal research platform Groß Schönebeck/Germany*

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In the surrounding of the deep geothermal research in-situ platform Groß Schönebeck of the German Research Centre for Geosciences Potsdam (GFZ Potsdam), high-resolution 3D seismic reflection measurements, accompanied by 3D VSP measurements in 2 existing deep research wells in the centre, were carried out in February/March 2017.

The survey area of 8 km x 8 km is located in the natural biosphere reserve Schorfheide, around 50 km NNE of Berlin, at the southern margin of the North German basin. The site serves as a reference for the development of geothermal technologies. The seismic investigations yield an improved imaging of the target region for further exploitation with a focus on reservoir depths of 4 to 4.3 km.

Modelling during the planning of an optimal recording configuration resulted in theoretical line spacings of 400 m for the receiver lines and 700 m for the source lines. As point spacing on the lines 50 m was chosen for source and receiver points to avoid spatial aliasing according to the existing reflector dips as well as to ensure sufficient vertical and horizontal resolution after migration. The contractor performing the seismic field work was the company DMT Essen.

All theoretical source and receiver points could be realized with only moderate shifts and nearly no skipping. As seismic source 4 simultaneously acting vibrators with a peak-force of 200 kN each were used, which (after detailed start-up tests) emitted at each source position 8 sweeps (12 s in length within a frequency band of 12-96 Hz) into the subsurface. The entire field program of in total 1832 source positions and 3240 receiver positions was brought to completion within 17 working days.

The subsequent first 3D seismic processing was performed as well by the contractor DMT/Petrologic Hannover. The resulting data volumina already show an extraordinary data quality in the form of spatially well traceable, reflecting layer boundaries in the subsurface, also below a thick salt package.

The accompanying 3D VSP measurements were performed in 2 existing 4.3 km deep wells using the Distributed Acoustic Sensing (DAS) technology on wireline cable with a pseudo channel spacing of 5 m. DAS is a relatively young method of data acquisition, which uses a fiber optic cable as an array of sensors for measuring the particle motion. The method analyses the strain variation on the fiber to characterize the acoustic signal. The VSP data were recorded during 4 days (contractor Schlumberger). The 61 vibroseis source points were arranged in a spiral pattern around the wells with offsets from 0.2 to 2 km.

Main objective of the VSP survey was to improve the seismic interpretation in the reservoir interval (horizon allocations, stratification, litho-units, spatial distribution of reflection interfaces) and to find potential occurrences of free gas and fractures generated by hydraulic stimulation. Results of both methods will be combined.

In the framework of ongoing seismic interpretation all reflections are now assigned to geologic formations, fault systems are detected and the entire 3D structure is consistently mapped. In addition, the processing is being improved, especially in the reservoir region. The effortful method of prestack depth migration is applied generating a sharper image of deep subsurface structures to deliver a solid base for a reliable interpretation, to allow for a kinematic modelling and to formulate valid statements for the further exploitation of geothermal resources in the North German basin. Based on these results a new research well at the site is planned.

P23 *Eastern segment of the "1-SB" profile – a 1200 km long integrated wide-angle reflection/ refraction and near-vertical reflection profile across the folded belts of the Southern Siberia, Russia*

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Wide-angle reflection/refraction and near-vertical (normal incidence) reflection data on the Eastern segment of the long-range "1-SB" profile were acquired in 2014-2016. "1-SB" profile crosses entire Southern Siberia from the Russian Far East in the east to the Urals in the west. The eastern segment of the profile starts at the boundary between Russia and China, runs northwards, crosses the area of folded belts of the Southern Siberia (three major folded areas: the Amur, Selenga-Stanovoy, and Baikal), and reaches the southern margin of the Siberian craton. Acquisition of the wide-angle data was held with explosives (3-5 tons charge) and groups of two powerful (40 ton-force) vibroseis sources activated at 52 shot points with average 30 km shot point interval; a pool of 4-channel digital autonomous recording units Rosa spaced at 5 km interval and each equipped with 900 m long geophone spread; 300 km maximum offset; 120 s record length. Acquisition of the near-vertical data was carried out along a crooked line using arrays of four 27-ton-force vibroseis sources at 100 m shot point interval, 50 m receiver spacing, 100 nominal CMP fold, split spread, 10 km maximum offset, 30 s correlated record length. The most prominent velocity heterogeneity (of 2.6-5.9 km/s) is observed in the upper part of the section (for the depth of less than 5 km). The local shallow low velocity zones mark depressions filled with Mesozoic-Cenozoic sediments. Velocities in consolidated crust are fairly homogeneous. Velocity variations are very smooth laterally. In vertical direction velocities grow from 6.0 to 6.9 km/s. The vertical velocity gradient is changing with depth, but there are no obvious refracting boundaries within the crystalline crust. A single wide-angle reflection boundary is observed in the crystalline crust. This interface is detected only at the interval of the most southern 300 km long part of the profile at the depth of 21-26 km. It corresponds to the top of the lower crust of the Amur folded area. The CMP reflection seismic image is subdivided into several domains according to the patterns in the lateral and vertical reflectivity. The upper crust is characterized by significant differences in reflectivity, steeply dipping reflectors, and sizable (up to 20-25 km high) "dome-like" structures. In general, zoning of the upper crust corresponds to the major tectonic units. The lower crust is characterized by a sub-horizontal lamination. A highly-reflective lower crust was found in the southern part of the profile. Lateral boundaries of some bright spots in the lower crust do not correlate with the boundaries between the major tectonic units at the surface. The study area is characterized by a fairly flat Moho especially in the southern third of the profile. The Moho depth varies from 40 to 45 km. The bottom of the crust is very well defined by the near-vertical reflections along the most extent of the "1-SB" eastern segment. It is noteworthy that the geologically significant boundary between two major tectonic units (the Amur and the Selenga-Stanovoy folded areas) is not noticeable in the Moho topography. Despite a traditionally expected thinning of the crust in rift zones we observe deepening of the Moho for at least 5 km in the Baikal rift zone down to the maximum depth in the study area. Near-vertical reflections from the base of the crust in Baikal zone are diffusive and very weak. Velocities in the uppermost mantle vary mainly between 8.2 and 8.4 km/s only locally decreasing down to 7.9 km/s below the northern flank of the Baikal rift zone.

P24 *Imaging Deep Structures Using Advanced Techniques*

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In this study, we demonstrate that the application of the wave equation datuming (WED) on two datasets acquired in Sicily and Tuscany is essential to improve signal/noise ratio extracting information previously hidden by approximate static corrections and near-surface noise. This algorithm allows obtaining a good imaging of geological features. Kirchhoff integral solution to scalar wave equation (using both near-field and far-field terms) can provide a basis computation to deal in the datuming with irregular surfaces and variable velocities. In the pre-stack domain, WED is applied in two steps: (i) common-source and (ii) common-receiver domains. Operating on a common-source gather, it has the effect of extrapolating receivers from one datum to another, and, because of reciprocity, operating on a common-receiver gather, it changes the datum of the source. Basically, WED is a process of upward or downward continuation of the wave-field between two arbitrarily shaped surfaces. Recalling main principles of the theory, we should consider the importance of distinguishing between migration and WED. WED produces an unmigrated time section at a specified datum plane; migration involves computing the wave-field at all depths from the wave-field at the surface. In addition to downward continuation, migration requires imaging principle. In this respect, WED is an ingredient of migration, when we apply migration as a downward continuation process. WED was applied to move shots and receivers to a given datum plane, removing time shifts related to topography and to near-surface velocity variations. The datuming procedure largely contributed to attenuate ground roll, enhance higher frequencies, increase resolution and improve the signal/noise ratio.

The first transect allowed exploring structures of Central Sicily showing the island fragmentation into blocks separated by lithospheric faults. A dramatic crustal thinning from the foreland towards the Caltanissetta trough signs the presence of a deep, rifted basin with Permian and Triassic clastics and carbonates or a zone of continental to oceanic transition. A highly impressive feature in the central zone corresponds to allochthonous terrains filling the trough synchronous with the Tyrrhenian opening. A huge anticline in the north corresponds to a southward push of Tyrrhenian mantle and asthenosphere contrasting a progressive northward migration of contractional tectonics active during late Pleistocene and leading the chain uplift.

The Tuscany dataset highlights the reflectivity of the deep interfaces and their extension, in particular of the major horizons H and K, which characterize the Geothermal Province. The unusual reflectivity of this crust should derive from a layering of sub-horizontal sills being fractured and filled by hydrothermal and thermo-metamorphic minerals.

In both cases, the WED application let us differentiate seismic facies, offering a direct image of ongoing tectonic setting and of variable lithology and petrophysical properties. Since WED application requires a reliable velocity field, we first proceeded to pick all first arrival times in the field records in order to perform a tomographic inversion of first breaks. This step allowed us to build a velocity model for near-surface sequences, where significant complexities are present, like highly variable lithology and rough topography. After WED, the processing continued in order to obtain a stack section and a post-stack migration was applied.

P25 *KNIPAS - exploring active seafloor spreading processes at segment-scale*

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Knipovich Ridge passive seismic experiment (KNIPAS) is a state-of-the-art seismological project that studies on segment scale the active spreading processes of an ultraslow mid-ocean ridge. The generation of new ocean floor is accompanied by characteristic seismicity that reflects ongoing spreading events and the physical state of the young lithosphere, and differs widely depending on spreading rate. While fast spreading ridges hardly show earthquakes that are large enough to be recorded on land, magmatic spreading events at the slowest spreading centres seem to be regularly preceded by earthquakes larger than M 5. The depth limit of earthquakes and their presence and absence reveal along-axis variations in the thermal and mechanical regime of the lithosphere. Therefore, it is necessary to record earthquakes locally with ocean bottom seismometers (OBS). Such surveys, however, typically have limited spatial extent and cannot reveal segment-scale spreading processes like along-axis melt flow, while spatially more extended data sets of hydro-acoustically recorded earthquakes yield no information on focal depth and can therefore not constrain lithospheric thickness or temperature.

The project KNIPAS instruments for the first time an entire ridge segment with OBS. During Polarstern cruise PS100 in July-September 2016 we deployed 23 OBS of the German Instrument Pool for Amphibian Seismology (DEPAS) along a 160 km long ridge section that covers Logachev Seamount and a neighbouring volcanic centre. An additional 5 OBS of the Polish Academy of Science, were deployed around Logachev Seamount by r/v Horyzont II. The instruments recorded seismicity until July-October 2017 depending on theirs capacity. Wide-angle seismic profiles across Logachev Seamount were acquired in Autumn 2017. The Maria S. Merian during cruise MSM68 recovered German OBSs and r/v Oceania during AREX2017-II cruise recovered Polish OBSs.

We have got a comprehensive seismological dataset consisting of an expected 9000 earthquakes M>1 and several dozens of well-recorded teleseismic events to study spatial variations of seismicity, thermal structure and lithospheric thickness of an ultraslow spreading ridge. In a joint project we combine the expertise of our work groups at AWI, the University of Potsdam and the Polish Academy of Sciences to study seismicity pattern, analyse the large-scale lithospheric structure with modern passive seismic methods to be adapted for the special conditions of marine seismic surveys and to image at high resolution the structure of a volcanic centre.

P26 *High P-wave speeds in the upper mantle and their possible association with superplumes*

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P-wave speeds of 8.7- 9.0 km/s are documented at sub-Moho depths within the Hikurangi (oceanic) plateau (HP) just east of and beneath North Island, New Zealand. These wave speeds represent a ~ 13% anomaly for their depth and are found on mutually perpendicular lines, and with a mix of active and passive seismic methods. The shallowest depth we observe these high speeds is 25 km. One determination of the high speeds is based on arrivals from a subduction zone earthquake recorded across an active array of 840 vertical and 300 horizontal-component seismographs along a ~ 90 km long line across the southern North Island. Excellent arrivals are recorded and once corrected for sedimentary basins show apparent P and S-wave speeds of 10.830.02 and 5.65 0.03 km/s respectively. A Vp/Vs ratio of 1.92 0.02 is thus implied. Once the 10 degree dip of the subducted plate (ie. the HP) is allowed for the true wave speed is calculated to be 8.7-8.8 km/s.

We examine both crustal thicknesses and the gravity edge -effect across the edge of the Hikurangi Plateau, to show that the plateau has shallower bathymetry than expected. We calculate that a ~ 0.5% decrease in density of a 120 km thick mantle lid for the plateau will satisfy both the bathymetric anomaly and the amplitude and wavelength of the gravity edge effect. Such a reduction in density is consistent with a depleted mantle linked to melting and plume formation. High Vp values combined with Vp/Vs ratios > 1.8 are also consistent with depleted mantle rocks (like Dunite), although some degree of crystallographic orientation is also required for our observations. More challenging is explaining fast wave-speeds in mutually perpendicular directions, within the horizontal plane. This requires an unusual radial form of anisotropy where there is horizontal dilation and flattening.

The HP is thought to have formed part of a once much larger oceanic plateau -the Ontong-Java-Manahiki- Hikurangi Plateau (OJPMHP)- the most voluminous Large Igneous Province (LIP) on the planet. We show numerically that in the heads of very large plumes, a strain fabric is formed that is dominated by vertical flattening, with low horizontal shear strain. If the anisotropy is the consequence of a shape fabric in the mantle then the flattening fabric will produce fast axes (with no preferred orientation) in the horizontal plane and the slow axis in the vertical direction. These high wave-speeds (>10% velocity anomaly), with this type of radial anisotropy, could be the characteristic signature of ancient super plumes.

P27 *Imaging exhumed lower continental crust in the distal Jequitinhonha basin, Brazil*

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Twelve combined wide-angle refraction and coincident multi-channel seismic profiles were acquired in the Jequitinhonha-Camamu-Almada, Jacuípe, and Sergipe-Alagoas basins, NE Brazil, during the SALSA experiment in 2014. Profiles SL11 and SL12 image the Jequitinhonha basin, perpendicularly to the coast, with 15 and 11 four-channel ocean-bottom seismometers, respectively. Profile SL10 runs parallel to the coast, crossing profiles SL11 and SL12, imaging the proximal Jequitinhonha and Camamu-Almada basins with 17 ocean-bottom seismometers.

Forward modelling, combined with pre-stack depth migration to increase the horizontal resolution of the velocity models, indicates that sediment thickness varies between 3.3 km and 6.2 km in the distal basin. Crustal thickness at the western edge of the profiles is of around 20 km, with velocity gradients indicating a continental origin. It decreases to less than 5 km in the distal basin, with high seismic velocities and gradients, not compatible with normal oceanic crust nor exhumed upper mantle. Typical oceanic crust is never imaged along these about 200 km-long profiles and we propose that the transitional crust in the Jequitinhonha basin is made of exhumed lower continental crust.

P28 *Seismic anisotropy of the crust and lithospheric mantle of Madagascar and Mozambique*

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We aim at improving our understanding of the dynamic of the lithosphere of the Mozambique Channel and surrounding continental landmasses. The study area is indeed characterised by high standing plateaus within a global extensive geodynamical context since the Gondwana dislocation and the opening of the Indian Ocean. Recent geophysical studies show a correlation between regions of highest topography with the presence of deep magmatic bodies. However, the characterisation of such features is still limited and the understanding of their origin and their evolution still highly debated. We propose here to shed new lights on the deep structure and the lithosphere dynamic by applying recent methodologies of passive seismology to a set a data coming from a two years deployment of at least 26 broadband seismometers (MACOMO project, MAdagascar COmores MOzambique, Wysession et al., 2011). The task consists of receiver functions analysis by focussing on seismic anisotropy signals which are indicators of the presence of dipping interface and/or material that was subject to deformation. By applying two different methodologies, we retrieve the average anisotropy within the crust and lithosphere as well as the orientation and depth of the main anisotropic fabrics (Bianchi et al., 2010; Schulte-Pelkum and Mahan, 2014, respectively). Our results complement previous SKS-splitting and S-wave tomography studies in the region.

P29 *Understanding the seismic anisotropy of the northeast Brazilian lithosphere: a receiver function analysis*

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We aim at improving our understanding of the current anisotropic fabrics under northeast Brazil, which may include deformation of the lithosphere from past tectonic processes and on-going mantle flow at asthenospheric levels. From the network composed of 75 seismic stations in the Borborema Province, we selected 39 seismographs from their back-azimuth coverage and performed receiver function analysis. We retrieved the average anisotropy within the crust and lithosphere as well as the orientation and depth of the main anisotropic fabrics by applying two different methodologies (Bianchi et al., 2010; Schulte-Pelkum and Mahan, 2014, respectively). Our results complement a previous SKS-splitting study in the region, which revealed a lack of splitting in the continental interior. We observe the presence of systematic anisotropy within the lithospheric mantle of the Borborema Province between 30 and 90 km depth with a global E-W orientation. Locally, differences in orientation between the average anisotropy and the main anisotropic layer suggest a complex lithospheric structure. The average anisotropy differs from one aggregated domain during the Brazilian Orogeny to another, suggesting inherited structures from at least the Neoproterozoic. The main anisotropic layer reveals a more recent overprinting in particular beneath stations located along the eastern margin, suggesting the presence of frozen anisotropy in the lithosphere due to stretching and rifting during the opening of the South Atlantic Ocean. Stations located in the continental interior also record the presence of seismic anisotropy, which exclude the absence of plate-scale anisotropic fabrics, as interpreted from unsplit SKS arrivals, and suggest the presence of layered anisotropic structures under the Province.

P30 *Evolution of the North-East Eurasian passive margin according to the Russian Arctic Geotransects*

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The Earth's crust and the upper mantle structure of the North-East Eurasian passive margin shelf and bathymetric trough have been identified by the interpretation of current deep seismics and gravity anomalies. The Chukchi Fold Belt, Wrangel-Herald Ridge, the De Long High, the North Chukchi Trough, the Mendeleev Rise, the Chukchi Basin and the Chukchi Plateau geological structure and evolution are discussed according to coordinated 3D-system of velocity and density models supplemented by geological data.

The coordinated 3D-system of models is based on 4 geotransects, that were acquired from 2005 to 2012. Wide-angle seismic reflection/refraction (WAR) profile with air-guns as seismic source and OBS crossed from the Chukchi Fold Belt up to the axial part of the North Chukchi Trough. The WAR profile with explosives seismic source and sea ice placed vertical geophones is its prolongation onto the Mendeleev Rise. The total length of those two South–North profiles is 1400-km. Two orthogonal WAR profiles with air-guns as seismic source and OBS crosses composite deep seismic profile with in the Mendeleev Rise (profile length is 740-km) and in the East Siberian and Chukchi Seas (profile length is 925-km). All WAR profiles were completed by multichannel seismic.

All major seismic sequences as well as Moho have been traced and harmonized in cross-points of velocity & density models: stratified sedimentary sequences, the metasediments, upper and lower crust. The Moho is changed from 28 to 36 km and its character is consistent with the regional tectonics: the highest position is fixed within troughs and the lowest – within rise and Ridges. Crystal upper crust is traced within all tectonics. So, no indication of oceanic crust was found. Upper crust including metasediments is most thick within the Chukchi Plateau (up to 20 km) and most thin in the axial part of the North Chukchi Trough (8-10 km). Within the Chukchi Fold Belt, Wrangel-Herald Ridge, the De Long High upper part is nearly 18-23 km, reduces to 10 km within the Mendeleev Rise. Last fact probably is the result of intraplate basic volcanism within the Mendeleev Rise.

Crust characteristics and geological data say about three ancient craton blocks (Wrangel, De Long and Mendeleev) and riftogenic trough (the North Chukchi Trough).

The North Chukchi Trough is considered as a riftogenic one with two cycles of riftogenic processes: post-Elsmirian and Mesozoic. The velocity model of sedimentary cover in the axial part of North Chukchi basin demonstrates a two-flat structure, which can be interpreted as the formation of two overlapping basins. The waveguide revealed in its section made it possible to justify the model of the North Chukchi basin formation in two stages, when the sources of demolition were alternately: in the Mesozoic time, the region of the Central Arctic uplifts (Mendeleev Rise), and after its subsidence to the bathyal depths in the Cenozoic, the Wrangel-Herald Ridge on the south. This once again confirms that Mendeleev Rise may be a fragment of an ancient craton Arctida.

P31 *The crustal structure of the Chatham Rise and Chatham Terrace - A key region for understanding the separation of Zealand from Antarctica*

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The submarine continental Chatham Rise extends up 1500 km east of New Zealand's South Island as part of the continent Zealandia. During the Cretaceous it underwent a twofold tectonic history: 1) At ~100 Ma, the long ongoing subduction of the Proto-Pacific plate at the eastern Gondwana margin abruptly ceased as the Hikurangi Plateau collided with the subduction trench. 2) At least since ~94 Ma after cessation of the subduction, the compressional regime was replaced by continental rifting as evident by the oldest known terrestrial graben sandstones on the Chatham Islands, development of metamorphic core complexes on the South Island and changing geochemical constraints (I-type to A-type granites) in western Marie Byrd Land, Antarctica. Little is known about the geodynamic processes that accompany the rifting as well as the nature, characteristics and extent of continental thinning at the southern margin of the Chatham Rise. We examine two deep crustal seismic refraction/wide-angle reflection lines crossing the southern margin of the Chatham Rise and adjacent Chatham Terrace, and a third deep crustal seismic profile at the southeasternmost part of the Chatham Rise. Modelling of P-wave velocities indicate variable thicknesses for the part of the Chatham Rise close to Chatham Island (~24 km), west of Wishbone Ridge (< 22 km), east of Wishbone Ridge (18 – 12 km), and the easternmost part (only up to ~13 km). While thicker parts of Chatham Rise are probably underlain by the subducted Hikurangi Plateau, the thinner parts of the crust are strongly affected by normal faulting. As part of the southern Chatham Rise margin, the elevated Chatham Terrace shows a crustal thickness between 10 and 7 km. On the Chatham Terrace, P-wave velocities exceeding 7 km/s at the crustal base probably related to magmatic underplating. Our results indicate that the Chatham Terrace has continental affinities as evident from graben structures obvious in the seismic reflection data and from continental-affinity rocks dredged from the Stuttgart Seamount. We suggest that magma-poor continental rifting led to the formation of the Chatham Terrace, Bounty Trough, Canterbury Basin as well as the metamorphic core complex exhumation in the Dunstin Range onshore New Zealand's South Island until ~84 Ma. Highly asymmetric westward propagation of the Pacific-Bellingshausen spreading ridge led to a magmatic overprint and formation of the Chatham Terrace seamounts, separation of the Bollons Seamount from the Bounty Platform and the breakup of the Chatham Rise and Campbell Plateau from Antarctica proceeded.

P32 *Quantifying Amplitude Fit in WAS modelling: AMPFIT preliminary tests*

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The ultimate objective of Wide-Angle Seismic (WAS) surveys is to provide an observational and quantitative base for geological modelling and interpretation. An issue of great importance for geological interpretation of WAS models is the estimate of uncertainty bounds of model parameters. Controlled source marine seismic acquisitions are still quite expensive experiments and standard processing and modelling strategies either use only arrival times or simply include a qualitative check on predicted amplitudes. Model evaluation from arrival time fit alone tend to overestimate the uncertainty bounds of model parameters when check on predicted amplitudes is integrated in the modelling process. Full Waveform Inversion (FWI) schemes were developed with the aim to overcome this inefficiency. However, for lithospheric scale transects, the acquisition geometry is usually too sparse and grid size too large for application of FWI.

We aim to approach the problem of quantifying the match of synthetic seismograms and seismic traces using a simplified strategy, that takes into account the amplitude and disregards the phase of the signal, thus bypassing a number of known issues of FWI. A more precise estimate of the confidence level of WAS velocity models will be obtained, namely concerning velocity gradients and velocity contrasts. Thus contributing to reduce geological interpretation indeterminacy, particularly critical on transitional domains of continental margins. Our final objective is to develop a simple tool to quantify amplitude fit in WAS modelling, able to provide a global fit evaluation, an offset dependent fit evaluation and a seismic phase fit evaluation. Since it requires only a pair of seismic record section, it can be used either to forward and inverse modelling procedures, providing that synthetic seismograms are generated accordingly to model parameterization. In June 2017 a proposal has been submitted to FCT to fund further code development and application to real data sets.

A crude and limited version of the code is tested with synthetic data generated from layered models for a comparison on energy content using time sliding windows. The tests are based on a normalised mean square residual of the energy differences and of the energy ratios. The results on synthetic data are so far promising. However, the tests clearly show that when comparing real data to synthetics, the misfit can be quite large with strong dependence on offset. This is due to the combined effect of modelling simplifications and data complexity. Preliminary tests on the contribution of each effect are under study.

P33 *Deep seismic structure across the Camamu triple junction (Brazil) from coincident wide-angle and multichannel seismic data*

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Twelve profiles with coincident multi-channel and wide-angle seismic were acquired during the SALSA experiment (Sergipe-ALagoas Seismic Acquisition) in order to image the Jequitinhonha-Camamu-Jacuípe-Sergipe-Alagoas segment of the NE Brazil continental margin. The SALSA cruise was held in 2014 aboard the R/V L'Atalante. The project is a collaboration between the Department of Marine Geosciences (IFREMER, France), the Laboratory of Oceanic Domain (IUEM: France), the Institute Dom Luiz (Lisbon University, Portugal), the Universidade de Brasilia (Brazil) and PETROBRAS (Brazil).

We present the results of profile SL09, extending from Sao Francisco Craton to the oceanic basin, across Almada basin and Camamu triple junction, trending NW-SE with 415 km long. A total of 18 OBS and 22 seismic stations (LSS), were deployed. A mix of forward and inverse wide-angle modelling was applied to obtain a P-wave velocity model of the crust and sub-crustal mantle. The sedimentary basin structure was constrained by MCS and OBS data whereas the basement was constrained only by wide-angle arrivals interpreted from the OBS and LSS records. A small event with epicentre very close to the onshore part of profile SL09 was detected and Pg arrivals provided further constrain on the continental crust velocity structure. The model was evaluated by indirect methods (hit-counts, resolution and spread point functions) and also by direct methods (Vmontecarlo). A 2-D gravity model consisting of homogeneous blocks was constructed from the seismic velocity model and the predicted anomalies fit the observation within a 16 mGal root-mean square error. The velocity model was gridded and the multichannel seismic was pre-stack depth migrated, with residual move-out control.

The main results can be summarized as follows: i) the Sao Francisco Craton is a 3 layer crust domain with velocities of ~6.15 km/s, ~6.3 km/s and ~6.9 km/s and total thickness ~40 km, overlaying a 8.1 km/s mantle; ii) the necking is sharp and occurs in a 60 km wide domain, where the crust thins bottom-up from ~37 km to ~5 km, encompassing a Moho slope of ~40%; at shallow levels we observe extensional faults and an Aptian salt body; iii) the Almada, Camamu and presumed oceanic basins comprise 6 sedimentary layers with velocities ranging from 1.8 km/s to 4.9 km/s and thickness of ~5 km; in the Almada and Camamu basins a few thin lenses inter-veal the sediments and produce velocity inversions; a seventh and deepest sedimentary layer, restricted to the Camamu basin, thickens towards the continent up to 2.5-3 km thick; iv) both Camamu and Almada domains present a 2 layer crust, ~5 km thick, with velocities of 6.0-6.3 km/s (Camamu) or 5.8-6.4 km/s (Almada) in the upper crust and 6.6-7.2 km/s in the lower crust; this lower crust thins to zero towards the ocean; v) in the necking, Camamu and Almada domains the Moho is reflective and 3 intra-mantelic sub-horizontal reflectors at ~20 km, ~30 km and ~45 km were imaged; vi) in the presumed oceanic domain the crust has only one layer, ~3 km thick, with velocity similar to Almada upper crust; however, the presence of lower crust is inferred to the SE end of the profile.

From the above and considering that the Camamu area is located at the triple junction between Jequitinhonha-Almada and Jaquipe-Sergipe-Alagoas segment and Tucano rift, we propose that it is an area of thinning paroxysm acting as a boutonnnière during South Atlantic formation.

P34 *Evidence for Rift Migration of the Hyper-Extended Margin in the Northeast South China Sea*

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The South China Sea is the largest marginal sea in the East and Southeast Asia. It was created among southern China continent, northern Luzon, and northern Indochina after periods of continental extension. Prior to the rifting, the whole region experienced a long period of compression and continued magmatism due to the subduction of the paleo-Pacific plate towards the northeast. It resulted in a vast record of plutons and volcanic was observed in South China and Taiwan and implicates the subduction late influence the region until late Mesozoic. In July–August 2016, 560 km of MCS reflection data and 730 km of wide-angle refraction data were acquired in the NE margins of the SCS. This experiment is to better understand the nature of the hyper-extended continental margins of the SCS and the data are the adequate complement to the seismic profiles of the TAIGER program acquired in 2009 which is lacking seismic coverage in the NE SCS continental margins. An outstanding question of the region is whether the continental extension prior the seafloor spreading results in a symmetric rifting due to low crust ductile flow as most scientists believe or the continental crust experienced hyper-extension results in an asymmetric extension. Here we present PSTM seismic imaging from a 280-km-long multi-channel and wide-angle seismic profiles to discuss our continental rifting of the NE SCS margins.

P35 *Co-located magmatic and non-magmatic rifted margins off south-west Australia*

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Rifted margins are generally identified as either being volcanic or non-volcanic. Volcanic margins are characterised as: having extrusive basalts, which maybe extensive if the melting of the up-welling mantle is augmented by an increase in temperature caused by a coincident hot-spot; the continent-ocean transition is overlain by seaward dipping reflectors, imaged on seismic data, caused by the thermal subsidence of lava flows; and anomalously high seismic velocities in the lower crust from underplating of the margin at the time of formation. The McKenzie pure shear stretching model is typically used to visualise the thinning prior to the breakup of the continental crust. The most extensively studied margin of this type is arguably the north-western margin of Europe, which besides being once a significant flood basalt province, has also been extensively explored for hydrocarbons that possibly exist in the pre- and syn-rift sediments that lie below the extrusive basalt layer. Non-volcanic margins represent the other extreme, as their name suggests there is little or no extrusive basalts produced at the margin and they are thought to occur when the rate of stretching is so slow that the mantle does not upwell fast enough to generate melt or the melt remains confined to the lower crust. Models for this type of margin include a detachment fault that penetrates through the crust into the upper mantle so extension can occur by simple shear, also known as the Wernicke model. Such a detachment has been imaged under the Galicia margin and analysis of these data shows that this reflection juxtaposes crustal granitic rocks against mafic mantle. Further out-board, in the continent-ocean transition zone, serpentinised peridotite is found at the seabed where the detachment fault has unroofed the underlying mantle.

Margins are classified by which of the two scenarios is dominant, however the Mentelle Basin and Naturaliste Plateau off south-west Australia shows the characteristics of both because it records the Early Cretaceous break-up of India and Australia, as well as the Late Cretaceous break-up of Australia and Antarctica. IODP leg 369 recently cored five sites, one in the Great Australian Bight and four in the Mentelle Basin to elucidate the complex rifting history of this area. The deepest hole (U1513) cored rift related basalts of Early Cretaceous(?) age related to the volcanic margin created by the rifting of India in an northwest-southeast direction. Although most of the Perth margin is non-volcanic, extensive volcanism documented on the Naturaliste Plateau suggests that this segment developed as a 'classic' volcanic rifted margin. Subsequent rifting between Australia and Antarctica, in a north-south direction, commenced in the Late Cretaceous and produced a 'classic' non-volcanic margin with rapid subsidence of the Naturaliste Plateau believed to have been caused by the southwards displacement of its lower lithosphere along a detachment fault with mantle rocks dredged from the seafloor to the south of the plateau.

Using data from site U1513 and coincident seismic data acquired by Geoscience Australia we will illustrate the tectonic evolution of both of these very different rifting events that have occurred at the same location.

P36 *Insights on the crustal structure of the Natal Valley from combined wide-angle and reflection seismic data (MOZ3/5 cruise), South Mozambique Margin*

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The Natal valley (South Mozambique margin) is a key area for the understanding of the SW Indian Ocean history since the Gondwana break-up, and widely, the structure of a margin system at the transition between divergent and strike-slip segments. As one part of the PAMELA project (PAssive Margins Exploration Laboratories), conducted by TOTAL, IFREMER, in collaboration with Université de Bretagne Occidentale, Université Rennes 1, Université Pierre and Marie Curie, CNRS et IFPEN, the Natal Valley and the East Limpopo margin have been explored during the MOZ3/5 cruise (2016), conducted onboard the R/V Pourquoi Pas?, through the acquisition of 7 wide-angle profiles and coincident marine multichannel (720 traces) seismic as well as potential field data. Simultaneously, land seismometers were deployed in the Mozambique coastal plains, extending six of those profiles on land for about 100 km in order to provide information on the onshore-offshore transition. Wide-angle seismic data are of major importance as they can provide constraints on the crustal structure of the margin and the position of the continent-ocean boundary in an area where the crustal nature is poorly known and largely controversial. The aim of this work is to present the first results on the crustal structure from P-waves velocity modeling along two perpendicular MZ1 & MZ7 wide-angle profiles crossing the Natal Valley in an E-W and NNW-SSE direction respectively, which reveal a crust up to 30 km thick below the Natal Valley and thus raises questions of a purely oceanic origin of the Valley.

The post-doc of Angélique Leprêtre was co-funded by TOTAL and IFREMER as part of the PAMELA (Passive Margin Exploration Laboratories) scientific project.

P37 *Crustal structure of the Sergipe Alagoas passive margin, NW Brazil, from combined wide-angle and reflection seismic data (SALSA cruise)*

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The structure and nature of the crust underlying the Camamu-Almada-Jequitinhonha-Sergipe-Alagoas basins System, in the NE Brazilian margin, were investigated based on the interpretation of 12 wide-angle seismic profiles acquired during the SALSA (Sergipe Alagoas Seismic Acquisition) experiment in 2014, a collaboration between IFREMER (France), PETROBRAS (Brazil), the IUEM (France), the Faculdade de Ciências da Universidade de Lisboa (IDL, Portugal), and the Universidade de Brasilia (Brazil). This study focuses on 4 wide-angle profiles (SL01 to SL04), oriented NW-SE, located in the northern part of the survey area. Along each profile, 15 OBS (Ocean Bottom Seismometers) where deployed along 200 km offshore, and 2 profiles extended 150 km onshore with 21 LSS (Land Seismic Station) each. A fifth profile (SL05) with 30 instruments crosses these 4 profiles at a position and in a direction close to the hingeline.

Forward modeling through combined interpretation of the multichannel seismic, the main reflected and refracted phases of the wide-angle, and gravity data allows us to precisely divide the margin in 3 domains, Continental, Necking and Oceanic domains, parallel to the hingeline of the platform, and reveals: 1) The unthinned continental crust (imaged on SL02 and SL04) is ~35 km thick and composed of 3 layers with velocity increasing from 5.5 to 6.85 km in the north and 5.0 to 7.2 km/s south; 2) The necking zone, where the crust thins to 10 km thickness, is about 100 km wide, and lower crustal velocity increases to 7.1 in the north (SL04-SL03), 7.5 (SL02) and 7.7 km/s (SL01) south as also observed along SL05; 3) A 8 km thick typical oceanic crust is observed beyond 150 km from the coast line toward the SE, as close as 80 km on SL03. It is composed of a thin upper layer (1–1.5 km) that presents velocity increasing from 4.8 to 5.8 km/s, a 2.5 km thick middle layer with a velocity of 6.0–6.8 km/s, and a 3-4 km thicker lower layer with thick with a velocity 6.9 to 7.1 km/s. 4) The area located between the necking zone and typical oceanic crust has been affected by the volcanism of the Bahia Seamounts chain related to a post-rift hotspot localized near the Middle Atlantic Ridge. Volcanic edifices rising up to 2.5 km from the basement's base level, and a lens reaching ~6 km thickness and 7.15 to 7.4 km/s velocity below the lower crust (underplate), are observed on SL02 and SL04; 5) The Moho is marked by a strong reflection on the wide-angle data, and the upper-mantle appears homogeneous in the study area with a velocity of 8.0 km/s at the Moho increasing to 8.15 km/s 30-40 km depth.

P38 *Deep structure across the Tucano rift and Jacuipe margin from onshore-offshore wide-angle seismic data*

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Acquisition of wide-angle reflection and refraction seismic data along passive continental margins is essential to precisely constrain their crustal architecture and understand processes leading to their formation. Such data were acquired for the first time along northeastern Brazilian margin in 2014 as part of the SALSA (Sergipe-ALagoas Seismic Acquisition) project: a collaboration between the Department of Marine Geosciences (IFREMER: Institut Français de Recherche pour l'Exploitation de la MER, France), the Laboratory of «Oceanic Domain» (IUEM: Institut Universitaire et Européen de la Mer, France), the Faculdade de Ciências da Universidade de Lisboa (IDL, Portugal), the Universidade de Brasilia (Brazil) and PETROBRAS (Brazil). Seismic shot, Multi-Channel Seismic acquisition (MCS) and Ocean Bottom Seismometers (OBS) deployments were performed by the N/O L'Atalante (IFREMER) along 12 profiles amongst which five were extended onshore by Land Seismic Stations (LSS). We will present here the initial results along three of these profiles (2 dip lines and 1 strike line) that image the deep crustal structure from the Tucano and Reconcavo Basins onshore to the Jacuipe Basin offshore. P-wave velocity models were constructed based on the joint interpretation of multi-channel and wide-angle seismic data using the RAYINVR software. Velocity models show that Tucano and Reconcavo Basins are underlain by well-defined continental crust from clear upper and lower crust refracted arrivals and reflected arrivals on the Moho. Velocities appear slightly lower than normal in both the upper and lower crust just beneath the rifted basins and the geometry of the Moho is flat at 39 km depth. Toward the coast, continental crust thins very sharply to less than 5 km thick below the Jacuipe basin. The necking and transition zones are also characterized in depth by a continuous and anomalously high velocity crustal body that extends offshore up to the normal oceanic crust. Crust seems absent locally coinciding with lower than normal mantle velocities. Finally the Jacuipe Volcanic complex corresponds to an area of very thin (~ 5 km thick) and anomalously high velocity crust underlain by unaltered mantle. In regards of the variations observed in the velocity structure of the Tucano rift and Jacuipe margin we will discuss the nature of these bodies and their geodynamic implications.

[1] The SALSA Project was led by D. Aslanian and M. Moulin, from Ifremer, and A. Viana, from Petrobras. Modelling of the SALSA profiles was done by A. Afilhado, M. Evain, F. Gallais, F. Klingelheofer, A. Loureiro, J.M. Pinheiro & P. Schnürle. Processing of the deep sounding reflection seismic data was done by P. Schnurle. 3D Wide-angle modelling by Nuno Dias. On-land operation was conducted by J. Soares, R. Fuck, M. Vinicius de Lima, N. Dias, L. Matias, A. Loureiro, C. Corela, J.L. Duarte, J. Pinheiro, D. Alves, M. Sobrinho, F. Lima, R. De Oliveira and P. Resende . Processing of the high resolution seismic data by A. Baltzer and M. Rabineau.

P39 *The crustal structure of the Porcupine Basin, offshore Ireland*

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The Porcupine Basin is a Mesozoic failed rift located in the North Atlantic margin (SW Ireland). In this study, we present a set of tomographic images obtained with travel-time tomography of wide-angle seismic data that provide the P-wave velocity crustal and uppermost mantle structure of the basin, in addition to Moho geometry variations along and across the basin axis. The tomographic results combined with neighboring seismic reflection profiles reveal that continental rifting in the North evolves to hyperextension in the center of the basin, where potential crustal break up occurs. Along the basin axis, the lithospheric extension is accompanied by increasing mantle hydration in agreement with the increased amount of crustal faulting, implying fault-controlled mantle hydration as in the Galicia margin. South of the hyperextended region, the crust thickens southwards where lower crustal velocities are anomalously fast for continental crust (i.e. > 7 km/s). These results strongly suggest that lithospheric extension along the basin axis have led to crustal break up and oceanic spreading in the center of the Porcupine Basin, where the prominent Porcupine Median Ridge is located. The integration of these results with surface maps of the post-rift sedimentary cover allow us to derive an empirical relationship between crustal thickness and post-rift sedimentary thickness that we use to present first order approximations of minimum stretching factors of the entire Porcupine Basin, and explore the lithospheric extension processes that shaped the South Porcupine Basin.
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P40 *3D wide-angle seismic tomography, MOZ3-5: Insights on Natal Valley, offshore Mozambique*

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The MOZ3-5 oceanographic cruises (2016) [Moulin & Aslanian 2016; Moulin & Evain, 2016] is part of PAMELA project (Passive Margin Exploration Laboratories), conducted by TOTAL, IFREMER, in collaboration with Universite de Bretagne Occidentale, Universite Rennes 1, Universite Pierre and Marie Curie, CNRS et IFPEN.

The main focus is the analysis of the Mozambique channel and aims to derive a lithosphere-scale evolutionary model of this area following a «source to sink» – «Mud to Mantle» approach.

The work that has been done concerns the Natal valley zone where four seismic profiles were acquired, two with N-S direction and the other two W-E direction. The data acquisition include coincident near vertical multi-channel and wide-angle seismics, bathymetry, magnetic and gravimetric data. The wide-angle data set is composed of 107 OBS (Ocean Bottom Seismometers) (MZ1-34+MZ2-23+MZ6-25+MZ7-35) and 84 LSS (Land Seismic Station) (MZ1-22+MZ2-20+MZ6-21+MZ7-21), spaced 12 km and 4-5 km, respectively. The work presented at the time focus on OBS data.

The data quality control is the first and a crucial part of the data processing work. The assessment of S/N ratio, ray coverage and penetration and OBS relocation process must be done before and other kind of data processing. This assessment was done by making catalogs of hydrophone and geophone for all the OBS allowing the offset symmetry checking, the pseudo-ray propagation and if the relocation process was correctly done. This process was done for in-line data and for in-line plus off-line data. After this, we have started the picking of each OBS station. For all the analyzed OBS we have more than 55000 picks, between water arrival and first reflected arrival. After doing the picking for all the stations, catalogs of picked and unpicked data were done for in-line and off-line data where the pseudo-ray coverage was plotted in order to better understand the relation between the picked data and the actual obtained ray coverage.

The evaluation and verification of data quality is crucial when working with WAS data. During the several verifications that should be done along the process, we can collect several parameters that can allow us to have a first general idea of the data behaviour – shot-point range, offset range and reduction velocity are some of those parameters.

The correlation between shot-point and offset is related with acquisition geometry and it is easy to show that the behavior of one of the parameters is similar to the other. However, there is little information if there is any relation between these parameters and bathymetry/topography, S/N ratio, knowed local geology and, more importantly, with homogeneity of the underground structure. If we can find any correlation, that information can be crucial in terms of forward modeling, inverse modeling or 3D tomography.

P41 *Seismic imaging of volcanism and rift system in the Okinawa Trough back-arc basin*

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Most of our understanding of rift system comes from investigations at intracontinental rift zones and magma-poor continental margins. In contrast, continental rifting at a subduction-influenced back-arc setting is rare and has not been studied in detail. As a unique example of this tectonic setting, we present crustal structures of the Ryukyu arc, southwest Japan, which forms a 1200-km-long arc system behind the Ryukyu subduction zone and has been currently undergoing regional extension on its back-arc side.

On the basis of MCS reflection and OBS refraction data, we have been exploring shallow volcanic system and fault structures related to the back-arc rifting process. In the northern area where the rifting rate is relatively low, wide rift basins exhibits significant asymmetry in faulting style and rapid transitions from normal-fault-dominant regions to strike-slip-fault-dominant regions occur. The variation in faulting patterns indicates complex stress regimes associated with the oblique rifting direction and the collision of the buoyant oceanic plateau with the overriding plate at the trench. Closer to the volcanic front, abundant magmatic conduits imaged as tubular transparent bodies in seismic reflection sections are developed within the shallow sediments, some of which host small fragments of dipping reflectors at the bottom of the tubes indicating intruded sills. The spatial distribution of the magmatic intrusions suggests that the arc volcanism has multiple active outlets on the seafloor which bifurcate at crustal depths and/or that the location of the volcanic front has been migrating trenchward over time (Arai et al., in revision).

On the contrary to the northern part, the southern Okinawa Trough shows an almost symmetric sedimentary basin with normal faults dipping inward (toward the rift axis). On the rift axis, narrow (2–7 km wide) intrusive structure resulted from passive upwelling of magma is clearly imaged. On the other hand, an active submarine volcano is located ~10 km away from the rift axis to the arc side. Beneath the back-arc basin, crust is significantly thinned and the thinnest part with 12 km thickness occurs directly beneath the rift axis, which is in a great contrast with ~25-km-thick crust (probably mostly retaining the original continental crust) in the northern Okinawa Trough. The velocity model also reveals that there exists a thick layer with Vp of 6.5–7.2 km/s at lower crustal levels. This lower crust-like structure may indicate that mantle materials have been accreted at the bottom of the crust during the crustal stretching and may be a source of the on-axis intrusive body (Arai et al., 2017).

P42 *Seismic interpretation of the Upper Jurassic carbonate buildups from the Nida Trough (S Poland)*

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The research area is located within the Nida Trough, which forms SE part of the Szczecin-Łódź-Miechów Synclinorium. It developed along the SW flank of the Mid-Polish Swell that was formed as a result of the Alpine (Late Cretaceous – Paleogene) inversion of the Mid-Polish Trough i.e. axial part of the epicontinental Polish Basin that belonged to the easternmost part of the Permian–Mesozoic epicontinental basins of Western and Central Europe. Palaeogeographically, the area of the present Nida Trough together with its prolongation towards SE i.e. towards the Carpathian foredeep and the Carpathians, was situated within a transition zone between the epicontinental Polish Basin and the Tethyan basins, characterized in Late Jurassic by a wide-spread carbonate sedimentation with diversity of depositional systems. In the Oxfordian, the Nida Trough was located mainly within the carbonate open shelf and, progressively from NE, towards the end of the Oxfordian and the beginning of the Early Kimmeridgian, partly within the shallow-water carbonate platform.

The reinterpretation of relatively dense coverage of 2D seismic data from the SE part of the Nida Trough proved presence of a system of isolated carbonate buildups in this part of the basin, in vicinity of Pińczów town. The objective of this study was to seismically characterize those organic buildups, identify their seismic signatures and classify reflection configuration patterns to analyze their internal structure and development. The interpretation was preceded by detailed well-to-seismic correlation based on high-resolution synthetic seismograms calculated for key calibration wells. For the proper location and further characterization of the Upper Jurassic carbonate buildups, a several identification criteria based on seismic facies analysis were used.

The analysis revealed existence of possible paleohighs beneath the carbonate buildups, significant lateral facies changes within the Upper Jurassic interval, high-angle margins of the identified buildups, and the presence of characteristics depositional wings. Interpretation was supported by seismic attribute analysis which provided more information on external extent of the analysed buildups. Lateral extent of particular buildups is in range of 400 – 1000 meters which estimated total height is around 150 – 200 meters. Most of the identified structures revealed characteristic mounded seismic facies type and chaotic reflection patterns within buildups. Seismic stratigraphic analysis allowed also for partial description of the origin and general evolution of the buildups. Analysed seismic profiles showed evidences of generally aggradational growth of the structures, which are commonly separated by local intra-biohermal basins. Results of seismic data interpretation suggest that the entire system of the Upper Jurassic carbonate buildups in the Nida Trough formed due to combined effect of at least partly tectonically controlled Late Jurassic (Oxfordian) paleorelief of sea bottom and of regional sea-level changes.

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P43 *Inversion-related Upper Cretaceous contourites within the Polish Basin – their seismic expression and geodynamic significance*

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The Polish Basin, together with its axial most subsiding part, the Mid-Polish Trough, formed the eastern part of the Permian–Mesozoic system of epicontinental basins of western and central Europe. Following its Permian rifting, the Polish Basin experienced long-term Mesozoic thermal subsidence. Its Late Cretaceous-Palaeogene inversion was associated with uplift of the axial part of the Polish Basin that led to formation of a regional anticlinal structure referred to as the Mid-Polish Anticlinorium, and with compressional reactivation and growth of salt diapirs in its central and northern part. Inversion-related localised uplift of basin floor led to formation of regional or local morphological barriers and slopes that focused the flow of bottom currents to localized routes. This was recently recognized using seismic reflection data from two segments of the Polish Basin. In its SE segment, the Upper Cretaceous succession from the NE flank of the Mid-Polish Anticlinorium is characterized by presence of low-angle progradational complex directed towards the NE, away from the regional inversion axis. Within this inversion-related syn-kinematic sedimentary succession buried contourite drifts have been recognized representing deposits of contour currents that were flowing along the slope formed by the Mid-Polish Anticlinorium, being progressively uplifted during Late Cretaceous. Another area where contourites have been recognized is located in NW segment of the Polish Basin, where complex system of salt structures was formed, including Szamotuły salt diapir located near Poznań. Local thickness reductions of the Upper Cretaceous syn-kinematic succession and local progressive unconformities, clearly visible on seismic data in vicinity of this diapir, indicate continuous growth of the salt structure during basin inversion. Uplifted and arched roof of this diapir created local intra-basinal morphological barrier, encircled by contour currents that formed contourites. The formation of the contourites hints that strong seafloor currents sculpted the seafloor over hundreds of thousands of years. The duration of deposition in the contourite pattern constrain the period of protrusion of inversion-related bathymetric barriers at the seabed. Our results provide independent evidence for bottom current paleo-circulation, supporting the regional reconstruction by Remin et al. (2016).

[1] Remin Z., Gruszczyński M., Marshall J.D., 2016, *Changes in paleo-circulation and the distribution of ammonite faunas at the Coniacian–Santonian transition in central Poland and western Ukraine*. Acta Geologica Polonica, 66(1): 107–124.

P44 *A regional graphite décollement level beneath the NW Pannonian Basin: crustal-scale implications*

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The so-called Transdanubian Conductivity Anomaly (TCA) of the Hungarian part of the NW Pannonian Basin has been well known for nearly three decades. The exceptionally low resistivity (i.e. 1-2 Ohmm) zone has a very large areal extent (on the order a few thousand square km) and it is a subsurface anomaly occurring at depth between circa 3-15 km with no outcrops. Various geological explanations of this enigmatic crustal-scale geophysical anomaly range from invoking sub-horizontal Alpine nappe contacts to subvertical dikes with graphite and/or saline fluid content. Only one possible analogue outcrop area of the high conductivity anomaly was considered so far, in the Drauzug/Gailtal area of the Eastern Alps in Austria, some 300 km to the West from the TCA area. Whereas there were previous attempts to find correspondence between the TCA and prominent seismic reflectors seen on 2D seismic reflection data acquired by research institutions, in this study we have systematically correlated, for the first time, the TCA with 2D and 3D industry seismic reflection data in the same area. Our results show a very strong correlation between the subsurface extent and position of TCA and various sub-horizontal Cretaceous Alpine nappe surfaces. In addition, we drew on the latest structural correlation of the Alpine nappe stack of the Transdanubian Central Range with its proper tectonic counterpart in the Eastern Alps. At the southern edge of the Upper Austroalpine units in northern Styria, in the Veitsch Nappe of the Greywacke Zone, numerous graphite localities are known historically. These laterally extensive graphite units between Lassing and Kohlbachgraben formed as the result of greenschist-grade metamorphism of a Carboniferous coal sequence during the Cretaceous. There are no well-penetrations of the age-equivalent graphitic units in NW Hungary known to date. We propose that the best explanation for the observed extent and geometry of the TCA is the presence of graphite in subhorizontal, tectonically thinned detachment surfaces in the Upper Austroalpine nappe edifice of NW Hungary.

P45 *Anomalous upper-mantle phases in the Western Carpathians: Indication of the ALCAPA and the European Plate contact*

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Seismic data from deep refraction and wide-angle reflection profiles intersecting the Western Carpathians and the Bohemian Massif show distinct upper-mantle phases with anomalous apparent velocities identified in the first and later arrivals. Their systematic analysis indicates that such phases are present in numerous seismic sections both for in-line and off-line shots. Modelling of these anomalous phases shows that their origin can be explained due to local structural anomalies near the crust/mantle Moho boundary at the contact of the Bohemian Massif and the Western Carpathians. The modelling also shows that the effect of these anomalies can be supported by anomalous upper-mantle structure in the same place or with structure at the deeper parts of the lithospheric mantle. In the former case, such anomalies are located in close lateral proximity of the Pieniny Klippen Belt representing the contact between the stable European Plate in the north and the ALCAPA (Alpine-Carpathian-Pannonian) microplate in the south. Thus, the complex local crust/mantle structure modelled from these phases suggests tectonic relation to the formation of the Carpathian orogen. The result is supported by correlation with the large-scale Carpathian conductivity anomaly modelled in the Carpathians at a mid-crustal level. Relative lateral position of these two structures together with the Pieniny Klippen Belt at the surface delineates a zone affected by deformations at various depths along the whole Western Carpathian arc. Tectonically, such course of the anomalous zone suggests that its origin is connected with the lithospheric deformations occurring near the contact of the European Plate and the ALCAPA microplate during the Carpathian orogeny, which also involves the interpretation of the latter case. Thus, both options are related to the collisional/transpressional processes during and after the Tertiary.

P46 *RomUkrSeis: the deep structure of the TESZ where it is obscured by the Eastern Carpathians*

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RomUkrSeis is a controlled source wide-angle reflection and refraction (WARR) profile acquired in August 2014. It is 675 km long, running roughly SW-NE from the Apuseni Mountains in Romania and the Transylvanian Basin (Tisza-Dacia) behind the arc of the eastern Carpathian orogeny, crossing this and terminating in the East European Craton (EEC) in central Ukraine. A well-constrained velocity model has been constructed along the RomUkrSeis profile from 350 single component seismic recorders and eleven shot points in a single deployment. The Eastern Carpathian arc and the complex tectonic processes that formed it in the Cenozoic have obscured the pre-existing Trans-European Suture Zone (TESZ), which is the transition zone between the EEC and terranes accreted to its southwest in pre-Cenozoic (especially Palaeozoic) times.

Relatively low velocities are determined throughout the whole crust along the RomUkrSeis profile. The velocities in the southwestern part of the model are comparable with those from the Pannonian Basin (Vp <6.6 km/s) observed elsewhere but the crustal thickness is higher, >30 km. There is a high velocity body (Vp ~6.36 km/s) at depths of 3-12 km at a location corresponding to the surface expression of the ophiolite formation of Apuseni Mts. Immediately below this body, lower velocities are found. In the central part of the model, there is a large sedimentary wedge that comprises the Cenozoic Carpathian foreland itself as well as older sedimentary units. The wedge consists of two thick layers of Vp ~4.7 and 5.35 km/s with a width of ~30 km, asymmetrically dipping to the SW and reaching a depth of ~15 km. Below it, up to a depth of 45 km, Vp of ~6.3 km/s is determined. On the EEC side of the model, the velocities near the base of the crust (to depths 33-43 km) reach Vp ~6.6 km/s. Strongly differentiated Moho depths are observed along the profile as a whole. Four segments can be identified from the southwest to the northeast, with depth variations from 32 to 50 km. Velocities below the Moho boundary are: 8.15-8.2 km/s and ~8.3-8.35 km/s below a sub-Moho discontinuity in the uppermost mantle (at depths ~52 km in the central part of the profile and ~47 km in its northeastern part).

A comparative study of the RomUkrSeis profile and two other WARR profiles that cross the Eastern Carpathians, PANCAKE to the northwest and VRANCEA 2001 to the southeast, could illuminate important aspects of the relationship between the emplacement of the Carpathian arc and the earlier crustal architecture of this fundamental tectonic transition zone.

P47 *Layered azimuthal anisotropy in the region adjacent to the Arabia-Eurasia collision zone*

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northeastern edge of the Arabian plate, where one of the largest collision-related deformation episodes on Earth is occurring. Broadband continuous seismic records used in this study are sourced from 23 permanent stations maintained by the National Center of Meteorology and Seismology of the UAE, plus 31 temporary stations run by the Petroleum Institute. Recording periods are generally 2.5 years (from June 2014 to December 2016). Nearly 1200 Empirical Green's Functions (EGFs) were computed for all simultaneously recording station pairs by cross-correlating the vertical component of 1 h segments, filtered in the range 0.03 and 2.0 Hz. Phase velocity dispersion measurements of the Rayleigh wave were calculated from the EGFs for periods ranging from 2 to 20 seconds. In order to characterise the effects of azimuthal variations of the interstation-averaged phase velocities, we invert them and map the ensued isotropic and anisotropic wavefield components using the inversion scheme of Debayle and Sambridge (2004). Smoothing regularisation is imposed through application of an a priori spatial correlation filter among points separated by an Lcorr distance, while an a priori model standard deviation sigma controls the amplitude of anomalies, thus acting as a damping constraint on the final solution.

Our results, which span the upper to lower crust, reveal a complex and stratified pattern of anisotropy that can be explained as induced by the extensive deformation inherited from the obduction of Tethyan oceanic lithosphere onto the Arabian rifted continental margin, and the ongoing relative motion of the Arabian plate towards Eurasia. We map orogen-parallel fast axes of anisotropy in the United Arab Emirates-Oman orogenic belt - where the Semail ophiolite is located - and observe a remarkable match with magnetic lineaments and main tectonic boundaries. To the west of the mountain belt, pervasive stress-induced deformation promoted by the Arabia-Eurasia tectonic interaction appears to propagate into the Arabian plate and dominates the anisotropy imprint in the upper crust. Possibly due to a change of rheology in the lower crust, orientations of anisotropy at higher periods are largely compatible with the directions of absolute plate motion. This is suggestive of a strong mechanical coupling in the lower lithosphere indicating that, at least in part, the drifting of the Arabian plate is being accommodated by viscous flow in the lower crust.

P48 *Passive seismic experiment in Sudetes, SW Poland*

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It has complex tectonic history ranging from the upper Proterozoic till the Quaternary. The crustal structure of this region is relatively well studied, e.g. by seismic wide-angle experiment SUDETES 2003. However, unlike for other parts of the Bohemian Massif where numerous seismic passive (teleseismic and regional) studies have been carried out, in Polish Sudetes only scarce data about the upper mantle properties were collected.

Therefore, in 2017, a passive seismic experiment was launched, involving 22 broadband seismic stations deployed in the area of Sudetes and Fore-Sudetic block, between Elbe Fault in SW and Odra Fault in NE. The measurements cover a ~200 x 100 km large area, with spacing between stations of ~30 km. The stations, deployed for a period of 18 months, will provide broadband recordings of local, regional and teleseismic events. Obtained data will be supplemented with the data from five permanent seismic stations, operating in this area in Poland and Czech Republic.

The aim of the experiment is to study the structure, seismic velocity variations including anisotropy distribution, and to map the upper mantle seismic discontinuities (Moho, lithosphere-asthenosphere boundary, mantle transition zone). The results will be compared with most recent results of petrological studies of crystal preferred orientation in upper mantle xenoliths found in Tertiary volcanics in Lower Silesia area. Based on obtained results, we will attempt to enhance the understanding of the evolution and deformations of the Sudetic lithosphere, including the impact of the Alpine orogeny on the present architecture of Sudetes.

The poster presents the experiment and first data examples.