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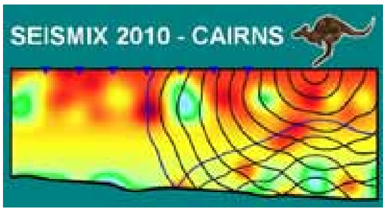

14th International Symposium on Deep Seismic Profiling of the Continents and their Margins

Compiled by D. M. Finlayson

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2010/24

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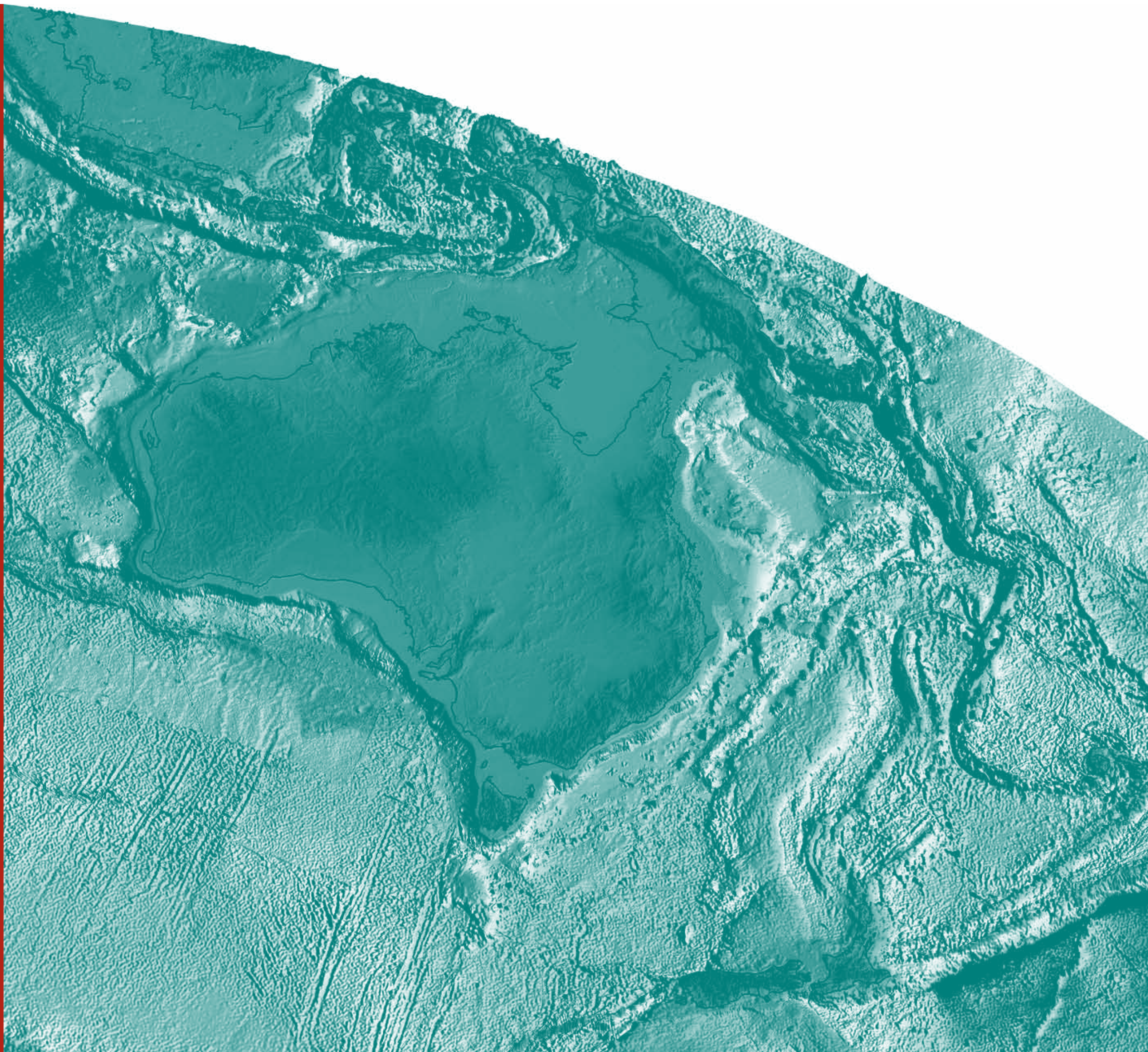

APPLYING GEOSCIENCE TO AUSTRALIA'S MOST IMPORTANT CHALLENGES

14th International Symposium on Deep Seismic Profiling of the Continents and their Margins

28 August – 3 September, 2010
Cairns, Queensland, Australia

SEISMIX 2010 - CAIRNS

Program and Abstracts

Compiled by D. M. Finlayson

Geoscience Australia
Record 2010/24

Geological Society of Australia
Geoscience Australia
Australian National University
International Geoscience Project (IGCP) Project 559

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14th International Symposium on

Deep Seismic Profiling of the Continents and their Margins

28 August – 3 September, 2010
Cairns, Queensland, Australia

General Information

Welcome

The Organising Committee of the 14th International Symposium on Deep Seismic Profiling of the Continents and their Margins welcomes you to the tropical North Queensland city of Cairns. We wish you an enjoyable and pleasant stay in the "Top End" of Australia and an inspiring and thought-provoking symposium.

Organising Committee

Bruce Goleby, Geoscience Australia, Canberra
Douglas Finlayson, IGCP Project 559, Canberra
Nick Stolz, Geoscience Australia, Canberra
Jenny Maher, Geoscience Australia, Canberra
Nick Rawlinson, Australian National University, Canberra
Leonie Jones, Geoscience Australia, Canberra

Sponsors

Geological Society of Australia: Specialist Group on Solid Earth Geophysics
Geoscience Australia
Australian National University
International Geoscience Programme (IGCP) Project 559

Venue

The Seismix 2010 symposium is being held at the Rydges Esplanade Resort Hotel, Cairns. The venue contact information is:

Rydges Esplanade Resort Hotel, Cairns
Corner The Esplanade and Kerwin Street
Cairns QLD 4870
Phone: +61 7 40449000

The Rydges Esplanade Resort Hotel is rated at 4½ stars in hotel guides and there are appropriate facilities and room services available. Ask at the reception desk for assistance with any aspect of your stay in the hotel. Please settle all accommodation accounts at the hotel reception desk prior to checkout.

Registration information

There will be a Seismix 2010 registration desk open at the symposium venue on Sunday 29 August from 2 pm until 6 pm. Delegates should endeavour to meet with the organisers at that time and receive their abstracts and other symposium information. This registration session will be followed by the symposium evening icebreaker function.

At other times during the symposium there will be an office open for ad hoc registrations and other business.

Meals

The symposium registration fee includes the Sunday ice-breaker function, lunches on five days, dinners on five days, including the symposium dinner, all coffee and tea during breaks and the mid-symposium excursion. On Wednesday, the day of the mid-symposium boat excursion to Green Island, a tour operator will provide catering. Additional tickets for the symposium dinner are available at a cost of Aus$128.

Morning tea/coffee	10.40-11.10 am
Lunch	12.30-1.20 pm
Afternoon tea/coffee	3.00-3.30 pm
Dinner	7.00 pm

All other catering is by personal arrangement with the hotel according to accommodation bookings and quotations. A cash bar service will be available at the symposium venue at the end of the day's proceedings and prior to invited talks.

Scientific program

As at previous Seismix symposia, the scientific program will involve a single schedule of oral presentations. The program of oral and poster paper presentations has been divided into five themes:

- Continental evolution
- Crust and mantle
- Continental margins
- Mineral, geothermal and CO_2 systems
- Seismic methods, data acquisition and modelling

Four invited talks will be presented during the symposium by Brian Kennett, Ramon Carbonell, Richard Hobbs and Takaya Iwasaki.

Seismix 2010 presentations

The Seismix 2010 scientific program will be presented in the Rydges Hotel's 1st floor functions area where there are facilities for both oral and poster presentations. There will also be an adjacent symposium business office and an area for preparing oral presentation material.

Oral presentations will use MS Powerpoint or Adobe PDF files and data image projectors as the principle means of projection. There will be two screens, with the same image being projected on both screens. Presenters should deliver their Powerpoint or PDF presentation files on a CD or memory stick to symposium staff in the preparation area the day before scheduled sessions. Authors requiring alternative equipment for oral presentations should contact symposium personnel well in advance of their lecture time. The organisers cannot guarantee that other facilities can be provided at short notice.

The time allocated for oral presentations is 20 minutes for both the talk and subsequent discussion. Ideally speakers should present their talk in about 15 minutes to allow 5 minutes for questions and comment.

Poster presentations will be displayed adjacent to the auditorium for oral presentations where morning and afternoon tea/coffee will be served. The size of the poster board is 2.4m wide x 1.8m high (2.32m x 1.12m useable space). Posters should be limited to fit this space. One poster board will be allocated to each of the papers listed in the program.

Symposium events

Sunday 29 August - Ice breaker, Rydges Hotel

The informal symposium icebreaker reception will be held on Sunday evening beginning at 6.00 pm. The venue will be at one of the relaxing garden/pool settings around the Rydges Hotel.

Wednesday 1 September - Mid-symposium excursion, Green Island

The coach for the mid-symposium excursion will leave the Rydges Hotel for the Cairns Wharf at 9.30 am. Delegates should wear clothing appropriate for beach combing, snorkelling and/or swimming, including shoes for wearing in sea water on hard coral surfaces. The 27 km catamaran trip to Green Island takes about 45 minutes. There are commercial operators on the island so take some Aus$ with you for equipment hire, glass bottom boats, etc. A buffet lunch will be provided by Seismix 2010 organisers. The boat will return to Cairns Wharf at about 5.30 pm and delegates can stroll the short distance back to the hotel.

Thursday 2 September - Symposium dinner, Hartley's Crocodile Farm

Hartley's Crocodile Farm is located about 30 km north of Cairns along the coast road. It is in a beautiful setting and well suited to a relaxing symposium dinner. The symposium organisers hope that the crocodiles have been fed before we arrive. The caterers, Ochre Restaurant and Catering, have an excellent reputation. Ochre Restaurant specialises in fresh local seafood, game, bush foods, premium Australian produce and regional Australian cuisine; Cairns dining at its best. A coach for diners will leave the Rydges Hotel at 6.30 pm and return well-fed diners at approximately 11.00 pm.

Post-symposium excursion

The post-symposium excursion is a four day excursion that commences on Saturday 4th September from the Rydges Esplanade Resort Hotel, Cairns, the day after the Symposium. It has been organised with significant input from the Geological Survey of Queensland and Geoscience Australia. The tour guides will be:

Ian Whitnall, Geological Survey of Queensland
Leonie Jones, Geoscience Australia

The excursion is planned to depart Cairns by coach and proceed through the Palaeozoic aged rocks of the Atherton Tableland hinterland, before intersecting the 2007 Deep Seismic transect that crosses the Tasman Line, a major north-south structure that extends for thousands of kilometres through eastern Australian, and separates the Palaeozoic rock outrops around Cairns from the Proterozoic rocks to the west. The Tasman Line structure continues to provide much debate amongst geologists as to its significance.

The excursion then heads towards the Georgetown Province, visiting sites showing some of Australia's youngest volcanism, the lava tubes at Undara National Park. The excursion will return to Cairns and inspect rock outcrop along other parts of the 2007 deep seismic profiling lines.

The post-symposium excursion fee covers field guide, bus transportation, accommodation from Saturday 4th September through Tuesday 7th September inclusive, i.e. four nights and all meals during the excursion, including accommodation in Cairns for the night after the excursion finishes. Arrangements, however, must be made for accommodation on the Friday night, 3 September, before starting the excursion.

Proceedings publication

It is expected that full papers resulting from those presented at the Seismix 2010 symposium will be published in an international journal. At this stage no final decision has been made regarding which journal will be involved. Seismix 2010 delegates will be informed of publication proposals at business meetings during the meeting in Cairns.

Symposium personnel

In Cairns the following persons have a role in the symposium organisation. They will have red coloured Seismix 2010 name badges. Ask them for assistance if required.

Bruce Goleby
Doug Finlayson
Nick Rawlinson
Leonie Jones
Ned Stolz
Andrew Greenwood
Mallory Young
Sara Pozgay
Aedon Talsma

Airport transport

Rydges Hotel reception staff will book airport transport and taxi services if requested. Various coach companies offer airport shuttle services including:

Cairns Luxury Coaches – Ph. 0414 658 002
Coral Reef Coaches – Ph. 07 4098 2800
Pacific Coaches – Ph. 07 4035 2565 or 0418 774 740
Krystal Transport – Ph. 07 4051 7456 or 0458 211 648

Black&White Taxi services are available – Ph. 131 008

Future Seismix meetings

Organisations, institutions and scientists interested in hosting the 15th Deep Seismic Profiling of the Continents and their Margins Symposium in 2012 should make this known to Seismix 2010 committee members in Cairns. Various business meetings will be held in Cairns at the Seismix 2010 symposium to discuss such matters.

Symposium web page

The symposium web page is located via the IGCP Project 559 web site – www.earthscrust.org

Follow the links to Seismix 2010 from the front page.

SEISMIX 2010, CAIRNS: SYMPOSIUM PROGRAM OUTLINE

TIME	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday
6:30-8:30		*Breakfast*	*Breakfast*	*Breakfast*	*Breakfast*	*Breakfast*
8:55		Announcements	Announcements		Announcements	Announcements
9:00		Welcome	D. White		N. Rawlinson	A.F. Morozov
9:20		F. Cook	Hajnal, Z.		M. Kanao	R. Stephenson
9:40		R.J. Korsch	S. Heinonen		W.-P. Chen	*Invited Talk*
10:00		Y.M. Erinchek	G.M. Gibson		L.D. Brown	*Richard Hobbs*
10:20		M.A. Garcia Juanatey	A. Malehmir		T. Ito	M. Malinowski
10:40		*Morning Tea*	*Morning Tea*		*Morning Tea*	*Morning Tea*
11:00						
11:10		S. Bogdanova	B. Milkereit		A. Oelke	A. Goncharov
11:30		R. Keller	M. Dehghannejad	*MID*	T. Iidaka	E. Lundberg
11:50		R.M. Clowes	M. Malinowski	*SYMPOSIUM*	H. Sato	Y. Roslov
12:10		R. Cayley	C. Cosma	*EXCURSION*	T.-K. Hong	E. Saygin
12:30						
12:40		*Lunch*	*Lunch*	*Green Island*	*Lunch*	*Lunch*
13:00						
13:20		Z. Zhang	N. Enescu		S. Yamakita	L.D. Brown
13:40		R. Carbonell	C. Krawczyk		J.M. Lee	C. Krawczyk
14:00		A. Rybalka	D. White		H. Sato	A. Roberts
14:20		I. Artemieva	A. Kell-Hills	*Coach departure from*	L.D. Brown	Y. Ito
14:40	*Registration*	H. Thybo	A. Reading	*Rydges Hotel for*	J. Hole	J. Ferahtia
15:00		*Afternoon Tea*	*Afternoon Tea*	*Cairns Wharf*	*Afternoon Tea*	*Afternoon Tea*
15:20				*9.30 am*		
15:30		A. Salnikov	H. Thybo		S. Gutjahr	C. Zelt
15:50		T. Fomin	I. Artemieva		A. Calvert	N. Stolz
16:10		E.D. Milshtein	G. Begg		S. Buske	Symposium close
16:30		S. Bogdanova	M. Salmon		G.M. Gibson	
16:50		R. J. Korsch	S.N. Kashubin		D. Snyder	
17:10						
17:40		*View Posters*	*View Posters*		*Invited talk*	
18:00	*Welcome*	*Invited Talk*	*Invited Talk*		*Takaya Iwasaki*	
18:20	*Icebreaker*	*Ramon Carbonell*	*Brian Kennett*			
18:40						
19:00					*Conference*	
19:20		*Dinner*	*Dinner*	*Dinner*	*Dinner*	
19:40						
20:00					*Hartley's*	
20:20		*View Posters*	*View Posters*	*View Posters*	*Crocodile Farm*	
20:40						
21:00		*Working Groups*	*Working Groups*	*Working Groups*	*Coach departs from*	
21:20		*Meetings*	*Meetings*	*Meetings*	*Rydges Hotel*	
21:40					*6.30 pm*	
22:00						

Cratonic evolution
Minerals, CO2, Geotherm
Crust & mantle

Continental margins
Data acquisition, modelling

Seismix 2010 – Oral presentations

* Indicates paper presenter

Sunday, 29 August

14.00 **Registration**

18.00 **Welcome icebreaker**

Monday, 30 August

9.00 – 9.20 **Symposium opening**

9.20 – 10.40 **Cratonic evolution**

THE MYTH OF CRUSTAL GROWTH: A SEISMIC PERSPECTIVE.
*Cook, F.

GEODYNAMIC IMPLICATIONS OF A DEEP SEISMIC REFLECTION TRANSECT FROM THE WESTERN EYRE PENINSULA IN SOUTH AUSTRALIA TO THE DARLING BASIN IN NEW SOUTH WALES.
*Korsch, R.J., Preiss, W.V., Blewett, R.S.,Cowley, W.M., Neumann, N.L., Fabris, A.J., Fraser, G.L., Dutch, R., Fomin, T., Holzschuh, J., Fricke, C.E., Reid, A.J., Carr, L.K. and Bendall, B.R.

NEW RESULTS FROM INTENSIVE STUDIES OF THE RUSSIAN PROGRAM – THE STATE NETWORK OF GEOLOGICAL-GEOPHYSICAL TRANSECTS AND DEEP BOREHOLES.
Lipilin, A.V., *Erinchek, Y.M., and Petrov, O.V.

CONDUCTIVITY MODELS DERIVED FROM MT DATA AND ITS CORRELATION WITH SEISMIC REFLECTION PROFILES IN WESTERN SKELLEFTE DISTRICT, NORTHERN SWEDEN.
*Garcia Juanatey, M.A., Hübert, J., Tryggvason, A., Dehghannejad, M. and Juhlin, C.

10.40 – 11.10 **Break**

11.10 – 12.30 **Cratonic evolution (continued)**

MEMOTATUR IN SE FENNOSCANDIA, EAST EUROPEAN CRATON.
*Bogdanova, S. and Trofimov, A.

SEISMIC IMAGES OF CONTINENTAL RIFTS: GLOBAL COMPARISONS.
*Keller, R.

THE NATURE OF THE MOHO TRANSITION IN NW CANADA FROM COMBINED NEAR-VERTICAL AND WIDE-ANGLE SEISMIC REFLECTION STUDIES.
*Clowes, R.M. and Oueity, J.

DEEP SEISMIC REFLECTION IMAGING OF THE EASTERN DELAMERIAN FOLD BELT, SOUTH AUSTRALIA AND WESTERN VICTORIA, AUSTRALIA.
Jones, L., *Cayley, R., Korsch, R., Rawling, T., Morand, V., Betts, P., Moore, D. and Kennett, B.L.N.

12.30 – 13.20 Lunch

13.20 – 15.00 Cratonic evolution (continued)

CRUSTAL STRUCTURE OF THE QILIAN OROGENIC BELT FROM WIDE-ANGLE SEISMIC PROFILING ON THE NORTH-EASTERN MARGIN OF THE TIBETAN PLATEAU.
*Zhang, Z., Tian, X., Bai, Z., Zhang, X., Zhao, B., Zhang, J., Shi, S., Chen, Y., Xu, T. and Teng, J.

SEISMIC INVESTIGATIONS ACROSS THE MOROCCAN ATLAS (SIMA).
*Carbonell, R., Harnafi, M., Gallart, J., Levander, A., Teixell, A., Ayarza, P., Kchikach, A., Amrhar, M. and Charroud, M.

CRUSTAL STRUCTURE ALONG THE POLAR-URALS TRANSECT, RUSSIA, BASED ON MULTIDISCIPLINARY DEEP SEISMIC AND INTEGRATED STUDIES.
*Rybalka, A., Petrov, G., Kashubina, T. and Aniskin, A.

ARE GLOBAL AND REGIONAL MODELS OF CRUSTAL STRUCTURE CONSISTENT WITH SEISMIC DATA? A EUROPEAN-SIBERIAN EXAMPLE.
*Artemieva, I., Thybo, H. and Cherepanova, Y.

CRUSTAL STRUCTURE AND TOPOGRAPHY IN SOUTHERN SCANDES, NORWAY.
*Thybo, H., Stratford, W. and Frasetto, A.

15.00 – 15.30 Break

15.30 – 17.10 Cratonic evolution (continued)

DEEP STRUCTURE OF NORTHEASTERN RUSSIA DERIVED FROM DSS SEISMIC INVESTIGATIONS ALONG GEOTRAVERSES.
*Salnikov, A., Efimov, A., Trigubovich, G., Yemanov, A., Solovyov, V., Lipilin, A. and Myasnikov, F.

COMBINED INTERPRETATION OF WIDE-ANGLE AND REFLECTION VIBROSEIS DATA, INCORPORATED WITH GRAVITY AND MAGNETOTELLURIC MODELLING, EYRE PENINSULA, GAWLER CRATON, SOUTH AUSTRALIA.
*Fomin, T., Fraser, G., Korsch, R., Nakamura, A., Meixner, A., Milligan, P. and Thiel, S.

3D DEEP STRUCTURAL MODEL OF THE YENISEY SHIELD (SIBERIAN PLATFORM) FROM GRAVITY MODELLING AND SEISMIC DATA.
*Milshtein, E.D., Mukhin, V.N., Erinchek, Y.M. and Egorkin, A.V.

TATSEIS IMAGING THE UPPER LITHOSPHERE AND ARCHEAN TO PALEOPROTEROZOIC EVOLUTION OF VOLGO-URALIA, EAST EUROPEAN CRATON.
*Bogdanova, S., Postnikov, A. and Trofimov, A.

GEODYNAMIC SIGNIFICANCE OF RESULTS FROM THE 2007 NORTH QUEENSLAND DEEP SEISMIC REFLECTION SURVEY.
*Korsch, R.J., Henson, P.A., Champion, D.C., Blewett, R.S., Huston, D.L., Nakamura, A., Holzschuh, J., Costelloe, R.D., Withnall, I.W., Hutton, L.J., Henderson, R.A., Fergusson, C.L., Collins, W.J. , Chopping, R., Williams, N.C. and Roy, I.G.

17.10 – 18.00 **Poster viewing**

18.00 – 18.40 **Invited talk**

RESOLVING THE CRUSTAL STRUCTURE AND EVOLUTION OF THE SOUTHWESTERN IBERIAN PENINSULA
Ramon Carbonell & others

19.00 **Dinner**

20.20 **Working group meetings**

Tuesday, 31 August

9.00 – 10.40 **Seismic imaging for mineral, petroleum, geothermal and CO_2 systems**

SEISMIC IMAGING OF THE FLIN FLON VMS MINING CAMP, TRANS-HUDSON OROGEN, CANADA

*White, D., Malinowski, M., Schetselaar, E. and Pehrsson, S.

FROM DEEP SEISMIC STUDIES TO MINERAL EXPLORATION.

*Hajnal, Z. [1], Pandit, B.[1,] Takacs, E.[1], Annesley, E.[2], White, D.[3], Reilkoff, B.[1], McCready, A.[4] and Wallster, D.[4]

SEISMIC IMAGING OF MASSIVE SULPHIDES IN PYHÄSALMI, FINLAND.

*Heinonen, S., Imaña, M., Kukkonen, I., and Heikkinen, P.

DEEP SEISMIC REFLECTION IMAGING OF A PALEOPROTEROZOIC- EARLY MESOPROTEROZOIC RIFT BASIN SUCCESSION AND RELATED PB-ZN MINERAL PROVINCE, THE MOUNT ISA INLIER.

*Gibson, G.M., Hutton, L.J., Korsch, R.J., Huston, D.L., Murphy, B.J., Withnal, I.W., Jupp, B. and Stewart, L.

SEISMIC DETECTION OF VMS DEPOSITS: LESSONS FROM HALFMILE LAKE, NEW BRUNSWICK, CANADA.

*Malehmir, A. and Bellefleur, G.

10.40 – 11.10 **Break**

11.10 – 12.30 Seismic imaging for mineral, petroleum, geothermal and CO_2 systems (continued)

3D SEISMIC IMAGING OF MASSIVE SULFIDES: GEOLOGY MATTERS.
*Milkereit, B., Bongajum, E. and Adam, E.

REFLECTION SEISMIC IMAGING IN THE SKELLEFTE ORE DISTRICT, NORTHERN SWEDEN: A FRAMEWORK FOR 3D/4D GEOLOGIC MODELLING.
*Dehghannejad, M., Juhlin, C., Malehmir, A., Skyttä, P. and Weihed, P.

3-D SEISMIC MODELLING IN THE FLIN FLON MINING CAMP, CANADA.
*Malinowski, M., White, D. and Schetselaar, E.

SURFACE AND BOREHOLE 3D SEISMIC IMAGING FOR MINE DEVELOPMENT.
*Cosma, C., Enescu, N., Wood, G. and O'Dowd, C.

12.30 – 13.20 Lunch

13.20 – 15.00 Seismic imaging for mineral, petroleum, geothermal and CO_2 systems (continued)

BOREHOLE SEISMIC MONITORING AT THE CO_2SINK SITE.
Cosma, C., *Enescu, N. and the CO_2SINK Team

SUBSEISMIC DEFORMATION ANALYSIS - A PREDICTION TOOL FOR A SAFE CO_2 RESERVOIR MANAGEMENT.
Tanner, D. and *Krawczyk, C.

TIME-LAPSE SEISMIC MONITORING OF THE IEA WEYBURN-MIDALE CO_2 STORAGE PROJECT.
*White, D.

CHARACTERIZING GREAT BASIN STRUCTURE FROM A 3D SEISMIC VOLUME, HAWTHORNE GEOTHERMAL PROSPECT, NEVADA, USA.
*Kell-Hills, A., Louie, J., Kent, G., Pullammanappallil, S., Sabin, A. and Lazaro, M.

AMBIENT SEISMIC ENERGY TECHNIQUES: THE HIGH FREQUENCY LIMIT AND APPLICATION TO UPPER CRUSTAL IMAGING AND GEOTHERMAL EXPLORATION.
*Reading, A., Graham, L., Heckscher, N. and Rawlinson, N.

15.00 – 15.30 Break

15.30 – 17.10 The continental crust and mantle.

MOHO AND MAGMATISM IN EXTENSIONAL SETTINGS.
*Thybo, H.

ARE MANTLE XENOLITHS REPRESENTATIVE OF THE CRATONIC MANTLE?
*Artemieva, I.

UNDERSTANDING CONTINENTAL STRUCTURE: INTEGRATING CRUST AND MANTLE INFORMATION.

*Begg, G., Griffin, W.L., O'Reilly, S.Y., Belousova, E. and Natapov, L.

AUSMOHO: THE MOHO MAP OF THE AUSTRALIAN CONTINENT.

*Salmon, M., Saygin, E. and the AusMoho Group.

THE POTENTIAL OF MULTI-WAVE SEISMIC FOR DETERMINING SEISMIC VELOCITIES IN DEEP WATER CONDITIONS: A TOOL FOR DISCRIMINATING OCEANIC AND CONTINENTAL CRUST.

*Kashubin, S.N.

17.10 – 18.00 Poster viewing

18.00 – 18.40 Invited talk

UNVEILING THE AUSTRALIAN LITHOSPHERE
Brian Kennett

19.00 Dinner

20.20 Working group meetings

Wednesday, 1 September

9.00 Seisimx 2010 mid-symposium excursion to Green Island – coach departs Rydges Hotel for the ferry harbour

19.00 Dinner

Thursday, 2 September

9.00 – 10.00 The continental crust and mantle (continued)

NEW RESULTS FROM THE WOMBAT TRANSPORTABLE ARRAY PROJECT IN SOUTHEAST AUSTRALIA.

*Rawlinson, N., Tkalcic, H. and Kennett, B.L.N.

BROADBAND SEISMICS DURING IPY IN EAST ANTARCTICA (AGAP/GAMSEIS).

*Kanao, M., Wiens, D., Nyblade, A., Tanaka, S. and Tsuboi, S.

LARGE-SCALE, VIRTUAL SEISMIC PROFILES: TECHNIQUE AND RESULTS.

*Chen, W-P., Yu, C., Ning, J-Y, and Tseng, T-L.

10.00 – 10.40 Active and passive continental margins

LITHOSPHERIC STRUCTURE BENEATH TAIWAN FROM REFLECTION AND CONVERSION ANALYSIS OF EXPLOSION AND EARTHQUAKE SOURCES AS PART OF PROJECT TAIGER.

*Brown, L.D., Quiros, D., Glasgow, D., Okaya, D., Wu, F. and Wang, C-Y.

NEW SCOPE EXTENDED BY SEISMIC PROFILING IN CENTRAL JAPAN.

*Ito, T., Kano, K., Ikeda, Y., Kojima, S., Yamakita, S., Tsumura, N., Iwasaki, T., Sato, H., Omura, K., Mizohata, S., Kikuchi, S., Murata, K., Abe, S., Takeda, T., Abe, S., Komada, N. and Yannis, P.

10.40 – 11.10 Break

11.10 – 12.30 Active and passive continental margins (continued)

SEISMIC IMAGING OF THE ALPINE FAULT, NEW ZEALAND, AT WHATAROA RIVER.

*Oelke, A., Buske, S. and Bannister, S.

SEISMIC IMAGES OF THE JAPANESE SUBDUCTION ZONE ESTIMATED FROM COMPARISON BETWEEN REFRACTION/REFLECTION AND RECEIVER FUNCTION ANALYSES.

*Iidaka, T., Igarashi, T. and Iwasaki, T.

BASIN FORMATION AND INVERSION OF THE BACK-ARC NIIGATA BASIN.

*Sato, H., Abe, S., Kawai, N , Saito, H., Kato, N., Iwasaki, T., Shiraishi, K., Ishiyama, T., and Inaba, M.

SEISMIC FEATURES OF THE EASTERN EURASIAN CONTINENTAL MARGIN.

*Hong, T-K., Choi, H. and He, X.

12.30 – 13.20 Lunch

13.20 – 15.00 Active and passive continental margins (continued)

COLLISIONAL AND BENDING PROCESSES OF THE SOUTHWESTERN JAPANESE ISLAND ARC.

*Yamakita, S., Murata, K., Kano, K., Ikeda, Y., Kojima, S., Iwasaki, T., Sato, H., Mizohata, S., Kikuchi, S., Abe, S., Suda, S., Tsumura, N. and Ito, T.

DEEP CRUSTAL STRUCTURE OF THE KOREAN PENINSULA: VELOCITY MODELS AND PRELIMINARY ANALYSES OF KCRT2004 AND KCRT2008.

*Lee, J.M., Moon, W., Baag, C-E., Jung, H., Kim, K.Y., Cho, H-M. and Choi, M-K.

DEEP SEISMIC REFLECTION PROFILING OF THE SUBDUCTION MEGATHRUST SYSTEM ACROSS THE SAGAMI TROUGH AND TOKYO BAY, CENTRAL JAPAN.

*Sato, H., Iwasaki, T., Abe, S., Saito, H., Kawanaka, T. and Hirata, N.

REFLECTION IMAGING OF DEEP VOLCANIC STRUCTURE BENEATH MONTSERRAT.

*Brown, L.D., Byerly, K., Irie, K. and Voight, B.

CONTROLLED-SOURCE SEISMIC INVESTIGATION OF THE GENERATION AND COLLAPSE OF A BATHOLITH COMPLEX, COAST MOUNTAINS, WESTERN CANADA.
*Hole, J., Wang, K., Stephenson, A., Spence, G., Miller, K., Harder, S., Kaip, G. and Clowes, R.

15.00 – 15.30 Break

15.30 – 17.10 Active and passive continental margins (continued)

SEISMIC IMAGES OF THE TREMOR REGION AROUND CHOLAME, CALIFORNIA.
*Gutjahr, S. and Buske, S.

ACTIVE CRUSTAL UNDERPLATING BENEATH NECHAKO BASIN.
*Calvert, A., Spratt, J. and Craven, J.

MULTISCALE SEISMIC IMAGING OF THE SAN-ANDREAS-FAULT SYSTEM.
*Buske, S., Gutjahr, S. and Reshetnikov, A.

A GREATER ROLE FOR TRANSFORM FAULTING IN THE FORMATION OF AUSTRALIA'S SOUTHERN PASSIVE MARGIN: A REASSESSMENT OF THE SEISMIC AND GEOLOGICAL RECORD.
*Gibson, G.M., Morse, M.J., Mitchell, C.H., Nayak, G., Stacey, A.R. and Totterdell, J.M.

SEDIMENTARY AND CRUSTAL STRUCTURE FROM THE ELLESMERE ISLAND AND GREENLAND CONTINENTAL SHELF ONTO THE LOMONOSOV RIDGE, ARCTIC OCEAN.
*Snyder, D., Jackson, H. R., Dahl-Jensen, T., Schimeld, J., Chian, D., Funck, T. and Asudeh, I.

17.10 – 17.40 Poster viewing

17.40 – 18.20 Invited talk

CRUSTAL AND UPPER MANTLE STRUCTURE OF AN ISLAND ARC FROM RECENT ACTIVE AND PASSIVE SEISMIC EXPEDITIONS IN JAPAN

Takaya Iwasaki

18.30 Symposium dinner - Hartley's Crocodile Farm

Coach departure from Rydges Hotel

Friday, 3 September

9.00 – 9.40 Active and passive continental margins (continued)

NORTH POLE – EQUATOR: PROPOSALS FOR A NEW INTERNATIONAL GEOTRANSECT, ARCTIC OCEAN – CHUKTKA – OKHOTSK SEA – PACIFIC OCEAN.
*Morozov, A.F., Erinchek, Y.M., Lipilin, A.V., and Petrov, O.V.

THE TOPOGRAPHY OF ELLESMERE ISLAND: MODEL TESTING WITH SEISMOLOGY.
*Stephenson, R., Oakey, G. and Nielsen, S.B.

9.40 – 10.20 Invited talk

SEISMIC OCEANOGRAPHY: NOW FOR SOMETHING COMPLETELY DIFFERENT
Richard Hobbs & others

10.20 – 10.40 Seismic data acquisition, processing and modelling

HIGH-RESOLUTION SEISMIC ATTENUATION IMAGING FROM FULL-WAVEFORM INVERSION.
*Malinowski, M., Ribodetti, A. and Operto, S.

10.40 – 11.10 Break

11.10 – 12.30 Seismic data acquisition, processing and modelling (continued)

UTILISATION OF SEISMIC INTERVAL VELOCITIES FOR DETERMINATION OF ROCK LITHOLOGY MAPPED BY SDRS AND DDRS ON THE WALLABY PLATEAU, OFFSHORE WESTERN AUSTRALIA.
*Goncharov, A. and Nelson, G.

HIGH RESOLUTION REFLECTION SEISMIC IMAGING OF THE ULLARED DEFORMATION ZONE, SOUTHERN SWEDEN.
*Lundberg, E. and Juhlin, C.

VELOCITY MODELS IN DEEP SEISMIC INVESTIGATIONS.
*Roslov, Y., Sakoulina, T. and Krupnova, N.

CRUSTAL STRUCTURE OF AUSTRALIA FROM AMBIENT NOISE TOMOGRAPHY.
*Saygin, E., Kennett, B.L.N. and Pozgay, S.

12.30 – 13.20 Lunch

13.20 – 15.00 Seismic data acquisition, processing and modelling (continued)

DEEP SEISMIC PROFILING WITH AMBIENT NOISE.
*Brown, L.D., Irie, K. and Quiros, D.

URBAN SHEAR-WAVE REFLECTION SEISMICS IN THE TRONDHEIM HARBOUR AREA, NORWAY.
*Krawczyk, C., Polom, U., L'Heureux, J-S., Hansen, L.' Lecomte, I. and Longva, O.

EMULATION: A FAST STOCHASTIC TECHNIQUE FOR JOINT CONSTRAINT.
*Roberts, A., Hobbs, R,, Goldstein, M., Moorkamp, M., Jegen, M. Heincke, B.

AUTOCORRELATION ANALYSIS OF AMBIENT NOISE IN NE JAPAN.
*Ito, Y., Chujo, K., Takagi, R., Hino, R., Suzuki, S., Yamada, T., Shinohara, M., Kanazawa, T., Murai, Y., Shiomi, K. and Obara, K.

SEISMIC NOISE REMOVAL USING IMAGE-BASED TECHNIQUES.
*Ferahtia, J., Djarfour, N. and Baddari, K.

15.00 – 15.30 Break

15.30 – 16.10 Seismic data acquisition, processing and modelling (continued)

FREQUENCY-DEPENDENT TRAVELTIME TOMOGRAPHY FOR NEAR-SURFACE SEISMIC DATA.
*Zelt, C. and Liu, H.

GEOSCIENCE AUSTRALIA'S DEEP CRUSTAL SEISMIC REFLECTION AND MAGNETOTELLURIC PROGRAMME, 2006-2010.
*Stolz, N., Jones, L., Costelloe, R., Duan, J., Fomin, T., Holzschuh, J., Maher, J., Milligan, P. and Nakamura, A.

16.10 – 16.30 Symposium close

Seismix 2010 – Poster presentations

(Poster papers are listed in alphabetical order by first author; presenter marked by an asterisk *)

CRUST AND UPPER MANTLE OF EUROPE, GREENLAND, AND THE NORTH ATLANTIC REGION: AN OVERVIEW.
*Artemieva, I. and Thybo, H.

THE SEISMIC SIGNATURE OF CRUSTAL MAGMA AND FLUID FROM DEEP SEISMIC SOUNDING DATA ACROSS THE TENGCHONG VOLCANIC AREA.
Bai, Z., Klemperer, S., Zhang, Z., Wang, C. and *Chen, Y.

MEMOTATUR IN SE FENNOSCANDIA, EAST EUROPEAN CRATON.
*Bogdanova, S. and Trofimov, A.

THE INDEPTH TRANSECT: A GEOPHYSICAL JOURNEY ACROSS THE TIBETAN PLATEAU.
*Brown, L.D., Zhao, W. and Team INDEPTH

SEISMIC IMAGING OF THE SUBDUCTION ZONE IN SOUTHERN CHILE.
*Buske, S., Gross, K., Shapiro, S. and Wigger, P.

MULTISCALE SEISMIC IMAGING OF THE SAN-ANDREAS-FAULT SYSTEM.
*Buske, S., Gutjahr, S. and Reshetnikov, A.

SEISMIC INVESTIGATIONS ACROSS THE MOROCCAN ATLAS (SIMA).
*Carbonell, R., Harnafi, M.' Gallart, J., Levander, A., Teixell, A., Ayarza, P., Kchikach, A., Amrhar, M. and Charroud, M.

SEISMIC ANISOTROPY OF CRUST AND MANTLE IN EAST TIBET AND NEIGHBOURING AREAS.
*Chen, Y., Zhang, Z., Sun, C. and Badal, J.

A NEW MODEL OF CRUSTAL STRUCTURE OF SIBERIA.
*Cherepanova, Y., Artemieva, I., and Hans Thybo, H.

THE NATURE OF THE MOHO TRANSITION IN NW CANADA FROM COMBINED NEAR-VERTICAL AND WIDE-ANGLE SEISMIC REFLECTION STUDIES.
*Clowes, R.M., and Oueity, J.

MANTLE WEDGE FLUIDS UNDER NE NORTH ISLAND, NEW ZEALAND.
*Davey, F., Reyners, M., and Ristau, J.

REFLECTION SEISMIC IMAGING IN THE SKELLEFTE ORE DISTRICT, NORTHERN SWEDEN: A FRAMEWORK FOR 3D/4D GEOLOGIC MODELLING.
*Dehghannejad, M., Juhlin, C., Malehmir, A., Skyttä, P. and Weihed, P.

RECEIVER FUNCTIONS OF MANTLE DISCONTINUITIES IN FENNOSCANDIA.
Frasetto, A. and *Thybo, H.

CONDUCTIVITY MODELS DERIVED FROM MT DATA AND ITS CORRELATION WITH SEISMIC REFLECTION PROFILES IN WESTERN SKELLEFTE DISTRICT, NORTHERN SWEDEN.
*Garcia Juanatey, M.A., Hübert, J., Tryggvason, A., Dehghannejad, M. and Juhlin, C.

RESOLVING COMPLEX STRUCTURES FROM VERTICAL SEISMIC PROFILE (VSP) SURVEYS: A CASE STUDY FROM THE ALPINE FAULT, NEW ZEALAND
*Greenwood, A., Toy, V. and Urosevic, M.

SEISMIC IMAGES OF THE TREMOR REGION AROUND CHOLAME, CALIFORNIA.
*Gutjahr, S. and Buske, S.

SEISMIC IMAGING OF MASSIVE SULPHIDES IN PYHÄSALMI, FINLAND.
*Heinonen, S., Imaña, M., Kukkonen, I., and Heikkinen, P.

SEISMIC OCEANOGRAPHY: NOW FOR SOMETHING COMPLETELY DIFFERENT.
*Hobbs, R., Grocke, D., Sargent, C. and Maloney, D.

AUTOCORRELATION ANALYSIS OF AMBIENT NOISE IN NE JAPAN.
*Ito, Y., Chujo, K., Takagi, R., Hino, R., Suzuki, S., Yamada, T., Shinohara, M., Kanazawa, T., Murai, Y., Shiomi, K. and Obara, K.

PECULIAR CONFIGURATION OF THE PLATE BENEATH CENTRAL JAPAN.
Ito, T., Komada, N., Mizohata, S., Kikuchi, S., Fujiwara, A., Abe, S., *Tsumura, N., Kojima, S., Kano, K., Omura, K., Takeda, T., Obara, K., Iwasaki, T., Yasutaka Ikeda, Y., Yamakita, S., Kaneda, H., Matsunami, K., Fukahata, Y., Sato, T., Hayakawa, M., and Takahashi, A.

COMPUTATIONAL MINERALOGY IN THE C2C PROJECT.
*Jochym, P.T.

NEW PLOTS FOR OLD: REPROCESSING OF GEOSCIENCE AUSTRALIA'S LEGACY SEISMIC REFLECTION DATA.
*Jones, L.E.A. and Barton, T.J.

DEEP SEISMIC REFLECTION IMAGING OF THE EASTERN DELAMERIAN FOLD BELT, SOUTH AUSTRALIA AND WESTERN VICTORIA, AUSTRALIA.
*Jones, L.E.A., Cayley, R., Korsch, R., Rawling, T., Morand, V., Betts, P., Moore, D. and Kennett, B.L.N.

SHALLOW REFLECTION IMAGING OF EAST ONGUL ISLAND, THE LÜTZOW-HOLM COMPLEX, EAST ANTARCTICA.
*Kanao, M., Takemoto, T., Fujiwara, A., Ito, K., and Ikawa, T.

BROADBAND SEISMICS DURING IPY IN EAST ANTARCTICA (AGAP/GAMSEIS).
*Kanao, M., Wiens, D., Nyblade, A., Tanaka, S. and Tsuboi, S.

INDEPTH IV WIDE-ANGLE SEISMIC IMAGING IN NORTHEAST TIBET.
*Karplus, M., Klemperer, S., Zhao, W., Wu, Z., Brown, L.D., Shi, D., Mechie, J. and Chen, C.

MULTI-WAVE DEEP SEISMIC FOR STRUCTURAL AND COMPOSITIONAL OFFSHORE STUDIES OF THE CRUST AND UPPER MANTLE (CASE STUDY OF THE SOUTH OKHOTSK DEEP TROUGH).
*Kashubin, S.N., Milshtein, E.D., Miasnikov, F.V., Bedenko, V.V., Verba, M.L., Atakov, A.I., Roslov, Y.V. and Sakulina, T.S.

CHARACTERIZING GREAT BASIN STRUCTURE FROM A 3D SEISMIC VOLUME, HAWTHORNE GEOTHERMAL PROSPECT, NEVADA, USA.
*Kell-Hills, A., Louie, J., Kent, G., Pullammanappallil, S., Sabin, A. and Lazaro, M.

INSTABILITY OF THE CRUSTAL THERMOBARIC ZONES OF LOW VELOCITY.
*Korchin, V.

GEODYNAMIC IMPLICATIONS OF A DEEP SEISMIC REFLECTION TRANSECT FROM THE WESTERN EYRE PENINSULA IN SOUTH AUSTRALIA TO THE DARLING BASIN IN NEW SOUTH WALES.
*Korsch, R.J., Preiss, W.V., Blewett, R.S., Cowley, W.M., Neumann, N.L., Fabris, A.J., Fraser, G.L., Dutch, R., Fomin, T., Holzschuh, J., Fricke, C.E., Reid, A.J., Carr, L.K. and Bendall, B.R.

GEODYNAMIC SIGNIFICANCE OF RESULTS FROM THE 2007 NORTH QUEENSLAND DEEP SEISMIC REFLECTION SURVEY.
*Korsch, R.J., Henson, P.A., Champion, D.C., Blewett, R.S., Huston, D.L., Nakamura, A., Holzschuh, J., Costelloe, R.D., Withnall, I.W., Hutton, L.J., Henderson, R.A., Fergusson, C.L., Collins, W.J. , Chopping, R., Williams, N.C. and Roy, I.G.

CRUSTAL STRUCTURE OF THE IZU COLLISION ZONE, CENTRAL JAPAN.
*Kurashimo, E., Sato, H., Abe, S., Kato, N., Ishikawa, M., Obara, K.

NEW RESULTS FROM INTENSIVE STUDIES OF THE RUSSIAN PROGRAM – THE STATE NETWORK OF GEOLOGICAL-GEOPHYSICAL TRANSECTS AND DEEP BOREHOLES.
Lipilin, A.V., , *Erinchek, Y.M., Petrov, O.V.

LINKING 3-D CRUSTAL VELOCITY AND REFLECTIVITY IMAGING BASED ON CELEBRATION 2000 DATA.
*Malinowski, M., Sroda, P., Grad, M., and Guterch, A.

CONVERTED-WAVE IMAGING IN THE FLIN FLON MINING CAMP, CANADA.
*Malinowski, M. and White, D.

A NEW MODEL OF THE P-WAVE VELOCITY DISTRIBUTION IN THE UPPER MANTLE BASED ON THE USARRAY DATA.
*Malinowski, M., Perchuc, E. and Dec, M.

GEOLOGICAL CO2 STORAGE IN SALINE AQUIFER: THE SPANISH SCIENTIFIC PILOT PLANT.
*Martí, D., Calahorrano, A., Alcalde, J., Palomeras, I., Ayarza, P., Carbonell, R. and Pérez-Estaún, A.

NORTH POLE – EQUATOR: PROPOSALS FOR A NEW INTERNATIONAL GEOTRANSECT, ARCTIC OCEAN – CHUKTKA – OKHOTSK SEA – PACIFIC OCEAN.
*Morozov, A.F., Erinchek, Y.M., Lipilin, A.V., and Petrov, O.V.

SEISMIC IMAGING OF THE ALPINE FAULT, NEW ZEALAND, AT WHATAROA RIVER.
*Oelke, A., Buske, S. and Bannister, S.

IBERSEIS WIDE-ANGLE S-VELOCITY MODELS: NEW CONSTRAINTS ON THE NATURE OF THE SW-IBERIA CRUST.
*Palomeras, I., Martí, D., Carbonell, R., Ayarza, P., Simancas, F., Martínez-Poyatos, D., Azor, A., González-Lodeiro, F. and Pérez-Estaún, A.

THE EARTH'S CRUST TYPES OF NORTHERN EURASIA FROM DEEP SEISMIC INVESTIGATIONS.
*Petrov, O.V., Kashubin, S.N., Shokalsky, S.P., Pavlenkova, N.I. and Poselov, V.A.

NEW HIGH-RESOLUTION SEISMIC IMAGING OF AUSTRALIAN LITHOSPHERE AND THE CMB WITH THE WOMBAT ARRAY.
*Pozgay, S., Rawlinson, N. and Tkalcic, H.

COMBINING AMBIENT SEISMIC AND RECEIVER FUNCTION ANALYSIS TOWARDS IMPROVED PASSIVE SEISMIC IMAGING ALONG CRUSTAL TRANSECTS.
*Reading, A., Tkalčić, H. and Kennett, B.L.N.

EMULATION: A FAST STOCHASTIC TECHNIQUE FOR JOINT CONSTRAINT.
*Roberts, A., Hobbs, R, , Goldstein, M., Moorkamp, M., Jegen, M. Heincke, B.

VELOCITY MODELS IN DEEP SEISMIC INVESTIGATIONS.
*Roslov, Y., Sakoulina, T. and Krupnova, N.

DEEP STRUCTURE OF THE EARTH'S CRUST OF THE OKHOTSK SEA SHELF FROM COMPLEX GEOPHYSICAL RESEARCHES ALONG PROFILE 2-DW-M, MAGADAN – SOUTHERN KURILE ISLANDS.
*Sakoulina, T.S., Verba, M.L., Roslov, Yu.V., Krupnova, N.A., Musin, M.V. and Serzhantov, R.B.

AUSMOHO: THE MOHO MAP OF THE AUSTRALIAN CONTINENT.
*Salmon, M., Saygin, E. and the AusMoho Group.

DEEP STRUCTURE OF LITHOSPHERE IN ALTAI-SAYANY SEISMIC REGION ON EVIDENCE DERIVED FROM EARTHQUAKES AND POWERFUL VIBRATOR SOURCES.
*Salnikov, A., Seleznev, V. , Solovyov, V. and Yemanov, A.

A RADICALLY NEW TECHNOLOGY FOR DEEP SEISMIC SOUNDING BY THE USE OF MOBILE SEISMIC VIBRATORS AND SELF-CONTAINED RECORDERS.
*Salnikov, A., Efimov, A., Trigubovich, G., Yemanov, A., Solovyov, V., Lipilin, A.

BASIN FORMATION AND INVERSION OF THE BACK-ARC, NIIGATA BASIN, CENTRAL JAPAN.
*Sato, H., Abe, S., Kawai, N., Saito, H., Kato, N., Iwasaki, T., Shiraishi, K., Ishiyama, T., and Inaba, M.

DEEP SEISMIC REFLECTION PROFILING OF THE SUBDUCTION MEGATHRUST SYSTEM ACROSS THE SAGAMI TROUGH AND TOKYO BAY, CENTRAL JAPAN.
*Sato, H., Iwasaki, T., Abe, S., Saito, H., Kawanaka, T. and Hirata, N.

GEOMETRY OF THE PHILIPPINE SEA SLAB BENEATH THE IZU COLLISION ZONE, CENTRAL JAPAN.
*Sato, H., Abe, S., Kurashimo, E., Iwasaki, T., Arai, R., Kato, N. and Hirata, N.

EARTHQUAKES IN UTTARANCHAL HIMALAYA, INDIA.
*Shandilya, A.

SEDIMENTARY AND CRUSTAL STRUCTURE FROM THE ELLESMERE ISLAND AND GREENLAND CONTINENTAL SHELF ONTO THE LOMONOSOV RIDGE, ARCTIC OCEAN.
*Snyder, D., Jackson, H. R., Dahl-Jensen, T., Schimeld, J., Chian, D., Funck, T. and Asudeh, I.

GEOSCIENCE AUSTRALIA'S DEEP CRUSTAL SEISMIC REFLECTION AND MAGNETOTELLURIC PROGRAMME, 2006-2010.

*Stolz, N., Jones, L., Costelloe, R., Duan, J., Fomin, T., Holzschuh, J., Maher, J., Milligan, P. and Nakamura, A.

MOHO DEPTH AND AGE IN SOUTHERN NORWAY.

Stratford, W. and *Thybo, H.

SKS SPLITTING MEASURE WITH HORIZONTAL COMPONENT MISALIGNMENT.

*Tian, X., Zhang, J., Si, S., Wang, J., Chen, Y. and Zhang, Z.

THE STRUCTURE OF THE DEEP CRUST AND THE DISTRIBUTION OF HYDROCARBON DEPOSITS IN THE SEDIMENTARY COVER: A NEW SEISMIC REFLECTION EXPERIMENT IN THE EASTERN PART OF THE RUSSIAN PLATFORM.

*Trofimov, V., Khromov, V., Romanov, Y., Trofimov, A., Nurgaliev, D., Borisov, A. and Lebedkin, P.

3-D QP STRUCTURE IN THE SOURCE REGION OF THE 2007 NOTO HANTO EARTHQUAKE.

*Tsumura, N., Yoshizumi, T., Kobayashi, R. and the Group for aftershock observation of the 2007 Noto Hanto Earthquake

IMAGING TURKEY'S CRUST WITH RECEIVER FUNCTIONS AND AMBIENT NOISE.

*Vanacore, E., Saygin, E., Cubuk, Y. and Tamaz, T.

THE BARENTS-KARA REGION FRAMEWORK FROM THE RESULTS OF DEEP SEISMIC PROFILING.

*Vinokurov, I., Kalenich, A., Katsev, V. and Matveev, Y.

RECOGNITION OF CARBONATE FACIES BY SEISMIC ATTRIBUTES: APPLICATION TO GEOTHERMAL EXPLORATION.

Von Hartmann, H., Buness, H., Schulz, R., *Krawczyk, C.M.

AMBIENT NOISE TOMOGRAPHY OF TASMANIA.

*Young, M. and Rawlinson, N.

CRUSTAL VELOCITY STRUCTURE OF THE CARIBBEAN-SOUTH AMERICA PLATE BOUNDARY BETWEEN 60W AND 70W FROM CONTROLLED-SOURCE SEISMIC DATA.

*Zelt, C., Christeson, G., Clark, S., Bezada, M., Magnani, B., Guedez, M., Levander, A. and Schmitz, M.

SEISMIX 2010 – Abstracts

(Abstracts are in alphabetical order by first author; presenter marked by an asterisk *)

Oral

Are global and regional models of crustal structure consistent with seismic data? A European-Siberian example.

***Artemieva, I.[1], Thybo, H.[1] and Cherepanova, Y.[1]**

1) University of Copenhagen, Denmark

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We compare global and regional models of the structure of the crust in an area that covers about 1/4 of the globe and encompasses most of Europe, West Siberia Basin, and the Siberian Craton. Our analysis is based on a new ("from scratch") compilation of all available seismic data for the region, acquired and interpreted from the late 1960-ies until present, and includes the results of seismic reflection, refraction and receiver functions studies. Unreliable constraints, such as based on interpolations, gravity modelling, and tectonic similarities, are intentionally excluded from the compilation. The new database comprises detailed and reliable information on the seismic structure of the crust for most of the tectonic structures of the region and allows for examination of spatial correlations with tectonic and geological structures. We are particularly interested if global and regional models of the structure of the crust are consistent with reliable seismic data. We compare such parameters as crustal thickness, thickness of sediments, and average crustal velocities with global crustal models CRUST5.1 and CRUST2.0 as well with a number of recent regional crustal models. The analysis indicates huge discrepancies between the actual seismic data and the widely used crustal models. In particular, the crustal thickness often deviates from the model values by +/- 10-15 km, and only few places deviate by less than 5 km. Similarly, we compare seismic structure of the crust for different tectonic settings in Europe and Siberia with the global averages for the same types of tectonic structures, and show that real crustal structure in Eurasia significantly deviates from the global averages.

Poster

Crust and upper mantle of Europe, Greenland, and the North Atlantic region: an overview.

***Artemieva, I.[1] and Thybo, H.[1]**

1) University of Copenhagen, Denmark

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We review the structure of the crust and the upper mantle in an area which covers about 1/8 of the globe and encompasses most of Europe, Iceland, Greenland, and Svalbard. Using the results from seismic (reflection and refraction profiles, P- and S-wave body-wave and surface-wave tomography), thermal, gravity, and petrologic studies (based both on the results of the authors and on literature compilations), we propose an integrated model of the structure and physical properties of the crust (a newly constrained model by the authors) and the upper mantle in the entire region down to a depth of 250-300 km. Our primary attention is to the lithosphere structure of the onshore parts of the region, but the less well constrained deep structure of the North Atlantic is also discussed. The results are summarized in a series of maps of lateral variations in crustal and lithospheric thicknesses, seismic shear wave velocity at different depth slices, heat flow and lithosphere temperatures, as well as density and compositional variations in the lithospheric mantle.

Oral

Are mantle xenoliths representative of the cratonic mantle?

***Artemieva, I.[1]**

1) University of Copenhagen, Denmark

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Three independent approaches are used to demonstrate that xenolith data on densities and seismic velocities in the Archean-Proterozoic lithospheric mantle (LM) may be non-representative of the intact (unsampled by mantle-derived peridotite xenoliths) cratonic mantle. The first example is based on buoyancy modelling for the East European Craton (EEC), that lacks surface relief despite huge amplitudes of topography at the top of the basement (20+ km), at the crustal base (ca. 30 km), and at the lithosphere-asthenosphere boundary (200+ km). The results indicate either a smaller density deficit (ca. 0.9 per cent) in the LM of the Archean-Paleoproterozoic parts of the EEC than predicted by global data on mantle xenoliths (ca. 1.5 per cent) or the presence of a strong convective downwelling in the mantle beneath the craton interior. The second example is based on the analysis of seismic velocity variations of a non-thermal origin in the continental LM. In agreement with xenolith data, strong positive velocity anomalies of non-thermal origin (attributed to mantle depletion) are determined for all of the cratons. However, in kimberlite provinces cratonic LM has much weaker positive compositional velocity anomalies than the adjacent "intact" cratonic mantle, implying that (pre-)kimberlite magmatism has melt-metasomatised the cratonic LM. The third example is based on the results of global gravity modelling in which the effect of spatially differential thermal expansion has been eliminated from mantle residual gravity (density) anomalies. These results indicate a large scatter of density deficit in the cratonic lithosphere, uncorrelated with crustal differentiation ages.

Poster

The seismic signature of crustal magma and fluid from deep seismic sounding data across the Tengchong volcanic area.

Bai, Z.[1], Klemperer, S.[2], Zhang, Z.[1], Wang, C.[3] and *Chen, Y.[1]

1) State Key Laboratory for Lithospheric Evolution, Institute of Geology and Geophysics, Chinese Academy of Science, Beijing, China, 2) Stanford University, USA, 3) Institute of Geophysics, China Earthquake Administration

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The weakened lithosphere around eastern margins of the Tibetan Plateau has been investigated by studying the average Pn and Sn velocities, the 3D upper mantle velocity variations of P wave and S wave, and imaging results from MT data. The Tengchong volcanic area is adjacent to the eastern Tibetan Plateau and famous for its springs, volcanic-geothermal activity, and as a major earthquake region of the Chinese mainland. To probe the deep crustal environment for the Tengchong volcanic-geothermal activity, a deep seismic sounding (DSS) project was carried out across study area in 1999. In this paper, the seismic signature of crustal magma and fluid is explored from the DSS data with the seismic attribute fusion (SAF) technique, which revealed four possible positions for magma generation, together with some locations for porous and fractured geothermal fluid conduits beneath the Tengchong volcanic area. The attributes studied not only included the V_p, V_s and V_p/V_s results derived from a new inversion method based on the No-Ray-Tomography technique, but also the frequency content of seismic waves. The bandwidth and high frequency energy of P-wave were also studied. The investigations also included assessing attributes such as the attenuation factor Q_p , shear wave splitting characteristics, and the amplitude ratio $A_s/(A_s+A_p)$ in this geothermal fusion process. Finally, our sub-surface geothermal fluid image indicated a mechanism for the surface hot springs: the large amount of heat and fluid released by the crystallization of magma were transmitted upward into the fluid-filled rock, and this fluid migrates upward along a fracture network under high pressure. Hence the widespread hot springs in Tengchong volcanic area were developed.

The subsurface geothermal fluid image, regional volcanic and geothermal activity, and seismicity suggest that the main area at risk of tectonic activity was concentrated to the south of Tengchong City, especially around the shot point (SP) Tuantian. Near this shotpoint there is a seismogenic environment for the occurrence of moderate-to-strong earthquakes. Precautions should be taken in this area against the risk of potential earthquake activity. Our geothermal fusion image also clearly revealed two remarkable features on the Moho discontinuity through which the heat from the upper mantle could be transmitted upward into the Earth’s crust.

Oral

Understanding continental structure: integrating crust and mantle information.

***Begg, G.1, Griffin, W.L.2, O'Reilly, S.Y.2, Belousova, E.2 and Natapov, L.2**

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Integration of geological, geophysical and geochemical data has enabled systematic mapping of the architecture, composition and history of the global Sub-Continental Lithospheric Mantle (SCLM). This work suggests that >70% of SCLM is of Archean derivation, a finding consistent with the > 60% Archean crustal growth figure derived from a global compilation of U-Pb and Hf isotope geochronology data (Belousova et al., in review). Most preserved Proterozoic (and much Phanerozoic) crust overlies Archean SCLM that has been variably refertilised and metasomatised by mantle melts associated with convergent margin, post-collisional, and mantle plume processes. This suggests that consideration of lithospheric preservation and recycling is crucial to understanding Earth evolution, including the concepts of crustal, as against continental, growth. In a recycling model, ancient, rigid, bouyant SCLM survives the rifting and accretionary processes of supercontinent cycles, whilst juvenile, fertile, dense SCLM typical of island arcs is largely returned to the convecting mantle. Significant areas of preserved post-Archean juvenile crust can be attributed to the complexities of plate tectonic processes. These include:- (i) obduction; and (ii) resurfacing. The latter may involve mantle-derived magmatism during regional extension, or follow rifting and detachment of variable (upper- to whole-) crustal thicknesses. Post-Archean continental net growth is therefore likely to be minimal. Plate tectonic processes implicit in supercontinent cycles redistribute continental lithosphere via continental collisions and microcontinent migrations. The interplay between mantle lithosphere, tectonic setting, and geodynamics generates the spectrum of features observed in studies of crustal architecture. Firstly, crustal shortening is a key outcome of collisional or accretionary processes that result in lithospheric mantle delamination. The symptomatic folds and thrusts are readily observed in multiple data sets, including geology and magnetics in plan-view, and magnetotellurics and reflection seismic in sectional-view. Secondly, segmentation of anhydrous depleted SCLM during rifting events results in SCLM domains with discrete boundaries, and a crust thinned by shallow-dipping extensional structures. These extensional features are readily imaged in seismic reflection studies, while both reflection and refraction studies may detect significant Moho offsets at domain boundaries. The exposure of significant tracts (hundreds of km across) of exposed SCLM outboard of thinned continental crust is a common feature of divergent margins through time. Rather than indicating stretching of SCLM, these features are more readily explained by crustal detachment facilitated by a weak mid-lower crust. Thirdly, transcurrent tectonics is likely to be focused along existing steep SCLM boundaries, which in turn will generate steeply-dipping crustal scale faults. The latter are difficult to image in crustal seismic studies. Fourthly, density increases in the lithosphere favor basin formation, driven by the addition of mantle melts to either the crust or SCLM. Lastly, both mantle convection (including mantle plumes), and the rise and fall of geotherms in the lithosphere, influence uplift and sedimentation patterns. Through careful integration of data types, with allowance for tectonic and geodynamic processes and an appreciation of the diversity of SCLM, we have our best chance to solve the mysteries of continental structure.

Oral and poster

MEMOTATUR in SE Fennoscandia, East European Craton.

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The CDP profile Mezen' III was carried out by SPETSGEOFIZIKA (Russia) and recently reproduced and interpreted in connection with the MEMOTATUR experiment. Mezen' III strikes SW-NE and runs ca. 500 km along the south-easternmost margin of the Fennoscandian crustal segment of the East European Craton, where that margin faces the Central Russian Suture Belt and northwestern Volgo-Uralia. In the Onega horst in the southwest, the crystalline crust is covered by ca. 2 km thick Mesoproterozoic to Paleozoic sedimentary deposits, which reach a thickness of ca. 10 km in the Mezen' rift system in the northeast. Concomitantly, the thickness of the crust changes from ca. 40 km in the southwest to ca. 35 km beneath the Mezen' rifts. With regard to crustal structure, the Mezen' III profile is situated within the Lapland-Kola collisional orogen that extends from the Archean domain of the Fennoscandian Baltic Shield (Daly et al., 2006) into the area of the Russian Platform, where it is hidden beneath a sedimentary cover. The profile stretches across the covered Belomorian Belt- and Kola terranes of that orogen, which have distinct seismic crustal patterns. The Belomorian Belt features fairly flat-lying wedges and blocks of rocks with various degrees of reflectivity, separated by extensive gently inclined reflectors. Previous studies indicate that, within the Belomorian Belt, relatively homogeneous transparent layers represent 2.8-2.7 Ga Archean granitoids, migmatites and granite gneisses, while layers with more contrasting and higher reflectivities, sometimes internally layered, correlate with meta-sedimentary and metavolcanic rocks. Sparsely, the latter also occur within the major, seismically little structured, seismic patterns of the lower and middle crust that has been "magmatically" homogenized. The presence of characteristic Early Paleoproterozoic mafic sills along some detachments is imaged as areas of high reflectivity and intensity. Within the Onega Horst (the Northern Dvina Block of the Belomorian Belt) Proterozoic and Paleozoic mafic dyke swarms recorded by magnetic and gravity anomalies cut the crust along numerous normal faults. The Moho is apparently uplifted beneath this block. The Kola Archean terranes and Paleoproterozoic belts, like the Murmansk, Keivy, Imandra-Varzuga, Tersk and others differ by having lesser amount of granitoids. There, the seismic patterns indicate a system of flat-lying and inclined extensive and thick blocks of varying, mostly high reflectivity. Mafic rocks appear to form a substantial part of the lower crust beneath the Kola terranes. These form a "crocodile-jaw" structure where they meet the Belomorian Belt in the middle crust, being both overthrusted and underthrusted in relation to that Belt within the part of the profile between 2450 and 2560 km. Moho offsets correspond well with the collisional tectonics.

Oral

TATSEIS imaging the upper lithosphere and Archean to Paleoproterozoic evolution of Volgo-Uralia, East European Craton.

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TATSEIS is a key CDP profile of the MEMOTATUR (MEzen'-MOscow-TATarstan-URal) seismic reflection experiment, which tested geophysical, particularly seismic, criteria in the search for hydrocarbon deposits. The high quality of the presently available seismic images together with other geophysical data and numerous drill-core materials allows new insight into the crustal and upper-mantle structure and evolution of Volgo-Uralia and Fennoscandia, two crustal segments of the East European Craton, and their crustal evolution. These segments have their own specific tectonic patterns and Paleoproterozoic crustal evolutions, and are separated by the wide Central Russian Suture Belt marked by the Meso to Neoproterozoic Mid-Russian aulacogen. The Paleo-to Neoarchean crust of Volgo-Uralia was reworked in the Paleoproterozoic, firstly between 2.5 and 2.0 Ga and later between ca. 1.9 and 1.8 Ga. Volgo-Uralia has a remarkable crustal structure featuring several circular patterns ("mosaics") of magnetic and gravity anomalies up to more than 350 km across. Tectonically, these have been interpreted as post-orogenic Paleoproterozoic domes developed in strongly stacked Neoarchean crust and were bounded by fault zones of various ages. TATSEIS, which runs NW-SE for more than 1000 km, transects several of these structures, namely the Oka-Volga megablock (OV) and the edge of the Upper Vyatka (UV), in the northwest, and the Middle Volga megablock (MV) in the southeast. These are separated by the Kama-Vyatka belt (KVB). The results indicate that the MV, KVB and partly UV differ very much from the OV by having the three-layered, mostly Archean crust with an up to 35 km thick lower crust and an up to 20 km thick "transparent" layer in the upper and the middle crust. The Moho is sharp with offsets up to 15 km. Numerous inclined reflectors, most probably faults, dip gently NW and complicate the lower crust, partly even penetrating the upper mantle down to ca. 60 km. In contrast, the Moho beneath OV is found at depths of ca. 55-60 km depth, being smooth and weakly expressed. Strong reflectors are absent in the semi-transparent lower and middle crust. All this suggests a mantle upwelling and underplating, and highly extended crust. Characteristic are listric faults, breaking in the upper and middle crust and flattening at depths of 30 to 40 km. A ca. 10 km thick extremely reflective upper crustal layer overlies the OV mantle diapir and partly rests atop the Neoarchean crust. Highly metamorphosed volcanic and sedimentary rocks with numerous mafic intrusions have been disclosed by drillings entering this layer. The whole sequence resembles the 2.5-2.0 Ga Karelian Supergroup of Fennoscandia and similar successions worldwide. In conclusions, TATSEIS evidences that the unusual tectonic structure of Volgo-Uralia with its large "domes" and "basins" is a result of mantle upwelling and attempted break-up of the Archean lithosphere during the Early Paleoproterozoic. Further work is needed to assess whether Volgo-Uralia was already away or rifted away from Fennoscandia during this large-scale event and had its own separate history until it was incorporated into the unified East European Craton at 1.8-1.7 Ga.

Oral

Deep seismic profiling with ambient noise.

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Seismic interferometry has become a well established technique for imaging lithospheric velocity variations by tomographic analysis of surface wave information from extended recordings of ambient noise. Perhaps less well known among the deep seismic community is that the same technique can extract body wave information, although this is a topic of substantial research related to the oil exploration. Since source costs are a major limiting factor for expanding coverage by deep seismic reflection profiling, the ambient noise technique deserves serious attention as an alternative to conventional controlled sources in deep reflection profiling. Examples of recordings of deep crustal (e.g. basement or deeper) reflection/refraction data using ambient sources are still rare. Here I review examples from Japan and the western U.S. as well as our own experience with using ambient noise techniques to detect and map crustal structure on Montserrat and Taiwan. If proven, this approach will have a major impact on the viability of future 2D, 3D and especially 4D crustal investigations.

Poster

The INDEPTH Transect: a geophysical journey across the Tibetan Plateau.

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In the summer of 2010, Project INDEPTH will essentially achieve its original vision of a modern geological and geophysical transect across of the Tibetan Plateau. INDEPTH IV, a suite of surveys focussed on the northeastern boundary of the Tibetan Plateau, represents the culmination of an initiative that began in 1992 with a simple multichannel reflection profile in the Himalayas, augmented by a modest wide-angle piggyback experiment. By the time INDEPTH reached the Qaidam Basin, both the techniques for probing, and concepts put forward to explain, the Himalaya-Tibet collision zone had undergone a dramatic evolution. In addition, the INDEPTH profiles now stand as but one of a number of major seismic experiments which have probed key aspects of lithospheric structure and process. Originally intended to focus primarily on the application of the then relatively novel multichannel seismic reflection technique to detail crustal structure, INDEPTH quickly evolved to integrate active (reflection, refraction) and passive (receiver function, tomographic inversion of earthquake recordings) seismology, and to link the seismic results with magnetotelluric observations in a particularly compelling manner. This combination proved critical to the interpretation of crustal melting at the southern margin of the plateau. INDEPTH IV, for example, choreographed reflection (P wave), refraction (P and S wave), receiver function and magnetotelluric profiles across the Kunlun Mountains with a regional 2D seismic array (ASCENT) to probe mantle structure from central Tibet to the Qilian Shan northeast of the Qaidam Basin. INDEPTH's targets have also shifted in response to the evolution of tectonic models emerging to explain the uplift of the plateau, from detailing the geometry of underthrusting of the Indian plate to the significance of channel flow in plateau uplift, to defining the mantle suture beneath central Tibet, to searching for evidence of southward underthrusting of Asia along the northern boundary of the plateau. Beyond their initial interpretations, INDEPTH results have served as important components in joint analysis with observations from other major seismic experiments in Tibet. The latest results from INDEPTH IV and the complementary ASCENT project are the focus of other presentations at this meeting. Here we take this opportunity to look back over the key findings of the INDEPTH traverse with the perspectives provided by subsequent geophysical surveys that have also confronted issues that were the focus of the INDEPTH effort.

Oral

Reflection imaging of deep volcanic structure beneath Montserrat.

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The SEA-CALIPSO experiment, carried out in December, 2007, was designed to image structure related to active volcanism beneath the island of Montserrat in the Caribbean. As part of that experiment, approximately 200 "Texan" recorders with 5 Hz geophones were deployed in 3 linear arrays at a nominal spacing of 100 m, primarily to record signals from an airgun source towed offshore around the island. One goal of this controlled source experiment was to probe for magma and related structure using reflected phases from the airguns. However, the wide-angle geometries imposed by topography and bathymetry greatly limited the effectiveness of this approach. Because the recorders were operating in continuous mode for three days, a number of microearthquakes near the active summit of Soufriere Hills Volcano (SVO) were also recorded. Here we report results of processing those recordings as multichannel CMP reflection sources, with emphasis on careful statics corrections and coherency enhancement. The results indicate the presence of subhorizontal reflectors at depths between 6 and 19 km, which we interpret as sill complexes emplaced beneath SVO. These results suggest that densely spaced (< 100 m) arrays array recording natural events in volcanic regions are a viable alternative to controlled source surveys, especially where access is severely restricted near active volcanic centres. In addition, continuous recording by the Texans enabled an attempt to extract body wave information from ambient noise. Application of cross correlation techniques were successful in recovering both direct and reflected P waves, suggesting that ambient noise may prove to be a new approach to deep seismic reflection profiling, especially in difficult terrain or with limited budgets.

Oral

Lithospheric structure beneath Taiwan from reflection and conversion analysis of explosion and earthquake sources as part of Project TAIGER.

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The land component of Project TAIGER included three co-located active and passive seismic transects across the key tectonic elements of Taiwan. These NW to SE traverses were occupied by broadband seismographs intended to record both teleseismic and local earthquake sources for tomographic and convertor imaging, then subsequently re-occupied by short period sensors deployed at much closer spacing to record explosive sources for reflection/refraction imaging. P to S and S to P receiver functions computed from the teleseismic recording provide new constraints on both crustal and lithospheric thickness. Reflections from the explosion sources are surprisingly few, but include both Moho events and an anomalous mid-crustal reflector (Datong bright spot) on the northernmost transect. Key results from the passive data include confirmation of a crustal "root" beneath east central Taiwan, with the crust thickening from approximately 30 km beneath the western plain to close to 50 km beneath the central range. The Taiwanese lithosphere appears to exhibit relatively little thinning with respect to the adjacent Asian lithosphere. Although recordings of test shots by TAIGER in central Taiwan indicate mid-crustal reflectors that could mark a subhorizontal decollement, these could only be traced to the vicinity of the Lishan Fault; plans for subsequent reflection profiling further east were cancelled by logistical constraints. Explosion recordings along transects to the south and north provide no clear reflection evidence of a regional decollement, although the Datong bright spot lies at an appropriate depth.

Poster

Seismic imaging of the subduction zone in Southern Chile.

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We present the results of a three-component reflection seismic survey across the seismogenic coupling zone in the area of the 1960 Valdivia earthquake in Southern Central Chile (38.2 deg S). This data set has been acquired within the framework of project TIPTEQ (from The Incoming Plate to megaThrust Earthquake Processes) which aimed at deriving the structural and petrophysical properties of the hypocentral area as well as the surrounding crust and mantle. Our main focus was on the application of advanced seismic imaging techniques in order to obtain a high-resolution structural image. We have applied Kirchhoff-Prestack-Depth-Migration (KPSDM) and Fresnel-Volume-Migration (FVM) to enhance the structural image as well as Reflection-Image-Spectroscopy (RIS) to characterize the subsurface in terms of its scattering properties. The KPSDM and FVM sections show varying reflectivity along the subducting Nazca plate. Below the coast the plate interface can be observed at 25 km depth as the sharp lower boundary of a 2-5 km thick, highly reflective region which we interpret as a subduction channel. The plate interface itself can be traced down to depths of 50-60 km where we observe strong reflectivity along the plate interface as well as in the continental mantle wedge above it. The sections show a segmented forearc crust and major features in the accretionary wedge like the Lanalhue fault zone can be identified. At the eastern end of the profile a bright west-dipping reflector appears almost perpendicular to the plate interface. The same processing sequence has been applied to the horizontal wavefield components of the seismic reflection data set. The S-wave image (SS) shows basically the same features as the P-wave image (PP) with only slightly more diffuse reflectivity. The subduction channel appears in both images at almost the same depth with a similar thickness along the plate interface. The application of RIS distinguishes between the frequency-selective seismic response of the different parts of this subduction environment. The variable reflectivity along the plate interface appears to be a high-frequency effect mainly caused by the heterogeneous overburden and is probably not a property of the interface itself. In the intermediate-frequency image the Lanalhue fault zone clearly separates the subsurface into an almost transparent western part and a highly reflective eastern part. Finally a combination of the different frequency-selective images shows additional structural details and demonstrates the main benefit of the RIS approach in terms of an improved subsurface characterization. We also present a comparison of the obtained seismic images with other geophysical data sets (local earthquake tomography, magnetotelluric images, etc.).

Oral and poster

Multiscale seismic imaging of the San-Andreas-Fault system.

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We have processed active and passive seismic data sets acquired in the vicinity of the San-Andreas-Fault (SAF) system at SAFOD and derived a detailed structural image of the fault system on multiple scales from the surface down to 10 km depth. On one hand we have processed an active 3-component seismic reflection data set (SAFOD2003). The imaging approach involves the separation of P- and S-waves and the subsequent application of our Fresnel-Volume-Migration technique which is particularly suited to image subvertical reflectors. The results are well resolved seismic images of the crustal structure across the SAF system and in particular in the direct vicinity of the SAFOD drill site. On the other hand we have processed passive seismic data sets acquired by an 80-level-3C-receiver array in the SAFOD main hole. We have located several seismic events which can be directly linked to the different fault branches. Furthermore we have exploited the reflected/scattered parts within the recorded wavefield by treating the events as pseudo-active sources with the hypocenter as the source point. This allows us to apply the same active seismic migration approaches to the corresponding passive seismic wavefield. Hence we have obtained high-resolution images of some fault branches in the vicinity of the borehole and the hypocenter which confirm the active surface seismic findings. We have combined our results also with additional available information from other geophysical disciplines (borehole, MT, etc.). This yields some new interesting insights into the crustal structure and the dynamics of this mega-shear zone on different scales and in particular in the vicinity of the SAFOD borehole.

Oral

Active crustal underplating beneath Nechako Basin.

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The volcanic-covered Nechako Basin of British Columbia is one of three intermontane basins in the Canadian Cordillera that lie between the Rocky Mountains in the east and the Coast Mountains in the west. The basin is bounded by strike-slip faults on its eastern and southwestern flanks and may comprise multiple sub-basins that developed during Eocene transtension. However, the evolution of the basin is poorly known, because the surface geology is largely obscured by glacial deposits and volcanic rocks. The east-west Anahim volcanic belt, which youngs to the east extends across the basin, with the most recent volcanism dated at 7200 years ago. To determine the tectonic controls on basin formation and support future hydrocarbon exploration in the area, Geoscience BC acquired 330 km of vibroseis reflection data in 2008, with four of the seven lines coincident with audiofrequency magnetotelluric profiles recorded the previous year. Since 1980s-vintage industry data appeared to be of poor quality, the 2008 seismic survey was designed to optimize signal penetration through the volcanic cover, ensure the recording of sub-volcanic reflections and maximise stack fold. The use of a 28 s-long 8-64 Hz upsweep with a 6 s listen time permitted the recovery of 18 s records through the use of extended correlation. In the upper crust, the Cretaceous sedimentary section, which is most prospective for hydrocarbon exploration, is well imaged, but only intermittently present. Eocene volcaniclastic sedimentary rocks are not particularly reflective. A ~10 ohm-m conductor is present at 0.5-1.5 km depth over much of the basin where Pliocene to Eocene volcanic rocks occur at the surface. In one area, the seismic data show that the conductor is bounded above and below by seismic reflectors, and the conductor appears to correspond to sedimentary strata that underlie the volcanics. Since this correlation does not exist in other areas where the conductor is present, the conductor may be due to fluids trapped in porous rocks that have been capped by volcanics that include permeability barriers. The seismic data also reveal subhorizontal lower crustal reflections at 8-12 s across the entire survey area with only isolated reflections in the mid-crust. Close to the volcanic line, higher amplitude reflections are present along a mid-crustal detachment, and these ~15 km deep reflectors correspond to localised mid-crustal conductors identified in the magnetotelluric survey. A swarm of small earthquakes, which began on 7 October 2007 and lasted approximately six months, is located at 27-31 km depth where lower crustal reflections are present, and 10-15 km beneath one of the mid-crustal conductors. We suggest that these earthquakes indicate the migration of magma in the lower crust, with melt moving upward to a midcrustal reservoir beneath the Anahim volcanic belt.

Oral

Resolving crustal structure and evolution of southwestern Iberian Peninsula.

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A relatively large variety of seismological tools have been employed, during the last decade, for imaging the structure of the lithosphere beneath the southern Iberia Peninsula and northern Africa. These include controlled source (active) deep normal incidence, wide-angle seismic reflection/refraction transects (IBERSEIS, ALCUDIA, SIMA), and natural source (passive) broad band seismic monitoring (TOPOIBERIA, SIBERIA). The multidisciplinary TOPOIBERIA project also included magnetotelluric data acquisition experiments and temporary GPS measurements. The thematic aim of this project TOPOIBERIA is to understand the interaction between deep and surface processes, by integrating research on geology, geophysics, and geodesy and numerical modelling. The active source deep seismic reflection data sets acquired in the southern Iberia Peninsula have provided an almost 700 km long high resolution normal incidence seismic images of the lithosphere from the Central Iberian Zone -CIZ- (South of Toledo, Central Spain) in the North to the Gulf of Cadiz (in the Southwest Spain). This data sets have revealed the internal architecture of the crust imaging a high amplitude, very reflective and high velocity body, known as the Iberian Reflective Body which has been interpreted as a the result of a peculiar evolutionary step, the action of a high temperature mantle plume affecting the southern part of the Iberian Peninsula during the Carboniferous. Furthermore, the seismic reflection data image acquired farther to the north places strong constraints on the way that deformation accommodates at upper and lower crustal levels and on the processes that control the development of normal faults and the tectonic model for crustal shortening and the emplacement of granitic plutons within the Central Iberian Zone. The whole seismic image suggests a strong decoupling between the upper and lower crust with a well defined mid-crustal discontinuity, most probably the brittle-to-ductile transition (the Conrad discontinuity). Partly coincident normal incidence data acquired within the CIZ indicates that there is most probably a tight relationship between the measured crustal thickening, the generation of normal faults and the emplacement of large amount of granites in central Iberia. The long offset, wide-angle seismic reflection/refraction data have placed constraints on the velocity structure of the upper mantle where a discontinuity has been modelled between 65 and 72 km depth. With respect to the natural source (passive) seismology different studies are currently being developed in the Southern Iberian Peninsula and North Africa. Preliminary results, concerning mainly the Betics-Rif orogenic system, include imaging using ambient noise and travel-time tomography, variations in crustal thickness from receiver functions, and mantle anisotropy from SKS splitting analyses.

Oral and poster

Seismic investigations across the Moroccan Atlas (SIMA).

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The Atlas Mountain range is a very young intra-continental Cenozoic orogenic belt located at the southern edge of the diffuse plate boundary zone separating Africa and Europe. The Atlas features topographic relief > 4000 m but geologic studies suggest it has experienced less than 20% shortening, thus raising the question of the origin of this high elevation. The small amount of shortening does not explain the high topographic relief without whole crustal involvement. Potential field geophysical studies and previous low resolution refraction experiments report a maximum crustal thickness of 40 km, suggesting that the range is out of isostatic equilibrium and that asthenospheric upwelling is needed to support the mountain load. In order to constrain the seismic velocity structure, the topography of the Mohorovicic discontinuity, and the crustal thickness across the Atlas mountains, a 700 km long deep seismic wide-angle reflection transect has been recently acquired by an international team. The north-south oriented transect extends from the Sahara Desert south of Merzouga near the Algeria border, to Ceuta at the Gibraltar arc (on the north coast of Morocco) crossing the High and Middle Atlas and the Rif mountain ranges. Seismic energy released at 6 shot points generated by detonating approximately 1 tonne of explosives was recorded by ~ 900 Reftek-125a (TEXAN) seismic recorders from the IRIS-PASSCAL pool. The seismic stations were deployed with an average station spacing of 650-750 m. The 6 shot points were located within the southern part of the transect with a shot spacing of ~60-70 km. The preliminary analysis of this high resolution data reveals: a relatively high signal-to-noise ratio; and interpreted PmP reflected phase which samples the crust mantle boundary. A second experiment aimed to sample in detail the Rif in northern Morocco is planned for 2011. SIMA is one component of the PICASSO research initiative. This multinational research programme includes a series of multi-disciplinary geophysical projects (The Spanish TopoIberia and Siberia Projects; the US-Spanish-Irish PICASSO project, with participation from Germany and France). These studies are designed to develop new understanding of the lithospheric processes that resulted in the present day geodynamic scenario of the western Mediterranean.

Oral

Large-scale, virtual seismic profiles: technique and results.

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We have developed a new approach to constructing deep-penetrating seismic profiles using earthquake-sources and successfully applied this technique over distances of up to 1,000 km in two geologically important regions. Along a north-south trending profile across southern and central Tibet, there are significant, regional variations in crustal thickness under near-constant elevation (~ 5 km above sea-level) over a distance of 550 km. The crust is as thick as 75 km in southern Tibet but shoals to just over 60 km under the Qiangtang Terrane in central Tibet where the deviation from Airy isostasy is equivalent to a thickness of over 10 km in missing crust. Northward thinning of crust occurs gradually over a distance of about 200 km where mechanical deformation, instead of pervasive magmatism, also seems to have disrupted the crust-mantle interface. Over a distance of nearly 1,000 km, an east-west trending profile, extending over the North China Craton, across the active Shanxi rift, and over the Ordos Plateau, also reveals intriguing changes in crustal thickness, almost by a factor of two over a distance of only about 100 km, which do not correlate well with topography. These examples demonstrate the power of this new approach which has some unique advantages: 1) Deep-penetration is virtually certain given the broadband nature and great power of earthquake-sources, and very large amplitude of wide-angle reflections, 2) low cost of operations, 3) negligible impact on the environment during field deployment, and 4) the same dataset is valuable for many other applications for basic research.

Poster

Seismic anisotropy of crust and mantle in east Tibet and neighbouring areas.

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The collision between India and Eurasia, which started approximately 50 Ma ago, has produced at least 2,000 km of convergence. Besides the crustal thickening, lateral extrusion is also suggested to accommodate the huge interaction. The east Tibet and neighbouring areas are therefore the ideal places for studying the continental deformation mechanism. Seismic anisotropy can help out to get an insight into the deformation of the crust and mantle beneath tectonically active domains. Based on the data from 123 broad-band digital seismic stations in Sichuan and Yunnan Provinces, China, the splitting parameters of Moho converted P to SV waves and core phase SKS were determined at each station using the grid searching method of minimum transverse energy and the stacking analysis method, where splitting is interpreted as the anisotropy of deformational fabrics at two different levels of the crust and mantle, respectively. Our results show that: (1) The fast polarization directions of PmS and SKS are relatively uniform and they exhibit primarily NW-SE trend in East Tibet (Songpan-Ganzi Block) and Sichuan Basin. (2) Farther south but north of latitude 26oN, in central Yunnan, both fast directions exhibit a clock-wise rotation, but present a systematic difference (the rotation angle from analysis of PmS is smaller than SKS). (3) South of latitude 26oN, both splittings exhibit a sharp transition and show a uniform pattern of E-W fast directions. We interpret the distributed patterns of shear wave splitting as the differential crust-mantle coupling/decoupling interaction controlled by the big boundary faults or sutures.

Poster

A new model of crustal structure of Siberia.

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We report a new model of the structure of the crust in Siberia that encompasses two large tectonic regions, the Paleozoic West Siberian Basin and the Precambrian Siberian craton. The area of study covers a significant part of north Eurasia and extends from the Ural mountains in the west to the Verkoyansk Ridge/Lena river in the east, and from the Arctic shelf in the north to the Tien Shan and Altay-Sayans mountains in the south. The new crustal model is based on our new ("from scratch") compilation of all available reliable seismic data and includes the results of seismic reflection, refraction and receiver functions studies, based on old and newly acquired seismic data (from the late 1960-ies until present). Seismic structure along seismic profiles is digitized with a 50 km lateral spacing which is comparable with the resolution of seismic models. Structural parameters based on gravity modelling, or tectonic similarities, or seismic data reported not along seismic reflection/refraction profiles but as interpolated contour maps are excluded from the new crustal database. Due to the uneven quality of seismic data related both to data acquisition problems and interpretation limitations, special attention is paid to the data quality problem, and quality parameters are incorporated into the new database of regional crustal structure. The present database comprises detailed and reliable information on the seismic structure of the crust for most of the tectonic structures of the region and provides valuable constraints for geophysical modelling of the mantle structure. We observe important spatial correlations between the crustal structure (thickness of the sediments, the basement, and different crustal layers, and average basement velocities) and tectonic and geological settings. Statistical analysis of age-dependence (we use tectono-thermal ages) of crustal parameters allows for distinguishing the effects of various tectonic processes on the crustal structure. The analysis provides the basis for studies of crustal evolution and geodynamic process in the region where the age of tectonic structures spans over ~4 Ga. Archean terranes have a large (39-44 km) thickness of consolidated crust (excluding sediments), which decreases in Paleo-Mesoproterozoic terranes to 34-42 km. Thickness of consolidated crust in Mesozoic and Cenozoic regions is 32-34 km only. The total crustal thickness (including the sedimentary layer) is the largest in the Paleoproterozoic and Mesoproterozoic regions of the Siberian Craton. A block with an unusually thick crust (47-58 km), bounded by the regions of thinned crust, extends in the longitudinal direction across the Siberian craton and cuts major tectonic boundaries which have sublatitudinal orientation. Low surface heat flow (on average around 20-22 microW/m^3) and the absence of the high-velocity (V_p>7.2 km/s) lower crustal layer in the block with the thick crust suggest that eclogitization in the crustal root was subdued, thus allowing preservation of the ultra thick, seismically distinguishable, crust.

Oral and poster

The nature of the Moho transition in NW Canada from combined near-vertical and wide-angle seismic reflection studies.

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The year 2009 marked one century since the discovery of the Mohorovičic discontinuity, the Moho or crust-mantle transition (CMT). However, the exact nature, characteristics and the manner in which the CMT formed remain one of the major uncertainties in lithospheric studies. Seismic data provide the main source for understanding the structure of the Moho and its evolution, although limited geologic studies by means of exposed sections (ophiolites or xenoliths) also provide important information. A number of qualitative seismic studies but only a few quantitative ones have specifically addressed this issue. According to recent work, the Moho is considered either a laterally and vertically heterogeneous transition zone or a change in the scale length of heterogeneities between lower crust and upper mantle. To quantitatively investigate the CMT, we analyze near-vertical incidence (NVI) and wide-angle reflection (WAR) data acquired along a 60 km segment of Line 1 of LITHOPROBE's SNORCLE seismic experiment beneath the Great Bear magmatic arc, a Paleoproterozoic domain in the Northwest Territories, Canada. We investigate the dynamic characteristics of Moho reflections by (1) calculating synthetic seismic signatures of both NVI and WAR data for a number of CMT models using 1- and 2-D wave propagation algorithms and (2) determining stochastic parameters of the lower crust and upper mantle from NVI sections from which synthetic signatures are calculated. Observations along the entire 725 km line 1 reveal Moho reflections characterized by subhorizontal layering and relatively uniform arrival time (~11.0 s), even beneath regions with different ages, such as the Archean Slave province and the Paleoproterozoic Wopmay orogen. This uniformity implies that post-amalgamation, regionally extensive processes have effectively modified rocks and reset the reflection Moho to a uniform depth (~33 km). Seismic NVI data from the lower crust of the Great Bear magmatic arc show lower crustal reflections that are listric into the Moho, ones that appear to be truncated by the Moho, or both. Such results indicate that re-equilibration of the Moho most likely involved different tectonic processes. From our model studies, only laterally and vertically heterogeneous models of a ~3 km thick CMT with either discontinuous layering or a lamellar structure with randomly distributed ellipses can properly simulate the dynamic characteristics of the observed wavefields for both NVI and WAR data. Stochastic analyses of the NVI data show very different heterogeneity properties for the lower crust [average horizontal correlation length = 700 m] and upper mantle [average horizontal correlation length = 150 m] with Hurst numbers, indicative of the degree of roughness of the heterogeneities, of ~0.3. The preferred model, comprising a 3-km-thick transition zone with stochastic characteristics of the crust and tri-modal velocity structure (6.9, 7.5 and 8.0 km/s) embedded within a deterministic velocity field above and below, is consistent with those developed from forward modelling. The models generated from these analyses are interpreted in terms of different re-equilibration mechanisms. One features a regional décollement; another is characterized by either thermal or metamorphic fronts. Both were likely involved in the development of the crust-mantle transition below the Great Bear magmatic arc.

Oral

The myth of crustal growth: a seismic perspective.

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Ever since the earliest days of regional deep seismic reflection profiling, it has been apparent that accreted terranes observed on the surface often do not project to substantial depths. Rather, in most cases they are detached and rest above deep crustal and upper mantle rocks to which they bear little or no genetic relationship. As a result, continental growth cannot be assumed to be proportional to the apparent area increase by terrane accretion. Regional crustal and lithospheric scale seismic reflection profiles provide opportunities to examine geometric relationships that can be used to retrodeform orogenic structures of accretionary orogens. Examples in North America on the east (Appalachians) and west (Cordillera) indicate that, prior to accretion of terranes, proto-North American continental rocks existed outboard of the position of the present margin. In western Canada, for example, results from geological observations have been combined with regional geophysical surveys to provide a coherent and consistent interpretation that much of the crust and lithosphere has been part of western North America (Laurentia) since Precambrian. Cross sections of the lithosphere illustrate that lower crustal rocks can be stratigraphically, geologically and seismically correlated from the ancient margin as much as 2/3 of the distance across the orogen. Retrodeformation of rocks that were deposited on or adjacent to the margin then leads to a conclusion that, prior to the onset of terrane accretion, the North American margin and associated rocks projected even farther west (today's coordinates), at least as far as the modern margin. Thus, as flakes of terranes were added to the surface in the western regions of the Cordillera, the North American lithosphere may have been foreshortened and/or tectonically eroded from below. As a result, the process of terrane accretion in western Canada apparently resulted in a net decretion of continental lithosphere. In addition to the presumed growth of continents by addition of terranes, the idea that continental crust and lithosphere have grown throughout geologic time derives in part from the belief that there is a proportional relationship between the amount of continental material fractionated from the mantle and the amount that the Earth has cooled. Interpretations vary from those in which nearly all continental material was fractionated early and that only recycling has occurred since the early Archean, to those in which there is essentially a steady increase in the amount of continental material from the early Archean to today. As Paleoproterozoic and Archean orogenic crustal structures appear to be similar to Phanerozoic crustal structures, the seismic results are consistent with interpretations with virtually no crustal growth since early in the Earth's history.

Oral

Borehole seismic monitoring at the CO_2SINK site.

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The CO_2SINK project, supported under the FP6 framework by the EU commission, researches geological CO_2 storage in a saline aquifer near the town of Ketzin, west of Berlin, Germany. The project operates an in situ laboratory aimed at promoting interdisciplinary work and bringing together conceptual engineering and scientific studies on geological storage into a full-fledged demonstration exercise of onshore storage. A comprehensive seismic monitoring program has been conducted within the CO_2SINK project. It comprises baseline and repeat observations at different scales in time and space: surface 3D and multi-line 2D, VSP (Vertical Seismic Profiling), MSP (Moving Source Profiling) and cross-hole. The CO_2SINK project started in April 2004 and is bound to end in 2010. Additional time lapse repeats are however being envisaged after the closure of the current project. The CO_2SINK seismic program has as goals to contribute to the understanding of the structural geometry of the site, to monitor the expansion of the CO_2 plume with time and to produce a cohesive interpretation of the seismic results at the kilometre-scale of the site, while resolving the geologic and structural details at a metre-scale in the vicinity of the injection site. We will present here results and methodology used for monitoring the CO_2 plume at medium and small scale, MSP and cross-well seismics. A baseline and three time-lapse repeat crosshole sessions were so far performed at Ketzin. A piezo-electric borehole source and a 12-level hydrophone chain were used covering a depth range from 450 m to 750 m. CO_2 has been injected at a depth of approximately 650 m. The cross-hole data have been analyzed to assess changes induced by injection. The analyses included tomographic inversions of P-wave travel-times and amplitudes, as well as covariance analyses between data sets measured in subsequent sessions. Significant variations of the first arrivals were not observed after injection. Conversely, a weak change of the amplitude level appeared after injection close to borehole KTZI-200 at the depth of the reservoir. This observation is consistent with the relatively fast break-through of the CO_2 in KTZI-200 and the absence at the date of the measurements of CO_2 in KTZI-202. More significant changes after injection have been identified by examining the covariance in a time window containing the first arrival. The covariance analysis produces indications of change due to both phase and amplitude. Changes due to injection have been revealed by covariance tomography while changes were not confidently detectable by classic P-wave tomography (velocity and amplitude). Classic tomography produced however a velocity model of main geological units. The bulk of the CO_2 injected until September 2008 did not migrate within the plane section defined by boreholes KTZI-200 and KTZI-202, which made its detection by cross-hole seismics a challenging task. To-date, activities towards extending cross-hole seismic analyses and integrating them with geoelectric data are also developing within an extended CO_2SINK Team, including researchers from Helmholtz Centre Potsdam - GFZ and Uppsala University.

Oral

Surface and borehole 3D seismic imaging for mine development.

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Mineral deposits are often hosted in deep geological features with variable dimensions and shapes, diverse orientations and complex physical properties. This combination of large depth and high variability is a challenge for the structural characterization of these deposits and their surroundings, especially when meter or sub-meter resolution is required. 3D seismic surveys performed on the ground surface have as primary targets horizontal and gently dipping bedding sequences. Steep faults are however only inferred indirectly. With VSP (Vertical Seismic Profiling), receivers are placed in boreholes and sources are deployed on surface. The vertical receiver arrays permit steeply inclined targets to be imaged directly, while the resolution increases because of the shorter distances from targets to receivers. Commonly, a short receiver chain is repeatedly moved to cover the whole borehole from the same shot point. This is however relatively time consuming and limits in practice the number of shot points. MSP (Multiple Source Profiling) is a variation of VSP where data are acquired with receivers placed at fixed locations in boreholes from a large number of shot points on surface. This presents the advantage that the data can be acquired at the same time with a surface 3D survey. MSP and VSP provide better dip coverage than data acquired on surface as well as means for building a robust 3D velocity model based on travel time inversion. The difference between VSP and MSP is in fact artificial, as a survey conducted with a sufficient number of receivers to cover the whole borehole would merge the two techniques into 3D VSP. In addition to 3D surface and 3D VSP, significantly more resolved - albeit also more local - images are obtained by side-scan seismic surveys, with sources and receives placed down hole. The IP (Image Point)-3D pre-stack migration is a novel 3D imaging technique developed to answer the need of integrating uneven and sparse combinations of surface and borehole seismic layouts. The method was originally developed as a 2D curved-path variation of Radon transform. The defining property of the IP migration is its ability to resolve images of targets of diverse orientations while strongly suppressing 'smiling' artifacts characteristic to unevenly covered layouts. Sharp 3D images of both bedding and faults are obtained by this novel technique, which increases significantly the level of detail and interpretability of the imaging exercise. Surface 3D, VSP/MSP and borehole side-scan were applied jointly within a pre-feasibility study for mine development of the Millennium uranium deposit, in the Athabasca basin of northern Saskatchewan, Canada. The rock quality directly surrounding the deposit is greatly reduced because of alteration and post Athabasca sandstone structures, which provide conduits for the migration of basin and meteoric fluids. This leads to significant risk for mine development and shaft sinking, because of the increased potential for water inflow into mine workings. To mitigate the risk involved with mining in such complex geology several projects were proposed as part of a pre-feasibility study. Of these, seismic methods were identified as the best tool to potentially identify alteration and structurally compromised zones.

Poster

Mantle wedge fluids under NE North Island, New Zealand.

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Crustal seismic reflection data across the eastern Bay of Plenty and Raukumara Peninsula margin image an intriguing localised zone of strong reflectivity at a depth of about 35 - 40 km (12 – 16 s TWT) that coincides with a local increase in seismicity. The zone lies between the Hikurangi subduction zone along eastern North Island and the extensional back-arc basin within central North Island (Taupo Volcanic Zone). It is within the mantle wedge as Moho is clearly imaged on the seismic reflection data and the top of the subducting slab is clearly defined by seismicity. The distribution of seismicity within the region shows the occurrence of two similar local seismicity hots spots in the mantle wedge, about 60 km to the northeast and to the southwest of the eastern Bay of Plenty zone, aligned sub-parallel to the plate boundary strike. In 3D these zones of seismicity form columns, about 10 - 15 km in diameter, in the mantle wedge, from the subducted plate at 50 km to about 30 km depth. Tomographic inversions of seismicity data show that the hot spots coincide with low Vp, low Vp/Vs and low Qp. The strong local reflectivity and concentrated seismicity suggest a partial melt or fluid origin. Focal mechanisms are variable but all have a nodal plane close to vertical, consistent with near vertical fractures and flow. The subducted plate is too shallow here for normal back-arc melt generation, but the lateral spacing of the inferred columnar flow suggests convective flow or density driven diapiric upwellings within the mantle wedge nose. The cause of the hotspots is inferred to be fluid, possibly partial melt, resulting from dewatering of the subducted Hikurangi Plateau, but the cause of the limited extent along the plate margin to the south is unknown.

Oral and poster

Reflection seismic imaging in the Skellefte Ore District, northern Sweden: a framework for 3D/4D geologic modelling.

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The Skellefte Ore District, an important metallogenic zone in northern Sweden, is well known for its volcanic-hosted massive sulphide deposits and new gold discoveries. As a part of a 4D geologic modelling project and in continuation of previous reflection seismic investigations, we collected four new seismic profiles, with a total length of more than 70 km, in the western and central parts of the Skellefte District during 2008 and 2009. The two western most profiles are located in the Kristineberg mining area and were collected to complement previous seismic data. Processing results of these data show a series of steeply and gently dipping reflections, some of which can be correlated with the main mineralization horizon in the Kristineberg mining area. Two enigmatic high-amplitude horizontal reflections observed at a depth of about 2 km may be important for locating new mineralizations. In general, our results in the Kristineberg area confirm previous geophysical interpretations and further improve our understanding of geological structures hosting mineralization at depth. Preliminary processing results from two nearly parallel seismic profiles in the central part of the Skellefte District show a relatively different seismic character from those of the Kristineberg area. Reflections are moderately dipping and may be associated with a regional shear zone in the study area. This shear zone appears to be spatially very important for some of the mineralizations observed along it. Thus, the seismic data can be significant in constraining the shear zone geometry at depth. To construct a 3D geologic model of the study area, results from reflection seismic data will be integrated with other geophysical and geological data. A 4D geologic model (time-component) of the study area will be constructed using geological restoration techniques to validate the main geological structures.

Oral

Seismic noise removal using image-based techniques.

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Nonlinear filtering is a technique commonly used in signal processing, especially in image processing. Unfortunately, its use still very limited in geophysics. Most current techniques to noise removal involve the use of linear filters. However, these techniques are less successful in identifying isolated spikes or in separating individual frequency components. This paper presents two image-based nonlinear filters namely the anisotropic diffusion filter and the trilateral filter for identifying and removing random and coherent noise from seismic data. Important aspects of these filters are their adaptive behaviour and signal preservation. Furthermore, they are easily implemented and less time and memory consuming compared to existing filters. We have successfully used these filters on synthetic and real seismic data corrupted by different percentages of noise. Result shows quite similar behaviour between anisotropic diffusion filter and trilateral filter.

Oral

Combined interpretation of wide-angle and reflection vibroseis data, incorporated with gravity and magnetotelluric modelling, Eyre Peninsula, Gawler Craton, South Australia.

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In 2008, Geoscience Australia, in conjunction with the Department of Primary Industries and Resources, South Australia, acquired regional seismic reflection, wide-angle refraction, gravity, and magnetotelluric (MT) data along a 250 km east-west transect across Eyre Peninsula, Gawler Craton, South Australia, as part of the Australian Government's Onshore Energy Security Program. These datasets provide complementary information on the crustal architecture and evolution of this part of the Archean-Proterozoic Gawler Craton. The seismic transect crosses several tectonic domain boundaries in the Gawler Craton and also the western boundary of the South Australian Heat Flow Anomaly (SAHFA). The wide-angle refraction and MT surveys were designed to supplement deep seismic reflection data, with velocity information for the upper crust, and electrical conductivity distribution from surface to the upper mantle. Twenty three recorders were deployed along the reflection transect as a fixed, wide-angle recording array, with 5 and 10 km spacing, using three-component seismometers. MT data were acquired along the seismic transect at 40 broadband sites, with 5 to 10 km spacing, and 12 long period sites, with 20 km spacing. Gravity data were acquired with 400 m spacing intervals. High-quality, 3-component, vibroseis wide-angle seismic data with offsets up to 70 km were collected simultaneously with the reflection survey using the same vibroseis source. The 2D velocity model derived from wide-angle data consists of three layers overlying basement. The model shows velocity variations in the upper crust and can be constrained down to a depth of 12 km by the first arrivals from major velocity boundaries. In the top layer, the velocity increases from 1.8 km/s to 3.6 km/s in the upper 200 m. The second layer, with a velocity of 5.7-5.85 km/s and a maximum thickness of 900 m, also includes two local bodies with a relatively lower velocity of 5.3-5.6 km/s. One of these bodies corresponds to surface outcrop of Corunna Conglomerate, which is not imaged by reflection data but is modelled as a lower density body from gravity data. The third layer, with velocity of 5.9-6.2 km/s, is interpreted to correspond to granite-gneissic composition and the bottom of the layer broadly correlates with the top of the mid-crustal basement interpreted from reflection data. Depth to this boundary varies from 5.5 km in the western part of the line to 1.3 km in the east, and velocities below it are around 6.3 km/s. Thus, the mid-crustal basement interpreted from the reflection data as a boundary between almost transparent and highly reflective crust, at 6 km in depth in the western part of the transect and shallowing to 1 km depth in the east, is consistent with the velocity model derived from wide-angle data. A local, near-surface, high velocity body (6.35-6.40 km/s) is interpreted towards the eastern end of the transect. This body corresponds with surface outcrop of the Paleoproterozoic Burkitt Granite and has been modelled with gravity data. The Burkitt Granite is an undeformed, hornblende-bearing granite, with high radiogenic heat production (17 $\mu W.m^{-3}$). Preliminary MT modelling shows a relatively resistive deep crust across most of the transect, with more conductive crust at the western end, and near the centre. The central conductivity anomaly may represent the northern extension of the Eyre Peninsula Conductivity Anomaly, previously recognised to the south. The MT model does not correlate neither with the major reflection seismic features nor the velocity distribution in the region. Combined interpretation of seismic data supplemented by other geophysical techniques and geological data has been used to improve geological understanding of this region.

Poster

Receiver functions of mantle discontinuities in Fennoscandia.

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Receiver functions from the Mantle Investigations of Norwegian Uplift Structure experiment (MAGNUS) are depth-converted using interval wavespeeds from AK-135 for the 410-km and 660-km discontinuities and combined using common-conversion-point stacking. This preliminary work shows a potentially complex mantle transition zone beneath southern Norway, with reduction in the amplitude of the 410-arrival and 20-30 km of shallowing of the 660-arrival beneath the axis of the Oslo Rift. To refine these measurements and place them in a regional context, we incorporate the MAGNUS dataset with permanent stations and previous temporary seismic deployments across Fennoscandia and northern Europe. New constraints on the depth to the lithosphere-asthenosphere boundary and character of the mantle-transition-zone will aid in understanding the causes for potentially recent uplift in the southern Scandes and the region of unusually slow upper mantle resolved beneath the region (Weidle and Maupin, 2008).

Oral and poster

Conductivity models derived from MT data and its correlation with seismic reflection profiles in western Skellefte District, northern Sweden.

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Sweden is a country with a long mining history and a status among the leading miners in Europe. Our area of study is the western part of the Skellefte District, a very rich mining district in northern Sweden. The main deposits of the area consist of volcanic-hosted massive sulphide (VHMS) ore deposits with polymetallic ore (containing zinc, copper, lead, gold and silver), copper ore and gold ore. Realizing that a better understanding of the geological structures and evolution of the area are necessary in order to succeed in exploration, a joint research project between industry and academia (VINNOVA 4D Modelling Project) was launched in 2008. The project aims at constructing a 3D geological model of the Skellefte District and its evolution over time. To accomplish these goals new geological and geophysical data have been acquired in the district, including MT and seismic reflection data that were recorded along the same profiles to facilitate joint interpretation. During the last two years 34 MT sites were installed along 35 km of seismic reflection data in three profiles in western Skellefte District. The spacing between the MT sites varies from 500 m to 1 km. Two of the profiles are close to the Kristineberg mine (one ~5 km long in N-S orientation and another ~10 km in E-W orientation), whereas the third profile is located further north with an approximate length of 18 km in a northeasterly direction. Due to the complicated geology of the area, it is challenging to meet the 2D assumptions required by the inversion process. Nevertheless, the resulting models from determinant inversion are in good agreement with the data and show several features that correlate with the surface geology and results from seismic reflection data. Even in some cases, the inclusion of seismic reflectors as a priori information in the inversion produce models with an improved data fit. The obtained conductivity models together with the seismic give valuable information that helps to delineate the extension in depth of the main geological units in the area.

Oral

Deep seismic reflection imaging of a Paleoproterozoic- Early Mesoproterozoic rift basin succession and related Pb-Zn mineral province, the Mount Isa Inlier.

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In 2006, as part of the Predictive Mineral Discovery Cooperative Research Centre, Geoscience Australia and the Geological Survey of Queensland, together with industry support, acquired some 850 km of deep crustal seismic reflection data through a variably deformed Paleoproterozoic-earliest Mesoproterozoic mineral province in the Mount Isa region of northern Australia. The main aim of the survey was to better determine crustal architecture and the structures that may have served as fluid conduits during mineralisation. Data were collected along six separate transects and complement the results of an earlier 1994 survey across the central part of the province, which captured upper crustal structure but returned a poorly imaged and weakly reflective middle to lower crust. The new data confirm the presence of nonreflective basement beneath most of the Mount Isa region in marked contrast to a conspicuously layered and highly reflective upper crust (≤ 4 sec TWT), dominated by west-vergent folds and thrusts in the east, and a well-preserved rift-basin geometry in the west. Basin geometry developed over 200 Ma of intracontinental rifting from 1800-1600 Ma, culminating in crustal thinning, passive margin formation and development of three vertically stacked sedimentary basins (Leichhardt, Calvert and Isa superbasins). Elements of all three superbasins have been captured in the seismic data, including many of the original basin-bounding faults that not only controlled basin shape but overall deepening of the sedimentary environment, in which conditions increasingly favoured deposition of deep water sedimentary facies (including black shales and turbidites) over platform carbonates and fluviatile-lacustrine successions. Sedimentation ceased with onset of deformation and metamorphism associated with the Isan orogeny. Pb-Zn mineralisation is hosted by platform or deep water facies within the two younger superbasins, and encompasses both Century- and Broken Hill-style mineralisation (Cannington), as well as Mount Isa type (MIT) deposits. Seismic sections show mineralised parts of the platform succession are commonly underlain at depth by partially or fully inverted growth faults and half-graben, raising questions about the timing and mechanism of ore formation in relation to basin formation. Ore formation at Century postdates sedimentation and more likely occurred during the initial stages of basin inversion by a process analogous to that which produces Mississippi Valley–type deposits. Seismic images further indicate that the likely conduit for mineralisation is an inverted extensional fault lying immediately below the mine succession. This fault, the Termite Range Fault, extends to sub-basin depths, and may have tapped mineralising fluids originating in either crystalline basement or older parts of the rift-basin sequence. In contrast, MIT deposits are thought to have formed contemporaneously with sedimentation in half-graben proximal to extensional faults of early Isa age. As at Century, such faults are now invariably inverted and could just as easily have acted as fluid conduits during basin inversion, rather than during basin formation alone. Cannington similarly may have formed during basin inversion, but the effects of Isan deformation are so pervasive that the original basin geometry is completely masked.

Oral

A greater role for transform faulting in the formation of Australia's southern passive margin: a reassessment of the seismic and geological record.

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Continental rifting and the separation of Australia from Antarctica was a protracted process, commencing in the Middle-Late Jurassic and progressing from west to east through successive stages of crustal extension, basement-involved syn-rift faulting and thermal subsidence until the Cenozoic. The resulting passive margin shares many of the same features as other magma-poor, non-volcanic continental margins, including a variably thinned and extended upper crust in which parallel arrays of rotated tilt blocks, half-graben and seaward-dipping normal faults are the most obvious feature in seismic reflection profiles. Seismic images indicate at least 15 km of preserved syn- and post-rift sediment in the Bight Basin and as much as 7 km of basin fill in the younger Otway Basin. Seismic reflection profiles further indicate that in more distal parts of the extended margin, middle to lower crustal rocks may be completely absent so that upper crustal sediments rest directly on exhumed sub-continental mantle. Such thinning is particularly well documented for the Bight Basin and appears to be peculiar to sections of the continental margin where crustal extension was roughly orthogonal or only moderately oblique, and broadly distributed. No distributed fault system or extremes of crustal thinning are evident in the immediately adjacent Duntroon Sub-basin or basins off western Tasmania where continental rifting took on a different form and was accommodated by strike-slip faulting and the formation of transform boundaries, albeit of very different ages and orientations. The older of the two transform boundaries (Bettong Fault System) dates from the initial stages of continental rifting and trends NW-SE, parallel to the direction of extension at that time; it developed contemporaneously with the onset of seafloor spreading in the Bight Basin at 83 Ma and now forms the southern margin of the Duntroon Sub-basin. This fault boundary originally dipped steeply seaward but has since been rotated into a shallower angle following tectonic unloading and accompanying isostatic rebound. Seismic sections through the Duntroon Sub-basin show northward thickening half-graben filled with late Jurassic to Early Cretaceous sediments and an inner basin high or hinge which may be an expression of basement uplift in the footwall of this major structure. A pre-existing intracontinental shear zone or basement fault controlled both the position and orientation of this transform boundary. Prior to the breakup of Gondwana this boundary was continuous with the Tasmanian-Antarctic Shear Zone and extended as far south as the South Tasman Rise. The other transform boundary off western Tasmania dates from the last stages of continental rifting and is well imaged in both seismic and aeromagnetic data. It is continuous along strike with the lower Paleozoic Avoca Fault, a north-south striking terrane boundary in central Victoria which was optimally oriented for reactivation following a change in the direction of continental rifting from NW-SE to north-south. Seismic sections through this sheared margin reveal a steep outward-dipping fault and associated basement high, inboard of which there are a number of related faults and deep, narrow sedimentary basins. These faults cut through the entire crust and have produced a step-like geometry in basement that is in marked contrast to that shown by sections of more normally extended continental crust.

Oral

Utilisation of seismic interval velocities for determination of rock lithology mapped by SDRs and DDRs on the Wallaby Plateau, offshore Western Australia.

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Seismic interval velocities derived from stacking velocities can provide some clues to determination of rock lithology. This concept has been applied to understand the divergent dipping reflector (DDR) and seaward dipping reflector (SDR) packages over the Wallaby Plateau and Wallaby Saddle that were imaged on the 2008/2009 seismic survey GA310 contracted by Geoscience Australia. Root mean square velocities (Vrms) used to calculate interval velocities (Vint) were derived from 8 km long cable data. Vrms were picked on traces after pre-stack time migration, and the 4th order normal move-out (NMO) correction was implemented. Therefore, distortions to interval velocities due to insufficient curvature of NMO curve at short offsets, structural dip and ray bending due to stratification are assumed to be largely suppressed. Consequently Vrms velocities are assumed to approximate average velocities. After derivation Vint were heavily smoothed to suppress short period spatial variations. These velocities were then co-analysed with reflection seismic images. Careful velocity analysis based on coherency evaluation using semblance and stacking plots was employed to select appropriate and representative locations within seismic profiles. Only velocity functions from these locations were used to support the following interpretations and conclusions. These velocity functions do not show systematic differences from the more reliable OBS-derived velocities for SDRs elsewhere down to 8s two-way time. This is taken as an indication of the validity of the Vint derived in this study for general lithological interpretation. Direct comparative analysis of Vint patterns between areas of significantly different water depth requires various water pressure related changes in velocity to be accounted for. There are controversies in approaches to water depth adjustment to seismic velocities, but a variation in water depth from 0 at one location to 2+ km at another location can result in compaction-related velocity increases exceeding 1 km/s. Thus, the method used in this study, although not ideal, is considered to be better than ignoring effects induced by the water loading. It was based on velocity-depth functions for Cenozoic and Mesozoic terrigenous lithologies from sonic log measurements in deep wells in West Siberia and on the Russian Platform. These were scaled back to reflect pressure differences between water (of density 1.03 gm/cm^3) and rock density below the sea floor. Vertical velocity gradient (rather than just velocity) variation was used to avoid dependence of water depth adjustment from absolute velocity values. Water depth adjusted seismic interval velocities result in a significantly different velocity profile and thus have a strong influence on the interpretation of rock lithology. Water depth correction of velocity data is believed to strengthen the lithologic understanding of DDR and SDR packages within the study area. A major uncertainty of this interpretation is due to a lack of the prototype velocity-depth model of SDRs and DDRs investigated globally.

Poster

Resolving complex structures from vertical seismic profile (VSP) surveys: a case study from the Alpine Fault, New Zealand

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The Alpine Fault in New Zealand offers a unique opportunity to study the physical properties and mechanics of a seismically active structure, by integrating borehole data with studies of an exhumed fault rock sequence. In the first stage of an International Continental Drilling Program (ICDP) supported project, a 150 m borehole is planned at Gaunt Creek, near Whataroa, South Island, New Zealand. Recovered core will provide the first complete section through the transition from predominately cataclastic to mylonitic fault rocks, and permanent seismicity and groundwater monitoring equipment will be installed in the borehole. Associated site characterization work includes active source seismology.

From surface geological investigations, it is predicted that the fault is moderately-dipping to the SE and juxtaposes two metamorphic/hard rock units over most of its depth. Reflection seismology in such a complex geological environment is not trivial and it is may be appropriate to image steeply dipping structures using borehole-based techniques such as Vertical Seismic Profiling (VSP). One way to estimate the value of field data, and to optimize acquisition geometries and processing procedures, is through numerical models, particularly if the geological model is relatively well known. Here we present results of two synthetic VSP models for the predicted Gaunt Creek sub-surface geology along a two-dimensional section perpendicular to fault strike; (A) a simple case with a single oblique dextral reverse fault and adjacent fault rock sequence; (B) a more complex model where near-surface slip has been partitioned between thrust and strike-slip fault segments. Typically, contacts between hard rocks show low reflectivity due to their low acoustic impedance contrasts, however mature fault zones are often reflective due to seismic anisotropy produced during the alignment of mineral grains. Consequently, a variety of different anisotropic parameters were tested for the cataclasites and ultramylonites within the fault zone model.

The synthetic borehole reflection seismograms generated for the two Gaunt Creek sections illustrate that:

1. Borehole reflection seismic sections suffer from lack of aperture in the down-dip direction. To compensate, large offsets and higher shot density will be required on the down-dip side of the borehole.
2. At large offsets wavefield identification is complex and correct separation of wavefields for imaging is difficult.
3. Due to the steep dips of lithological units, the velocity field varies laterally and it is necessary to determine a 2D velocity model from all shot gathers prior to migration.
4. Seismic anisotropy significantly changes the model response.
5. Modelling of each individual geologic setting is required prior to acquisition.

Oral and poster

Seismic images of the tremor region around Cholame, California.

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We present seismic reflection images of the central California Coast Ranges including the tremor region around Cholame from reprocessing the industry reflection profile "SJ-6". The SJ-6 seismic reflection profile was acquired in 1981 over a distance of about 180 km from Morro Bay to the Sierra Nevada foothills in South Central California. The profile runs across several prominent fault systems, e.g. the Riconada Fault (RF) in the western part as well as the San Juan Fault (SJF) and the San Andreas Fault (SAF) in its central part. The latter includes the region of increased tremor activity near Cholame, as reported recently by several authors. We have recorrelated the original field data to 26 seconds two-way traveltime which allows us to image the crust and uppermost mantle down to approximately 40 km depth. A 3D tomographic velocity model derived from local earthquake data (Thurber et al., 2006, Lin et al., 2010) was used and Kirchhoff prestack depth migration as well as Fresnel-Volume-Migration were applied to the data set. Both imaging techniques were implemented in 3D by taking into account the true shot and receiver locations. The imaged subsurface volume itself was divided into three separate parts to correctly account for the significant kink in the profile line near the SAF. The most prominent features in the resulting images are areas of high reflectivity down to 30 km depth in particular in the central western part of the profile corresponding to the Salinian Block between the RF and the SAF. In the southwestern part from Morro Bay to Cholame strong reflectors can be identified that are dipping slightly to the northeast at depths of around 15-25 km. In the range of the surface traces of the SJF and the SAF a broad zone of high reflectivity is located at depths of 20 km to 35 km. Below the region of the surface trace of the SJF vertical reflectors occur down to depths of approx. 5 km. In the area of the San Joaquin Valley in the eastern part of the profile slightly west dipping sediments show up at depths of 2-10 km. These sediments are folded and faulted below the region of the Kettleman Hills. Steeper west dipping reflectors can be identified below the uppermost sedimentary layers down to depths of approx. 20 km. The resulting images are compared to existing interpretations (Trehu and Wheeler, 1987; Bloch et al., 1993) and discussed in the frame of the suggested tremor locations (Nadeau et al., 2009) in that area.

Oral

From deep seismic studies to mineral exploration.

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In the mid 1990's, deep seismic investigations established that the characteristic convergent margin type crustal structures were directly influential in the placement of mineralization within the eastern margin of the Athabasca Basin. The deposits are shown to be associated with deep-seated shear zones that originated during Trans-Hudson orogeny, and have been reactivated during and after the deposition of the basin fill sandstones. Subsequently several very successful 2D and 3D surveys were initiated in search for these indicative fracture zones of the uranium ore deposits. Examples from results of the original LITHOPROBE industry study, investigations at Shea Creek, McArthur River and the Midwest-Northeast projects provide an insight into the level of progress achieved by the high-resolution seismic methods in the Athabasca Basin. Seismic properties of the Athabasca sandstones and underlying basement have been determined through in situ borehole measurements. Reflectivity within the sandstones is generally weak, being associated primarily with variations in fracture density, porosity and degree of silicification. The basement unconformity and regolith, a prime target of exploration, is widely imaged as it is characterized by variable but generally distinct reflectivity. Results from the McArthur River mine site suggest that the spatial coincidence of seismically imaged anomalous velocity zones and deep-seated faults that offset the unconformity may be a more broadly applicable exploration targeting tool. 3D seismic imaging near existing ore zones can define the local structural controls on the mineralization and point the way to new targets, thus leading to more efficient exploration drilling programs. Furthermore, seismically generated structural maps of the unconformity and rock competence properties may play a significant role at the outset of mine planning.

Oral and poster

Seismic imaging of massive sulphides in Pyhäsalmi, Finland.

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The giant (>70Mt) Pyhäsalmi Zn-Cu ore deposit in Central Finland is a volcanogenic massive sulfide (VHMS) that has been actively mined since 1962, and expected mine life extends to 2018. The architecture and structure of the deposit indicate a substantial ore potential beyond known reserves which motivates active exploration using a combination of deep penetrating geophysical techniques and drilling. The Pyhäsalmi deposit is enclosed within the rocks of contrasting acoustic properties, such as mica-cordierite schists, felsic volcanics and unaltered mafic rocks. Contacts between these rock units are likely detected with reflection seismic method. HIRE (High Resoution Reflection Seismics for ore Exploration 2007-2010) is a project led by the Geological Survey of Finland and with 11 industrial partners. Pyhäsalmi is one of the 16 targets of the reflection survey. The survey contained a network of 2D seismic reflection lines with the total length of almost 30 km. The shot and receiver group intervals were 50 m and 12.5 m, respectively. The aims of the Pyhäsalmi survey are to gain understanding about geological structures at depth, to study the possible seismic signal produced by the known ore deposit, to better understand the structural control of the ore deposit and to provide new drilling targets for exploration. The commercially processed seismic data of the HIRE-survey revealed complicated reflectivity patterns caused by the complex geological structure of the area. The main feature of the area is a strongly reflective 1-2 km thick structure which dips towards E-NE in the eastern part of the study area, but which is subhorizontal in the western part. The deep ore body lies at an interface between mica schist and unaltered rocks on top of this large-scale structure. Due to strong deformation, lithological contacts close to surface are mostly subvertical, which causes difficulties to reflection seismic technique better suited for imaging the horizontal and moderately dipping structures. Although the commercially processed data are of good quality, reprocessing using unconventional techniques and careful parameter selection tailored for Pyhäsalmi case may improve the resolution and imaging power of the seismic data. Reprocessing of the seismic data aims at (i) gaining more information about structures and lithological contacts from shot gathers, (ii) enhancing the stack quality especially in the shallow part of the section, (iii) imaging better steeply dipping structures and (iiii) making an improved velocity model that could be utilized in the interpretation of the data. Pyhäsalmi mine is part of the ProMine project of the European Union with aims to build a 4D model of the mineralized region. The HIRE seismic data will also be incorporated in this model. Adjustment and validation of the seismic interpretation will be aided by new drill hole data, geological modelling, and the results of the full waveform sonic and gamma-gamma density logging obtained from recent exploration drillholes. The final goal of this currently ongoing work is to obtain a geologically and geophysically robust 3D model of the Pyhäsalmi area with indications of promising exploration targets.

Oral and poster

Seismic oceanography: now for something completely different.

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Recent developments have opened a new opportunity for the seismic reflection method for interdisciplinary research into ocean structure and processes. Understanding and quantifying processes such as mixing are vital if we are to be able to predict how the oceans will react to changes in climate. The last sustained period of high global temperatures was during the Cretaceous. During this time large parts of the ocean became anoxic creating deposits of black shales which are the principal sources of todays oil and gas reserves. The Naturaliste Plateau and adjacent Mentelle Basin is one such deposit and being at a high latitude will, through IODP drilling, reveal new data about climate stability. In this talk I will review seismic oceanography then focus on the recent work on mapping the black shales in the Metelle Basin.

Oral

Controlled-source seismic investigation of the generation and collapse of a batholith complex, Coast Mountains, western Canada.

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In 2009, the BATHOLITHS project acquired a 400-km long refraction and wide-angle reflection seismic survey across the Coast Mountains of British Columbia, Canada, a Jurassic to Eocene continental arc batholith complex. Granitic batholiths created by magmatic differentiation in arcs above subduction zones make continental crust more felsic than the original materials derived from the mantle. However, differentiation from a mafic protolith results in a large volume of ultramafic residual that is petrologically part of the crust, not changing the bulk composition. This residue may reside hidden beneath the geophysical Moho, or it may have delaminated to sink into the mantle due to its relative density. Delamination may occur during subduction or during the collapse of the arc after subduction stops, and may coincide with a commonly observed late pulse of magmatism. As part of the BATHOLITHS multi-disciplinary investigation of these processes, traveltimes from the seismic survey were used to build a 2-D P-wave velocity model of the crust. East of the batholith complex, surface Mesozoic sedimentary and volcanic rocks are indicated by velocities of 4-5 km/s to 2-5 km depth. Beneath this basin, the Stikine terrane, an accreted late Paleozoic to early Mesozoic island arc, has felsic seismic velocities of 5.8-6.2 km/s to at least 15 km depth. To the west in the continental arc complex, velocities of 5.6-6.2 km/s indicate granitic rocks to at least 15 km depth. A seismic reflector is observed at ~20 km depth beneath Stikinia but does not extend into the arc complex. Based on wide-angle reflections, the lower crust has a velocity of ~6.8 km/s under Stikinia, indicating mafic rocks, but <6.7 km/s within the arc complex, indicating a composition intermediate between mafic and felsic. A strong seismic reflector is observed at ~25 km depth only beneath the highest mountains and youngest batholiths in the eastern part of the batholith complex. The Moho is at 30-33 km depth under the western Coast Mountains and dips eastward to maximum of 38-40 km beneath the highest mountains. The Moho is at 35-38 km depth under Stikinia east of the arc. The upper mantle has a slow velocity of ~7.9 km/s under the arc complex and a fast velocity of ~8.1 km/s under Stikinia. A tectonic interpretation of these features is underway.

Oral

Seismic features of the eastern Eurasian continental margin.

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The Korean Peninsula and its neighbouring regions compose the far-eastern continental margin of the Eurasia plate, and have experienced complex tectonic evolutions including continental collisions and a rifting. Such complex tectonic evolutions accompanied significant lithospheric deformation. Seismic properties allow us to understand both the tectonic evolution history and the nature of continental margin. The crustal and upper mantle structures of this region have been poorly understood. We investigate seismic velocities on the Moho, seismic attenuation and shear-wave splitting in the crust of this region. We also present focal-mechanism solutions of the events in this region. We find strong correlation of seismic velocities and attenuation with the tectonic structures. Also, the Conrad discontinuity is clearly identified from analyses of regional seismic waveforms. The fast polarization directions of crustal shear waves appear to be highly correlated with the ambient stress field that is inferred from the focal-mechanism analysis. High-speed subductions of the Pacific and Philippine Sea plates beneath the Japanese islands make contraction in the region around the East Sea (Sea of Japan), causing reverse activation of paleo-tectonic structures.

Oral

Seismic images of the Japanese subduction zone estimated from comparison between refraction/reflection and receiver function analyses.

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The seismic reflection/refraction studies reveal the seismic structure of the crust and uppermost mantle. However, we can only obtain the seismic structure along the survey line. Recently, the receiver function analysis has been used for the detection of boundaries below the seismic station. The teleseismic data can be used for the detection of the boundaries below the seismic station. The plate boundary and Moho discontinuity are sharp boundaries with large velocity jump. Those boundaries have been detected by receiver function method as the first order boundary. The regional variation of the configuration of boundaries has been mapped. It is important to know the shape of a subducting slab in order to understand the mechanisms of interplate earthquakes and the process of subduction. In southwestern Japan, the configuration models of the subducting Philippine Sea slab have been presented by the use of seismicity data and converted phases. Many seismic studies have been done to declare the configuration of the subducting Philippine Sea plate in the southwestern Japan. The configuration models of the subducting Philippine Sea slab are consistent at the western part of southwestern Japan. However, the configuration of the subducting Philippine Sea plate at the eastern part of Japan was not confirmed yet. In that region, the configuration of the Philippine Sea slab from receiver function analyses is considered to be bent. On the other hand, the configuration estimated by seismic tomography studies suggested that the shape of Philippine Sea slab was smooth laterally. The configuration of the Philippine Sea slab has not yet been confirmed at the eastern part of southwestern Japan. A seismic survey with artificial sources was done in southwestern Japan. The seismic structure of the southwestern Japan was examined by comparing the receiver function image and refraction/reflection images. The configuration of the Philippine Sea plate is obtained at the eastern part of southwestern Japan. Our model of the Philippine Sea slab is consistent with that estimated from seismic tomography studies. The Philippine Sea plate does not bend sharply at the eastern part of the southwestern Japan. We can trace the Philippine Sea slab to a depth of 45 km. The configuration of the slab deeper than 45 km was not revealed. A seismic survey found a reflector in the mantle wedge just beneath the source area of the 2000 Western Tottori earthquake. The very weak image of the boundary was detected by the receiver function analysis using the spatially dense array. This study of the seismic structure by comparing the refraction/reflection images and receiver function image is very useful in defining the tectonic configuration across the region.

Oral

New scope extended by seismic profiling in central Japan.

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Two new deep seismic profiles, "Southern and Central Japan Alps Transect (SCAT)" and "Northern Mino Transect (NORM)" were conducted in the geologically complex part of central Japanese island arc in 2008 and 2009, respectively. The SCAT at the southeastern margin of the central arc provided a 90-km-long seismic line across two major structural boundaries, the Itoigawa-Shizuoka Tectonic Line (ISTL) and the Median Tectonic Line (MTL). The former divides the arc into the Northeast and the Southeast Japan, and the latter does into the Inner and Outer zones. The SCAT reveals the highly complex crustal structure formed by the collision of Izu-Bonin arc against the Japanese island arc with the bending of the Japanese island arc. In addition, it also presents three predominant reflectors which probably correspond to the retreated upper surfaces of the Philippine Sea plate since the initiation of its subduction. This strongly suggests that the subduction of the plate has been controlling the tectonics there since Miocene to the present. The NORM was conducted with a 70-km-long seismic line at the northwestern margin of the central Japanese island arc where the upper surface of the PHS is estimated to form a NW-trending broad anticline-like ridge (Hirose et al., 2007). As estimated, the NORM profile shows that the upper surface of the Philippine Sea plate rises up close to the Moho of the arc. The upper mantle thickness between the upper surface of the plate and the Moho is probably only about several km. This strongly suggests that the configuration and motion of the plate directly controls the active crustal movements. The results of SCAT and NORM produce leading idea that the essential factor controlling the tectonics in the central Japanese island arc is surely the configuration and motion of the Philippine Sea plate. This gives us new scope for tectonic research there against the traditional idea that the subduction of the Pacific plate and/or the pushing of northeast Japan to southwest Japan control the tectonics of the central part of the arc.

Oral and poster

Autocorrelation analysis of ambient noise in NE Japan.

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Seismic interferometry is a technique used to estimate the detailed properties of Earth by analysing the velocity boundary of seismic waves. These patterns are constructed by correlating and summing pairs of seismic traces with one another to estimate the Green's functions as a response of subsurface elastic properties. Here, we evaluate the detectability of subsurface velocity discontinuities such as the subducting plate interface and the Moho discontinuity beneath the northeastern Japan subduction zone by using ocean-bottom and onshore seismic networks. We calculate the autocorrelation functions (ACFs) of noise with a time-window length of 120 s at ocean-bottom seismometers deployed by the University of Tokyo, Tohoku University, and Hokkaido University on the landward slope of the Japan Trench in northeastern Japan. We also calculate the ACFs at Hi-net stations operated by the National Research Institute of Earth Science and Disaster Preventions that are located in northeastern Japan Island. A filtered 1-h trace in the frequency band 0.5-2 Hz is used to calculate the autocorrelation by a 1-bit correlation technique. By taking the ensemble average of ACFs over 24 h, the one-day ACFs are calculated for more than 300 days at each station. We assumed that the ACF is now derived for a random wavefield excited by a stochastic distribution of sources or scatterers; these are assumed to have random excitation times and random phase and amplitude characteristics. A plane wave from stochastic sources or scatterers is vertically incident on a seismic station. Then, the body wave reflects at a surface, and the refection reflects a subsurface velocity boundary again. The reflection could be observed as a PxP reflection at the station. We considered that the typical phases in the ACFs correspond to PxP reflections from the subsurface velocity boundary: we compared a distribution of PxP reflectors with the depth of the plate boundary and the Moho discontinuity. It was found that the depths of typical reflectors are consistent with those of the subducting plate interface and the Moho discontinuity of the landward plate, although some reflectors do not correspond to known discontinuities beneath the Japan Island.

Poster

Peculiar configuration of the plate beneath central Japan.

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The Deep Seismic Profiling, “Northern Mino Transect 2009” (NORM) was successfully made from September 30 to October 20 in 2009 in cooperation with the National Research Centre for Disaster Prevention (NIED) in the northern Mino district, north-western part of Central Japan, beneath which the upper surface of the Philippine Sea Plate (PHS) forms a broad anticline-like structure with a NW-plunging hinge. The location of the hinge seems to correspond to the biggest hinge in the mega kink structure of the Mino belt, which was formed in association with the bending of the Japanese island arc during the middle Miocene. Furthermore the trace of the Yanagase Fault, a major active fault in the Central Japan, is running close to the biggest hinge in the mega kink structure, whereas the trace of the Neodani Fault, another major active fault, is also along one of the hinges. This correspondence among three kinds of the structures mentioned above suggests essential relationship between the subducting PHS and the overlying crustal structures in the northwestern part of Central Japan. Thus the NORM was aimed to reveal the whole crustal structure and the geometry of the upper surface of the PHS. In order to accomplish the aim a 90-km long seismic line was set up from eastern part of Shiga Pref. to central part of Gifu Pref. crossing at high angle with the trend of the three kinds of structures mentioned above. The line was composed of two segments, E-W trending western and NE-SW eastern segments, for the purpose of quasi-3-dimensional processing. 8 dynamite shots (100kg, 200kg) and 2 Vibroseis shots (280, 300 sweeps) were used as powerful sources, and 10-Hz receivers were arranged at about 50-m intervals. Recording times were 30 s for vibroseis sources and 64 s for dynamite shots. Satisfactory data sets were obtained at high S/N in the nighttime. The following significant results are provided, although the processing is still in progress. 1) A predominant deep reflective zone is traceable from the western to the eastern ends of the seismic line. As it occurs at TWT 9-11 s in the west segment, and at TWT 10-12 s in the east segment, it dips at about 10 degrees eastward. 2) Intermittent weak reflections are recognized in places at approximately 2 s beneath the deep reflective zone mentioned in 1). 3) Above the deep reflective zone, notable reflectors also occur at 3 and 6 s, which are expected to be useful to reveal geological structures in the crust.

Oral

Crustal and upper mantle structure of an island arc from recent active and passive seismic expeditions in Japan.

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The Japanese Islands are composed of several island arcs developed along subduction zones in the eastern margin of the Asian Continent. Their crustal evolutions have been dominated by complex tectonic processes including plate subduction, accretion, backarc spreading and arc-arc collision. The NE Japan Arc, which includes NE Japan and western Hokkaido, is overriding the subducting Pacific Plate. The SW Japan Arc consists of the western half of Honshu and Kyushu, beneath which the Philippine Sea Plate (PHS Plate) is subducted. During most of Mesozoic to early Miocene time, these arcs were situated along the subduction zone in the eastern margin of the Asian Continent, and rotated to their present locations by backarc opening of the Sea of Japan in 20-14 Ma. Tensional tress regime responsible for this backarc spreading changed into the compressional regime at the time of 2-3 Ma. Crustal studies of the Japanese Islands using controlled seismic sources were started in the 1950's. In the recent 20 years, crustal and upper mantle studies in Japan progressed very much due to the introduction of near-vertical reflection method. Several crustal and upper mantle cross sections of island arc system were provided both for NE and SW Japan arcs. Subduction structures along the Japan Trench and Nankai Trough have been investigated by intensive marine expeditions. Onshore-offshore wide-angle reflection experiments elucidated heterogeneous structure of the subducted oceanic plate, in which the plate boundary with steady aseismic creep beneath the SW Japan arc is characterized by anomalously strong reflection, probably dominated by dehydrated fluid from the subducted oceanic lithosphere. This is in marked contrast with non-reflective structure of the locked part (mega-thrust zone). Now, mega-spray fault systems developed away from the PHS plate has been intensively surveyed for the 1923 Kanto earth-quake area. Inhomogeneous structures developed within the island arc are being surveyed both by active and passive source experiments. Seismic reflection profiling in NE Japan arc elucidated clear listric active fault systems formed by the process of the Miocene backarc basin. Very dense aftershock observations for recent inland earthquakes along the backarc side of the NE Japan clarified rupture mechanisms dominated by complicated basin structure associated with the backarc spreading and local structural anomaly to which crustal fluids play an important role. For the Atototsugawa Fault system in central Japan, combined passive and active source experiments elucidated a low velocity anomaly where fluid, localized just beneath the fault asperity, is a key factor for earthquake generation. Now, the similar intensive expedition has been undertaken in the Nobi Fault system, the largest inland earthquake fault of 1891 Nobi event (M=8.0) Collision structure between NE Japan arc and Kuril forearc by reflection and refraction experiments shows a clear crustal delamination (crocodile pattern) of the Kuril arc crust, which occurs at the brittle-ductile boundary, and significant structural deformation in the fold-and-thrust belt. Island chains belonging to Izu-Bonin arc collided against the central Japan. Intensive active source survey strongly indicates that the upper and middle crusts of the Izu-Bonin arc were scrapped off and thrust into the central Japan.

Poster

Computational mineralogy in the C2C project.

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An overall review of results of numerical studies carried out in the Crust to Core European project will be presented. The numerical approach introduced at the New Zealand symposium and used by several groups within Crust to Core EU (MRTN) project allowed us to derive a number of macroscopic properties of various minerals and provided answers to some long-standing physical questions. We have derived the mechanical properties (density, seismic velocities) of various magnesium and iron orthosilicates over a wide range of pressures and temperatures. We have also investigated in detail the phase diagram of the magnesium orthosilicate crystal and analysed the stability and possible existence of the Wadsleyite II phase in the Transition Zone conditions. The quantum molecular-dynamics analysis of the structure of the magnesium hydroxide crystal revealed a peculiar dynamical structure of the hydrogen lattice in this crystal. Structural properties extracted from these calculations explained apparent contradictions in laboratory measurements of structural properties of this mineral. Since the brucite crystal is a model case for a wider group of layered crystals with hydrogen-reach separation layers, the structural properties revealed in our calculations may indicate the presence of similar phenomena in more complicated materials of this type.

Oral and poster

Deep seismic reflection imaging of the eastern Delamerian Fold Belt, South Australia and western Victoria, Australia.

Jones, L.E.A.[1], *Cayley, R.[2], Korsch, R.[1], Rawling, T.[2], Morand, V.[2], Betts, P.[3], Moore, D.[3] and Kennett, B.L.N.[4]

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A deep seismic reflection profile was acquired in South Australia and Victoria in November 2009 by Geoscience Australia with project partners AuScope, Geoscience Victoria, and Primary Industries and Resources South Australia (PIRSA). Along with previously acquired deep seismic reflection data, this 145 km long line completes a continuous east-west transect across the eastern Delamerian Fold Belt into the western Lachlan Fold Belt. The project aims included determining tectonic vergence during and after amalgamation of the Gondwana Supercontinent, understanding the transition from passive margin (Rodinia breakup) to convergent margin (Tasmanides orogenesis), and locating the so-called “Tasman Line”, the extent of Proterozoic continental crust. 20 s shot records were acquired with 3 IVI Hemi-50 (25 tonne) vibrators at 80 m VP, using three 12 s varisweeps, 6-64 Hz, 10-90 Hz and 8-76 Hz. A 300 channel split spread with 40 m group interval resulted in 75 fold high quality data. Key processing steps included crooked line geometry, refraction statics using an intermediate datum approach, spectral equalisation, automatic residual statics keyed on deep reflectors, and three pass stacking velocity analysis every 4 km. Dip moveout (DMO) correction and Kirchhoff migration proved essential for near-surface imaging of dipping reflectors corresponding to major faults. Major features on the recent profile include the Moho at 10 to 11 s TWT, deepening at the westward end of the line, with sub-Moho reflectivity evident at around 14 s. A highly reflective package at 3-5 s TWT rises eastwards to reach the surface in the vicinity of the Yarramyljup Fault, and correlates with mapped Cambrian(?) mafic and ultramafic igneous successions. Upper crustal low seismic reflectivity to the west corresponds to the Glenelg River Metamorphic Complex (GRMC) comprising schist, gneiss, migmatite and syn-tectonic granites. The seismic has revealed several sub-parallel hanging wall splays west of the Yarramyljup Fault, constituting a set of gently to moderately west-dipping thrust faults that have emplaced the GRMC east over a Grampians-Stavely Zone footwall of low grade Late Cambrian igneous and deep marine sedimentary rocks. These thrust faults suggest inversion of an Early Cambrian back arc or marginal basin, the locus of high-T peak GRMC metamorphism developed along the passive eastern margin of Gondwanaland. On the western end of the profile, the structures are predominantly east-dipping, with a major feature extending from the lower crust to around 1 s TWT or shallower. This coincides with the western margin of high-T GRMC metamorphism in overlying rocks, and the eastern margin of a basement high of probable Mesoproterozoic crystalline basement, and thus may represent a partly-inverted extensional boundary developed in Mesoproterozoic cratonic crust during Rodinia breakup. The seismic data appear to show that Mesoproterozoic cratonic rocks, direct correlates of those exposed west of the so-called “Tasman Line”, may continue southeast (beneath a quite thin Cambrian veneer) as far as the footwall of the Moyston Fault. One implication is that the Early Palaeozoic Moyston Fault marks the position of a shallowly buried “Tasman line”, the buried “toe-plate” of rifted Mesoproterozoic continental crust contiguous with the greater Australian craton.

Poster

New plots for old: reprocessing of Geoscience Australia's legacy seismic reflection data.

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Geoscience Australia has more than 50 years experience in the acquisition of deep crustal onshore seismic data, beginning with analogue low-fold explosive data, progressing through digital explosive data, and finally, in the last 12 years, moving into the digital vibroseis era. Over the years, shot data in a variety of formats has been recovered from a variety of media, both in-house and by external contractors. Processing through to final stack stage was used as a QC tool for transcription of some of the older analogue surveys, and proved so successful that the reprocessed data was released for interpretation. In other cases, more recent digital explosive surveys have benefited from reprocessing using modern processing algorithms.

Key modules in Paradigm Geophysical's Disco/Focus software used by Geoscience Australia for reprocessing old data include refraction statics, spectral equalisation, stacking velocity analysis, surface consistent automatic residual statics and coherency enhancement. Coherency enhancement is commonly carried out on both NMO corrected shots and stack sections, with several iterations of NMO and autostatics. With the irregular offset distribution and low fold of legacy explosive data, dip moveout (DMO) correction is not possible, but due to the shorter spreads is not as critical as for modern high fold vibroseis data. Nevertheless, "poor man's DMO" has proved successful in the shallow section, by the simple expedient of omitting 25% of the traces with the longest offsets.

Examples of transcribed analogue surveys include the 6-fold 1969 Braidwood Seismic Survey in New South Wales and the mostly single fold 1975 Galilee Basin Seismic Survey in Queensland. Major improvements in reflector imaging were achieved for the 1992 Otway Basin Seismic Survey in South Australia and Victoria, mainly due to the application of spectral equalisation and coherency enhancement on shots. Shallow imaging was greatly enhanced by detailed velocity analysis for an important crustal transect, the 1994 Mt Isa Seismic Survey, in Queensland. Results of Geoscience Australia's in-house reprocessing are on a par with, if not better than, industry reprocessing of selected surveys.

Oral and poster

Broadband seismics during IPY in East Antarctica (AGAP/GAMSEIS).

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The 'Antarctica`s GAmburtsev Province / GAmburtsev Mountain SEISmic experiment (AGAP / GAMSEIS) (International Polar Year (IPY), #147)' is an internationally coordinated deployment of more than 35 broadband seismographs over the crest of the Gambursev Mountains (Dome-A – Dome-F area). The seismological investigations provide detailed information on crustal thickness and mantle structure and make key constraints on the origin of the Gamburtsev Mountains, and more broadly on the structure and evolution of the East Antarctic craton and subglacial environment. In terms of the study on deep interior of the Earth, together with crust – mantle studies, teleseismic waveforms observed by the GAMSEIS have an advantage for investigating the lower mantle, the D" layer and the CMB. By using seismographs as a large aperture array, many earthquakes will be observable at the GAMSEIS profile. The epicentral distance range from 60° to 90° would be especially suitable for the observation of the D" reflected phases as well as the core reflected phases of ScS and PcP. The events from 90° to 130° would be appropriate for the observation of the core diffracted phases of Pdiff, and Sdiff, and a core phase of SKS. Reflectivity waveform synthetics for S and ScS phases of the Fiji event to the GAMSEIS profile demonstrated heterogeneous structure around the D" layer. Thus the IPY broadband deployment in East Antarctica is expected to be an important opportunity for supporting the Federation of Digital Seismographic Network (FDSN) in southern high latitude. From GAMSEIS data obtained in 2008-09, local and regional seismic signals associated with ice sheet movement and meteorological variations were recorded; together with significant number of teleseismic events. The detection of seismic signals from phenomenon at the base of the ice sheet, such as outburst floods from sub-glacial lakes could be expected from detailed analyses. In this presentation, in addition to the study of the Earth's deep interior, several remarkable detected signals are demonstrated involving meteorological and sub-glacial environment.

Poster

Shallow reflection imaging of East Ongul Island, the Lützow-Holm Complex, East Antarctica.

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The shallow reflection surveys were carried out in 2007 and 2010 Austral summers in the East Ongul Island, of the Lützow-Holm Complex (LHC), East Antarctica. The LHC is defined geologically as one of the Pan-African terrains of Eastern Dronning Maud Land. The multi-channel reflection surveys targeted to achieve the image of laminated layering of metamorphic rocks of the surface (down to few hundreds of meters) of the crystalline crust. Two surveys were conducted in two seasons of Austral summer in total length of profile of 500 m along the main traffic load across the East Ongul Island. The 24 channel acquisition system was utilized by dense geophones with interval of 12.5 m. The AD sampling interval was applied for 0.5 ms in order to detect the detailed structure of laminated layers for the basement metamorphic rocks (with P-wave velocity of 6 km/s). Seismic sources in 25 m interval were utilized with combining by weight drop (40 kg, 5 times stacking) and the hammer shots (20 times stacking). The obtained data include clear first P-arrivals in far offset distance. The energy of P-S converted waves was significantly enhanced because of the characteristics of the seismic sources. Pre-stacked images could give rise to the efficient information about the metamorphic layering of hornblende gneiss, garnet gneiss and pyroxene gneiss appearing on the surface bedrocks, together with fault systems / intrusion of pegmatite in the vicinity of the Ongul Islands. The achieved local imaging by reflections would give one of the hints for the formation of the LHC, as the Pan-African mobile belt of Gondwana super-continent.

Poster

INDEPTH IV wide-angle seismic imaging in northeast Tibet.

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The INDEPTH IV active source seismic profile revealed active growth of the high Tibetan Plateau to the north through injection of Tibetan crust outwards from the Kunlun Mountains beneath an indenting Qaidam Basin crustal wedge. Our 270-km wide-angle reflection and refraction profile is the highest resolution profile to date imaging (from south to north) the Songpan-Ganzi terrane crust, the South Kunlun Fault, the Kunlun Suture (collinear with the North Kunlun Fault), the Kunlun Mountains, the North Kunlun Thrust system, and the Qaidam Basin. The Kunlun-Qaidam area is the location of a transition from thicker (c. 70 km) Tibetan crust to thinner (c. 52 km) Qaidam Basin crust as well as a steep topographic boundary between the Kunlun Mountains and Qaidam Basin near the location of the North Kunlun Thrusts. Our final p-wave velocity model indicates the northern extent of thickened crust is farther north than previously suggested, c. 100 km north of the Kunlun Suture, and suggests a “double Moho” structure beneath c. 30 km of the southern Qaidam Basin.

The seismic profile incorporated 5 large (>1000 kg) and 105 small (60-100 kg) explosions and over 2000 seismometers with 650-m spacing at the profile ends and 50- to 100-m spacing across the central 100-km of the profile. Two off-end earthquakes also provided valuable constraints on the deep structure. First-arrival refraction ray tracing and least-squares inversion yielded a crustal p-wave velocity model for the top 15 km of the crust. Ray tracing of deeper intracrustal and Moho reflections constrained the deeper velocity model down to 70 km. The final model features considerable differences between the Qaidam Basin and the Songpan-Ganzi terranes, including higher crustal velocities beneath Qaidam and an 18-km deepening of the Moho from 52 km to 70 km located beneath the southern Qaidam Basin. The 18-km offset is located c. 100 km north of the Kunlun Suture, farther north than inferred from previous seismic studies. A 50-52 km deep reflector beneath the Songpan-Ganzi terrane and Kunlun Mountains may represent an older, shallower Moho. The shallow Qaidam Basin Moho at 52 km depth is underlain by crustal material north of the northernmost extent of the deeper Moho reflection. We tested our seismic velocity model by converting our p-wave velocity model to a density model and testing model-predicted Bouguer anomalies against measured Bouguer gravity from the Tibet Geoscience Transect. Our gravity modelling provides additional validation of our velocity model and the new northern extent of thickened crust beneath south Qaidam. Based on the velocity and density models, we propose a new tectonic model of this area featuring a rigid Qaidam crustal wedge over which the Tibetan upper crust is thrust to the north and beneath which the Tibetan lower crust is extruding or flowing to the north.

Oral

The potential of multi-wave seismic for determining seismic velocities in deep water conditions: a tool for discriminating oceanic and continental crust.

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The presence of a thick ocean water layer creates certain difficulties in estimation of velocities in the sedimentary cover and in the upper part of consolidated crust by seismic methods. The main reason is that refracted waves propagating in these layers are not first arrivals. However, multicomponent observations with ocean-bottom stations provide data for interpretation of converted and multiple waves corresponding to these depths. An example of multi-wave interpretation of seismic data from the profile over the South-Okhotsk deep trough is shown. P- and S-wave velocities of the sedimentary cover were estimated and a low velocity layer in the upper part of the consolidated crust was revealed by utilization of multiple and converted waves. In contrast to a previous interpretations, which considers the crust of the South-Okhotsk deep trough to be oceanic, the new data allow an interpretation that the crust from this region is thinned and strained continental crust.

Poster

Multi-wave deep seismic for structural and compositional offshore studies of the crust and upper mantle (case study of the South Okhotsk Deep Trough).

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The results of reprocessing and reinterpretation of 3-component data from a fragment of the 2-DV-M profile across the South-Okhotsk deep trough in the Okhotsk Sea are presented here. Four groups of seismic waves were identified: (1) compressional waves, that are usually registered and interpreted in DSS studies – Pg, PiP, PmP and Pn; (2) their shear equivalents (normally registered on horizontal components) – Sg, SiS, SmS; (3) converted waves (registered on both vertical and horizontal components with P-wave kinematics, but S-wave polarization at the registration point and vice versa); (4) multiples, those related to reflections from the sea bottom and reflections from sharp discontinuities in the sedimentary cover. The later two groups, which are typical in offshore seismic studies, usually obstruct identification of principal monotype waves that are traditionally used in DSS. However, in certain cases, utilization of these waves increases the detail and accuracy of velocity models that, along with utilization of S-waves, increases the information content of marine seismic data. Use of all wave types in interpretation of DSS data enables detailed P- and S-wave velocity sections of the crust and upper mantle to be made. Cross-sections of the South-Okhotsk deep trough illustrate this approach. The obtained velocity and Vp/Vs ratio parameters provide a structural and compositional model of the crust and upper mantle of this region.

Oral

Seismic images of continental rifts: global comparisons.

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Rifting is one of the major processes that affect the evolution of the continents and many rifts have been the target of large seismic experiments. Continental rifting sometimes leads to continental breakup and the formation of new oceans, but more often it does not. This is presumably due to extension not progressing sufficiently to form a new plate margin resulting in a major structure that remains isolated in an intra-plate environment. The Southern Oklahoma aulacogen and the Dniepr-Donets basin are such features, and the Rio Grande rift and continental portion of the East African rift system may be destined to be modern examples. As more detailed geophysical and geological studies of rifts have become available in recent years, a complex picture of rift structure and evolution has emerged. Global patterns that reveal the connections between lithospheric structure (deep and shallow), magmatism (amount and style), amount of extension, uplift, and older structures remain elusive. However, recent seismic studies of modern and paleo rifts in North America, East Africa, and Europe make it possible to make some general observations: 1) Magmatism in rifts is modest without the presence of a (pre-existing?) thermal anomaly in the mantle. 2) Magmatic modification of the crust takes many forms which probably depend on the nature of older structures present and the state of the lithosphere when rifting is initiated (i.e. cold vs. hot; mantle fertility; water in the mantle, etc.). 3) There is no clear relation between amount of extension and the amount of magmatic modification of the crust. 4) Brittle deformation in the upper crustal is complex, often asymmetrical, and older features often play important roles in focusing deformation. However on a lithospheric scale, rift structure is usually symmetrical. 5) A better understanding of rift processes is emerging as we achieve higher levels of integration of a wide variety of geoscience data.

Oral and poster

Characterizing Great Basin structure from a 3D seismic volume, Hawthorne Geothermal Prospect, Nevada, USA.

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3D seismic data collected by the U.S. Navy Geothermal Programs Office on the Hawthorne Ammunitions Depot, Nevada provide a rare opportunity to examine the range of Western USA Great Basin extensional structures appearing in a seismic reflection volume. These industry-quality data, released for academic use, allow us to explore the potential for three distinctly different geologic structures known to exist in the region. The seismic volume shows indications of low-angle normal faulting, high-angle basin-ward step faulting, and also magmatic sill intrusions. Observations of both ancient and active low-angle faults in near proximity to other geothermal sites in the Nevada Great Basin (e.g., Abbott et al., 2001) allow comparisons to the Hawthorne data, which show high-amplitude reflections that dip ~20° basinward from the Wassuk Range front. A series of offsets in shallow stratigraphy traced to offsets in deeper high amplitude events suggest alternatively the presence of normal faults stepping down into the basin, a typical controlling structure for geothermal systems in the Great Basin (Blackwell et al., 1999). The seismic data also show numerous signatures common to magmatic sill intrusions as studied by Kluesner and others (2009) in the Gulf of California, and to other studies in the North Sea. Interpreting high amplitude synclinal features as saucer-shaped sills that have intruded an existing fault plane allows explanation for circular events seen in horizontal sections, as well as the origin of the high amplitude events. The lack of well data close to the dominant seismic features so far prevents positive identification of the features seen in the seismic data, so our interpretations used only observations from the 3D volume. By presenting possibilities for dominant structures within this geothermal site, we help to characterize possible controls on geothermal resources around the Great Basin.

Oral

Unveiling the Australian Lithosphere.

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The number of permanent high-quality seismic stations in Australia is relatively low, in part because of the modest levels of seismic activity. In consequence studies of Australian structure have relied heavily on the use of portable instrumentation, from early studies of the nuclear tests in central Australia through to the systematic coverage of the continent with portable broad-band instrumentation since 1992. The favourable distribution of earthquake belts to the north and east, with less frequent seismicity along the mid-ocean ridge to the south has allowed high quality surface wave tomography to map out the larger scale variations in shear wave speed variation. Unusually it is also possible to exploit refracted body waves for tomographic studies of P and S wavespeed variations and attenuation. We are therefore able to provide an independent cross-check on the surface wave results and to provide a synthesis of structure extending well into the upper mantle. At the crustal scale a sustained program of reflection profiling by Geoscience Australia in association with the State Surveys has provided detailed information on areas of potential economic importance. Recently infrastructure funding through AuScope has allowed extra investment in areas of scientific interest. In southeastern Australia additional constraints on the 3-D seismic structure are provided from an ongoing campaign of dense deployments of short-period instruments (the WOMBAT project). Receiver function studies at the portable and permanent stations provide insight into crustal and uppermost mantle conditions. The broad-scale deployment of portable instruments has allowed the exploitation of seismic noise correlation methods to extract information on higher frequency surface waves and thereby image the crustal structure. As a result we are close to being able to map out the 3-D variations in the full lithosphere at larger scales across the whole continent, and in some detail in the southeast.

Poster

Instability of the crustal thermobaric zones of low velocity.

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In recent years fragmentary crustal low velocity zones were revealed by DSS profiles at depths of 5-22 km around the Earth. However, their nature remains not quite clear. Interdisciplinary interpretation of DSS data including petrophysical thermobaric modelling of the lithospheric composition brings more insight into the nature of these anomalous zones. In most cases they are considered as thermodynamical phenomena rather than a result of changing composition when mineral material is transformed by pressure and temperature at the depth of their occurrence. Multi-method laboratory studies of samples show that under PT conditions at 5-15 km depths rocks are subjected to cataclastic and dilatational changes. A major mechanism responsible for this behaviour is a resultant effect of irregular and differently oriented tensions in the sample. In contacts between grains they reach values which exceed the strength limit of individual minerals that destroys the integrity of the medium at a microlevel. Here the rocks are characterized by low Young and shear modulii, high brittleness (low Poissons (fs) ratio), high decompaction (high dilatancy), low thermal conductivity (ƒÉ). The decompacted state of rocks at 5-20 km depths is a fundamental characteristic of the Earth's crust. It results from the reverse effects of pressure and temperature at these depths. The inversion zones established by laboratory experiments in most cases coincide closely with low velocity zones in the Earth's crust from DSS profiles. As low velocity zones result from temperature destruction of rocks uncompensated by pressure at 5-18 km depths, changes in T at these depths can lead to change in intensity of the thickness of these zones and rate of decrease in V_p within them. Crustal thermobaric zones are shown to increase, decrease and disappear depending on □ÝT/ÝH, □ÝP/ÝH, ƒÉ, and T. Instability of the crustal thermobaric zones of low velocity result in their episodic occurrence in the crust and their vertical and horizontal migration depending on temperature fluctuations in the crust.

Oral and poster

Geodynamic implications of a deep seismic reflection transect from the western Eyre Peninsula in South Australia to the Darling Basin in New South Wales.

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Over the last fifteen years, Geoscience Australia, in part through its current Onshore Energy Security Program, in conjunction with Primary Industries and Resources South Australia (PIRSA), the Geological Survey of New South Wales (Industry & Investment NSW), the Australian Geodynamics Cooperative Research Centre, and the Predictive Mineral Discovery Cooperative Research Centre, has acquired several deep seismic reflection profiles, which, when combined, form an east-west transect about 870 km long in southern Australia, from the western Eyre Peninsula to the Darling Basin. This provides a near complete cross-section of the crust across the Gawler Craton, Adelaide Rift System, Curnamona Province, Koonenberry Belt and Darling Basin. The seismic data vary from low-fold, dynamite-source to higher-fold, vibroseis-source data. The entire region is dominated by east-dipping faults, some of which originated as basin-bounding extensional faults, but most appear also to have a thrust sense of movement overprinting the extension. In the Gawler Craton, an inferred shallow, thin-skinned thrust belt occurs to the west of an inferred thick-skinned thrust belt. The boundary between the two thrust belts, the Kalinjala Mylonite Zone, was active at least during the ~1740-1715 Ma Kimban Orogeny, with probable extensional movement at that time. Thrust movement possibly occurred during the ~1600 Ma Olarian Orogeny. The Curnamona Province also has two styles of thrusting which are linked to a westward-propagating thrust system. A shallow, thin-skinned thrust belt, principally in the Olary Domain in South Australia, consists of a series of thrusts that link onto a shallow detachment at a depth of ~6-9 km. Further west, the thrusts die out and the deformation is expressed as a series of folds above a subhorizontal decollement. To the east, in the Broken Hill Domain in New South Wales, a thick-skinned thrust system cuts deep into the core of the orogen. Because the thrust system includes individual folds and thrusts that are interpreted as F3, it is inferred to have formed late during the ~1600 Ma Olarian Orogeny. The westward-propagating nature of the thrust system, and its size, indicate that it was driven by a major event, either backarc contraction related to a subduction zone located to the southeast, a collision or intraplate deformation. The Olarian structures may have been reactivated during Neoproterozoic and/or Paleozoic (Delamerian) deformational events. Shear zones exhibiting this timing are well documented at the surface in the southern Curnamona Province. Also, Delamerian deformation is seen towards the eastern end of the transect, in the Koonenberry Belt, and towards the west, in the Adelaide Rift System, where Neoproterozoic rocks are strongly deformed. At least four discrete seismic provinces have been recognised in the middle to lower crust along the seismic transect. All of these seismic provinces are bounded by east-dipping, crustal-penetrating fault zones which extend to the Moho. Each seismic province has a very different seismic reflectivity to the adjacent seismic province, suggesting that each is a unique piece of middle to lower crust, consisting of different lithologies, with a different geological history and structural architecture. Timing of amalgamation of the seismic provinces with each other, prior to the deposition of the Paleoproterozoic-Neoproterozoic sedimentary packages mapped at the surface, is poorly constrained.

Oral and poster

Geodynamic significance of results from the 2007 north Queensland deep seismic reflection survey.

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As part of initiatives by the Australian and Queensland Governments to support energy security and mineral exploration, a deep seismic reflection and magnetotelluric survey was conducted in 2007 to establish the architecture and geodynamic framework of north Queensland. With additional support from AuScope, nearly 1400 km of seismic data were acquired along four lines, extending from near Cloncurry in the west to almost the Queensland coast. Important results based on the interpretation of the deep seismic data include: (1) A major, west-dipping, Paleoproterozoic (or older) crustal boundary, which we interpret as a suture, separates relatively nonreflective, thick crust of the Mt Isa Province in the west from thinner, two layered crust (based on seismic reflectivity) to the east. This boundary is also imaged by the magnetotelluric data and 3D inversions of aeromagnetic and gravity data. (2) East of the Mt Isa Province, the lower crust is highly reflective and has been subdivided into three mappable seismic provinces (Numil, Abingdon and Agwamin) which have not been traced to the surface. Granites sampled at the surface above the western Numil and central Abingdon Seismic Provinces have broadly similar Nd model ages, suggesting that both provinces may have had a broadly similar geological history. By contrast, granites sampled above the eastern Agwamin Seismic Province have much younger Nd model ages, suggesting a significantly younger-aged lower crust; thus, the Agwamin Seismic Province may contain a strong Grenvillean-age component. (3) To the west of Croydon, a second major crustal boundary also dips west or southwest, offsetting the Moho and extending below it. It is interpreted as a fossil subduction zone. This marks the boundary between the Numil and Abingdon Seismic Provinces, and is overlain by the Etheridge Province in the upper crust, indicating that the boundary is older than ~1720 Ma. (4) A previously unknown sedimentary basin, the Millungera Basin, was discovered below the Jurassic-Cretaceous Eromanga-Carpentaria basin system. The geometry of internal stratigraphic sequences, and of the eastern, post-depositional thrust margin, indicate that the original succession was much thicker than preserved today. It is interpreted, in part, to nonconformably overlie granite bodies. (5) In the east, the Greenvale and Charters Towers Provinces have been mapped on the surface as two discrete provinces. The seismic interpretation raises the possibility that these two provinces are continuous in the subsurface, and also extend northward to beneath the Hodgkinson Province, originally forming part of an extensive Neoproterozoic-Cambrian passive margin. (6) Continuation of the Neoproterozoic-Cambrian passive margin at depth beneath the Hodgkinson and Broken River Provinces suggests that these provinces (which formed in an oceanic environment, as an accretionary wedge at a convergent margin) have been thrust westwards onto the older continental passive margin. (7) The Tasman Line, originally defined to represent the eastern limit of Precambrian rocks in Australia, is an east-dipping fault beneath the Hodgkinson Province, but is a different, west-dipping fault beneath the Etheridge Province. These geometries suggest that the Tasman Line is more complex than originally interpreted, and needs to be redefined.

Oral

Urban shear-wave reflection seismics in the Trondheim Harbour area, Norway.

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A shallow, high-resolution reflection shear-wave seismic survey was carried out in mid-summer 2008 in the harbour area of Trondheim, Norway, that suffers from prominent landslide events in the last decades. The harbour has been built on man-made land fillings at the coast of the Trondheim Fjord in several expansions implicated in some submarine landslides, which are reported since about 100 years. Whereas high-resolution marine seismic methods mapped the fjord area in detail in the range of decimeters, the seismic investigation below the infilled and paved harbour area was a difficult challenge. Therefore, SH-polarized shear-wave reflection seismics was applied experimentally, and the field configuration was especially adapted for the application on paved surfaces with underlying soft soil of estimated more than 150 m thickness. A land streamer system of 120 channels (geophone interval of 1 m) was used in combination with LIAG's newly developed shear-wave vibrator buggy of 30 kN peak force. This mini truck is designed for full environment-friendly urban use and enables fast and sensitive operation within a seismic survey area. The sweep parameters were configured to 25-100 Hz range, 10 s duration, using 14 s recording time sampled by 1 ms interval. Shear wave frequencies above the used frequency range, which can also be generated by the seismic source, were avoided consciously to prevent disturbing air wave reflections during operation. For an advantageous solution for the seismic imaging of the subsoil down to the bedrock a grid of 4.2 profile-km was gathered. The data recorded achieved finally a highly resolved image of the structure of the sediment body with ca. 1 m vertical resolution, clear detection of the bedrock, and probably deeper structures. The profiles were processed up to FD time migration, and indicate that slip planes, turbidity masses and other features relevant for geohazards are present within the top of the bedrock. Due to the clear and continuous reflection events, also the shear-wave velocity could be calculated at least down to the bedrock to indicate the dynamic stiffness parameters of the sediment layers.

Poster

Crustal structure of the Izu Collision Zone, central Japan.

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In central Japan, the Philippine Sea Plate (PHP) subducts beneath the Tokyo Metropolitan area, the Kanto region. In western Kanto region, the Izu-Bonin arc (IBA) within the PHP has been colliding from the south with the Honshu arc, forming a complex structure called the Izu-Collision Zone (ICZ). Several active faults were formed in and around the ICZ. The geometry of the subducting PHP and the overlying crustal structure of the ICZ are important to constrain the process of earthquake occurrence and the crustal evolution process associated with arc-arc collision. The Japanese islands, including the ICZ, are covered with dense arrays of permanent seismic stations, which provide good constraints on velocity structures by a tomographic method. Such studies reveal a general picture of the lithospheric structure such as a descending plate configuration (e.g. Matsubara et al., 2008). However, since an average spacing of the permanent station is typically 20 km, a detailed structure in the upper crust, which is imperative for an understanding of the active tectonics, cannot be well constrained by permanent array alone. A series of dense seismic array observations were undertaken in 2005, 2008 and 2009 to obtain a detailed structural image beneath the ICZ. The 2005 seismic array observation was carried out across the northwestern part of the ICZ. Forty three-component portable seismographs were deployed on a 40-km-long survey line trending NNE-SSW and waveforms were continuously recorded during a three-month period from January, 2006. The 2008 seismic array observation was carried out across the northern part of the ICZ. Seventy-five three-component portable seismographs were deployed on a 55-km-long survey line trending ENE-WSW with 500 to 750 m intervals and waveforms were continuously recorded during a four-month period from October, 2008. The 2009 seismic array observation was carried out across the northeastern part of the ICZ. Seventy-five three-component portable seismographs were deployed on a 55-km-long survey line in the north-south direction with 500 to 750 m intervals and waveforms were continuously recorded during a four-month period from November, 2009. In order to obtain a high-resolution velocity model, a well-controlled hypocenter is essential. Due to this, we combined the seismic array data with permanent seismic station data. P- and S-wave arrival time data were obtained from 610 events and 35,042 P- and 29,527 S-wave arrival times were used for the inversion analysis. Arrival times of local earthquakes were used in a joint inversion for earthquake locations and 3-D Vp and Vp/Vs structures, using the iterative damped least-squares algorithm, simul2000 (Thurber and Eberhart-Phillips, 1999). The seismic velocity structure shows that high Vp and low Vp/Vs zones exist beneath the Tanzawa Mountains and Misaka Mountains, which considered as fragments of the IBA. A low Vp and low Vp/Vs zone exists along the estimated deeper extension of the active faults. We obtained a seismic velocity model revealing good correlations with the surface geology along the profile.

Oral

Deep crustal structure of the Korean Peninsula: velocity models and preliminary analyses of KCRT2004 and KCRT2008.

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The crustal wide-angle reflection and refraction survey (KCRT2008) was carried out along a 300 km survey line of NW-SE direction in the central part of South Korea in November 2008, after we reported the velocity model of the KCRT2002 and the preliminary result of the KCRT2004 survey lines in SEISMIX 2008. We present a new interpretation of seismic data along the 340-km-long NNW-SSE profile, extended from the Precambrian Gyeonggi Massif to the Cretaceous Gyeongsang Basin (KCRT2004), and the 300-km-long NW-SE profile (KCRT2008), which is roughly parallel and located approximately 100 km north of the KCRT2002 survey line. Along this new survey line, that crosses four different tectonic structures, 593 portable seismometers were deployed with approximately 500-m intervals and 8 shots, with charges ranging from 250 to 1500 kg, were exploded.

The crustal velocity model developed by 2D forward modeling is illustrated by stacks of layered media, the velocities of which are laterally varying. The crust consists of three parts: the upper, middle, and lower crust with P-wave velocities of 5.50–6.28, 6.27–6.40, and 6.45–6.95 km/s, respectively. S-wave velocities for each crustal unit, constrained by Sg and SmS phases, range 2.82–3.63, 3.62–3.70, and 3.70–3.91 km/s, respectively. The average P- and S-wave velocities of the crust are estimated to be approximately 6.26 and 3.62 km/s, respectively. Pn velocity of 7.82–7.88 km/s is lower than that (7.90–7.96 km/s) found from KCRT2002 experiment. The lower crust has a strong vertical P-wave velocity gradient. Depth to the Moho gradually increases from 29 km at the northern end of the profile up to 34.9 km at the southern end. The mid-crustal reflections at depths of 16 km and 24 km are recognized in part, and velocity modeling shows weak velocity contrast across those boundaries. The Vp/Vs ratio of crustal material is estimated to be 1.73 for the upper and middle crust in general, while a low Vp/Vs ratio of 1.68–1.71 is observed extending down to the depth of 10 km under the Gyeonggi Massif. The increase of Vp/Vs ratio with depth from 1.73 to 1.79 in the lower middle and lower crust may reflect a normal decrease of silica minerals in the continental crust. In view of both P-wave velocity and Vp/Vs ratio, it appears that the upper and middle crust is dominantly felsic in composition and the lower crust is intermediate. The average Vp/Vs ratio is assessed to be 1.74 that is lower than the average value 1.78 for the bulk continental crust. The average P-wave velocity (6.26 km/s), Vp/Vs ratio (1.74), and thickness (32 km) of the crust under KCRT2004 profile could be correlated with a specific crustal type, Mesozoic-Cenozoic belts, which are tectonically still active with considerable surface relief and crustal thickness variations.
The preliminary interpretation using 8 record sections from KCRT2008 experiment is now completed. Travel times of P- (Pg, PmP, Pn) and S-wave phases (Sg, SmS) are identified. The preliminary result of layered crustal velocity model, using forward modeling of 2D ray tracing with P-wave phases, shows that the crust thickness varies from 30 to 34 km. It is thickest below the central part of the survey line and it becomes shallower at the northwestern and southeastern parts of the survey line, which is a similar trend to that of KCRT2002.

Oral and poster

New results from intensive studies of the Russian program – the State network of geological-geophysical transects and deep boreholes.

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The new program of deep studies has been started in Russia from 1995. The main target is to organize a network of combined geophysical transects and interfacing deep boreholes through the continental part of Russia and their margins. Approximately 20,000 km of deep seismic profiling including more than 10,000 km of offshore profiles, several boreholes with the depth over 3.5 km have been executed within the framework of this state program. Seismic deep profiling in Northeast Russia (2-DV and 2-DV-A profiles), Polar Urals (Polar Uralian transect), in the Sea of Okhotsk (2-DV-M profile) were accomplished; the drilling of Voronezh deep hole situated in the Voronezh massif of the East European Platform and Onega deep hole located in the Onega structure of Fennoscandian shield have been fulfilled during the last 3 years. The paper focuses on the main recent results under the Program of "THE STATE NETWORK OF GEOLOGICAL-GEOPHYSICAL TRANSECTS AND DEEP BOREHOLES" and current projects on deep studies in the Arctic Ocean, Far East, and West Siberia.

Oral

High resolution reflection seismic imaging of the Ullared Deformation Zone, southern Sweden.

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The Ullared Deformation Zone (UDZ) is one of a few structures worldwide known to contain decompressed eclogite facies rocks of Precambrian age. Given the unique nature of the Ullared eclogites, a 15 km long reflection seismic profile was acquired across the UDZ in April 2007. The principal objective of the profile was to provide geometrical information on the deformation zone at depth. Understanding the geometry of the shear zone is the first important step towards understanding the tectonic setting in which the eclogites were brought to the surface. The profile was acquired along a crooked profile. In high grade gneissic terrains, sub-horizontal structures cannot be expected to be present. The structures causing the reflections may be very complex. Steeply dipping and out of the plane reflections are common. Complex geometry and a crooked line recording geometry will significantly reduce coherency of the stacking if standard 2D processing is applied. For a crooked 2D profile, the midpoints are scattered, in the case of the UDZ profile this cross-profile scattering is up to 1400 m. The positive aspect of this geometry is, however, that it is possible to deduce the dip in the cross profile direction and, thereby, calculate the true dip and strike of reflective structures. In the present study two different methods were used in order to obtain information of the true 3D geometry of the structures. Cross-dip analysis, as described by Wu et al. (1995) and an azimuthal binning procedure, similar to recently used methods by Tsumura et al. (2009) and Kashubin and Juhlin (2010) for analyzing the strike of structures. The present outline of the UDZ, Möller (1997), was based on aero-magnetic data and UDZ was interpreted as a shear zone or possibly a shear zone system. The new reflection seismic data and a detailed magnetic anomaly interpretation were used to update the boundaries of the UDZ and also to highlight some areas of the UDZ that need to be further investigated.

Oral

Seismic detection of VMS deposits: lessons from Halfmile Lake, New Brunswick, Canada.

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Geophysical exploration of volcanogenic massive sulfide (VMS) deposits traditionally has relied on non-seismic methods such as electromagnetic and potential field techniques. However, the increasing ambiguity of these methods with depth makes seismic reflection methods favorable for targeting deep-seated >1000 m VMS deposits. The localized and isolated nature of massive sulfide deposits and their significantly contrasting elastic properties can generate complex scattering wavefield that may include P-P, P-S, S-P and S-S wave-modes. We present seismic signature of a deep-seated VMS deposit (about 1200 m), known as Deep zone, at Halfmile Lake on 2D, 3D, and three component VSP data. We show that the Deep zone displays remarkable characteristics on surface 3D seismic data which include: (1) amplitude variations along the diffraction, with the highest amplitudes occurring at the northern flank of the diffraction, an indication that the deep VMS deposit mainly dips to the north, (2) large and asymmetric semicircular diffraction signature relative to the location of the Deep zone, indicating that the deposit does not lie at the center of the diffraction in time slices or on the apex in inline sections and (3) two zero-amplitude segments that might be an indication of phase reversal or an effect from the shape of the VMS deposit. This diagnostic scattering signature further suggests that prestack DMO and poststack migration algorithm is the most helpful approach for the processing of data acquired for the purposes of base-metal exploration. Multi-component VSP data confirms presence of multi wave-mode seismic signal at the Deep zone. Finite difference modeling of the seismic wavefield based on available petrophysical data also indicates that wave-mode conversion at the Deep zone should be detected on surface seismic data. No three-component surface 3D seismic data is available in the Halfmile Lake area. Therefore, we have investigated the possible presence of P-S, S-P, and S-S wave-modes scattered at the Deep zone on a 3D surface seismic data acquired using point explosive sources and vertical geophones. Results from a target-oriented azimuthal scattering analysis based on a 3D prestack migration reveals amplitude anomalies at the location of the base-metal lens for S-P waves and possibly P-S waves. The identification of S-P and P-S wave modes confirms that mode-converted scattering occurring at the deep sulfide lens was recorded on the 3D data. However, the real potential of these complementary wave modes for mineral exploration will only be realistically achieved using shear-wave and multi-component surveys.

Poster

Linking 3-D crustal velocity and reflectivity imaging based on CELEBRATION 2000 data.

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We present a multi-step strategy for imaging crustal structure based on the data from a dense wide-angle reflection/refraction survey called CELEBRATION 2000. The target area covers ca. 500 by 500 km in SE Poland and represents a complex geological setting from old Precambrian platform (East European Craton, EEC), through the crustal blocks (terranes) that form the Trans-European Suture Zone (TESZ) to the young Alpine orogen - the Carpathians. During the first step, the first-arrival tomography was implemented. Contrasting velocity distributions in various geological units makes the tomographic inversion challenging. For this reason, much attention was paid to the inversion methodology. We tested "multioffset" and "multiscale" approaches. By increasing the offset range in the "multioffset" inversion we have independently constrained different depth ranges of our model. We have found that the "multiscale" method i.e., the gradual stepping from bigger to smaller model cells produced the preferred solution. Results of first-arrival tomography were subsequently used in the next step, where a reflection tomography was applied to PmP arrivals to constrain Moho structure. We tested two different inversion strategies using two different algorithms: (i) coupled inversion of Pg and PmP arrivals to constrain both the crustal velocities and the Moho depths; (ii) decoupled inversion of PmP arrivals only using previously obtained smooth 3-D crustal velocity model. The coupled inversion results in a much smoother crustal velocity field than the one previously obtained by inversion of first arrivals only. Also, the obtained Moho structure is much smoother than the Moho map compiled from the existing two-dimensional models. Decoupled inversion of the PmP reflections provides Moho structure comparable in resolution to the compiled map. As the final step in the crustal imaging workflow, we applied a customized 3-D reflection processing. Data were binned using 5 x 5 km CMP bins with a maximum fold of 75. A minimalistic processing was then applied to the data, including trace editing, band pass filtering, deconvolution, median dip filtering. NMO corrections were applied using smooth velocity field from step one (converted to RMS velocities) or a constant Vp=6000 m/s. Data were subsequently stacked, post-stack processed using FX deconvolution and depth-converted using tomographic velocity field. Surprisingly rich reflectivity is observed in the middle/lower crust and around the Moho, that could be spatially correlated in some places. However, comparison of the Moho depths derived from step two with the reflectivity patterns provides no obvious correlations. This suggests that the reflection processing applied to wide-angle data portrays more the transitional nature of the Moho discontinuity, which is usually inferred as a single interface in traveltime modelling.

Oral

3-D seismic modelling in the Flin Flon mining camp, Canada.

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A comprehensive seismic survey for VMS ore exploration was recently conducted in the Flin Flon mining camp (Trans-Hudson Orogen, Canada). The seismic project comprised a total of 75 km of high-resolution 2-D profiles and a 14 sq km 3-D survey. Processing of the vertical-component data for P-wave reflections reveals prominent reflectivity associated with contacts between the metasedimentary and mafic volcanic rocks, as well as moderately dipping reflectivity within the polydeformed volcanic rocks including the main rhyolite horizon which hosts the VMS deposits. However, complex volcanic stratigraphy of the Flin Flon mining camp makes the interpretation of the 3-D seismic data especially challenging. Toward providing further constraints on the interpretation of seismic data, we have performed 3-D seismic forward modelling on a detailed geological model constructed for the camp, both in stack and prestack (i.e. simulating the complete 3-D survey) mode. A 3-D geological model of the Flin Flon mining camp was created based on an extensive set of drillholes, surface geology, interpretation of the 2-D seismic profiles and predictive modelling. The original model was generalized into six lithofacies and the elastic rock properties were assigned based on the rock property measurements on core samples. 3-D forward seismic modelling implemented the phase-screen method, which allows the calculation of an approximate (narrow angle) but fast solution to the elastic wave equation in complex 3-D media. To simulate the 3D stack volume, initial simulations were conducted by using the "exploding reflector" mode (plane-wave simulation) both for the whole model and for the ore lenses only. Ultimately, the prestack data simulations were performed, by calculating the individual shot-gathers using the real survey 3-D geometry. A total number of 934 shot points were simulated, each recording 23 lines. Data were binned using the same bin parameters as the original 3-D survey (25 m inline bin size and 12.5 m crossline bin size) and processed in a similar manner up to DMO and post-stack migration phase. Comparison of the "exploding reflector" simulation performed for the original model and for the ore bodies only with the processed 3-D DMO volume suggests that the lack of a clear ore body response in the real data (namely the diffraction patterns) can be mainly attributed to the wave interference arising from the complex volcanic stratigraphy. Alternatively, it could be due to the fact that the most of the ore lenses included in the 3-D model have been already mined out. However, the mined out ore was back-filled with material that should still produce a significant acoustic impedance contrast with the host rock. In fact, a close examination of the results of modelling and the real data suggests that the bright dipping reflectors in the 3-D DMO volume correspond to the down-dip diffracted energy of the ore bodies. As our model includes the known ore bodies, we can use predicted seismic data in combination with the 3-D seismic survey for direct ore targeting.

Poster

Converted-wave imaging in the Flin Flon mining camp, Canada.

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Seismic exploration for ore deposits rely mostly on utilizing reflected P-wave energy. However, the elastic properties of the host rock – ore deposit system should produce a complex, multimode reflected wavefield. Multimode converted waves originating from a sulphide lens were reported for VSP data, however the P-S converted wave techniques are rarely applied to surface seismics datasets acquired in a hardrock environments. Here we show the potential of the converted-wave imaging applied to the high-resolution data acquired in the Flin Flon VMS mining camp (Trans-Hudson Orogen, Canada). Seismic investigations in this area have been conducted as a part of the Canadian Targetted Geoscience Initiative-3 (TGI-3). The seismic project comprised a total of 75 km of high-resolution 2-D profiles and a 14 km^2 3-D survey, acquired using 3-C digital sensors, thus making converted wave imaging feasible. Converted-wave processing was performed for 3 selected profiles for which the best PP images were obtained, using a tailored PS processing workflow. One of the crucial steps was the determination of the S-wave statics. We followed a procedure developed by Snyder et al. (2008), where the statics were determined from the stack of the LMO-corrected radial component receiver gathers. The PS data were binned for stacking using a classic asymptotic common-reflection point (ACRP) binning technique with a constant Vp/Vs ratio of 1.75 as representative for basaltic rocks. This technique may not be strictly valid for the crooked line data acquisition or the significant dip component in the data. The transformation from CMP sorted to CRP sorted PS data could be achieved by the application of the DMO operator (Den Rooijen, 1991). Following this approach, we use ACRP-binned data to calculate residual static corrections, but later on we return to standard CMP binning and the PS DMO is performed in this domain. The obtained PS sections are of good quality and in some places the observed reflectivity is richer than in the PP sections, hence showing a potential for being a complementary source of information to the PP images. The response of an existing VMS ore lens was identified in PP and PS data for one of the lines with a help of a 2D synthetic modelling. Application of a diffraction-stack prestack migration to a dip line shows an interesting shallow anomaly, that correlates well with an uneconomic ore body, and which was not identified in the PP section.

Oral

High-resolution seismic attenuation imaging from full-waveform inversion.

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Recent applications of the frequency domain full-waveform inversion (FWI) provided detailed P-wave velocity models in various geological settings. In those studies the acoustic approximation for the wave propagation was used, however the waveforms obviously contain much more information, that might be used for a multi-parameter FWI (MFWI), e.g. for the recovery of density and attenuation. The most straightforward approach is the viscoacoustic approximation, under which joint inversion for velocity and attenuation might be performed. We have applied the MFWI method to the wide-aperture data acquired in central Poland along a 50-km long profile during GRUNDY 2003 seismic experiment. The input to the inversion was the same as in case of the acoustic inversion presented by Malinowski and Operto (2008), except that the amplitude versus offset information was preserved. We have tested two different inversion strategies. The first one, called "coupled" inversion, consists of inverting sequentially 13 frequency components ranging from 4 to 16 Hz both for Qp and Vp. The second one, called "decoupled" inversion, used the same frequency components, but the starting velocity model at each frequency was taken from the acoustic FWI results (e.g. Kamei and Pratt, 2008). Hence, during the "decoupled" inversion, the contribution of Qp perturbations was preferred over the changes in Vp. Contrary to findings of Kamei and Pratt (2008), simultaneous inversion for Vp and Q provided the preferred model of Q. The application of the MFWI resulted in the improvement of the velocity model as well as it improved the data fit in the frequency domain. The recovered attenuation model is geologically justified and interpretable in terms of the rock properties. The high attenuation zone in our model correlates well with the low-resistivity zone as determined by well-logs, hence it could be attributed to the presence of the mineralized fluids within Lower Jurassic sandstones. Based on the recent laboratory measurements (McCann and Sothcott, 2009), Qp and Vp could be jointly used as the indicators of the permeability in sandstones. Medium velocity sandstones (Vp=3500-4500 m/s) with the Qp > 60-70 are highly permeable. In our case, it came out that the entire Jurassic sequence between ca. 1000 and 2200 m depths fulfils this condition. Since it is well known phenomena in the Polish Basin, that the Middle/Lower Jurassic sandstones show good reservoir properties, with high permeabilities, we can conclude that if only we have sandstones in our stratigraphic column (which is the case here except the Upper Jurassic carbonates), they could be highly permeable.

Poster

A new model of the P-wave velocity distribution in the upper mantle based on the USArray data.

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We discuss different models of P-wave velocity distribution in the upper mantle below two different tectonic areas of North America: tectonically active western part and tectonically stable central part. We model the travel time data from natural earthquakes recorded in the far-regional mode up to 3000 km. On that basis we derive a new one-dimensional P-wave velocity model (MP-1) down to the depths of the transition zone for both mentioned regions. Significant differences in the first-arrival travel times observed for distances between 800-1800 km (up to 5 s) suggests that the distribution of P-wave velocities has an influence on the travel times and distribution of main discontinuities located below 100 km depth. For the tectonically active region we observe a discontinuity at ca. 300 km depth, characterized by a refracted wave with velocity of 8.7-8.9 km/s and clearly observed reflected wave. For the stable part of the continent, the arrivals from 300-km discontinuity are obscured by other arrivals. For the western part of the US, we found also a low-velocity zone atop 400 km depth and a significant depression of the 410-km discontinuity. Our model deviates significantly from the standard seismological models, however it emphasizes some features observed in the mineral-physics based models (like iPREF), i.e. the increase in velocity at ca. 350 km depth. Most of the elements present in our model could be explained by multiple subduction processes that brought both the fluids and a MORB component into the upper mantle.

Poster

Geological CO_2 storage in saline aquifer: the Spanish scientific pilot plant.

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The carbon dioxide (CO2) capture and storage (CCS) is at present time the most suitable strategy to face the increasing necessity of reducing global warming associated with fossil fuels emissions. The artificial long-term CO2 storing into geological formations simulating natural oil and gas reservoirs has been studied during the last decade and recently put into practice. One of the main European initiatives in terms of CCS is the implementation of the first Spanish pilot test site for geological storage in Hontomin (Burgos, Spain), carried out by the Spanish Government, by means of the state-own Foundation CIUDEN. This is the first part of a multidisciplinary experiment that aims at demonstrating that a Geological Capture and Storage of CO2 is technologically feasible and environmentally safe. The pilot test site will allow to investigate, at real scale, the different aspects related with CO2 storage in order to validate and/or develop new methodologies and technologies for CO2 injection, characterization of the reservoir rock and seal, CO2 plume monitoring, escape pathways imaging and risk assessment. Geologically, the pilot test site will be set in a potential dome-shape reservoir that presents the optimal size and geologic requirements (depth, porosity, seal thickness, reservoir formations and water salinity) for a research CO2 storage site. In summer 2010 the site characterization will start with several innovative, non-standard seismic experiments including: 1) a 5x5 km 3D seismic survey, 2) 2 three-component 2D seismic cross profiles and 3) a seis-movie device, a new tool for reservoir monitoring developed by CGGVeritas Services, that includes one 80 m-depth source and a linear array of 80 receivers with 10 m interval. Additionally, the injection borehole will have permanent seismic instrumentation to obtain a vertical seismic profile (VSP) with 60 3-component geophones separated 10 m along the injection point and a borehole Sparker seismic source. This source will be also used to make crosshole records with geophones deployed in a nearby monitoring borehole. This seismic data set is expected to bring detailed images of the subsurface structure, in order to have a good characterization before and after the CO2 injection and subsequent monitoring.

Oral

3D seismic imaging of massive sulfides: geology matters.

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In a mineral exploration setting, velocity and density contrasts between the targets and background largely control the appropriateness of seismic reflection methods. Recent case studies have shown that massive sulfides, with their relatively high densities, provide more than the required impedance contrasts in typical host (crystalline) rocks to produce strong reflections of seismic waves. However, these deposits are sometimes embedded within strongly heterogeneous geological backgrounds, where perturbations in velocities and densities (as well as anisotropy) can be higher than 10%. Depending on the inhomogeneities and the scattering regime, reflections from sulfide deposits may or may not be distinguishable at the surface from geological background "noise". In addition, the interpretation of 3D seismic data based on borehole geophysical data and exploration drilling point towards systematic errors in the positioning (errors in depth and dip) of bright target reflectors. These observations pose a huge problem in adequate interpretation which is already compounded by the effects of the acquisition geometry, and the data processing routines implemented to produce the final stacked and migrated images. The motivation for the results presented comes from 3D seismic data from the Sudbury impact structure (Ni-Cu mineral deposits), the Louvicourt mine (Cu-Zn) and the Matagami area (Zn-Pb) in Canada, where several local bright spot reflections can be correlated with massive sulfide mineralizations.

Oral

3D deep structural model of the Yenisey Shield (Siberian Platform) from gravity modelling and seismic data.

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Six DSS transects and middle-scale gravity data are the base of modelling of Yenisey Shield deep structure. Solid modeling is reached due to coordination, of continuously distributed crust density with the topography of basement and Moho received from seismic data. Complexity technique of 3D density modeling is connected with geological structure: conjugate space of Yenisey shield with areas of thick sedimentary cover (up to 8 km) of the Western-Siberia plate on the west and the Siberian platform on the east. The original technique of 3D modelling is based on the gravity tomography method. It is constructed on iterative process of the sequential analysis of wave-length anomaly characteristics, which are used for estimation of the depth and intensity of abnormal mass sources of gravity field. Finding in such a way the distribution of field sources in the lower half-space is transformed in density model taking into account the aprioristic geophysical information. The specified global seismic models, in the context of a defined geology-geophysical situation and petrodensity parameters, are used as the aprioristic data. The final models are 3D crust local density model and density distribution model. Study of crust local density profiles received from 3D models allows us to specify the Moho topography and the large-contrast intra-crustal boundary relief. 3D density model shows lateral and depth heterogeneities. The deep structure is represented by topographic maps of the Moho, basement and two intra-crustal interfaces with density parameters on them.

Oral and poster

North Pole – Equator: proposals for a new international geotransect, Arctic Ocean – Chuktka – Okhotsk Sea – Pacific Ocean.

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Russian scientists carried out a large number of seismic profiles in Northeast Russia, Arctic Ocean and Okhotsk Sea in the last decade. The transects follow one another in submeridional direction from 84 deg. N in the Arctic Ocean, through Chukotka to Magadan and further across the Okhotsk Sea up to the Kurils. So, a composite geotransect approximately 5,000 km long can be constructed. Offshore geophysical investigations included: DSS seismics with on ice explosive shots and on ice seismic recording in the Arctics; digital ocean-bottom 3-component seismic stations and air-guns in the East Siberian Sea and Okhotsk Sea; deep CDP seismics with floating cable in ice-free water areas; magnetic and gravity field observations. On shore deep studies included: wide-angle seismics with explosive shots and high-energy vibrators; deep CDP with vibrators and magnetotelluric investigations. In the land-sea transition zone, special observations providing registration of on-shore and off-shore shots by on-shore and off-shore seismic array were carried out. The most of fulfilled observations are processed now, and preliminary deep sections of the crust and upper mantle are constructed for the fragments of these profiles. In the nearest future, Russian geologists plan to finish processing of all obtained data and start construction of an integrated deep section. The composite transect crosses different geological structures, which are of fundamental importance for understanding the evolution of the Earth's crust: passive continental margin of the Arctic Basin and Northern Eurasia, the continental fold areas and slope, the deep-water trough. Taking it into account, Russian scientists consider it reasonable to continue this composite transect to the south, into the Pacific Ocean. We propose that interested countries take part in these investigations for the purpose of further construction a composite deep section through the whole Northern Hemisphere from the North Pole to the Equator.

Oral and poster

Seismic imaging of the Alpine Fault, New Zealand, at Whataroa River.

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We have reprocessed the Whataroa98 reflection seismic data set which runs along the Whataroa River valley perpendicular to the Alpine Fault on the west coast of the South Island (New Zealand). The central task of this survey was to image the crustal structure in the vicinity of the Alpine Fault, which itself is assumed to dip at an angle of about 45 degrees down to depths of at least 15 km. The profile line has a total length of about 25 km with 636 receivers at approximately 40 m receiver spacing. So far we used approximately 20 shot records of the survey from both sides of the fault. In a first step we used some of these shot records for a first-arrival tomographic velocity inversion. The resulting velocity model covered the uppermost part and was blended with the available large-scale SIGHT98 velocity model down to 30 km depth. The second step was to pre-stack migrate the single shot gathers. We performed this migration separately for the shots from each side of the fault. We found that the shot records on the hanging wall illuminate the dipping fault from "above" and that the fault system itself is fairly complex consisting of several fault strands 1-2 km apart and with (expected) dip angles of about 40-60 degrees. Not quite as expected we also found that those shots and receivers at far offset (e.g. 15 km) from the fault allowed us to image the dipping fault from "below" by overturning waves. The comparison of the separate fault strands illuminated from each side shows that their locations are in good agreement and that actually the same fault strands were imaged. It is clear that the complexity and heterogeneity of the hanging wall is a major issue for imaging from "above" and therefore the imaging from "below" helps to clarify the structure of the fault system. For this type of imaging it is crucially important to have a good velocity model which is valid for both sides of the fault as well as for different depth levels.

Poster

IBERSEIS wide-angle S-velocity models: new constraints on the nature of the SW-Iberia crust.

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The SW-Iberian Peninsula was studied with the two wide-angle seismic reflection transects acquired in 2003. Both transects cross the three tectonic provinces in the area that are part of the Variscan Belt: South Portuguesse Zone (SPZ), Ossa-Morena Zone (OMZ) and Central Iberia Zone (CIZ). The data were acquired by 650 vertical component seismographs (TEXANS seismic recorders) from the IRIS-PASSCAL Instrument Centre, using explosive sources with charge sizes ranging from 500 to 1000 kg. Both transects, A and B, are, approximately, 300 km long with station spacing of 400 m and 150 m respectively. The relatively small station spacing favoured the lateral correlation of the seismic events and provided resolution enough for the identification of shear-waves arrivals. The most prominent reflection S-wave phase recorded by the vertical component sensors corresponds to the SmS which is nearly horizontal for a velocity reduction of 4600 m/s. This phase can be followed up to normal incidence at 18 s TWTT. First arrivals (Sg) are also clear in all shot records. Two S-wave velocity models have been derived by iterative forward modelling. Resulting S-velocity models provide new constraints on the nature of the crust beneath the Variscan of SW-Iberia. P and S velocity models show a high velocity area at mid crustal levels, that has been interpreted as a mafic intrusion. Vp/Vs relationship has been also calculated to constraint the crustal composition. The resulting images present a mid- to lower-crust with a Vp/Vs > 1.73 that implies a crust with a high content in mafic components.

Poster

The Earth's crust types of northern Eurasia from deep seismic investigations.

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The typification of the Earth's crust is proposed on the base of summarizing of velocity models from deep seismic of continental Russia and adjacent seas. Suggested typification is compared to the published data of the other regions all over the world. Correspondence of distinguished crust types with main geotectonic structures in Northern Eurasia: platforms, fold areas, intercontinental rift systems, passive and active continental margins, abyssal oceanic plains, underwater uplifts etc. is considered.

Poster

New High-Resolution Seismic Imaging of Australian Lithosphere and the CMB with the WOMBAT Array.

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Since 2001, Australia's WOMBAT array has been leap-frogging across the continent. Each subarray within WOMBAT consists of 30-72 short-period seismometers with solid-state recorders deployed for 6-12 months. Station spacing is 15-50 km, resulting in high-resolution coverage at the continent scale. To date, over 500 short-period stations have been deployed in SE Australia. Furthermore, the lack of anthropogenic noise for most stations, and the presence of low attenuation in parts of the upper mantle, enable good signal-to-noise ratio and make the dataset ripe for detailed seismic investigations beyond that of travel time tomography. We extend prior travel time tomography studies to utilize amplitude data for analysis of the attenuation structure of the lithosphere and upper mantle. We modify the adaptive stacking code of Rawlinson & Kennett [2004] to include frequency-dependent differential dt* attenuation measurements. Initial analysis of teleseismic P waves recorded using only a preliminary dataset of 100 stations shows good structural coherency with travel time tomography. Further high-resolution studies will provide a comprehensive picture of the attenuation structure of the Australian lithosphere and will enable direct comparison and integrative interpretation between observed velocity and attenuation anomalies. Furthermore, we analyse differential PcP-P travel times from the large number of subduction zone earthquakes along Australia's northern and eastern borders. Surface projections of PcP bounce points are clustered directly beneath the large region spanning northern Australia and mid-latitude regions of SE Asia, significantly improving resolution of the deep mantle beneath this area. From a preliminary dataset using only 100 stations, we record high quality PcP for several thousand earthquake-station pairs; we expect significantly more high quality PcP-P measurements from all 500 stations. Our goal with this new dataset is to produce high-resolution images of the seismic structure at the base of the mantle.

Oral

New results from the WOMBAT transportable array project in southeast Australia.

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The WOMBAT project began in 1998, with the deployment of three 40 station short period arrays in western Victoria and southeast South Australia over three consecutive years. To date, over 550 stations have now been deployed via 13 separate array movements, with several new deployments scheduled in coming years. Station spacing varies between 15 km in Tasmania (an island state south of Victoria) and 50 km on the mainland. The large number and relatively uniform distribution of stations provide a unique opportunity to study the structure and composition of the lithosphere beneath southeast Australia using a variety of passive seismic techniques, including crustal receiver functions, teleseismic traveltime and attenuation tomography, multi-resolution regional tomography, and ambient noise tomography. In this presentation, results from three recent studies that make use of WOMBAT data are discussed. The intraplate location of the Australian continent means that local seismicity is insufficient for high resolution imaging using temporary array deployments. However, frequent large earthquakes from surrounding seismogenic zones, particularly from the north and east, make teleseismic tomography a viable proposition. Since the early deployments in the late 1990s, teleseismic tomography has been performed on individual sub-arrays, but not collectively, partly due to the difficulty of joining data from adjacent arrays. Recently, teleseismic arrival time residuals from seven of the mainland deployments were simultaneously inverted for perturbations in 3-D P-wave velocity structure. The resultant images reveal a range of features, including pronounced velocity contrasts related to the transition between Precambrian central-western Australia, and Phanerozoic eastern Australia. Ambient noise tomography, which is rapidly becoming a technique of choice in many passive experiments, has also been simultaneously applied to seven of the mainland sub-arrays. Rayleigh wave empirical Green's functions, extracted from the cross-correlation of traces from simultaneously recording station pairs, range in period between 2-25 s, which allows structure to be imaged almost throughout the full thickness of the crust. Group velocity maps obtained using group traveltime tomography clearly distinguish between hard-rock and sedimentary domains near the surface. Interestingly, at both near-surface and mid-lower crustal depths, there is little sign of the Palaeozoic suture zones that are inferred from gravity and magnetic data. One of the more interesting features to be imaged are pre-Tertiary infrabasins beneath the Murray Basin, about which little is known. Crustal receiver functions have been extracted from the 57 station SEAL3 sub-array in central eastern NSW, and used to constrain variations in shear wavespeed beneath each station. Results from these receiver function inversions are being used to create a detailed Moho map of the region, which can then be integrated into an Australia-wide Moho map that is currently being developed.

Poster

Combining ambient seismic and receiver function analysis towards improved passive seismic imaging along crustal transects.

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The potential for combining ambient and conventional receiver function analysis of data from an extensive passive seismic experiment, CAPRA, is investigated. High-fidelity broadband seismic stations were deployed from the northern Pilbara in a north-south transect extending to a point approximately 100 km southwest of Meekatharra. This transect samples the Pilbara Craton, Capricorn Orogen, and the Narryer and Murchison Terranes of the Yilgarn Craton. Station separation was nominally 40-45 km. The field deployment was a natural development of previous, reconnaissance-level deployments which spanned the West Australian Craton at the scale of the main terrane groups. During this earlier work, the variability of the Capricorn Orogen in terms of crustal structure was identified, but the station density was not sufficient to define the variability of structure within the Capricorn. This previous work also took place prior to the revolution in seismology whereby ambient seismic energy techniques were discovered which allow higher resolution determinations of structure to be made of the upper crust. The crustal structure is determined by using earthquake records from teleseismic events which sample the upper mantle and crust beneath the recording stations. Upper crustal structure is also deduced from waveforms derived from the cross-correlation of ambient seismic energy between stations and is combined with the mid- and lower crustal, and upper mantle structure derived from the receiver function analysis. We find that the architecture of the lithosphere for stations in the southern Pilbara, Capricorn and northern Yilgarn shows incremental variation between stations with a deepening Moho from north to south across the traverse. Characteristic seismic wavespeeds are variable with a slightly reduced lower crustal wavespeed being characteristic for the stations located within the Capricorn Orogen. The broad receiver function arrivals associated with the Moho beneath the Capricorn indicate a transitional lower crust to upper mantle layer in contrast to the sharp Moho that characterises the Pilbara and more southerly Yilgarn. Upper crustal structure deduced from ambient seismic energy technique shows some correlation with ancient basin structures.

Oral

Ambient seismic energy techniques: the high frequency limit and application to upper crustal imaging and geothermal exploration.

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Techniques using ambient seismic energy, previously considered as ‘seismic noise’, have come to recent prominence as a means of improving the resolution of upper crustal tomographic images. In previous work, passive seismic arrays deployed at station spacings of approximately 15-20 km have been used to infer regional tectonic structure using teleseismic arrivals, and data from these stations have been processed to extract the information inherent in the ambient energy with considerable success. In this work, we investigate the potential for pushing the high frequency limit of this style of seismic data acquisition and analysis. Two field experiments have been carried out to examine the characteristics of available ambient energy and the effect of factors such station-station separation on structure that may be potentially deduced by seismic means. The first, ASET1, took place between December 2008 and May 2009 in central Tasmania. A line of 3-component short-period recorders was deployed across a region of relatively well known, contrasting geology. Station spacings of 0.5, 1.0, 2.0, 4.0, 8.0 and 14.0 km were incorporated into the line of 10 stations. Also located in central Tasmania, the ASET2 deployment took place from October 2009 to June 2010. It consisted of a roughly diamond-shaped, unstructured cluster of 16 stations, with spacings between 4.0 and 28.0 km. In the course of the experiment, 7 stations were redeployed, making 23 station locations in total. The aims of the experiments were two-fold: 1 - establish optimum deployment and data-handling protocols for this style of ambient seismic crustal imaging and 2 - improve the determination of seismic structure in the region spanned by the seismic stations. The location spanned by ASET1 is an area of relatively well-known geological structure, including some stratigraphic boreholes near-by and was designed as a pilot/control study. The location spanned by ASET2 falls within the geothermal energy exploration license of the leading Tasmanian geothermal exploration company. The group velocity tomographic maps and sections, and modelled S-wavespeed profiles and cross-sections enable constraints to be placed on sub-surface lithology and structure.

Oral and poster

Emulation: a fast stochastic technique for joint constraint.

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The joint inversion of multiple large 3D datasets has been the goal of geophysicists for a number of years. Two kinds of approaches currently exist for addressing this kind of problem, traditional deterministic inversion schemes, and more recently developed Bayesian search methods such as Markov Chain Monte Carlo (MCMC). The limiting factor to date for practically implementing each of these has been computational cost, both time and financial. At the heart of schemes designed to determine Earth structure is also the question of how to deal with the uncertainty in our data measurements and modelling assumptions. Here we present a practicable Bayesian-based approach, known as `emulation'. Emulation, rather than aiming to invert for a particular solution, for an observed dataset, and given our uncertainties and other prior beliefs about our structure, seeks to rapidly discard implausible model space. Emulation is a method used with considerable success in a variety of scientific and technical disciplines, such as in astronomy, where the evolution of the universe has been modelled using this technique. The petroleum industry has also employed emulation for the history-matching of reservoirs, and it is increasingly being used in climate modelling. The method involves building a fast-to-compute uncertainty-calibrated approximation to a forward model simulator (for example a forward seismic travel time code). This is done by modelling the output data from a number of forward simulator runs with a computationally cheap function, and then fitting the coefficients defining this function to the model parameters. By calibrating the error of the emulator output with respect to the full model simulator output, we can then use this to screen out large areas of model space which contain only implausible models. We apply this method to jointly constrain seismic, gravity and MT datasets, identifying commonly plausible models, and using successive emulation cycles to further constrain the plausible model space for a 1D problem. The technique allows us to test over two hundred million models with an investment of only a few thousand forward simulator runs, obtaining an effective speed increase of several orders of magnitude over running the full simulator. Emulation does not just give a huge speed increase over running the full simulator. It also allows us to avoid a number of issues associated with standard inversion techniques, such as the inversion of large matrices and data smoothing, weighting and regularisation. Being Bayesian in nature, it very naturally allows us to fully incorporate all our sources of uncertainty and prior beliefs about the structure in question, and the result is not simply "the best-fitting model", but the whole distribution of plausible models, given our observed data, uncertainties and beliefs.

Oral and poster

Velocity models in deep seismic investigations.

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There are two main seismic methods used for offshore deep structure investigations: multichannel seismic with long streamers and wide angle profiling with Ocean Bottom Seismometers. The multichannel seismic outputs are seismic section and stacking velocities which can be recalculated into interval velocities by means of Dix approach. Forward modelling and tomography are main tools to process wide angle data. So at least three velocity models can be derived from offshore seismic investigations: Dix velocities, velocity model used in forward modelling and tomographic velocities. What are relations among all these models? Some speculations based on Russian shelf deep seismic investigations are presented. The examples cover lines 4-AR in Barents-Kara region, 5-AR in Eastern Siberian Sea and 2-DV-M in the Sea of Okhotsk. All these lines are characterized with good quality seismic data acquired. The key seismic parameters were as follows: streamer length - 8000 meters, air gun array volume – 4000 cub. inches, OBS space – 10 km, single air gun volume – 8000 cub. inches. Standard multichannel seismic processing, forward modelling and tomographic approach were applied for these data and velocity models were obtained and analysed. The main conclusion is as follows: no one velocity model is perfect and each of them has own advantages and disadvantages. Integration of these models can produce more reliable results.

Oral

Crustal structure along the Polar-Urals transect, Russia, based on multidisciplinary deep seismic and integrated studies.

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The 300-km-long Polar-Urals transect, the third deep transect of the new generation across the Uralian Orogenic Belt, was acquired in 2006-2008. The first two were the South-Urals transect (URSEIS'1995) and Middle-Urals transect (ESRU'1993-2004). The Uralian mountain belt is over 2000 km long and, according to peculiarities of geological structure, it is usually divided into four segments along the belt: Southern Urals, Middle and Northern Urals, Sub-Polar Urals and Polar Urals. The Polar-Urals transect was located in a west-east direction near the junction zone between Sub-Polar and Polar Urals. Thus, three transects represent the main common features of the entire orogen and give an idea about the peculiarities of each segment.

The field studies within the Polar-Urals Transect Project included: 45-fold near-vertical CMP reflection seismic profiling (non explosive impulse source, shot spacing – 100 m, geophone spacing – 50 m, record length – 30 s), wide-angle seismic studies (6 dynamite sourced shots, shot spacing - 50 km, 3C-receiver spacing – 3 km), receiver functions studies (3C-receiver spacing – 3 km), magnetotelluric sounding (1 km receiver spacing for shallow and middle crustal studies, 15-20 km spacing for deep studies), geological observations along several discrete routes in the exposed part. Laboratory and office studies included: geochemical and isotope-geochronological studies of samples, obtained from the field work; analysis and transformations of gravity, magnetic and geological maps from electronic archives in the 50-km-wide band along the transect.

The seismic sections derived from the near-vertical, wide-angle and teleseismic data along the Polar-Urals transect differ from each other in some respect, but can supplement each other, indicating different aspects of the media. The reflection seismic CMP section and section of electrical resistivity show distinct division of the crust into three domains from west to east in the upper- and mid-crustal levels. These domains correspond to the rather reflective and conductive (in the upper crust) folded and thrust eastern margin of the East-Europen paleo-continent; the nearly transparent and non-conductive Voykar paleo-island arc terrain; and the highly reflective and conductive (especially in the middle crust) East-Uralian heterogeneous microcontinent, hidden under sediments of the West-Siberian basin. In general, the CMP seismic section demonstrates a bivergent structure of the Polar Urals, similar to that of the Southern and Middle Urals. In contrast to other segments of the Urals, the lower crust is practically transparent in the near-vertical seismic section of the Polar-Urals transect and the Moho discontinuity is invisible. The Moho boundary is detected only by wide-angle seismic data. Unlike other segments, in the velocity model derived from these data, neither lower crustal layers nor Moho boundary indicate any depression. The Moho boundary is anomalously deep (52-55 km) in the Pre-Uralian and the East-Uralian parts of the Polar-Urals transect with boundary velocities in the upper mantle (7.85-8.15 km/s) which are anomalously low for the Urals. The lower boundary of the highly-reflective and conductive object in the middle crust in the eastern part of the Polar-Urals transect is at least 15 km higher than the Moho boundary. The nature and fluid saturation of the upper part of this anomalous object will be investigated by a deep drill-hole, which started in 2010.

Poster

Deep structure of the Earth's crust of the Okhotsk Sea shelf from complex geophysical researches along Profile 2-DW-M, Magadan – Southern Kurile Islands.

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Research into the deep structure of the Okhotsk Sea region (Russian Far East) has been carried out on the basis of combined interpretation of geological and geophysical data obtained by "Sevmorgeo" State Company in 2008 along the Profile 2-DW-M. The profile is 1700 km long and it is located in a sub-meridional direction in the Okhotsk Sea, down into the Pacific Ocean. To construct a geological model of the Earth's crust we have used the results of geological, seismic, magnetic and gravimetric research. The seismic research included wide-angle reflection/refraction profiling (WARRP), multichannel seismic profiling (MCS), and shallow seismic profiling.

Geophysical fields, structure of sedimentary cover, structure of the crust and the upper mantle, and the location of deep faults are shown in the models presented in this paper. A geological model of the Okhotsk Sea along the profile section has been developed. The structural correlation between the Central Okhotsk High and the Okhotsk Sea north coast geological structure has been discovered. A geodynamic model for the continent - Pacific Ocean transition has been created.

Oral and poster

AusMoho: the Moho map of the Australian continent.

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Seismic data coverage of the Australian continent has greatly increased of the last 10 years, providing us with the opportunity to update our knowledge of the depth and nature of the crust-mantle transition across Australia. We present a new crustal thickness map of Australia estimated from the compilation of seismic receiver functions, tomographic images, seismic reflection and refraction profiles. This map represents the current status of the AusMoho project, which ultimately aims to image the Australian continental crust with a 50 km resolution. Currently the Moho map consists of over 300 data points and includes data from 3-component broadband and short-period stations deployed in the last 15 years and large-scale seismic reflection and refraction profiles conducted in the last 35 years. The new Moho map provides information about the present day large-scale crustal structures that define the geological provinces of Australia and will supply much needed constraints for use in broad-scale geophysical imaging of the Australian continent. The most striking feature of the Moho depth map is the short wavelength transition from the thickest Proterozoic crust (61 km) in central Australia with the thin crust (~30 km) of Phanerozoic eastern Australia. Current projects in New South Wales, South Australia and Queensland will provide additional points and the BILBY array through the centre of Australia will provide more detail where the crustal thickness is changing rapidly.

Oral

Deep structure of northeastern Russia derived from DSS seismic investigations along geotraverses.

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As of now, handling a fundamental problem, i.e. building up a mineral resources potential of the state, is associated with studying deep levels of the Earth's crust. In this case geophysical technologies, which allow one to prepare a data bank for deep forecasting of mineragenetic zones, become more significant. Therefore, investigations of lithosphere by geophysical survey base lines are one of the most important trends at the federal level. As to deep seismic investigations North-Eastern Russia falls into poorly known areas. In 2001-2008 field operations were carried out along geophysical survey base lines 2-DV from the town of Magadan (the Sea of Okhotsk coast) to the Long Strait coast (the Arctic Ocean) about 2100 km in extent and 2-DV-A from the town of Pevek to the town of Khatyrka about 1100 km in extent. Seismic measurements along the lines were made by CDP, RCM and DSS methods. Electrical exploration was carried out by MTS, AMTS and DMTS methods. Geochemical and petrophysical studies, gravity and magnetometer surveys were also conducted.

The interpretation by 2D seismic tomography was accompanied by independent interpretation of Moho reflections and refractions by methods of individual seismic sounding. Refraction Pn data made it possible to construct composite reduced time-distance curves, apparent- and boundary-velocity plots. Special quadratic time fields were constructed on evidence derived from the Moho reflections. Depths down to the Moho discontinuity on the line of interest were determined by means of Moho reflections and refractions. Generalized depth seismic sections along the 2-DV and 2-DV-A survey base lines are based on the seismic tomography section of the Earth's crust, Moho location on evidence derived from head and supercritical reflected waves, and cover the structure of the earth's crust and upper mantle to a depth of about 60 km.

Four layers, namely volcanogenic-sedimentary, granite-gneiss, granulite and basite ones, are arbitrarily identified from the velocity pattern in the Earth's crust. Comparing the depth section of the Earth's crust resulting from DSS studies conducted on the 2-DV line with previously established tectonic zoning, one can see the relation between velocity anomalies and structural tectonic features of the area. Thus, the Okhotsk-Chukotsk volcanogenic belt doubly intersected by the line has a block of thicker consolidated crust at a sacrifice in thickening of the basite layer. Consequently, the M-discontinuity deepens to 43 kilometers and more, and boundary and formation velocities decrease. A certain relationship of the Moho relief to the structures of the Yana-Kolyma folded system is revealed. Positive landforms of the Moho discontinuity are in agreement with synclinoria, and negative ones with uplifts. Geological and geophysical studies have provided a body of new information on detailed distribution of velocities in the Earth's crust and upper mantle, hypsometry of the Moho discontinuity, which allows for drawing important inferences about the structure and evolution of the area, about the relationship between deep structures of the Earth's crust and a surface structure, for proving a depth model of the area and estimating, from this viewpoint, a metallogenic potential of North-Eastern Russia.

Poster

Deep structure of lithosphere in Altai-Sayany seismic region on evidence derived from earthquakes and powerful vibrator sources.

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The Altai-Sayany region in Russia belongs to the most seismically active regions along with the Baikal Rift Zone, Kamchatka, and the Caucasus Mountains. Throughout the second half of the last century there were a number of strong earthquakes in southern Altai (Busingolsk, 1991, M=6.5; Chuya, 2003, M=7.5). Geodynamic situations within particular structural units do not only depend on regional and local mechanical processes caused by the development of mineral deposits, construction of artificial water storages, changes of water level in large intracontinental basins, etc., but also on global tectonic forces, such as the movement of Hindustan in a westward direction into the Eurasian plate, which defines the seismicity of Central Asia. The joint action of external and internal forces tends to increase seismicity and form fresh seismogenic zones, which, in its turn, results in major and moderate earthquakes.

In recent years within the Altai-Sayany Fold Region various institutions have made studies into the geodynamic situation and made forecasts of the seismic danger using innovative technologies in the context of federal and international programs. These are deep vibroseis investigations performed with powerful mobile and stationary vibrator sources and new methods of seismic interpretation. In the upper mantle of the region, areas of lower and higher boundary velocities of P waves are apparent. The depth of the Moho discontinuity has been determined and varies in this region from 40 to 60 km. Practically isotropic areas with maximum anisotropy factors of 1–3% and zones of evident elastic anisotropy to 10–12% are identified in the upper mantle of the Altai-Sayan region in interpreting an anisotropic medium model. We have also established changes in the preferred orientation of the highest values of boundary velocity ellipses in some areas of the upper mantle.

In the upper Earth's crust we have established anisotropy factors varying from 1 to 9 %, which may be testimony to the existence of very strong stresses or systems of oriented jointing there responsible for the effect of anisotropy of rather thick rock strata. It is found that the isotropic area detected in the southwestern part of the region and showing minimum anisotropy factors correlates with the zone of maximum seismic activity in the Altai-Sayany region. Interpreted seismic data enable a solid model of the Earth's crust and upper mantle of the Altai-Sayany region to be developed, and extensive blocks differing widely in elastic parameters (for example, $V_P/(\gamma-1)$) to be identified, which may testify that the Earth's crust has a considerably inhomogeneous composition. Analyzed results suggest that the largest earthquakes of the Altai-Sayany folded region should be confined to block boundaries with different values of the above parameter. The extended aftershock zone of the Chuya earthquake correlates with the transition zone of high to low values of the parameter. The aftershock zone itself is at a tangent to the boundaries of inhomogeneous blocks. It seems likely that media occurring between homogeneous (in elastic properties) blocks are less firm (more dislocated by regional and local faults), which promotes aftershock process accompanied by liberation of the energy accumulated in the Earth's crust.

Poster

A radically new technology for deep seismic sounding by the use of mobile seismic vibrators and self-contained recorders.

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Interest in investigations of the deep structure of the Earth's crust has quickened in the past few years. It is due to scientists and practical geologists progressively finding an intimate connection between features of the deep structure of the Earth's crust and upper mantle, on one hand, and distributional patterns of ore and non-metallic minerals as well as earthquake focuses, on the other. However, deep seismic sounding (DSS) performed with the use of boreholes, big shots and less-than-conditioned spreads is connected with its technological inefficiency, high cost, risk and in many cases with impossibility of performance for reasons of ecology.
Long-term theoretical and experimental studies carried out in organizations of RF Ministry of Natural Resources and Russian Academy of Sciences, with the aim to develop an up-to-date technique for deep seismic investigations, have resulted in criteria of best spreads excitation sources and recording equipment used in profile work. According to these studies a rational complex of deep seismic investigations incorporates work using the CDP method to study the structure of the Earth's crust and upper mantle, correlation refraction method (CRM) to map index boundaries in the upper and middle parts of the Earth's crust determining structural and velocity parameters, and DSS to study deep boundaries (crust and upper-mantle boundaries, M discontinuity,) and compressional-velocity conditions in the Earth's crust and upper mantle. Carrying out DSS and CRM studies we realize a radically new technology for excitation and observation of seismic transients.

The new technology is free from negative limitations, inherent in classical technologies, and so allows much room for its application under any conditions, including industrial estates, reserves, hydroelectric power stations, atomic power-stations. It is based on detailed deep seismic multiwave studies using multiple overlapping spreads and powerful seismic vibrators, which generate seismic waves of high radiation stability, and also remote self-contained recorders. Powerful 40-60 t vibrators engineered by joint efforts of the Siberian Branch of the Russian Academy of Sciences and SNIIGGiMS provide vibroseis records at 300 to 350 km that compare well with those of powerful 3 to 5 tonne shots in wells and basins. The methods were strictly checked, and at present they have been successfully used in studying the deep structure of the Earth's crust and upper mantle in the Altai-Sayan earthquake-risk region and along the geotraverses in the north-east of Russia.

We have studied in detail the wave field of vibrators at distances of 0 to 300 km, obtained fresh evidence on elastic P- and S-wave characteristics in the Earth's crust and upper mantle, and revealed the main structural elements of the Altai-Sayan region (Tom-Kolyvan Folded Zone, Salair Ridge, Kuznetsk Trough). We also detected elastic anisotropy on the Moho and its almost complete absence in the upper Earth's crust. The profile 2-DV runs across island-arc units of the Koni-Murgalsk Arc and structures of the Yana-Kolyma Fold Region. The crust is 43-47 km thick over the most profile except its extreme south, where the crust shows its minimum thickness (35 km) immediately below the city of Magadan.

Poster

Geometry of the Philippine Sea slab beneath the Izu Collision Zone, central Japan.

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The subducted Philippine Sea slab beneath Kanto is important as seismic sources of damaging earthquake for Tokyo metropolitan area. Due to shallow subduction of Philippine Sea plate (PHS), intraslab earthquake of PHS can produce significant damage of Tokyo metropolitan area. The subucted PHS slab is laying on the Pacific plate on the northeastern part of the Kanto area and more information on the detailed structure on subducted PHS slab is needed for better understanding the mechanisms of the slab-slab interaction and construction of source fault models. The geometry of upper surface of PHS north of the Izu collision zone has been revealed by seismic profiling (Sato et al., 2005; 2006; Arai et al., 2009). The upper surface of PHS is identified as north dipping reflectors at 30-40 km in depth beneath the NW of the Izu collision zone. By seismic survey along the eastern part of the Kanto Mountain in 2003, northeast of the Izu collision zone, the upper surface of PHS is marked by northward dipping reflections at 25 km in depth. The depth change suggests the westward dipping of the upper surface of PHS or existence of a fault, which generated the change in depth. To reveal precise geometry of the PHS slab beneath the Kanto Mountains, we carried out deep seismic profiling along 60-km seismic line trending ENE to WSW. The receiver interval was 50 m. We deployed 5-km-long cable-type recorder system and off-line recorders (MS2000, JGI). Seismic sources were explosives of 100-300kg TNT at seven sites and stationary sweeps (ca. 250) by four vibroseis trucks (IVI Hemi) at three sites. The obtained low-fold stack seismic section portrays ridge-shaped reflectors, which are interpreted from the PHS slab at 8.5-12 s (TWT) in the western half of the section and at 7-8 s (TWT) in the eastern half of the section. These reflectors correspond to the PHS slab in the 2005 Odawara- Yamanashi seismic line and the 2003 eastern Kanto Mountains seismic line, respectively. The direction of the axis of the ridge accords well with regional PHS geometry obtained by earthquake tomography (Nakajima and Hasegawa, 2009). The western flank shows steeper dip angle than the one of eastern flank. Upper surface of the eastern flank of the PHS ruptured in 1923 Kanto earthquake. The ridge behaved as a segmentation boundary of the megathrust earthquake.

Oral and poster

Basin formation and inversion of the back-arc, Niigata Basin, central Japan.

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Associated with the opening of the Japan Sea, volcanic rift-basins have been developed along the Japan Sea coast of northern Honshu. The Niigata basin, central Japan, is one of such basins and filled by thick (< 7 km) Neogene sediments. By subsequent convergence since the Pliocene, an arc-parallel fold-and-thrust-belt has been developed along the Miocene rift-basins. In this belt devastating earthquakes, such as 1964 Niigata (M7.4), 2004 Chuetsu (M6.8) and 2007 Chuetsu-oki (M6.8) earthquakes, occurred by reverse faulting. Due to thick Neogene sediments, relationship between active faults/folds at or near the surface and deep-sited seismogenic source faults is poorly understood. To reveal the crustal structure, in particular geometry of source faults, onshore-offshore integrated deep seismic profiling was undertaken along the two seismic lines in 2008 and 2009. The 2009 Aizu-Sado seismic line is a 135 km long, onshore-offshore seismic line across Niigata basin and Sado island, which is located in the eastern part of Japan Sea. The 2008 Sanjo-Yahiko seismic line (Sato et al., 2009) is located 20 km south of the seismic line and trending parallel to it. The seismic source was air-gun (3020 cu. inch), four vibroseis trucks and explosives (< 200kg). Along the Sado strait, seismic data was acquired using two-ships to make large offset shot gather. Seismic signals were recorded by ocean bottom cables, cable-connected-recording system and offline recorders, forming a maximum 2400 channels receiver array. The basin fill consists of early to middle Miocene volcaniclastic rocks and overlying Neogene sedimentary rocks showing upward coarsening facies deposited under bathyal to fluvial environment. Main features of basin development, such as early Miocene normal faulting, associated with the formation of Japan Sea, and shortening deformation since Pliocene, are well demonstrated on the seismic sections. Particularly, boundary between pre-Tertiary meta-sedimentary rocks and Miocene felsic volcanics were identified by velocity profile deduced by diving wave tomography and it enabled us to identify the geometry of extensional rift-basin. It is very difficult to distinguish meta-sedimentary rocks from volcaniclastic rocks by seismic facies or pattern of reflections. Fault reactivation of Miocene normal faulting to reverse faulting is common style of deformation. The fault reactivation processes of the eastern boundary fault of the Nagaoka plane, which shows 3 mm/year of late Quaternary vertical slip rate, is well documented by seismic sections. During the extensional deformation associated with Japan Sea, due to progressive "double-door" opening of SW and NE Honshu arcs, transfer zones are commonly developed in the Niigata sedimentary basin. Present day the rift-parallel Miocene normal faults reactivated as reverse faults, and their segmentation is strongly controlled by transverse faults formed during the extensional deformation. For better estimation of seismogenic source faults and its segmentation in an inverted rift-basin, the information of basin development plays significant role.

Oral and poster

Deep seismic reflection profiling of the subduction megathrust system across the Sagami Trough and Tokyo Bay, central Japan.

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Beneath metropolitan Tokyo, the Philippine Sea plate, in particular the fore arc portion of the Izu-Bonin Island Arc, has been subducted. Subduction megathrust beneath Tokyo generated M-8 class earthquakes, such as the 1923 Kanto (M7.9) and 1703 Genroku (M8.0) earthquakes. Due to the buoyant subduction of the Izu-Bonin arc, the megathrust lies in a very shallow part of the crust. The Kozu-Matsuda Fault (KMF), probable splay fault from the megathrust, is distributed onshore. In 2009, we acquired the deep seismic reflection data across the toe of the thrust system to reveal the connectivity of the probable splay fault to the megathrust. Together with the deep seismic section acquired in 2003, we show a 120-km-long deep seismic reflection profile from the front to 30 km in depth and discuss the geometry and characteristics of the thrust system. We performed deep seismic profiling across the Sagami Trough for a 70-km-long seismic line in September 2009, using two ships for offshore seismic data acquisition: a gun-ship with a 3020 cu. inch air-gun and a cable-ship with a 2 km long, streamer cable and a 480 cu. inch air-gun. The seismic signals were recorded at Miura and Izu peninsulas located both ends of the seismic line. On both sides of the onshore line, off-line recorders were deployed along a 20 km seismic line segment at 50 m intervals. Seismic reflection data were acquired by different offset of ships making large-offset gathers. The northeast end of the seismic line connected with the 2003 Tokyo Bay seismic line. The obtained seismic section portrays the detailed geometry of the subduction megathrust including splay faults. The offshore extension of the KMF merges to the megathrust at depth of 8 km and shallower part shows high-angle, suggesting strike-slip component of the oblique subduction. According to the co-seismic crustal deformation, the slip of the 1923 Kanto earthquake occurred along the main megathrust. According to the paleoseismic trenching survey of the splay fault (KMF), KMF displaced from AD 1100 to 1350 (Kanagawa Pref., 2005). Shimazaki et al. (2009: JpGU meeting) found the tsunami sediments correlatable to the 1923 Kanto, the 1703 Genroku and 1293 seismic event. Judging from the connectivity of KMF to the megathrust, the seismic event of AD 1293 was caused by displacement of the megathrust and the splay fault (KMF). From the coseismic crustal deformation and seismic waveforms of the 1923 Kanto earthquake, the locations of asperities were well determined (Sato et al., 2005). The distribution of slip deficit on the plate interface determined by GPS (Sagiya and Sato, 2005) accords well to the estimated asperity zone. On the seismic reflection profile, the asperity zone (stacked plate interface) is marked by poor reflection from the fault surface and the plate interface is clearly identified as strong reflectors at the deeper steady creeping zone and shallow part of the megathrust. Comparing with velocity profile by diving wave tomography, the asperity zone is marked by the area of Vp > 6 km/s. Also the asperity zone of 1923 Kato earthquake lies on the zone of low-angle dip of the megathrust.

Oral

Crustal structure of Australia from ambient noise tomography.

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We cross-correlate the ambient seismic noise recorded at broadband stations located across Australia to image the crustal seismic velocity structure. The cross-correlation of the seismic noise yields a 2-D Earth's impulse response between two stations, where the propagation of this wavelet is affected by the heterogeneity of the Earth. The cross-correlation of the ambient seismic noise recorded at the vertical components create a Rayleigh wave type Green's function. The cross-correlation of the transverse components leads to a Love wave type Green's function, which has sensitivity to the structures at shallower depths than Rayleigh wave for the same period. Similar to the earthquake generated surface waves, the Green's function dispersion is exploited by applying the multiple filtering analysis to estimate the group velocity of the Rayleigh and Love waves at different periods. We apply this method at different periods from 3 s to 50 s. The group wave traveltimes obtained from multiple filter analysis for Rayleigh and Love wave Green's functions are then inverted with a nonlinear iterative tomographic schema to create 2-D tomographic images. We merge Rayleigh and Love wave tomographic images, and then sample these images with a grid interval of $2^o x 2^o$ to create an input model for the 1-D depth inversion. The 1-D inversion method is carried to create the 3-D Moho crustal map of Australia. The variation of the crustal depths marks the cratonic structure in the West, and Phanerozic structure in the East. The images are compared with the AusMoho crustal model derived from seismic reflection and receiver function methods to assess the reliability of the images from the ambient seismic noise tomography.

Poster

Earthquakes in Uttaranchal Himalaya, India.

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On the basis of the seismic records of seismic events in Uttaranchal, a review of the events has been completed and the probabilities of the earthquake has been calculated in that part of Garhwal-Kumaun-Himalaya in Uttaranchal. In the southern part of outer Himalaya, thrust zones are expected to produce long term probabilities of large earthquakes of magnitude more than 6 on Richter scale which have, on average, 5 to 20 mm reactivation and neotectonic uplifts along the shear zones. Based on the historical seismic records, these zones are considered likely have future earthquakes on these areas which are subject to long term slip rate and displacement. Historical records of seismic events in this part of the Himalaya have earthquake intensities varying from 4 to 6.0 on Richter scale. The 1905 Kangra earthquake was recorded as more than 7.0 on the Richter scale, the 1883 Garhwal earthquake 6.0, the 1920 and 1991 Utterkashi earthquakes 5.6 and 6.8 respectively, the 1999 Chamoli earthquake 6.5, and the 1970 Dehradun earthquake also a Richter magnitude of 6.5. The approach followed for the calculation of probabilities of future earthquake activity employed the estimated recurrence times with a model that assumes probability increases with elapsed time from the large earthquakes on the fault/thrust zone areas. Using these calculated probabilities, the estimated natural disaster/hazards in the newly constituted Indian state of Uttaranchal in the Himalayan Mountain Belt can be deduced.

Oral and poster

Sedimentary and crustal structure from the Ellesmere Island and Greenland continental shelf onto the Lomonosov Ridge, Arctic Ocean.

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On the northern passive margin of Ellesmere Island and Greenland, two long wide-angle seismic reflection/refraction (WAR) profiles and a short vertical incident reflection profile were acquired. The WAR seismic source was explosives and the receivers were vertical geophones placed on the sea ice. A 440 km long North-South profile that crossed the shelf, a bathymetric trough and onto the Lomonosov Ridge was completed. In addition, a 110 km long profile along the trough was completed. P wave velocity models were created by forward and inverse modelling. On the shelf modelling indicates a 12 km deep sedimentary basin consisting of three layers with velocities of 2.1-2.2 km/s, 3.1-3.2 km/s and 4.3-5.2 km/s. Between the 3.1-3.2 km/s and 4.3-5.2 km/s layers there is a velocity discontinuity that dips seaward, consistent with a regional unconformity. The 4.3-5.2 km/s layer is interpreted to be Paleozoic to Mesozoic age strata, based on local and regional geological constraints. Beneath these layers, velocities of 5.4-5.9 km/s are correlated with metasedimentary rocks that outcrop along the coast. These four layers continue from the shelf onto the Lomonosov Ridge. On the Ridge, the bathymetric contours define a plateau 220 km across. The plateau is a basement high, confirmed by short reflection profiles and the velocities of 5.9-6.5 km/s. Radial magnetic anomalies emanate from the plateau indicating the volcanic nature of this feature. A lower crustal velocity of 6.2-6.7 km/s, within the range identified on the Lomonosov Ridge near the Pole and typical of rifted continental crust, is interpreted along the entire line. The Moho, based on the WAR data, has significant relief from 17 to 27 km that is confirmed by gravity modelling and consistent with the regional tectonics. In the trough, Moho shallows eastward from a maximum depth of 19 km to 16 km. No indication of oceanic crust was found in the bathymetric trough.

Oral

The topography of Ellesmere Island: model testing with seismology.

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Ellesmere Island, in Canada's Arctic, comprises a series of ~SW-NE trending tectonic provinces, the crustal structure and geological expression of which represent a combination of interplate, accretionary orogenesis in the Palaeozoic (Caledonian equivalent and Ellesmerian orogenies) and intraplate orogenesis in the Palaeogene (Eurekan Orogeny). The present-day topography of Ellesmere Island is closely related to the crustal architecture of these tectonic provinces, which includes the adjacent polar continental margin. The first-order crustal structure of the area has been deduced from the regional gravity field: the high topography of northwest Ellesmere Island is isostatically compensated by a thick crust; the Hazen Trough (Hazen Foldbelt) running most of the length of central Ellesmere Island is underlain by a shallow Moho; and the central Ellesmere fold-and-thrust belt loads (Greenland-Laurentian) cratonic basement that flexes to the northwest beneath it. The first-order geological and crustal structure can be explained by a model, supported by the preliminary analogue modelling results, that depends on lithosphere-scale structures imposed during Palaeozoic orogenesis being reactivated during Eurekan (Palaeogene) intraplate shortening ("mega-basin inversion"). In order to test this model, and to complement the scarce seismological data that are available in the area (only two receiver function estimates of Moho depth), a passive seismology campaign is underway. Eight temporary seismic observatories were installed, using instruments and equipment provided by SEIS-UK, across Ellesmere Island in June and July of this year and will be removed in 2012. The objectives are to collect sufficient high quality seismological data to allow first-order (i) receiver function analyses for crustal structure (Moho depth and other first-order discontinuities) at key (additional) locations (comprising the structurally diverse elements of the Eurekan Orogen); (ii) shear-wave splitting analyses to determine the presence, geometry, and character of lithosphere anisotropy predicted by the tectonic model; and (iii) surface wave studies to determine lithosphere thickness and for joint inversion studies in this frontier region.

Oral and poster

Geoscience Australia's deep crustal seismic reflection and magnetotelluric programme, 2006-2010.

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Geoscience Australia has been acquiring deep crustal reflection seismic transects throughout Australia since the 1960s. The results of these surveys have motivated major interpretations of important geological regions, contributed to the development of continental-scale geodynamic models, and improved understanding about large-scale controls on mineral systems. Over the past five years, Geoscience Australia has acquired over 6000 km of deep crustal seismic reflection data under the auspices of the Predictive Mineral Discovery Cooperative Research Centre (pmd*CRC), Onshore Energy Security Program (OESP), AuScope Earth Imaging (part of the National Collaborative Research Infrastructure Strategy), and all mainland State and Territory governments. These seismic datasets continue to underpin fundamental research into the geodynamics of the Australian continent and provide the third dimension for pre-competitive geoscience information related to mineral and energy resources in selected provinces and basins.
Regional seismic reflection surveys currently utilise three Hemi 50 or 60 vibrators at 80 m VP with 40 m group interval, resulting in 75 fold data to 20 s TWT. In-house processing is aimed at providing a whole of crust image, without sacrificing shallow detail. Gravity readings are also collected along the lines at 400 m intervals to assist integrated regional interpretations based on the seismic traverses. Magnetotelluric (MT) soundings, including both broad-band and long period, have been acquired along most traverses. MT provides an image of the conductivity of the crust which is complementary to the structural information obtained from reflection seismic. Geoscience Australia is currently developing an in-house MT processing and modelling capability.

Examples of surveys related to understanding geodynamics and mineral potential include: the 2006 Victorian and 2009 Delamerian surveys across the Palaeozoic Delamerian and Lachlan Fold Belts in Victoria, the 2010 West Australian surveys in the Proterozoic Capricorn Orogen and across the Archean Youanmi Province in the northern Yilgarn. Other surveys have targeted frontier petroleum provinces. Deep crustal seismic not only images the sedimentary section within a basin, but also provides insights into the crustal architecture of sedimentary basins and their tectonic relationship to older basement terranes. The 2007 North Queensland survey revealed a previously unidentified sedimentary basin, the Millungera Basin, with both hydrocarbon and geothermal potential. The 2008 Rankins Springs survey imaged a much thicker Devonian sedimentary succession than expected in the Yathong Trough, in an under-explored part of the Darling Basin in New South Wales. In addition, the deep crustal seismic programme has identified regions with geothermal potential, particularly where possible heat producing granite bodies are blanketed by a thick sedimentary succession.

Poster

Moho depth and age in southern Norway.

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Moho ages beneath the Fennoscandian shield are highly variable due to the method of crustal accretion and to the long history of extensional and compressional tectonics. In southern Norway, the Moho and crust are inferred to be the youngest of the shield, however, it is likely that a large discrepancy between crustal age and Moho age exists beneath the high southern Scandes where the Caledonian orogeny was in effect. Moho structure in southern Norway was targeted recently with a seismic refraction study (Magnus-Rex - Mantle investigations of Norwegian uplift Structure, refraction experiment). Three _400 km long active source seismic profiles across the high southern Scandes Mountains, the youngest section of the Fennoscandian shield were recorded. Moho depths beneath the high mountains are 36-40 km, thinning towards the Atlantic Margin and the Oslo graben. A new Moho depth map is constructed for southern Norway by compiling new depth measurements with previous refraction Moho measurements. Gaining better constraint on Moho depths in this area is timely, as debate over the source of support for the mountains has provided the impetus for a new focus project, TopoScandesdeep, to find the depth and mechanisms of compensation. P and S-wave arrivals were recorded in the Magnus-Rex project, from which Poisson ratios for the crust in southern Norway are calculated. Unusually strong S-wave arrivals allow rare insight into crustal Poisson's ratio structure that is not normally available from active source data and are usually determined by earthquake tomography studies where only bulk crustal values are available. An average Poisson's ratio of 0.25 is calculated for the crust in southern Norway, suggesting it is predominantly of felsic-intermediate composition and lacks any significant mafic lower crust. This differs significantly from the adjacent crust in the Svecofennian domain of the Fennoscandian shield where Moho depths reach 50 km and an up to 20 km thick mafic lower crust is present. The vast difference in Moho depths in the Fennoscandian shield are, therefore, mostly due to the variation in thickness of the high Vp lower crust. These new data on Moho depth, lower crustal thickness and crustal composition provide new insights into the processes that have led to both the uplift and maintenance of the southern Scandes Mountains.

Poster

Geodynamic modelling of the coupled plate mantle system: lessons from the junction.

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Plate tectonics and mantle convection form a dynamically coupled system that has shaped the Earth for billions of years. Modelling these processes allows the fundamental parameters that drive the geological evolution of the Earth, including surface uplift and subsidence, erosion, sedimentation, and volcanism through time to be examined. Advances in high performance computing, modelling software and a swathe of global geological datasets are facilitating higher resolution exploration of geodynamic processes that ultimately shape the earth at multiple scales. We connect the geodynamic modelling code Terra with the GPlates plate reconstruction software, to couple the Earth's plate motion history and the configuration of plate boundaries over the last 140 Ma to mantle convection. Here we use this methodology to focus on the Junction between Australia, the Eastern Neo-Tethys and Panthalassa, one of the most ill constrained plate boundaries through time due to a lack of preserved in-situ oceanic crust. This presents a challenge as the geodynamics of this area have profound impacts on our understanding of the evolution of the tectonically complex adjacent regions during the early Mesozoic. Seismic tomography images slab material, which has been subducted along this junction since the Jurassic Period, representing the history of surface kinematic evolution in the deep mantle. Coupled plate kinematic and mantle convection models allow us to use seismic tomography to constrain the evolution of this area. We compared the seismic tomography models of Montelli, Li and Grand[1] and found fast seismic anomalies interpreted as subducted slab material in the lower mantle where the Junction would have been in the Mesozoic. Our forward geodynamic models assimilate data describing dynamic plate boundaries, plate motions for the last 140 Ma and mantle rheology. By coupling mantle convection and plate tectonics we provide a holistic approach to modelling Earth evolution.

[1] Tomography models freely available from
http://geon.unavco.org/unavco/IDV_datasource_tomo.html

Oral and poster

Subseismic deformation analysis - a prediction tool for a safe CO_2 reservoir management.

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The evolution of a reservoir is mostly affected by deformation. Large-scale, subsurface structure and deformation is typically identified by seismic data, small-scale fractures by well data. However, faulting at the medium sub-seismic scale plays an important role, e.g. in gas or geothermal reservoirs. Large individual reservoirs can be disrupted by faults enhancing fluid flow, or producing compartmentalized deposits due to cementation of fractures. Thus, between both scales, seismic and well data, we lack a deeper understanding of how deformation scales in the sub-seismic region. Bridging this gap will allow to make predictions about the future development of a reservoir, the generation of possible pathways due to changes in the stress regime, and thus to judge storage safety. To start tackling this problem, a 3-D reflection seismic data set in the North German Basin was analysed with respect to structure and faults in great detail, calibrated by well data. This led to the determination of magnitude and distribution of deformation and its accumulation in space and time on the seismic scale. The structural interpretation unravels the kinematics in the North German Basin with extensional events during basin initiation and later inversion. For further quantitative deformation and fracture prediction on the sub-seismic scale, two different approaches are introduced. Increased resolution of subtle tectonic lineaments is achieved by coherency processing yielding together with geostatistic tools the distribution of low- and high-strain zones in the region. Independently, the distribution and quantification of the strain magnitude is predicted from 3-D retro-deformation of the identified structures. For the fault structure analysed, it shows major-strain magnitudes between 5-15% up to 1.5 km away from a fault trace, and variable deviations orientation of associated extensional fractures. The small scale is represented by FMI data from borehole measurements, showing main fault directions and densities. These well data allow the validation of our sub-seismic deformation analysis. In summary, the good correlation of results across the different scales makes the prediction of small-scale faults/fractures possible. The suggested seismo-mechanical workflow requires principally the 3-D coverage of a region. It yields in great detail both the tectonic history of a region as well as predictions for the genesis of structures below the resolution of reflection seismic techniques.

Oral

Crustal structure and topography in southern Scandes, Norway.

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Resolving the uplift history of southern Norway is hindered by the lack of constraint available from the geologic record. Sediments that often contain information of burial and uplift history have long since been stripped from the onshore regions in southern Norway, and geophysical, dating methods and geomorphological studies are the remaining means of unraveling uplift history. Constraints on topographic evolution and uplift models in southern Norway have been further enhanced by a recent crustal scale refraction project. Magnus-Rex (Mantle investigation of Norwegian uplift Structure, refraction experiment) recorded three approx. 400 km long active source seismic profiles across the high southern Scandes Mountains. The goal of the project is to determine crustal thickness and establish whether these mountains are supported at depth by a crustal root or by other processes. The southern Scandes Mountains were formed during the Caledonian Orogeny around 440 Ma. These mountains, which reach elevations of up to about 2.5 km, are comprised of one or more palaeic (denudation) surfaces of rolling relief that are incised by fluvial and glacial erosion. Extreme vertical glacial incision of up to 1000 m cuts into the surfaces in the western fjords, while the valleys of eastern Norway are more fluvial in character. Climatic controls on topography here are the Neogene - Recent effects of rebound due to removal of the Fennoscandian ice sheet and isostatic rebound due to incisional erosion. However, unknown tectonic uplift mechanisms may also be in effect, and separating the tectonic and climate-based vertical motions is often difficult. Sediment and rock has been removed by the formation of the palaeic surfaces and uplift measurements cannot be directly related to present elevations. Estimates so far have indicated that rebound due to incisional erosion has a small effect of about 500 m on surface elevation. Results from Magnus-Rex indicate the crust beneath the high mountains is up to 40 km thick. This thickness implies that the high elevations of the southern Scandes Mountains are not entirely compensated by an Airy type of isostatic model, and other mechanisms for uplift and sustained topographic relief must be in effect. Moreover, there is an observed lateral offset between the highest mountains and the thickest crust beneath the southern Scandes indicating that the Moho topography is modulated by the flexural strength of the lithosphere. We relate new crustal thickness measurements to observed topography to quantify how much of the present elevation of the southern Scandes Mountains can be accounted for by crustal thickness alone. This new understanding of crustal structure can be used to help separate the climatic and tectonic effects on landscape evolution of the southern Scandes Mountains.

Oral

Moho and magmatism in extensional settings.

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The Moho is defined by an abrupt change in seismic velocity, which is often attributed to the petrological crust-mantle boundary. However, other types of transitions may explain observed pronounced seismic reflections, such as metamorphic changes in iso-chemical rocks from granulitic lower crustal rocks to eclogitic facies, pronounced shear zones, or magmatic intrusions. Therefore, it is of crucial importance to have high-resolution models of the seismic velocity around the Moho. Further, the seismic reflectivity in normal-incidence and wide-angle may provide valuable constraints on the structure at the crust-mantle boundary. In areas influenced by strong magmatism with mantle source, e.g. at rift zones and other extended regions, the resulting transition between crust and mantle may assume several forms. New data from a >100 km long and 20 km thick non-reflective zone in the Danish Basin with extremely high seismic velocity (6.8-7.8 km/s) demonstrates that the Moho reflector at the base of the high-velocity body is interrupted in a ca. 20 km wide zone. The high velocity body is interpreted as a mafic batholith in the crust, and the Moho-free zone as the feeder channels of the batholith. Variation in seismic amplitude along the strike of the batholith provides indication for the mafic content of the deepest rocks in the body. We further observe extremely strong wide-angle reflectivity from a ca. 4 km thick zone with high velocity, extending for up to 100 km away from the batholith. We interpret this reflective depth interval as a zone of magmatic underplating in the form of sills, which intruded during the late stage of the formation of the batholith. The magma probably had the same source as the body, and it intruded along the Moho in the late stage of magmatism due to pressure changes caused by cooling. The presently active rift zones in Eastern Africa and at Lake Baikal thicker, as well as extinct rift zones, show extremely strong reflectivity of the lower crust and upper mantle. All rifting models predict Moho uplift due to crustal thinning, and reduced seismic velocity in the uppermost mantle due to decompression or heating from the Earth‘s interior. However, seismic data from several rift zones show no or very little Moho topography that can be related to the rifting process. At all these rift zones, we observe a localized zone in the lower crust which has exceptionally high seismic velocity and is highly reflective. We suggest that rift related crustal thinning took place, but the expected Moho uplift was compensated by magmatic intrusion into the lower crust at the high-velocity zone. This finding has significant implications for modelling the evolution of sedimentary basins around rift structures. As such, compelling evidence is emerging for a strong role of magmatism on the character of the Moho interface, not least in extensional areas.

Poster

SKS splitting measure with horizontal component misalignment.

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Measurement of the SKS splitting parameters has become a popular tool to study the deformation in the upper mantle, but the misalignment of the station horizontal components may result in the false measurements. Both the misorientation of the sensors and the complex shallow structure beneath station may be important factors to lead to the misalignment of the station horizontal components. In this paper, we show the misalignment of the horizontal components at the permanent station ULN due to the misorientation of the sensors, and another example at the permanent station BJT due to the complex shallow structure. We suggest that splitting analysis should be repeated with different assumed angles of misalignment and the corrected measurement of SKS splitting parameters should be obtained by matching two criteria: (1) search the horizontal rotating angle for the global smallest transverse energy using the Trans-min method; (2) the results from the Trans-min method and the Eigen-min method should be consistent.

Poster

The structure of the deep crust and the distribution of hydrocarbon deposits in the sedimentary cover: a new seismic reflection experiment in the eastern part of the Russian Platform.

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A composite, ca. 3000 km-long geotraverse across the Mezen and Moscow Syneclises, the Volga-Ural Anteclise and the Southern Urals has recently been constructed by the integration and co-processing of data from the CDP UralSeis and TatSeis profiles and several regional reflection seismic profiles. The aims of this "MEMOTATUR" (MEzen'-MOscow-TATarstan-URal) experiment were to: a) elaborate the criteria to identify deep hydrocarbon deposits by seismic data on the giant oil-and-gas fields in the Volga-Ural Anteclise, and (b) use these criteria for hydrocarbon prospecting in the poorly-explored Moscow and Mezen Syneclises.

In this presentation, we describe the techniques, which were used to construct MEMOTATUR, and consider structural features of the deep crust in the Volga-Ural oil-and-gas province and their relationships with the structure of the sedimentary cover and its hydrocarbon content. The upper lithosphere beneath the Volga-Ural province is characterized by 1) the presence of inclined reflectors running throughout the entire crust and, in some cases, enter the upper mantle, 2) the presence of numerous sub-vertical amplitude anomalies in the uppermost crust, and 3) a strongly deformed and broken Moho discontinuity.

Seismic, gravity and magnetic data, and core materials from deep wells suggest that both kinds of the seismic anomalies image zones of faulting and fracturing, and are interrelated being parts of one single crustal fault system. In relatively simple cases, the seismically detected deep faults are connected with fault structures and flexures in the sedimentary cover, entrapping hydrocarbon deposits. In areas of strong faulting, 3D seismic modelling is required to study such patterns. However, coupled with other geophysical surveys and geological results, the MEMOTATUR seismic criteria can now be used in hydrocarbon prospecting and exploration.

Poster

3-D Q_p structure in the source region of the 2007 Noto Hanto earthquake.

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A shallow inland earthquake of M6.7 struck on the west coast of Noto Peninsula, Japan on March, 2007. Immediately after the main shock, temporary seismic observation was deployed by members of universities and research institutes, adding to the previous seismic stations operated by NIED, JMA, Kyoto University, University of Tokyo, and Japanese University Group of the Joint Seismic Observations at Niigata-Kobe Tectonic Zone. Seismic data from such dense observation network made it possible to determine a detailed subsurface structure. Then we mapped a seismic attenuation (Q) structure in the source region of the 2007 Noto Hanto earthquake. We applied a joint inversion method, in which the 3-dimensional attenuation structure, source effects, and site effects are deconvolved, to multiply recorded data from many microearthquakes [Tsumura et al., 2000]. Amplitude spectra were calculated by FFT for a time window of 1.0 s, beginning from the P arrivals. In this study, we used 7926 spectra data for 161 events which were recorded at 70 stations. The results show low-Q zone in the northwestern part of the main shock fault and high Q zone in the southeastern part beneath the western coast of the Noto Peninsula. The aftershock hypocenters are located on the plane of the boundary between high and low Q zones. The extension to the surface of this Q boundary corresponds well with the active fault (F-14). Beneath the inland area, estimated Q becomes lower than that of the western coast area. Especially low Q zone is seen at the main shock fault, where aftershocks' activity is high. The values of the low Q zone become half of those of surrounding area. In the deeper part, where another seismic activity is seen outside of the main shock fault, Q values become low. In conjunction with other geophysical data, these attenuation features might be caused by the rupture of the Noto Hanto Earthquake.

Poster

Imaging Turkey's crust with receiver functions and ambient noise.

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Here we present preliminary results detailing the crustal structure of Turkey from a combination of receiver function and ambient seismic noise tomography analysis. We use over 250 3-component broadband stations from permanent and temporary networks in Turkey and surrounding regions to image structure in Turkey from a combination of receiver function and ambient seismic noise tomography from crust to upper-mantle. To date, receiver functions for teleseismic events between the period between 2008 and 2009 have been calculated using frequency domain deconvolution for approximately 120 of the available stations. Using the methodology of Niu and James (2002), the receiver functions are analyzed to joint solve for Vp/Vs ratio and Moho conversion depth. The resulting maps show a highly variable Moho with depths ranging between ~35 km and 58 km depth as well as a variable but generally high average Vp/Vs ratio with median values closer to 1.8 rather than 1.73. Rayleigh and Love wave group velocities extracted from the cross-correlations of ambient seismic noise are used in a nonlinear iterative tomographic inversion. Then the velocity models from the tomographic inversions are used in a joint inversion to create the Moho depth map of the region. We combine the receiver function results with results from ambient noise tomography to generate a comprehensive interpretation of the Moho and crustal structure of Turkey. The results mark the complex structure of the region. The seismic images from western Turkey show low velocities possibly linked to the elevated temperatures or fluid content. The images for central Turkey show low velocities for shallow depths but seismic velocity increases with depth; this also coincides with the geothermal potential of the region. The complex wavespeed images for eastern Turkey marks the effects of the ongoing geological processes such as the active collision of Anatolian block and Arabian plate.

Poster

The Barents-Kara region framework from the results of deep seismic profiling.

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Since 1995 the State Company "Sevmorgeo", in cooperation with other organizations of MNR RF and RAS, has been carrying out complex geological and geophysical research involving the recording of basic profiles across the continental shelf of the Russian Federation. In Barents-Kara region four such profiles (1-AR, 2-AR, 3-AR & 4-AR) have been investigated to date. It has been established that the Barents-Kara region consists of three blocks with different ages within the crystalline basement of continental margin. There is the Timan-Pechora plate of the Baikalian age of consolidation, the Svalbard (Barents) plate of the Greenvillian age and the Kara plate of the Late Karelian age. Evolution of the Precambrian complexes of the Barents-Kara region crystalline basement is determined by its geo-historical position at the junction of three cratons of Archaean – Early Proterozoic consolidation age: Laurentia, Baltica and Siberia. An exception is made for the South-Kara area representing a residual fragment of oceanic crust. Since Middle Paleozoic time the main process in that region has been rifting that has caused the creation of sedimentary basins.

Poster

Recognition of carbonate facies by seismic attributes: application to geothermal exploration.

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For hydrogeothermal energy production in Germany low enthalpy reservoirs (at 3-5 km depth, average temperature 100-150 °C) are used. At many sites natural permeability of the rocks is not sufficient for economic operation. Therefore, the value of reservoirs is often bound to small scale geologic features as e.g. fracture systems, karstified limestone or locally varying facies. We investigate the relevance of 3D seismic methods for the exploration risk mitigation of hydrogeothermal reservoirs, and analysed a 3D seismic volume covering carbonate structures in the Bavarian Molasse.

The upper Jurassic (Malm) carbonate platform in the subsurface of the Bavarian Molasse Basin is a major target for hydrogeothermal exploration. It comprises about 600 m of alterations of reefs, recifal limestone and layered limestone. Principally, the abundance of coral reefs relative to other limestone facies increased during the Upper Jurassic. Most of the area was sub-aerially exposed, resulting in the formation of karst by dissolving the carbonate rocks. The subsurface suffered horst and graben structuring during Cretaceous. During Tertiary, the shelf was flexed downwards by the load of the Alpine Orogeny and the Molasse Basin has been filled with debris from the Alps.

The partition of different facies is a main target of the seismic interpretation, since reef facies exhibit in principle a higher porosity, which can be further increased significantly by karst formation. Facies analysis is hindered by tectonic processes starting with the development of the Molasse basin. The original surface of the carbonate platform cannot be reconstructed directly. Instead, the lowermost sediment covering the platform at the beginning of Cretaceous, the limestone Purbeck unit, has to be analysed. The transition from Purbeck to the underlying topmost Upper Jurassic, consisting mainly of coral reefs and reef debris, as well as the transition of this unit to the underlying layered limestone facies, shows strong variations with respect to amplitude and phase of seismic data. These result from the strong heterogeneity of carbonate compared to clastic sedimentation.

However, the sedimentary sequence shows a characteristic velocity profile, which can be used to map automatically the boundaries of the sedimentary units. Since the units have thicknesses smaller than the seismic wavelet, we used absolute maxima and minima inside a window. Resulting layer thicknesses relate to different geological models, indicating the distribution of reefs, troughs, swells and slopes. We also used additional attributes to support our interpretation, as e.g. energy buildup and instantaneous frequency.

The layered limestone facies of the Upper Jurassic shows a stratification of limestones, marls and clays. The thicknesses of the single layers are well below seismic resolution. However, the reflected signals interfere, and their amplitudes get frequency dependent. This effect is exploited by spectral decomposition: the interference increases the higher frequency components. We could use this for a mapping of the layered limestone facies. The results show, in accordance with our geological model, that layered limestone facies prevails in the stratigraphical lower layers of the carbonate platform.

Oral

Time-lapse seismic monitoring of the IEA Weyburn-Midale CO_2 storage project.

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2010 marks the 10th anniversary of the IEA GHG Weyburn-Midale CO_2 Monitoring and Storage Project whose focus has made Weyburn-Midale the most extensively studied CO_2 storage site in the world. More than 15 million tonnes of CO_2 have been stored at Weyburn-Midale since 2000, with current total field injection rates (new and recycled) of 13,000 tonnes per day. Geophysical monitoring at Weyburn has been spearheaded by time-lapse 3D seismic monitoring that clearly identifies the spread of CO_2 in the reservoir. Maximum associated decreases in acoustic impedance of 12% that are observed in the immediate vicinity of horizontal CO_2 injection wells are explained by increased pore pressure (~7 MPa) and CO_2 saturation. The 3D seismic data have also been utilized to assess the integrity of the reservoir caprock by mapping fracture-related anisotropy using amplitude-versus-offset-and-azimuth (AVOA) techniques. Areas where anisotropy exceeds regional background levels are identified and represent target areas for follow-up inspection and comparison with other data sets. Of the large-scale commercial CCS pilot projects, only the IEA GHG Weyburn-Midale CO_2 Monitoring and Storage Project has included passive seismic monitoring. Microseimicity rates correlate with periods of elevated CO_2 injection rates, and also with changes in production activities in nearby wells. The distribution of injection-related event locations also appears to correlate with the regions of CO_2 saturation that have been identified using time-lapse seismics. However, overall the rates of seismicity are low. The low rates of microseismicity indicate that the reservoir is not undergoing significant geomechanical deformation.

Oral

Seismic imaging of the Flin Flon VMS mining camp, Trans-Hudson Orogen, Canada.

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High-resolution seismic reflection images have been acquired for the Flin Flon VMS mining camp within the Trans-Hudson Orogen in central Canada. The main goals of the seismic project were to constrain the 3D geological model for the camp and to provide a guide for ongoing exploration. Laboratory rock property measurements and in situ downhole geophysical logs demonstrate that significant variations in acoustic impedance exist amongst rocks from the camp including contacts between rhyolites (the primary ore-bearing zone) or sandstones and gabbros or basalts, from sulphide occurrences and from shear zones in the mafic rocks. A 3D model is presented which is constructed by integrated interpretation of the 2D seismic images with surface and borehole geology and rock properties. The 3D model portrays the camp geology as a thrust-imbricated stack which has been variably reoriented by subsequent folding and strike-slip faulting. Of importance for further exploration, structural repetition of the "mine horizon" at depth is demonstrated and the "mine footwall" is mapped in 3D.

Oral

Collisional and bending processes of the southwestern Japanese Island Arc.

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The bending of the eastern terminal of the Southwest Japan Island Arc was made in southeastern Chubu by the combination of the opening of the Japan Sea with the collision of the Izu-Bonin Arc on the Philippine Sea plate in middle Miocene. The outline of the bending process has been drawn as 2-dimensional illustrations based on the surface geology there (e.g. Kano et al., 1990, 2002), but not as 3-dimensional ones yet. The following 3 deep seismic profiles, however, make it possible to reconstruct the process 3-dimensionally. (1) Shikoku-Chugoku profile (Ito et al., 2009), (2) Western Kii profile (Matsuoka, 2000), and (3) Southern-Central Japan Alps Transect (Ito et al, this symposium). The former two profiles provide a general cross section of the Southwest Japan which is thought to preserve the original section before the bending, and the latter the present section down to the upper surface of the Philippine Sea plate which is different from the general section in some points. We reconstruct the bending process with 3-dimensional numerical models derived from the general section and deformed in some simple processes to represent both the surface geology and the section approximately. The reasonable reconstruction makes it clear that the bending process was composed of flexure with a vertical axis (counterclockwise, about 45 degrees) + fault displacement (55 km, left-lateral) + heterogeneous pure shear (up to 60% shortening and 130% stretching). Thus, these profiles firstly present essential information on the bending process of the Southwest Japan island arc.

Poster

Ambient noise tomography of Tasmania.

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The WOMBAT rolling seismic array project in southeast Australia, which to date has deployed over 550 seismic stations during 12 separate array movements, provides an unprecedented opportunity to examine the structure and composition of the lithosphere using various passive seismic imaging techniques. Previous studies have focused on receiver functions, teleseismic tomography, and ambient noise tomography; in the latter case, group velocity maps of the mainland region have led to an improved understanding of the Murray Basin and Palaeozoic basement structure. Although useful, group velocity maps do not provide direct information on depth variations of seismic properties, and more conventional parameters, such as shear and P-wavespeed, are not readily forthcoming, making geological interpretation more difficult. In this study, we investigate ambient noise tomography methods that attempt to directly image 3-D shear wavespeed, rather than the more traditional approach of producing group velocity maps at various periods. One previously established method infers shear wavespeed from group and phase dispersion curves. However, the extraction of reliable phase information is challenging, particularly if only relatively short period surface wave information is recorded, such as when very local, high density arrays are deployed. We demonstrate this difficulty with the 41 station SETA sub-array (located in southern Tasmania) of the WOMBAT project, which has an inter-station spacing of only 20 km. About 9 months of vertical-component data from the SETA array was cross-correlated and stacked to approximate the Rayleigh wave Green's functions for all possible station pairs. A time-frequency analysis (FTAN) procedure was used to apply narrowband filters to these Green's functions and generate group velocity dispersion curves for periods of 1~8 seconds. This period range results from the short interstation distances and relatively small geographical coverage of the array. Phase velocity dispersion curves are to be calculated via a far-field approximation and image transformation technique, as well as a method that uses FTAN results combined with 1-D shear velocity models to resolve the phase ambiguity term. These dispersion curves will then enable the inversion for a 3-D shear velocity model of the region. In addition to implementing this approach to image 3-D seismic structure in southeast Australia, we aim to develop an alternative means of using ambient noise to map shear velocity structure via direct waveform inversion and hence bypass the intermediate steps of dispersion curve analysis.

Oral

Frequency-dependent traveltime tomography for near-surface seismic data.

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Finite-frequency traveltime tomography (FFTT) was developed in global seismology about 10 years ago. By taking frequency into account, a more accurate estimation of velocity anomalies is theoretically possible, both in terms of anomaly magnitude and spatial resolution. However, the results have not always been clear when dealing with real data because of the inherit non-uniqueness of the inverse problem, and hence the need to use regularization to seek the minimum-structure model. The theory of FFTT is generally not applicable to controlled-source data for two main reasons: (1) controlled-source data consists of picked times, not delay times with respect to a synthetic derived from a reference model, and (2) for typical controlled-source data, there is no reference model known in advance for which the synthetic waveforms would be close enough to the recorded seismograms to yield a meaningful delay time. A new approach designed specifically for controlled-source (picked) data called frequency-dependent traveltime tomography (FDTT) is presented. The slight name change is intentional for two reasons (1) FDTT theory is completely different from FFTT theory, and (2) the frequency content of picked data is not precisely defined, and therefore inversions at different frequencies, such as the center or maximum frequency, are possible, with the resultant models being frequency dependent. FDTT uses wavelength-dependent velocity smoothing as part of a wavefront tracking scheme to calculate frequency-dependent traveltimes and the appropriate sensitivity kernels. The most important application of FDTT is in near-surface studies since there is a strong potential for ray theory to be invalid given typical seismic wavelengths and the length scale of heterogeneities in the near surface. Applications of FDTT to realistic synthetic data and real data from a groundwater contamination site are presented in which the minimum-structure model is estimated using smoothing regularization. These models contain better resolved velocity anomalies with higher spatial resolution than the equivalent infinite-frequency-derived models. In addition, given the typical width of the sensitivity kernels in near-surface studies, it is possible to perform stable traveltime tomography without regularization and thereby allow the data alone to determine the final model structure. For the equivalent fit to the data, the unregularized models contain more structure than the corresponding minimum-structure models. For applications to real data, this additional structure may be real, but it must be interpreted with caution since it is merely consistent with the data, not required by the data.

Poster

Crustal velocity structure of the Caribbean-South America plate boundary between 60W and 70W from controlled-source seismic data.

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We present the results from five wide-angle seismic profiles collected onshore and offshore Venezuela in 2004 as part of the Broadband Ocean Land Investigation of Venezuela and the Antilles arc Region project (BOLIVAR). The study area is the diffuse plate boundary between South America (SA) and the SE Caribbean plate (CAR) covering roughly 1000 km by 500 km. Over the past 55 My the Leeward Antilles island arc that borders the CAR plate has been colliding obliquely with the SA continent resulting in a collision front that has migrated from west to east. The five wide-angle profiles sample different stages of the time-transgressive margin from west to east, each crossing the margin perpendicularly. This presentation contrasts and compares the crustal velocity structure across the margin as sampled by these five profiles to better understand the tectonic processes that are responsible for the evolution and present-day configuration of the plate boundary. Each of the wide-angle profiles is about 500 km long and includes both onshore and offshore shots and receivers, except the easternmost profile, which is entirely offshore. The dense wide-angle data were modelled in the same way along each profile using a two-step, layer-stripping approach: (1) the first-arrival times were tomographically inverted for a smooth velocity model of the upper and middle crust, and (2) the lower crust, Moho, and uppermost mantle were determined by simultaneous inversion of PmP and Pn while keeping the upper and middle crust from the first step fixed. The five models show significant lateral heterogeneity across the margin, as they cross features including normal oceanic crust, oceanic plateau crust, an accretionary wedge, active and remnant island arcs, forearc and foreland basins, a major strike-slip system, a fold and thrust belt, and the edge of cratonic continental crust. This presentation focuses on the variations between the five profiles of the Moho structure and velocity structure of the tectonic units that comprise the diffuse plate. The main findings are (1) continuity of the Aves and Leeward Antilles Arc based on velocity and crustal thickness, (2) high crustal velocities at all depths within the arcs compared to the adjacent South American continent, (3) an offset in the Moho beneath the strike-slip fault system at 64W and 67W, more pronounced in the east, suggesting that deformation is not confined to the crust, and (4) a general smoothing and flattening of Moho topography from the youngest to oldest parts of the margin (east to west), suggesting a “relaxation” of the Moho.

Oral

Crustal structure of the Qilian Orogenic Belt from wide-angle seismic profiling on the north-eastern margin of the Tibetan Plateau.

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Qilian orogenic belt, located at the north-eastern edge of the Tibet, is a Caledonian orogenic belt that was reactivated by the collision between India and Asia. GPS measurements indicate Tibetan plateau is expanding in the northeast of the plateau, and Qilian tectonic block becomes important place to understand the north-eastward crustal growth of the plateau. In order to reconstruct crustal structure beneath the tectonic block and provide constrains to understand Qilian Caledonian orogenic mechanism and lateral (N-E) expansion of the plateau, we carried out a totally 430-km-long wide-angle seismic experiment in 2008 and 2009 along a 430-km-long inline profile across Qilian orogenic belt and a 300-km-long cross-line profile, with support of SinoProbe-02-02.

We present a crustal P-wave velocity structure model along the in-line wide-angle seismic profile, and find that crustal thickness thins from about 52 km under the southwest end of the profile to about 49 km at the northeast end of the profile, consistent with the results from another two wide-angle seismic profiles by Liu et al. (2006) and Zhang et al. (2008). The remarkable features of the crustal velocity model include: (1) Kunlun (or the western Qingling block) and Qilian terrane are clearly distinguished with the northern margin fault of western Qingling Mts (or ultra-higher pressure belt) as the boundary between them in our crustal velocity model; The crusts of these two tectonic blocks are thickened both in the upper and lower crust, and their crusts can be divided into upper and lower crust with thickness about 27 km and 22-26 km, respectively; (2) P-wave velocity is very low for whole crust, especially in the lower crust (6.3-6.6 km/s) beneath Qilian terrane; (3) there is one lower velocity layer (about 5.7 km/s) with thickness of 7-8 km in upper crust beneath the south segment of the profile, and 6.2-6.3 km/s higher velocity layer with thickness of about 5 km in upper crust beneath the north segment of the profile; (3) two lower velocity zones at depth range of 25-30 km beneath segment of the profile are imaged, and are inferred to be partial melting magma bodies as seismic evidences of two periods of exhumation events from Caledonian northward Qilian continental or oceanic subductions.

The analyses of shot seismic data reveal that there are weak or absence of strong seismic reflections from lower crust on in-line shot gathers which suggests the transparent lower crust beneath Qilian tectonic block, but well-developed reflections from off-line shot gathers. The discrepancy of the development of crustal reflections between NE-SW and NW-SE, and the very low of crustal velocity may suggest crust of the northeastern Tibet grows from crustal flowing predominantly in the direction of NE-SW, which matches with surface GPS measurement.