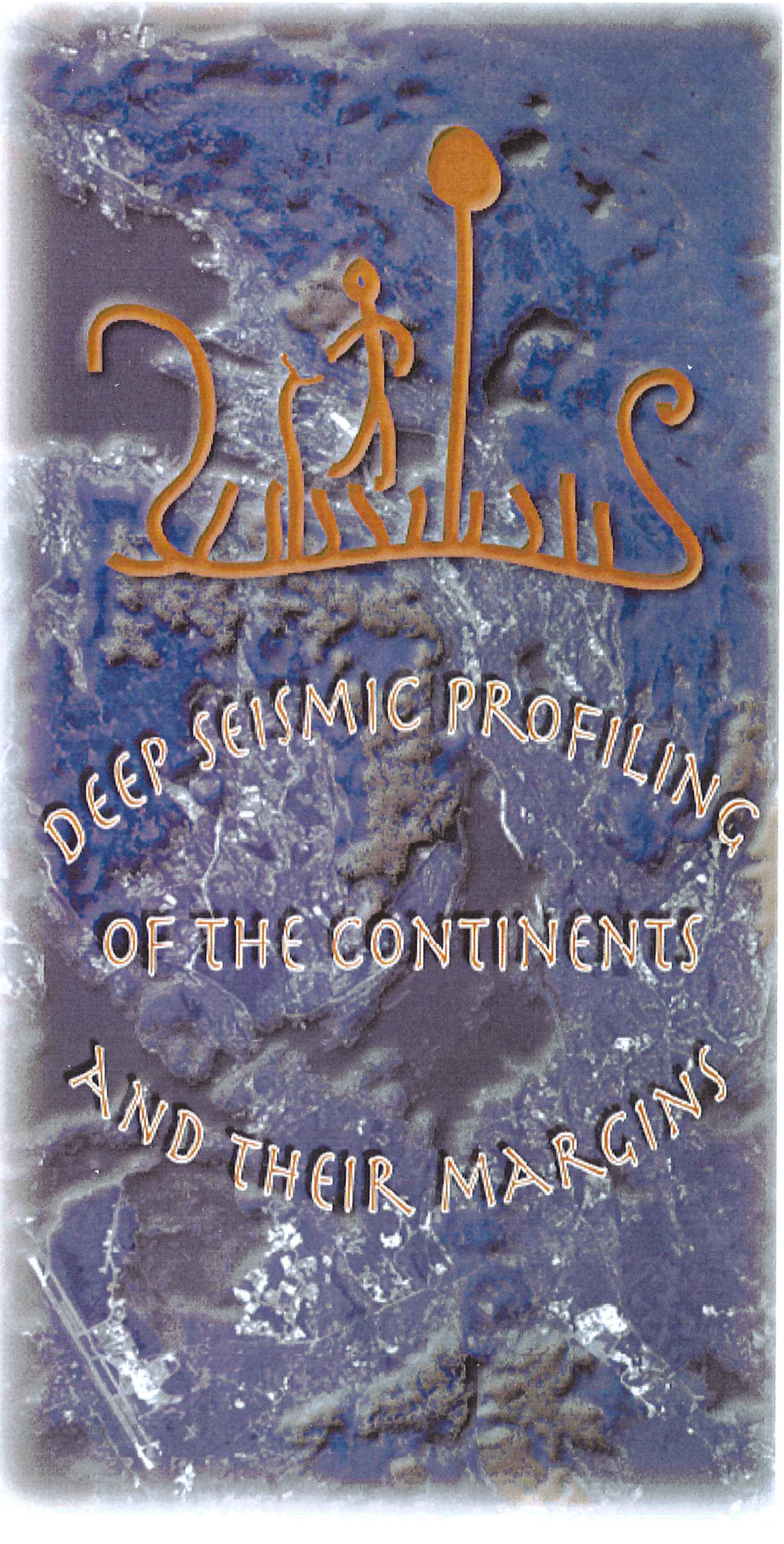
University of Bergen
Norway

18-23 June 2000, Ulvik, Norway

University of Copenhagen
Denmark



University of Bergen

The Millennial

9th International Symposium on

DEEP SEISMIC PROFILING

OF THE CONTINENTS AND THEIR MARGINS

18-23 June 2000

Brakanes Hotel Conference Centre, Ulvik, Norway

University of Copenhagen

General Information

Welcome

The Organising Committee of the 9th International Symposium on Deep Seismic Profiling of the Continents welcomes you to the Brakanes Hotel Conference Centre, Ulvik, Norway. We thank all participants for attending the meeting, and we wish you an enjoyable conference and stay in scenic Norway.

Sponsors

We appreciate the support provided for this meeting from:

Norwegian Research Council

Danish Natural Science Research Council

University of Copenhagen

University of Bergen

International Lithosphere Programme (ILP)

Refraction Technology Inc. (REFTEK)

Scientific programme

Oral Presentations

All talks will be held in the Conference Centre. The time allotted to each presentation (15 min., 30 min. for invited presentations) is intended for both the talk and discussion. Ideally, talks will last for 12 min. to allow for questions and discussion. Chairmen are recommended to give a warning after 10 min. and again after 12 min.

Audio-visual equipment

The Conference Centre is equipped with two 35 mm slide projectors, two overhead projectors, and two screens. PC slide equipment is also available.

Speaker ready room

Slide carousels are available in the Conference Centre. A room in the Conference Centre is available for pre-projection. Please return the empty carousels to the projectionist promptly.

Poster Displays

All posters are allocated one side of a single 1.60m width x 1.20m height board, unless otherwise requested. Posters will be on display in the Conference Centre. Authors are asked to indicate when they will be in attendance at the poster.

Poster presenters may locate their poster board by their number in the programme. Posters should be put up on Monday or Wednesday morning for the two poster periods, respectively. All posters must be taken down before 16:00 on Friday 23th.

Poster sessions will be from 19:30 to 21:00 Monday to Thursday.

Evening meetings

To stimulate debate on key points that can influence our future research, two evening discussions are planned:

Tuesday 20 June, 21:00-22:00: Global Committee On Interdisciplinary Lithospheric Surveys (COILS), Larry Brown (Cornell).

Thursday 22 June, 21:00-22:00: The EarthScope programme, Leonard Johnson (NSF).

Please see Page 5 for further details.

Meeting room

A meeting room is available for any sub-group to meet. Bookings should be made through the conference office.

Proceedings Volume

The Organising Committee has made preliminary arrangements with the publishers of Elsevier for a Special Symposium Proceedings issue of the journal Tectonophysics. This issue will continue the series of special issues from previous symposia. In order to ensure the widest dissemination of the results presented in this symposium we strongly encourage the participants to publish their presentations. The volume will consist of a series of short papers combined with some longer contributions, e.g. based on invited presentations. Please inform the organisers during the meeting about your contribution (title, authors, and anticipated number of manuscript pages, figures, and printed pages). The competition for pages in such volumes is usually strong, and only submissions before the deadline can be expected to be included in the volume. All manuscripts will undergo the usual rigorous review procedure for Tectonophysics. We expect the volume to be ready for submission to approval by the editor-in-chief by 1 September 2001, about one year after the conference. Final deadline for submission is 20 November 2000 to Hans Thybo, Geological Institute, Øster Voldgade 10, DK-1350 Copenhagen K, Denmark, email thybo@geol.ku.dk.

Social and sightseeing activities

Information on the programme for accompanying persons will be posted in the hall of the Conference centre. Tourist brochures are available in the lounge of the hotel.

1) On Sunday evening (20:30) there will be an Icebreaker party at the Conference Centre.

2) Pre-symposium one-day excursion to Bergen Arcs, Holsnoy area.

The theme of the excursion is processes and petrophysical properties of crustal root zones in the Caledonides of Western Norway. The excursion area is some 30 km north-west of Bergen (the island of Holsnoy) and transport is by bus. The bus leaves at Sunday 18 June at 0830 hrs from the Rica Travel Hotel in Bergen and returns to Bergen in the afternoon. At 1700 hrs the bus proceeds to the Brakanes Hotel in Ulvik in time for dinner and icebreaker reception.

3) Symposium excursions - Ulvik - Vøringsfossen and Ulvik - Osa.

Time: 20 and 22 June in the afternoon; duration ca 4 hours by bus.

These trips allow you to visit local tourist favourite spots: the 160 metre Vøringfossen waterfall in Eidsfjord and Osa close to Ulvik. In the latter case the buses will proceed up to the high plateau at 1000 metres for spectacular views above the Hardangerfjord. These tours are free of charge. Please, sign up for these excursions on the form at the registration desk upon arrival.

4) St. Hans bonfire at Brakanes Hotel shoreline.

Time: Friday 23 June (Sankt Hans Aften) after the Symposium banquet in the evening.

There is a centuries old tradition in the Nordic countries for celebrating Mid-Summer with a bonfire, folklore entertainment, dancing and so forth. An unforgettable evening!

5) Accompanying guest's program. Tours from Brakanes Hotel. Time: Daily; transport by Symposium bus.

The Hardangerfjord has many places to explore. There are some interesting farms within walking distance. We will try to arrange for a one-day painting course. We will provide free transportation, but tickets for museums etc. will need to be paid for. We aim to have mostly half-day trips. The program will be flexible to the wishes of participants and the weather. Obviously, all participants will have access to hotel facilities. We ask accompanying persons who are interested in attending this programme, to identify themselve at the Registration desk.

6) Scenic Fjord Country excursion by train and boat. Time: Saturday 24 June; please sign up at the office.

You will go by the symposium bus from Ulvik to Voss and continue by train to Myrdal, from where we will take the local "scenic" train to Flåm at Sognefjord (ca. 2 hrs.). We proceed by ship on the fjord to Gudvangen (2 hrs.). Here we board our bus to go directly to Bergen (arr. 14.45). The bus proceeds directly to the airport for afternoon departures (15.30). The cost of this excursion will be about NOK 300 because symposium transport is used. You can take this tour independently on Sunday 18 June starting in Bergen at about 0830 hrs and ending in Voss in the afternoon. However, without using the symposium transport this trip will cost you about NOK 500.

Logistics

Meals

All meals will be served at the restaurant of the Brakanes Centre. Meal hours are:

Breakfast: 07:00-08:45

Lunch: 12:15-14:00

Dinner: 18:00-19:30

Refreshment breaks

Coffee, tea and refreshments will be served at the Conference Centre during coffee breaks.

Conference Office

The Conference Office is at the Registration desk. It will be staffed by members of the Organising Committee, normally from 10:30 to 11:00 and from 17:00 to 18:00. Internet access will be available from 09:00 to 20:00

At the end of the conference

Return to Bergen Airport, Saturday 24 June in the morning, either direct or via the Fjord Cruise (details above). Details on departure time will be announced during the conference.

Special announcements

Program changes and any other announcements will be posted in the hall of the Conference Centre.

Participants wishing to display any notice may do so on poster boards and tables allocated for this purpose at the entrance of the Conference Centre. A table will be also available in the Reception Hall of the hotel.

Next and Future Meetings

Scientists who may wish to host the 10th International Symposium on Deep Seismic Reflection Profiling in 2002 must communicate their interest to the Organising Committee before the end of the 9th symposium.

Organising Committee

Hans Thybo, Tanni Abramovitz, Lars Nielsen, Andrew Ross and Gabriela Fernandez Viejo
Geological Institute, University of Copenhagen

Eystein Husebye, Bjørg Berg, Stig Hestholm, Norbjørg Kaland, Dagfinn Snartemo and Yura V. Federenko, Institute of Solid Earth Physics, University of Bergen

Email: seismix2000@geo.geol.ku.dk Web page: http://www.geol.ku.dk/seismix2000

Special Forums

The discussion leaders for our two evening special forums (21.00 Tuesday and Thursday) have provided us with a short summary of the main topics for discussion:

21.00 Tuesday 20th June

COILS - COMMITTEE ON INTERDISCIPLINARY LITHOSPHERIC SURVEYS

Larry Brown, Onno Oncken and Barry Drummond

Co-ordinating Committee 8 of the ILP – the Committee On Interdisciplinary Lithospheric Surveys (COILS) - was established to facilitate communication and collaboration amongst scientists undertaking research into the deep lithosphere. In particular, its formation recognises that major advances in our understanding of the structure and evolution of the lithosphere have come from multidisciplinary studies based around deep geophysical imaging.

The need for COILS was recognized at the 7th International Symposium on Deep Seismic Profiling of the Continents and their Margins, held in California in 1996. Informal discussions between interested scientists continued for another year, and the ILP agreed just prior to the 8th International Symposium in Spain in 1998, that a Coordinating Committee would provide an appropriate focus. Three people (Larry Brown, Cornell University, USA; Onno Oncken, GeoForschungsZentrum Potsdam, Germany; and Barry Drummond, Australian Geological Survey Organization) were asked to establish the committee. They have subsequently been appointed as co-chairmen.

Specific goals of COILS are to:

- promote international coordination of funding targeted for lithospheric surveys
- foster identification of global scientific priorities for future surveys (via focussed international workshops, for example)
- facilitate participation of scientists from countries lacking the resources to mount a major experiment independently
- identify and facilitate access to instrumentation, on an international basis, for carrying out future surveys
- preserve and facilitate access to the valuable archives of data already collected, large portions of which are in danger of evaporating due to neglect just when global syntheses are ripe for development
- establish and maintain an up-to-date website reporting on the status of continental lithospheric initiatives worldwide

Current status of activities related to COILS are reported on the COILS website: http://www.gfz-potsdam.de/pb4/ilp/pro_cc_coils.htm. A discussion of COILS initiatives related to the goals outlined above will be held at the 9th International Symposium on Deep Seismic Profiling in Ulvik, Norway.

21.00 Thursday 22nd June

EARTHSCOPE - A LOOK INTO A CONTINENT

Leonard Johnson, US National Science Foundation

EarthScope is a distributed, multi-purpose set of instruments and observatories that will expand the observational capabilities of the Earth Sciences and permit us to greatly increase our understanding of the structure, evolution and dynamics of a continent. Advances in theory, computing, and the technology of optical and radio telescopes have allowed us to look upward, ever deeper into the universe. Similarly, theorectical, computational, and technological advances in seismology, satellite geodesy, and drilling and downhole instrumentation provide the tools to make major advances in looking downward into the planet. EarthScope embraces these developments and seeks to link several observational facilities under consideration by the Earth Sciences Division at the U.S. National Science

Foundation (NSF-EAR), the U.S. Geological Survey (USGS), and NASA into a single integrated effort. These observational facilities provide a framework for broad, integrated studies across the Earth Sciences, including research on earthquakes and seismic hazards, magmatic systems and volcanic hazards, lithospheric dynamics, regional tectonics, continental structure and evolution, and fluids in the crust.

EarthScope is being proposed through the NSF Major Research Equipment (MRE) Program. It will consist of the following components: a) a continental scale array of broad-band and short-period seismometers to provide a coherent 3-D image of the lithosphere and deeper Earth (USArray); b) fixed arrays of strainmeters and Global Positioning System (GPS) receivers to measure real-time deformation on a plate boundary scale (Plate Boundary Observatory - PBO); c) a deep borehole observatory along the San Andreas fault to directly measure the physical conditions under which earthquakes occur (San Andreas Fault Obervatory at Depth - SAFOD); and d) satellite-generated Interferometric Synthetic Aperture Radar images of tectonically active regions of the continent (INSAR).

ORAL PRESENTATIONS SUMMARY

TIME AM	Monday 19th June Active Continental Margins	Tuesday 20th June Continental Accretion and Collision	Wednesday 21th June The Continental Mantle	Thursday 22nd June Integrated Multidisciplinary Studies	Friday 23rd June Seismic Techniques
9.00	Oncken O. et al. **INVITED**	van der Velden A. J & Cook F. A.	Christensen N.I.	Fuis G. et al. **INVITED**	Zelt C. et al. **INVITED**
9.15		Hollister L.S. et al.	Nielsen L. et al.		
9.30	Kodaira S. et al.	Morozov I.B. et al.	Mooney W. D. & Kaban M. K.	Bogdanova S. et al.	Barton P.J. et al.
9.45	Ito T. et al.	Hammer P.T.C. & Clowes R.M.	Pavlenkova N.I.	Meltzer A. et al.	Morozov I.B. & Smithson S.B.
10.00	Iwasaki T. et al.	Cook F.A. et al.	Ross A.R. et al.	Krawczyk C.M. et al.	Levander A.
10.15	Ito T. , Yamakita, S.,et al.	Funck T. et al.	Egorkin A.V.	Morgan J. & Warner M.	Schiøtt C. et al.
10.30	**COFFEE BREAK**	**COFFEE BREAK**	**COFFEE BREAK**	**COFFEE BREAK**	**COFFEE BREAK**
11.00	Crosson R.S. et al.	Snyder, D.S.B. **INVITED**	Smithson S.B. & Morozova E.A., **INVITED**	Brown L.D.	Goncharov A. et al.
11.15	Lelgemann H. et al.			Drummond B.J. et al.	Mereu R.
11.30	Sato H. et al.	Juhlin C. et al.	Hurich C.A.	Korsch R.J. et al.	Roy-Chowdhury K.
11.45	Ikawa T. et al.	Lassen A. & Thybo H.	Knapp J.H.	Goleby B.R. et al.	Warner M. et al.
12.00	Moriya T. et al.	Laigle M. , Thybo, H., et al.	Balling N.	Olesen O. et al.	Louie J. et al.
12.15	**LUNCH BREAK**	**LUNCH BREAK**	**LUNCH BREAK**	**LUNCH BREAK**	**LUNCH BREAK**
TIME PM	**Monday 19th June Continental Accretion and Collision I**	**EXCURSION**	**Wednesday 21th June Continental Rifts and Basins**	**EXCURSION**	**Friday 23rd June Passive Continental Margins**
2.15	Klemperer S. & Fliedner M		Abramovitz T. et al.		Carbonell R. et al.
2.30	Diebold J.& Hollister L.		Arlitt R. et al.		White R.S. **INVITED**
2.45	Lüschen E. et al.		Fernandez-Viejo G. et al.		
3.00	Maercklin N., Meissner, R., et al..		McBride J.H.		Cramez C. et al.
3.15	Rabbel W. et al.		Johnson R. A. & Mohapatra G.K.		Reid I.D. et al.
3.30	**COFFEE BREAK**		**COFFEE BREAK**		**COFFEE BREAK**
4.00	Yurov Yu. G. et al.		Keller G. R. **INVITED**		Breivik A.J. et al.
4.15	Keller G.R.				Wheeler W. & Karpuz R.
4.30	Berzin R.G. et al.		Stephenson, R.A., et al.		Leythaeuser, et al.
4.45	Carbonell R. et al.		Diaconescu C.C. & Knapp J.H.		

ORAL PROGRAMME

Oral Programme

Monday 19th June Morning

Active Continental Margins		**Chairs: Simon Klemperer & Wolfgang Rabbel**
9.00	Oncken O. & Berlin-Potsdam Andes Research Group	How similar are the Andean and Tibetan plateaus? - results from the integrated experiment ANCORP'96 **INVITED**
9.30	Kodaira S., Takahashi N., Nakanishi A., Miura S., Park J-O., Obana K. & Kaneda Y.	Imaging of a subducting seamount in the Nankai seismogenic zone by using a super densely deployed OBS array
9.45	Ito T., Arita K., Moriya T., Kimura G. & Ikawa T.	Delamination-wedge structure and growth of continental crust caused by the Hi Daka Arc-Arc collision, Hokkaido, Japan
10.00	Iwasaki T., Moriya T., Arita K., Hirata N., Sato H., Ito T. & Yoshii T.	1999 Hokkaido Transect, Japan (J-multidisciplinary crustal study for arc-arc collision zone)
10.15	Ito T., Yamakita S., Matsuoka T., Tsumura N., Nakamura H., Iwasaki T., Hirata N., Sato H., Ikawa T. & Kawanaka T.	Post-accretionary subhorizontal fault in the Mesozoic accretionary complexes in the Kii Peninsula, southwest Japan, revealed by the recent seismic reflection study
10.30		**COFFEE**
11.00	Crosson R.S., Symons N.P., Creager K.C., Preston L.A., van Wagoner T., Brocher T.M., Parsons T., Fisher M., Trehu A. & Miller K.	3-D structure of the Cascadia forearc region from SHIPS active experiment and earthquake observations: Tomographic inversion and wide-angle reflection analysis provide a high resolution view into the core of the Cascadia forearc complex
11.15	Lelgemann H., Flueh E.R., Klaeschen D., Bialas J., Reichert C. and the GINCO Working Group	Crustal structure along the Central Sunda Arc
11.30	Sato H., Iwasaki T., Hirata N., Hasegawa A., Kurashimo E., Ikawa T. and Research Group for 1997 Northern Honshu Transect	Crustal structure, evolution and activity of Northern Honshu, Japan: Northern Honshu Transect-97, 98 Results
11.45	Ikawa T., Onishi M., Ito T., Kawamura T. & Hirata N.	Deep seismic reflection experiment with a highly dense array of seismograms, north of the median tectonic line (MTL), Shikoku, Japan
12.00	Moriya T., Iwasaki T.,Sakai S., Takeda T.,Otsuka K.,Yoashii T.,Ozel O., Tanaka A.,Okubo K.	Intermediate crustal layer in the active island arc
12.15		**LUNCH**

Monday 19th June Afternoon

Continental Accretion and Collision I		Chairs: David Snyder & Rolf Meissner
14.15	Klemperer S. & Fliedner M.	Seismic velocity structure of continental and oceanic arcs – What does it take to make continents?
14.30	Diebold J. & Hollister L.	Marine seismic data from the accreted terranes of southeast Alaska and British Columbia
15.45	Lüschen E., Gebrande H., Bopp M., Stiller M., Grassl H., Millahn K., Bertelli L., Zulian C., Borrini D. and TRANSALP Group	Transalp - deep seismic reflection traverse across the eastern Alps
15.00	Maercklin N., Meissner R. & Mechie J.	Indepth III, a wide-angle profile across the Banggong-Nuijang Suture; southern Tibet
15.15	Rabbel W., Beilecke Th., Lüschen E., Gebrande H., Borm G., Kueck J., Bram K., Druivenga G. & Smithson S.	Vertical seismic profiling to 8550 m depth - new results from the continental deep drillhole KTB (S Germany)
15.30		**COFFEE**
16.00	Yurov Yu. G., Berzin R.G. & Morozov A. Ph.	Digitizing of the continuous DSS profiling data: Targets and preliminary results
16.15	Keller G.R.	CELEBRATION 2000: A Seismic Investigation of Lithospheric Structure in the Trans-European Suture/Carpathian Mountains
16.30	Berzin R.G., Yurov Yu G. & Pavlenkova N.I.	CDP and DSS data for Kem-Uchta profile (the Baltic Shield)
16.45	Carbonell R., Gallart J. & Estaun A.	Imaging and Modelling a Heterogeneous Mantle Boundary: The Case of the Southern Urals

Poster viewing between 19.30 and 21.00

Tuesday 20th June Morning

Continental Accretion and Collision II		Chairs: Walter Mooney & Fred Cook
9.00	van der Velden A.J. & Cook F. A.	Archean arc-continent collision in the Slave Province, northern Canada: A reinterpretation of lithoprobe SNORCLE line 1
9.15	Hollister L.S., Andronicos C.L., Smithson S.B. & Morozov I.B.	Basalt underplating and crustal extension during the formation of the Coast Mountains batholith, British Columbia and Alaska
9.30	Morozov I.B., Smithson S.B., Hollister L.S. & Christensen N.I.	Building continental crust: The accrete model
9.45	Hammer P.T.C. & Clowes R.M.	Lithospheric structure across the Cordilleran orogen of NW british Columbia, Canada: Lithoprobe seismic wide-angle and near-vertical incidence profiling
10.00	Cook F.A., Clowes R.M., Snyder D.B., van der Velden A.J., Hall K.W. & Vasudevan K.	Lithoprobe SNORCLE reflection survey 1999-2000: The northern Canadian Cordillera
10.15	Funck T., Louden K.E., Hall J. & Reid I.D.	A combined onshore-offshore wide-angle seismic experiment in Labrador - application of 2-D forward modeling, 3-D tomography and prestack-depth migration
10.30		**COFFEE**
11.00	Snyder D.B.	The shape of cratons **INVITED**
11.30	Juhlin C., Elming S.-Å., Mellqvist C., Öhlander B., Weihed P. & Wikström A.	Onshore crustal reflectivity of the Archean-Proterozoic boundary and comparison with BABEL Lines 2 and 3, northern Sweden
11.45	Lassen A. & Thybo H.	Evidence of Sveconorwegian orogenic structures below the Danish area and their possible influence on the formation of overlying palaeozoic sedimentary basins, from interpretation of commercial reflection seismic data
12.00	Laigle M., Thybo H., Bayer U.	New seismic images of Caledonian collision structures beneath the North Sea basement high (Denmark)
12.15		**LUNCH**

AFTERNOON EXCURSION

Poster viewing between 19.30 and 21.00

21.00 **SPECIAL FORUM**	**Committee On Interdisciplinary Lithospheric Surveys (COILS)**	
	Larry Brown	

Wednesday 21st June Morning

The Continental Mantle		**Chairs: Larry Brown & Ron Clowes**
9.00	Christensen N.I.	Continental mantle seismic anisotropy: A new look at the Twin Sisters massif
9.15	Nielsen L., Thybo H. & Egorkin A.	Constraints on scattering bodies in the 100-200 km depth range from waveform modelling of PNE seismic profile Kraton
9.30	Mooney W.D. & Kaban M.K.	Structure of the lithosphere in the SW United States
9.45	Pavlenkova N.I.	Global seismic boundaries and weak zones in the crust and upper mantle
10.00	Ross A.R., Thybo H. & Egorkin A.	Ultra-deep seismic reflections: Images from the Earth's core
10.15	Egorkin A.V.	Structure of the upper mantle transition zone from the PNE data
10.30		**COFFEE**
11.00	Smithson S.B. & Morozova E.A.	Seismic reflections on the continental Moho **INVITED**
11.30	Hurich C.A.	Links between wave mechanics, wave field statistics and the heterogeneity of the crust and upper mantle
11.45	Knapp J.H.	The Flannan and W reflectors revisited: The smoking gun of Early Tertiary lithosphere-scale extension
12.00	Balling N.	Sub-crustal seismic reflectors beneath the North Sea - relict subduction and extensional shear zones
12.15		**LUNCH**

Wednesday 21st June Afternoon

14.15	Abramovitz T., Thybo H. & Perchuc E.	The 8 degree discontinuity interpreted from FENNOLORA P- and S-wave seismic data
14.30	Arlitt R., Shomali H., Kissling E., Ansorge J., Roberts R. & TOR Working Group	P-wave velocity structure of the lithosphere-asthenosphere system across the TESZ in Denmark

Continental Rifts and Basins

Chairs: John McBride & Randy Keller

14.45	Fernandez-Viejo G., Thybo H. & Laigle M.	Reprocessing of MONA LISA deep seismic reflection data: The paleozoic rift in the North Sea
15.00	McBride J.H.	Reviving deep geophysics in the central USA mid-continent
15.15	Johnson R. A. & Mohapatra G. K.	Extension and structural evolution of the Great Salt Lake, Utah: A subsurface view of the eastern margin of the Great Basin, western U.S.
15.30		**COFFEE**
16.00	Keller G. Randy	The Kenya Rift and the southern Great Basin, USA: A comparison of a narrow rift and a wide rift **INVITED**
16.30	Stephenson R.A. & the DOBRE Working Group	"DOBRE" - Donbas Foldbelt (SE Ukraine) deep seismic refraction and reflection profiling
16.45	Diaconescu C. C. & Knapp J.H.	First deep seismic reflection image of the South Caspian Basin, Central Eurasia: Evidence for episodic subduction

Poster viewing between 19.30 and 21.00

Thursday 22nd June Morning

Integrated Multi-disciplinary Studies		Chairs: Ramon Carbonell & Barry Drummond
9.00	Fuis G., Ryberg T., Godfrey N.J., Okaya D.A.	Crustal structure and tectonics along the LARSE transects, southern California, USA **INVITED**
9.30	Bogdanova S. & EUROBRIDGE Seismic Working Group	The multidisciplinary EUROBRIDGE: A seismic record of 2000 million years of crustal history
9.45	Meltzer A., Christensen N., Changxing Long	Crustal heterogeneity and anisotropy of an active metamorphic massif, Nanga Parbat, Western Himalaya
10.00	Krawczyk C.M. & North German Basin Research Group	The Northeast German Basin - seismic imaging and dynamic evolution of an intracontinental basin
10.15	Morgan J. & Warner M.	Multidisciplinary study of the Chicxulub impact structure
10.30		**COFFEE**
11.00	Brown L.D.	25 years of deep seismic profiling at Cornell
11.15	Drummond B.J., Cox S.F. & Goleby B.R.	The role of fluids in the formation of regional-scale detachment surfaces
11.30	Korsch R.J., Glen R.A., Jones L.E.A., Johnstone D.W., Finlayson D.M. & Lawrie K.C.	Deep seismic imaging of an ancient convergent plate margin, eastern Lachlan Orogen, Australia
11.45	Goleby B.R., Korsch R.J., Drummond B.J., Fomin T., Owen A.J. & Bell B.	Three-dimensional crustal structure from deep seismic reflection data in the Archaean granite-greenstone Yilgard Craton, Western Australia
12.00	Olesen O., Smethurst M.A., Torsvik T.H. & Bidstrup T.	Sveconorwegian instrusives beneath the Norwegian-Danish basin
12.15		**LUNCH**

AFTERNOON EXCURSION

Poster viewing between 19.30 and 21.00

21.00 SPECIAL FORUM — **EARTHSCOPE - A look into a continent**

Leonard Johnson (NSF)

Friday 23rd June Morning

	Seismic Techniques	**Chairs: Mike Warner & Alan Levander**
9.00	Zelt C., Naumenko J., Sain K., Zelt B., Sawyer D. & Barton P.	Assessment of 2D and 3D velocity models derived from wide-angle traveltime data **INVITED**
9.30	Barton P.J., Barker N. & di Nicola-Carena E.	Rapid automatic 2D velocity images in depth and time from refracted arrivals
9.45	Morozov I.B. & Smithson S.B.	Broad utilization of seismic data from long-range refraction profiles: Imaging crustal reverberations and scattering
10.00	Levander A.	The heterogeneity of the lithosphere
10.15	Schiøtt C., Jacobsen B.H. & Balling N.	Wide-angle seismic traveltime inversion using a Fresnel zone based procedure
10.30		**COFFEE**
11.00	Goncharov A., Petkovic P., Fomin T. & Symonds P.	Australian north west shelf, crustal reflectivity and bulk seismic velocity: A problem relationship
11.15	Mereu R.	The origin of the intra-crustal discontinuities
11.30	Roy-Chowdhury K.	Seismic images and the ground truth
11.45	Warner M., Stekl I., Pratt G. & Hicks G.	Full-wavefield tomography: Theory and practice
12.00	Louie J., Henrys S. & Bannister S.	Multicomponent imaging of the Hikurangi subduction interface from local-earthquake seismograms
12.15		**LUNCH**

Friday 23rd June Afternoon

	Passive Continental Margins	**Chairs: Rolf Mjelde & Penny Barton**
14.15	Carbonell R., Marti D., Tryggvason A. & Pérez-Estaún A.	High resolution geophysical characterization of a granite pluton
14.30	White R.S.	Rifting and magmatism on continental margins **INVITED**
15.00	Cramez C., Jackson M.P.A. & Geiss Bernard	The Rockall Trough as an analogue for breakup of the South Atlantic Ocean

15.15	Reid I.D., Chian D. & Jackson H.R.	Crustal structure of an extended continental margin northeast of Newfoundland
15.30		**COFFEE**
16.00	Breivik A.J., Mjelde R. Grogan P., Shimamura H., Murai Y., Nishimura Y. & Kuwano A.	Modelling of wide-angle seismic data from ocean bottom seismometers southeast of Svalbard: A Caledonide suture recognized?
16.15	Wheeler W. & Karpuz R.	Deep crustal architecture of the Vøring margin, mid-Norway
16.30	Leythaeuser T., Flueh E.R. & Reston T.	The Structure of the Iberian Margin at 41 degree 2': MCS and OBH Results

Sankt Hans' Aften Bonfire and Banquet

POSTER PROGRAMME

Poster Programme

Posters will be on display for 2 days with poster viewing sessions between 19.30 and 21.00 each day

Active Continental Margins

MONDAY 19th -TUESDAY 20th

ACM-1	Van Avendonk H., Holbrook W.S., Okaya D., Austin J. and the SIGHT Group	Wide-angle imaging of the structure of the Australian-Pacific plate boundary, South Island, New Zealand, SIGHT transect I
ACM-2	Scherwath M., Stern T., Davey F., Okaya D. Henrys S., Davies R., Kleffmann S. and the SIGHT group	Crustal structure and continental collision: SIGHT line 2, New Zealand
ACM-3	Kleffmann S., Stern T., SIGHT Team	Geophysical evidence for crustal fluids in a region of active continental convergence - the South Island of New Zealand
ACM-4	Bialas J., Kukowski N. and the GEOPECO Working Group	Marine Geophysical Investigations Across the Continental Margin of Peru: First Results of the GEOPECO Cruise
ACM-5	Abreu V., Talwani M., Teas P., Covington G., Johnson E. & Bally A.	Bangladesh: Example of an onshore continental/oceanic transition
ACM-6	Gaedicke C., Schlüter H.-U., Roeser H., Meyer H. & Prexl A.	Seismic imaging and dynamic evolution of the Indian plate boundary off Pakistan
ACM-7	Filonenko V.P.	Crustal types in the active continental margins (Ochotsk Sea - the Pacific zone)
ACM-8	Research Group for 1997 Northern Honshu Transect Japan	Crustal section across northern Honshu arc as revealed from onshore and offshore wide-angle seismic profiles
ACM-9	Iwasaki T., Arita K., Hirata N., Sato H., Kurashimo E., Ito T., Ozawa T., Kawanaka T. & Ikawa T.	Crustal section of arc-arc collision zone, Hokkaido, Japan, from seismic reflection profiling
ACM-10	Katsumata K., Wada N., Moriya T. & Kasahara M.	Seismic tomography beneath Hidaka Mountains, Hokkaido, Japan, from dense seismic network data
ACM-11	Moriya T., Ohtsuka K., Taira T. Iwasaki T., Takeda T., Yamada T., Ohtake K., Gouke K., Matusshima T. & Miyamachi H.	Seismic refraction/wide-angle reflection profiling across Arc-Arc collision zone, Central Hokkaido, Japan
ACM-12	Moriya T., Iwasaki T., Sakai S., Takeda T., Otsuka K., Yoashii T., Ozel O., Tanaka A. & Okubo K.	Relation between P-wave velocity and thermal structures in the crust beneath Japanese island arc
ACM-13	Yamaguchi K., Yokokura T., Kano N., Kiguchi T., Ohtaki T., Tanaka A. & Sato H.	Shallow seismic profiling in the Tanakura tectonic line, northeast Honshu arc, Japan

ACM-14	Yokokura T., Yamaguchi K., Miyazaki T. & Kano N.	Lower crustal reflectors and an earthquake swarm in the northern Miyagi area, northeastern Japan: Two different effects of water
ACM-15	Kurashimo E., Tokunaga M., Iwasaki T., Hirata N., Kodaira S., Kaneda Y., Ito K., Nishida R. & Ikawa T.	Deep structure beneath the eastern Shikoku, SW Japan, revealed by seismic refraction/wide-angle reflection profiling
ACM-16	Kasahara K., Yamakita S., Ito T., Kawamura T., Iwasaki T. & Ikawa T.	Seismic reflection profilings from the Median Tectonic Line (MTL) to the accretionary complexes, Kii Peninsula, southwest Japan
ACM-17	Ito K. & Shibutani T.	Seismogenic layer and crustal structure in southwest Japan
ACM-18	Miura S., Tsuru T., Takahashi N., Kodaira S., Nakanishi A., Park J.-O. & Kaneda Y.	Structural variation along the Japan Trench obtained by multichannel and wide-angle onshore-offshore seismic data
ACM-19	Otsuka K., Moriya B.T., Sakai S., Yoshii B.T., Koizumi T., Yamazaki F., Sasaki Y., Ito K., Matsumura B.K. & Tazaki B.K.	Crustal structure of Fujihashi-Kamigori profile, in the western part of Ho Nsyu, Japan, by refraction and wide-angle reflection experiment
ACM-20	Nakanishi A., Kodaira S., Takahashi N., Miura S., Park J.O. & Kaneda Y.	Crustal transects of the Nankai Trough seismogenic zone - summary of recent Jamstec seismic studies
ACM-21	Sato H., Hirata N., Iwasaki T., Kurashimo E., Ikeda Y., Koshiya S., Imaizumi T., Ikawa T., Ito T. & Hasegawa A.	Deep to shallow seismic reflection profiling across the Backbone Range of Northern Honshu, Japan
ACM-22	Orito M., Sato H., Ito T., Hirakawa K., Ikeda Y. & Ikawa T.	Active growth fault-bend folding in the frontal part of Hidaka thrust system, Hokkaido, Japan
ACM-23	Sato H., Iwasaki T., Hirata N., Hasegawa A., Kurashimo E., Ikawa T. and Research Group for 1997 Northern Honshu Transect	Crustal structure, evolution and activity of Northern Honshu, Japan: Northern Honshu Transect-97, 98 Results
ACM-24	Lelgemann H., Flueh E.R., Klaeschen D., Bialas J., Reichert C. and the GINCO Working Group	Crustal structure along the Central Sunda Arc
ACM-25	Sanina I.A., Gontovaya L.I., Stepanova M.A.	Velocity inhomogeneities of the Earth's crust and upper mantle in the Kamchatka region
ACM-26	Park J.-O., Tsuru T., Takahashi N., Kodaira S., Nakanishi A., Miura S. & Kaneda Y.	Underplating and dewatering in the Nankai seismogenic zone
ACM-27	Ikawa T., Onishi M., Ito T., Kawamura T. & Hirata N.	Deep seismic reflection experiment with a highly dense array of seismograms, north of the median tectonic line (MTL), Shikoku, Japan

Continental Accretion and Collision

MONDAY 19th -TUESDAY 20th

CAC-1	Hinsch R., Krawczyk C.M., Gaedicke C., Giraudo R. & Demuro D.	Imaging an evolving thrust sheet in the Bolivian Orocline: From 2-D seismic lines to a 3-D model of an oblique deformation front
CAC-2	Kanao M., Tsutsui T., Murakami H., Miyamachi H., Toda S., Yanagisawa M. Minta T., Kaminuma K., Shibuya K., Shiraishi K. and SEAL Geotransect Group	Deep seismic refraction experiments in 1999 on the Mizuho Plateau, East Antarctica: The SEAL project
CAC-3	Hajnal Z. & Nemeth B.	History of the Trans-Hudson orogen from seismic signatures
CAC-4	Shoshitaishvili Elena & Johnson Roy A.	Three-component recording over the Cheyenne Belt, SE Wyoming
CAC-5	Keller G. R., Snelson C., Harder S., Rumple H.M. & Prodehl C.	Continental Dynamics - Rocky Mountain Project (CD-ROM): A 1000 km Long Refraction Profile in the Western U.S.
CAC-6	Miller K.C., Levander A. and Correspondents for the CD-ROM Working Group	Continental Dynamics - Rocky Mountain Project (CD-ROM): Deep Seismic Reflection Profiling Experiments in Northern New Mexico, United States
CAC-7	Miller K.C. & Eshete T.	Possible Origins for Seismic Reflections in the Proterozoic Southern Granite-Rhyolite Province of Texas and New Mexico, USA
CAC-8	Wan X., Morozova E.A., Boyd III N.G.K., Smithson S.B., Keller G.R., Miller K., Levander A. & Karlstrom K.E.	Seismic reflection profiling of the central Rockies for crustal evolution and crustal structure: The CD-ROM project
CAC-9	Korsch R.J., Barton T.J., Drummond B.J., Finlayson D.M., Fomin T., Goleby B.R., Johnstone D.W., Jones L.E.A., Mifsud J. & Owen A.J.	Crustal thrust systems in the Phanerozoic Tasman orogenic system, eastern Australia
CAC-10	Eberhart-Phillips D. & Bannister S.	Southern Alps, New Zealand, three-dimensional seismic velocity structure
CAC-11	Trofimov V.A.	CDP seismics in the study of the pre-Cambrian basement structure in the east of the Russian platform
CAC-12	Sharov V.I. & Trofimov V.A.	Seismic studies of geodynamic systems in the crust and upper mantle of the Volgo-Urals region (Russian platform
CAC-13	Friberg M., Juhlin C., Perez-Estaun A. & Bliznetsov M.	New reflection seismic data image the crust and Moho under western Siberia
CAC-14	Brown D., Juhlin C., Tryggvason A., Steer D., Friberg M., Ayarza P. & Beckholmen M.	The crustal architecture of the Southern and Middle Urals from the URSEIS, ESRU, and Alapaev reflection seismic profiles

CAC-15	Berzin R.G., Kulakov S.I., Suleimanov A.K., Davidova T.V., Zamozhnaya N.G., Morozov A.F. & Minz M.V.	Crustal structure at the Karelian-Belomorian boundary, Baltic Shield
CAC-16	Luosto U., Pavlenkova N.I., Yliniemi J. & Yurov Yu. G.	3-D crustal velocity model of the Baltic Shield
CAC-17	Juhojuntti N., Juhlin C. & Dyrelius D.	Crustal reflectivity underneath the Central Scandinavian Caledonides
CAC-18	Abramovitz T., Nielsen L., Laigle M., Fernandez-Viejo G. & Thybo H.	MONA LISA: A seismic key to North Sea Tectonic Evolution
CAC-19	Pedreira D., Pulgar J.A. & Gallart J.	Collisional crustal structures from the western Pyrenees to the Cantabrian Mountains and the Iberian Chain
CAC-20	Maerchlin N., Meissner R. & Mechie J.	Indepth III, a wide-angle profile across the Banggong-Nuijang suture; southern Tibet
CAC-21	van der Velden Arie J. & Cook Frederick A.	Archean arc-continent collision in the Slave Province, northern Canada: A reinterpretation of lithoprobe SNORCLE line 1
CAC-22	Funck T., Louden K.E., Hall J. & Reid I.D.	A combined onshore-offshore wide-angle seismic experiment in Labrador - application of 2-D forward modeling, 3-D tomography and prestack-depth migration
CAC-23	Rabbel W., Beilecke Th., Lüschen E., Gebrande H., Borm G., Kueck J., Bram K., Druivenga G. & Smithson S.	Vertical seismic profiling to 8550 m depth - new results from the continental deep drillhole KTB (S Germany)
CAC-24	Bao-Jun Yang Cai Liu Gian-Rew Tang Qin-Xue Li Xuan Feng and Hai-Shan Zheng	The configuration characteristics of Moho interpreted from the deep seismic data in Anda-Zhaozhou zone, NE China

The Continental Mantle

WEDNESDAY 21st- THURSDAY 22nd

TCM-1	Kostyuchenko S., Solodilov L.N., Egorkin A.V., Mooney W.D. & Chulick G.	Crustal and upper mantle structure of North America and Russia
TCM-2	Nielsen L., Thybo H. & Solodilov L.	Low velocities and strong scattering below the 8 degree discontinuity along PNE profile Kraton in Siberia
TCM-3	Morozova E.A., Morozov I.B., Smithson S.B. & Solodilov L.N.	Crust-upper mantle coupling from profile quartz in Russia
TCM-4	Pavlenkova G.A., Priestly K. & Cipar J.	Crust and upper mantle structure along "RIFT" profile (Siberian Craton)
TCM-5	Drummond B.J., Goleby B.R., Barton T.J. & Korsch R.J.	The Moho as a detachment surface
TCM-6	Soloviev V., Seleznev V.S. & Zhemchugova I.V.	Upper mantle of the Altai-Sayan fold area from data of areal seismological observations

Continental Rifts and Basins

WEDNESDAY 21st- THURSDAY 22nd

CRB-1	Breivik A.J., Mjelde R., Grogan P., Shimamura H., Murai Y., Nishimura Y. & Kuwano A.	P-wave modeling of wide angle seismic data from ocean bottom seismometers southeast of Svalbard
CRB-2	Breivik A.J., Mjelde R., Grogan P., Shimamura H., Murai Y., Nishimura Y. & Kuwano A.	S-wave and gravity modeling based on P-wave models of wide angle seismic data from ocean bottom seismometers southeast of Svalbard
CRB-3	Franke D., Hinz K., Neben S., Block M. & Roeser H.A.	The Laptev Sea rift
CRB-4	Knapp J.H., Diaconescu C.C., Connor J.A. & McBride J.H.	Imaging the thickest (?) sedimentary basin in Earth history: Deep seismic reflection profiling of the South Caspian Basin
CRB-5	Korja A. & Heikkinen P.	Formation of the Baltic Sea paleorift - implications of the BABEL profiles
CRB-6	Balling N., Nielsen L. and MONA LISA Working Group	Seismic reflection and refraction evidence for crustal thinning beneath the Central Graben, North Sea
CRB-7	Fernandez-Viejo G., Thybo H. & Laigle M.	New images from the MONA LISA deep seismic data: Reprocessing and pre-stack depth migration of selected areas
CRB-8	Scheck M., V. Otto U. Bayer A. M. Marotta M. Grad H. Thybo	The Elbe fault system in the NE-German Basin - a basement-controlled weakness zone?
CRB-9	Stephenson R.A. & the DOBRE Working Group	"DOBRE" - Donbas Foldbelt (SE Ukraine) deep seismic refraction and reflection profiling
CRB-10	McBride J.H. & Kolata D.R.	A new Precambrian geologic province beneath the Illinois Basin, USA
CRB-11	McBride J.H. & White N.J.	Crustal structure of Moray Firth basin, North Sea, from deep seismic reflection, subsidence modeling, and gravity
CRB-12	McBride J.H., White R.S. & Smallwood J.R.	Must magmatic addition to the lower crust produce reflectivity?
CRB-13	Suvorov V.D., Mishenkina Z.R., Sheludko I.F., Petrick G.V. & Melnik E.A.	Uppermost mantle beneath the eastern part of Siberian craton and adjacent fold areas
CRB-14	S. Kostyuchenko, A. Egorkin and L. Solodilov	Nature and peculiarities of the rifts and basins of the continental margin of Northeastern Europe

Integrated Multi-disciplinary Studies

WEDNESDAY 21st- THURSDAY 22nd

IMS-1	Fuis G., Ryberg T., Godfrey N.J., Okaya D.A.	Crustal structure and tectonics along the LARSE transects, southern California, USA

IMS-2	Godfrey N.J., Okaya D.A. & Fuis G.S.	Lower-crustal deformation beneath the Los Angeles region, southern California: Results from LARSE Lines 1 and 2
IMS-3	Rupp J.A.	Integration of seismic reflection, gravity and magnetic analysis to define a buried Precambrian basinal depositional setting: A Greenville Foreland sequence?
IMS-4	Jochym P.T. & Krzywiec P.	Quantum mechanical study of properties of the forsterite (Mg2SiO4) under high pressure - preliminary results
IMS-5	Zientara P. & Krzywiec P.	Integration of deep seismic reflection and refraction data, N Poland - preliminary results
IMS-6	Lebedev T.S.	The use of the results of combined petrophysical PT-studies of a core of the Krivoy Rog ultradeep borehole (Central Ukrainian Shield) to set up a deep petrovelocity model of the Earth's crust of the region of drilling
IMS-7	Goleby B.R., Korsch R.J., Drummond B.J., Fomin T., Owen A.J. & Bell B.	Three-dimensional crustal structure from deep seismic reflection data in the Archaean granite-greenstone Yilgard Craton, Western Australia
IMS-8	Korsch R.J., Glen R.A., Jones L.E.A., Johnstone D.W., Finlayson D.M. & Lawrie K.C.	Deep seismic imaging of an ancient convergent plate margin, eastern Lachlan Orogen, Australia
IMS-9	Drummond B.J., Cox S.F. & Goleby B.R.	The role of fluids in the formation of regional-scale detachment surfaces

	Seismic Techniques	**WEDNESDAY 21st- THURSDAY 22nd**
STE-1	Dana D., Levander A., Morozov I.B., Zelt C.A. Symes W.W., Araya K.	High resolution seismic investigations at a shallow groundwater contamination site
STE-2	Bergman B. & Juhlin C.	3-D structure of bedrock at Lilla Laxemar from high-resolution reflection seismic studies, southeastern Sweden
STE-3	Martí D., Tryggvason A., Carbonell R. & Pérez-Estaún A.	High resolution seismic tomography: Characterization of the Albalá granite
STE-4	Johnson R.A. & Shoshitaishvili E.	Implications of noise removal in 3-component vibroseis data
STE-5	Hansen T.M., Jacobsen B.H. & Balling N.	Efficient modeling of complexity in main phase arrivals
STE-6	Vasudevan K. & Cook F.A.	Empirical mode skeltonization: A new multi-resolution approach to deep crustal seismic interpretation
STE-7	Sanina I.A., Riznichenko O. Yu and SVEKALAPKO Working group	Small-aperture seismic array in Russian Karelia
STE-8	Project INDEPTH Seismic Team and Larry Brown	Hyperseismic profiling in project INDEPTH

STE-9	Pananont P.	AVO and Deep Seismic Bright Spots
STE-10	Juhojuntti N., Louie J. & Juhlin C.	Imaging crustal reflectivity in Southern Iceland using earthquake sources
STE-11	Godfrey N.J., Christensen N.I. & Okaya D.A.	Anisotropy of schists: Contribution of crustal anisotropy to active-source seismic experiments and shear-wave splitting observations
STE-12	Okaya D.A., Christensen N. & Godfrey N.J.	Elastic wave propagation in anisotropic material possessing arbitrary internal tilt: Haast Schist terrane, South Island, New Zealand
STE-13	Schiøtt C., Jacobsen B.H. & Balling N.	Wide-angle seismic traveltime inversion using a Fresnel zone based procedure
STE-14	Emanov A., Seleznev V. & Korshik N.	Processing of head waves for system of observations with multiple overlappings
STE-15	Sakoulina T., Yu Roslov Vinnick A. & Kopylova A.	On technique for ocean-bottom seismic data processing: Investigations on Barents Sea shelf
STE-16	Li Qinghe & Zhang Yuansheng	3D seismic tomography by using traveltime and waveform of multiphase and application to crustal structure in the northern margin of Qinghai-Tibet Plateau
STE-17	Seleznev V.S., Soloviev A.F., Emanov A.F.	Deep vibroseismic sounding in Siberia
STE-18	Carpenter M.E., Singh S.C., Barton P. & Jakubowicz .H.	Imaging Basement Fault Blocks With Wide-Angle Multi-Channel Data
STE-19	Morozov I.B. & Levander A. R.	Depth focusing and pre-stack migration of wide-angle crustal and shallow seismic records
STE-20	Zelt Colin A. , Sain Kalachand , Naumenko Julia V. , Sawyer Dale S. and Reddy P.R.	Tomographic assessment of 2-D crustal velocity models obtained from wide-angle seismic traveltime data

Passive Continental Margins

WEDNESDAY 21st- THURSDAY 22nd

PCM-1	Zelt C.A. & Sawyer D.S.	Simultaneous wide-angle and zero-offset traveltime inversion for 2D velocity structure of the Iberia margin
PCM-2	Gallastegui J., Pulgar J.A., Gallart J.	Crustal images of Mesozoic extension and Alpine compression at the North Iberian Margin
PCM-3	Leythaeuser T., Flueh E.R. & Reston T.	The Structure of the Iberian Margin at 41 degree 2': MCS and OBH Results
PCM-4	Schümann T., Ellouz N., Hinz K., Gerling P., Keppler H., Meyer H. & Roeser H.	The initial phase of the South Atlantic rift - new seismic data of the Argentine passive continental margin
PCM-5	Talwani M. & Abreu V.	Early opening - inferences from U.S. east coast margin and South Atlantic conjugate margins

PCM-6	Fliedner M.M., White R.S., Christie P.A.F. & Hoare R.	Imaging crustal structure on the European continental margin in the presence of significant basalt flows and sills
PCM-7	Reid I.D., Chian D. & Jackson H.R.	Crustal structure of an extended continental margin northeast of Newfoundland
PCM-8	Goncharov A., Fomin T., Kritski A., Petkovic P., Pylypenko V. & Sayers J.	Combined near-vertical and wide-angle reflection and refraction studies of the Australian North West Shelf
PCM-9	Kleffmann S., Hackney R., Hollingsworth D., Goleby B., Dentith M. & Powell C.	Deep seismic reflection profiling of the Proterozoic Hamersley Province, Western Australia
PCM-10	Breivik A.J., Mjelde R., Grogan P. & Shimamura H.	S-wave and gravity modeling based on P-wave models of wide angle seismic data - from ocean bottom seismometers southeast of Svalbard

ORAL ABSTRACTS

Active Continental Margins **Monday 19th June, Morning**

9.00 **INVITED**

HOW SIMILAR ARE THE ANDEAN AND TIBETAN PLATEAUS? - RESULTS FROM THE INTEGRATED EXPERIMENT ANCORP'96

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The transect ANCORP'96 imaged the central Andes (21°S) with an integrated geophysical experiment that comprised reflection and wide angle seismology, receiver function analysis, tomography from teleseismic data, and potential field data. The features observed at the Andean margin and plateau down to depths > 200 km are interpreted to be related to overpressured fluids and melts caught below petrologically sealed boundaries in the middle crust, at the plate interface, and in the mantle below the plateau. The Altiplano plateau is composed of a thin brittle, upper crust detached from a weak, aseismic lower crust underthrust from the east. The related geophysical properties precisely coincide with areas of Neogene to present magmatism and high attenuation in the mantle. This observation suggests that the geophysical properties are controlled by melts rather than fluids that underly, in a patchlike manner, most of the plateau. Some of these relationships have recently also been reported for the Tibetan plateau from the INDEPTH experiment. It is here suggested that overthickened crust under active plateau areas develops these properties irrespective of the geodynamic environment and therefore develops a seismic appearance different from that of cold stacked crust.

9.30

IMAGING OF A SUBDUCTING SEAMOUNT IN THE NANKAI SEISMOGENIC ZONE BY USING A SUPER DENSELY DEPLOYED OBS ARRAY

S. Kodaira(1), N. Takahashi(1), A. Nakanishi(1), S. Miura(1), J.-O. Park(1), K.Obana(1) & Y. Kaneda(1)
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The Nankai Trough is a vigorous subduction zone where large earthquakes have been recorded since the seventh century with a recurrence time of 100-200 years. The 1946 Nankaido earthquake is well know as an unusual event among these earthquakes, i.e., a rupture zone estimated from long period geodetic data is more than twice as large as that derived from shorter period seismic data. In the summer of 1999, Japan Marine Science and Technology Center performed a high-resolution deep seismic survey by using a super densely deployed Ocean Bottom Seismograph (OBS) at the center this earthquake rupture zone. 98 OBSs were deployed with spacing of 1.6 km on a 185 km long profile, and a large air-gun array (207 L) was fired at every 200 m in order to obtain wide-angle seismic data. The wide-angle seismic profile was extended on land. Seismic signals both from the air-gun array and land explosions were recorded by the OBSs and land seismic stations. Conventional 2D seismic reflection data were also acquired along a part of the same profile. First arrival refraction tomography method was applied to the data from the densely deployed OBSs. From the obtained seismic velocity image, we detected a subducting seamount of dimensions 13 km thick by 50 km wide by 10 km depth. The seismic velocity image also shows that the seamount is now colliding with the Japanese island arc crust. We propose a possible rupture scenario for the Nankaido earthquake from this result here, i.e., seismo-tunamigenic brittle rupture stopped due to strong coupling at the subducting seamount, with only tunamigenic slow slip propagating beyond the seamount.

9.45

DELAMINATION-WEDGE STRUCTURE AND GROWTH OF CONTINENTAL CRUST CAUSED BY THE HI DAKA ARC-ARC COLLISION, HOKKAIDO, JAPAN

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Recent seismic reflection experiments across the Hidaka Mountain range has revealed a delamination-wedge structure beneath the Hidaka collision zone between the Northeast Japan and the Kuril arcs. A new quasi-3D processing method provides an excellent profile by merging 3 sets of the experiment data, which makes it possible to reconstruct the following whole lithospheric structure: The Kuril arc lower crust is delaminated at about 23 km deep. The upperhalf (upper crust + upper portion of the lower crust) of the Kuril arc is thrust westward over the Northeast Japan arc along the Hidaka Main Thrust (HMT), while the lower half (lower portion of the lower crust + the upper mantle) descends down. The wedge of the Northeast Japan arc is intruded into the delaminated Kuril arc. The Pacific plate is subducting north-northwestward beneath the delamination-wedge structure. The P-wave velocity of the wedge is about 5.5 to 6.0 km/sec, considerably slower than the delaminated lower crust of the Kuril arc. This implies the wedge has been severely crushed through the collision. In reality seismicity is concentrated near the tip of the wedge of the Northeast Japan arc. A W-verging foreland fold-and-thrust belt has been growing since the initiation of the collision in Miocene, and its active front has reached 80 km west of HMT. A W-verging hinterland fold-and-thrust belt has been also growing probably since Pliocene. The relationship between the delamination-wedge structure and the master detachments of both fold-and-thrust belts is still unknown. The delamination-wedge structure and its underlying subduction system inevitably provide the following process. (1) The delaminated lower portion of the lower crust, which is the most mafic in the crust, is split from the main part of the crust. (2) In the wedge side, the lower portion of the lower crust is sharpened through wedging. (3) The mafic-rich materials from both lower portions are conveyed down into the upper mantle by the underlying subduction system. Thus the delamination-wedge structure produces a mafic-poor merger of island arc crusts, which becomes a nucleus of continental crust.

10.00

1999 HOKKAIDO TRANSECT, JAPAN (J-MULTIDISCIPLINARY CRUSTAL STUDY FOR ARC-ARC COLLISION ZONE)

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The central part of the Hokkaido Island, northern Japan, is known as an ongoing collision zone between Kuril Forearc (KA) and the Northeast Japan Arc (JA) since Middle Miocene. A multidisciplinary project for elucidating various scale structural heterogeneity and crustal evolution/deformation process of this region was started in 1999. A 227-km long refraction/wide-angle reflection profile was shot to determine the whole crustal structure from JA to KA. A seismic reflection survey was concentrated in the easternmost part of KA, where the crustal delamination is expected to occur. As natural earthquake observation, more than 100 permanent and temporal seismic have been operating to reveal the relation between the earthquake activity and crustal heterogeneity. According to the preliminary analysis, KA is covered with 0.3-4km thick highly deformed sedimentary layer, beneath which two distinct reflectors are imaged. The upper reflector shows an eastward dip while the lower one inclines westward. This reflection pattern strongly suggests the delamination structure associated with the arc-arc collision. Seismic energy from dynamite shots for the refraction profile shows remarkable attenuation beneath the collision zone, also indicating complex geometry of crustal layers.

10.15

POST-ACCRETIONARY SUBHORIZONTAL FAULT IN THE MESOZOIC ACCRETIONARY COMPLEXES IN THE KII PENINSULA, SOUTHWEST JAPAN, REVEALED BY THE RECENT SEISMIC REFLECTION STUDY

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A 15-km-long deep seismic reflection profiling was made across the ENE-trending Chichibu Belt mainly comprising Jurassic accretionary complexes, which lies between the Sambagawa Belt (Cretaceous high P/T metamorphic belt) on the north and the Shimanto Belt. (Cretaceous accretionary complexes) on the south. The new processing method (quasi 3-D) has successfully provided the considerably excellent image. The image exhibits that a sub-horizontal fault at about 2 sec. in t.w.t. (about 5 km deep) thrusts the Chichibu Belt and the Sambagawa Belt over the Shimanto Belt. This fault is considered a post-accretionary one because it truncates the structure of all these belts, including folding in the Chichibu and Sambagawa belts and accretionary strucure of the Shimanto Belt.

Furthermore three prominent reflectors are found in the southern part of the seismic line; a N-dipping at about 6.5 sec., subhorizontal at about 10 sec., and a N-dipping at about 13 sec. The first may correspond to the thrust between the Cretaceous and Paleogene accretionary complexes, the second to the Moho, and the third to the upper surface of the subducting Philippine Sea plate.

11.00

3-D STRUCTURE OF THE CASCADIA FOREARC REGION FROM SHIPS ACTIVE EXPERIMENT AND EARTHQUAKE OBSERVATIONS: TOMOGRAPHIC INVERSION AND WIDE-ANGLE REFLECTION ANALYSIS PROVIDE A HIGH RESOLUTION VIEW INTO THE CORE OF THE CASCADIA FOREARC COMPLEX

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SHIPS (Seismic Hazards in Puget Sound) was a large scale airgun deployment in the inland waterways of western Washington State and western British Columbia. The coincidence of SHIPS travel time data in the Puget Sound basin with earthquake arrival time data from the Pacific Northwest Seismograph Network has allowed us to carry out high resolution joint travel time inversion for structure to depths of approximately 60 km over a portion of the Cascadia forearc margin. This region is underlain by the mafic Crescent/Siletz volcanic basement with P velocity of about 7 km/s, which is in turn underlain by lower velocity subducted accretionary prism rocks gradational with in rocks of the Olympic uplift further to the west. The 3-D velocity model fits both airgun and earthquake picks to approximately .1 s RMS overall. Simple variance reduction from a best fitting 1-D model to our preferred 3-D model exceeds 90%. Details of structure variation are remarkably clear in the crust grading into a mantle wedge and subducted slab. Wide-angle P wave reflections from what appears to be the moho of the subducted Juan de Fuca plate are interpreted using travel times from the 3-D tomographic model. Preliminary results of this reflection analysis suggest that a population of intra-slab earthquake hypocenters may originate in the crust rather than the upper mantle of the subducted slab.

11.15

CRUSTAL STRUCTURE ALONG THE CENTRAL SUNDA ARC

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A series of geoscientific investigations on the Sunda Arc off Indonesia contributes new insights into the structure and geodynamics of the subduction zone at the transition from frontal to oblique collision. The Sunda Arc plate boundary is characterized by the variation of different geophysical parameters, most strikingly the relative direction of kinematic motion of the Indian plate as it subducts beneath Eurasia. A grid of marine seismic wide-angle profiles including four wide-angle strike lines were acquired in 1999. The main profiles coincide with multichannel lines across the subduction complex. Initial traveltime analysis on the wide-angle data reveal rather high upper crustal velocities within the outer arc high. Lateral velocity variations across the wedge are significant, though the velocity field is generally smoother on profiles characterized by oblique collision. The Moho reflection of the downgoing slab is present on most of the data and could be verified to a depth of more than 25 km underneath the accretionary complex. The high quality multichannel data displays a coverage of 3000%. Despite the extremely rough seafloor topography, reflectivity is high. Initial results from a combined interpretation of the reflection and refraction data is presented which constrain the crustal structure along the central Sunda Arc subduction zone.

11.30

CRUSTAL STRUCTURE, EVOLUTION AND ACTIVITY OF NORTHERN HONSHU, JAPAN: NORTHERN HONSHU TRANSECT- 97, 98 RESULTS

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The northern Honshu is a classical example of a trench-arc-back arc system. A multidisciplinary project to reveal the crustal structure and activity, including a 600-km long refraction/wide-angle reflection profiling, a 50-km long reflection profiling across the Backbone Range, observation of natural earthquakes by about100 of temporal and permanent seismic stations and morphotectonic research to detect the long-term behavior of crustal movements, was carried out from 1997 to 1998. The resultant crustal structure by wide-angle reflection across the northern Honshu is well explained by the factors of the Miocene crustal stretching associated with the opening of the Sea of Japan and igneous underplating since the late Miocene. Deep seismic profiling across the Backbone Range revealed the pop-up structure bounded by reverse active faults, which are produced by the subsequent EW compression since the late Pliocene. Detailed image of seismic tomography using natural micro-earthquakes suggests that the deeper extensions of active faults are demonstrated as zones showing lower P-wave velocity. General structure and active tectonics are strongly controlled by the Miocene back arc spreading and inversion tectonics; Miocene normal faults reactivated as reverse faults.

11.45

DEEP SEISMIC REFLECTION EXPERIMENT WITH A HIGHLY DENSE ARRAY OF SEISMOGRAMS, NORTH OF THE MEDIAN TECTONIC LINE (MTL), SHIKOKU, JAPAN

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A 12-km long deep seismic reflection experiment was successfully conducted for the Median Tectonic Line (MTL) and its underlying structures with the following unconventional specifications. (1) Sparse shot spacing: 2 shot points located at both terminations of the seismic line. (2) Relatively strong shots: 500- and 100-kg dynamites. (3) A highly dense array of seismograms: 50-m interval. The result exhibits prominent imaging of deep events: N-dipping events at about 3.0 and 4.5 sec. at the southern end of the line, and 6.5 sec., and the Moho (?) at 11.5 sec. The shallower and the deeper events of the former are continuously connected with the MTL and the fault between the Sambagawa metamorphic rocks and the Cretaceous Shimanto group, respectively, in the profile across the MTL by conventional specifications (Ito et al., 1996). This result gives us the convincing evidence that the MTL dips at about 40 to 50 degrees northward at depth. Even such unconventional specifications as this experiment, if a highly dense array of seismograms is equipped, can produce scientifically significant results. Thus this experiment also provides useful information for preparing less expensive profilings.

12.00

INTERMEDIATE CRUSTAL LAYER IN THE ACTIVE ISLAND ARC

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From results of deep seismic profiling conducted by Research Group for Explosion Seismology (RGES) in recent decade, we found crustal intermediate layers of which P-wave velocity is about 6.4 km/s which is intermediate value of those of upper and lower crust, beneath active island arc regions. The intermediate layers are lying in the depth range between 10 and 20 km, just beneath out side regions of the volcanic front of Hokkaido, Tohoku and Northern Kanto. A comparison the P-wave velocities with thermal distribution data which is compiled by Geological Survey of Japan, shows that the upper surface of the intermediate layer correspond to 500° C which is almost same as top of the lower crustal layer. Beneath non-volcanic western Honshu, the intermediate layer could not be found. We interpreted that the intermediate layer is composed from transient materials in which granitic materials changing into mafic one by hydrothermal and magma processes.

Continental Accretion and Collision I — Monday 19th June, Afternoon

14.15

SEISMIC VELOCITY STRUCTURE OF CONTINENTAL AND OCEANIC ARCS - WHAT DOES IT TAKE TO MAKE CONTINENTS?

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We have measured the seismic velocity structure of the active Aleutian magmatic arc, both where it is intra-oceanic (the Aleutian Islands in the Pacific Ocean), and where it is intra-continental (the easternmost Aleutian Islands and the Alaskan Peninsula on the Bering Shelf); and we compare this to other arcs. A velocity-depth profile laterally-averaged along the volcanic line of the intra-oceanic Aleutian arc has velocities greater than the +1-σ bound of the Christensen & Mooney "reference average crustal model", despite the high temperature of the volcanically active arc which should depress the velocities by ~ 0.1 km/s. Velocity-depth profiles averaged along the colder fore-arc of the intra-oceanic Aleutian arc have velocities about 2 σ above the Christensen & Mooney average.

If accretion of intra-oceanic arcs creates average continental crust, then intra-oceanic arcs typified by our Aleutian arc structure require (1) additional magmatic differentiation to create a more silicic upper and middle crust, possibly caused by repeated episodes of magmatism, and (2) loss of a lower-crustal mafic layer, either removal by delamination or apparent loss by increase of velocity of the deep crust to sub-Moho velocities. One mode of repeated magmatic episodes is suggested by the intra-continental Aleutian arc which, although built by intrusion into older oceanic and oceanic-arc terranes of the Alaska Peninsula, now has a velocity structure and thickness (30 to 40 km) not easily distinguishable from average continental crust. A second mode of repeated magmatic episodes is evidenced by the Izu-Ogasawara arc which, although built as an intra-oceanic arc, has experienced intra-arc rifting (creating a back-arc basin and relict arc) and which, though only about 20 km thick, has a velocity structure that would lie fairly close to the "reference average crustal model" if all units were doubled in thickness

14.30

MARINE SEISMIC DATA FROM THE ACCRETED TERRANES OF SOUTHEAST ALASKA AND BRITISH COLUMBIA

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R/V EWING acquired 1700 km of deep penetration MCS data across the accreted terranes and principal terrane boundaries of SE Alaska. Narrow Fjordlike waterways and rough, shallow bottom produce artifacts which were partly removed by prestack velocity filtering and statics corrections based on a model obtained from brute stacks. In Dixon Entrance we have imaged crustal reflectors and Moho across the fundamental pair of structural boundaries separating the Alexander, Wrangellia, and North America terranes. The eastern margin of the Alexander terrane features strong crustal reflectors, mostly dipping gently (ca. 12 degrees) WSW. Moho reflections within this zone are stronger and more continuous than those seen in the terranes to the east. A broad Moho arch, about 3 km high, 100 km wide, and striking NNE, is defined by two E-W profiles, 45 km apart. Minimum Moho two-way time is 8 seconds, corresponding to a Moho depth of approximately 26 km. It is likely that this crustal arching is the result of the Tertiary extension forming Queen Charlotte Basin. The overall strike of the arch is oblique to nearby terrane boundaries, to graben and half-graben structures previously mapped in Dixon Entrance and Hecate Strait, and to the trend of Queen Charlotte Basin, which lies to the south. The zone of thin crust defined by this Moho arch is apparently discontinuous with similar zones mapped in Hecate Strait and Queen Charlotte Basin, suggesting their creation by oblique extension (transtension).

The strike of the Dixon Entrance Moho arch is subparallel to and centered between theadjacent terrane boundaries, and similar arches are observed, centered within adjacent terranes to the east. This suggests that post-accretion crustal extension may be controlled by accretionary fabrics.

14.45

TRANSALP – DEEP SEISMIC REFLECTION TRAVERSE ACROSS THE EASTERN ALPS

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First results of a 340 km long deep seismic reflection profile between Munich and Venice are presented, acquired in 1998 and 1999 by a German-Austrian-Italian research group. This survey forms part of a multidisciplinary international research programme for investigating the orogenic processes driven by the collision of the European and Adriatic-African continental lithosperic plates. The main seismic components are a Vibroseis survey aiming at resolution of the upper crustal structures, a low-fold explosive survey for deeper lithospheric structures, cross-line recording for 3-D control and earthquake monitoring by a stationary network of 3-component stations for tomographic and seismo-tectonic purposes. The Vibroseis survey shows the Molasse basins and the folded Calcareous Alps at the northern and southern ends of the traverse. Despite of sub-vertically dipping structures in the central Alps, predominantly southward dipping structures are seen throughout the crust in the northern central part, northward dipping structures in the southern part. The crust-mantle boundary is clearly imaged by the accompanying explosive survey, dipping from 30 km depth beneath the Bavarian Molasse to 50-55 km depth in the central part.

15.00

INDEPTH III, A WIDE-ANGLE PROFILE ACROSS THE BANGGONG-NUIJANG SUTURE, SOUTHERN TIBET

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In summer 1998, a seismic wide-angle profile (INDEPTH III = GEDEPTH II) with a total length of 400km was observed in southern Tibet. In total, 14 short period and 35 broad-band seismometers recorded signals from 14 shot points yielding a dense network of overlapping travel time branches. In the centre of the profile, the Bangong-Nuijang Suture (BNS) is crossed which is clearly observed by large delay times and diffractions. The BNS stands out as a broad zone of low velocities down to a depth of at least 25 km. Based on velocities below 6.5 km/s, we modelled a sialic upper crust down to 30 to 35 km, underlain by a 7.0 km/s lower crust down to about 60 km in the northern Chantang Block and about 70 km in the southern Tibet block. These data are compatible with those of the INDEPTH II studies in the Tibet Block further south. However, no low velocity layer was detected along our profile. In spite of our high quality recordings no reliable Moho events could be observed (except from one shot-point). For our model low frequency signals of Pn waves from nearby earthquakes had to be added. It seems doubtful whether the BNS is still connected to the deep subcrustal lithosphere, seen in the recent recordings of receiver functions.

15.15

VERTICAL SEISMIC PROFILING TO 8550 M DEPTH - NEW RESULTS FROM THE CONTINENTAL DEEP DRILLHOLE KTB (S GERMANY)

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A comprehensive program of seismic borehole measurements comprising Vertical Seismic Profiling and Moving Source Profiling is performed in the superdeep borehole of the Continental Deep Drilling Program (KTB), Germany. The deepest part of this borehole (from 6000 m to 8500 m) has now been sampled for the first time by Vertical Seismic Profiling applying a newly developed HP/HT-borehole-geophone. The most important targets are: a major thrust-related fault intersecting the well at 7 km depth (so-called SE1 reflection), stacks of steeply inclined deformed felsic and mafic layers, fluid filled fractures of varying spatial density and orientation, and the so-called Erbendorf body, a highly reflective mid-crustal layer 2 km below the end of the borehole. The three-component records of the VSP show compressional, shear and converted waves, both in transmission and reflection. The seismic arrivals carry signal energy between 10 and 250 Hz imaging geological structure at scale lengths between some 100 m and some 5 m, respectively. Amphibolite units show an average P-wave velocity of 6500 m/s with local variation of 10% caused by fractures and anisotropy. The influence of anisotropy is also observed in a Gneiss sequence where changes in the dip of foliation create a low velocity layer of 5500 m/s between 8000 and 8500 m depth. Measurements will be completed in May 2000. The project is funded by DFG, ICDP, and NSF. Further significant financial, personnel and technical support has been provided by the GFZ Potsdam and GGA Hannover.

16.00

DIGITIZING OF THE CONTINUOUS DSS PROFILING DATA: TARGETS AND PRELIMINARY RESULTS

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During '60-70's, the Ministry for Geology of the former USSR committed vast funding to investigations of the continental crust by continuous refraction and wide-angle reflection profiling or by deep seismic sounding (DSS). The USSR territory was criss-crossed by seismic profiles which were more detailed than any other profiles in the world. The observations have been carried out using 48-60 channels analog instruments with geophone spacing of 100 m and shot-point spacing of 40-60 km. The seismograms were recorded on photographic papers by the wiggle trace mode. The digital retrieval and processing of these data was supported by Ministry of Natural Resources (MNR) of Russia and by INTAS, and for this aim in 'Spetsgeofizika' EDP Center was established. Seismograms of 340 km DSS profile was chosen for digitizing. The profile had extremely detailed observations (about 150 independent traces per one km and 20 km shot spacing). It crosses the Karpinsky Swell in the southern part of East-European Craton. Using a special software developed in Moscow, about 300 48-channel seismograms were digitized and recorded in format SEG Y. Several direct, reversed and overlapping record sections were done and a preliminary 2D velocity model of the crust was developed.

16.15

CELEBRATION 2000: A SEISMIC INVESTIGATION OF LITHOSPHERIC STRUCTURE IN THE TRANS-EUROPEAN SUTURE/CARPATHIAN MOUNTAINS

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One of the major tectonic questions in Europe centers on the structure and evolution of the southwest margin of the East European craton (Baltica) and the role that this margin played in the evolution of the Carpathian Mountains region. In general, this margin is assumed to be the Tornquist-Teisseyre Zone (TTZ) that extends across Europe approximately from northwest to southeast. The Polish segment of the TTZ is a part of Trans-European Suture Zone (TESZ) region. In order to investigate these features, a new program of deep geological and geophysical investigations is being undertaken in SE Poland, the Slovak Republic, the Czech Republic, Hungary, Austria and Italy and is an extension of the EUROPROBE TESZ and PANCARDI projects. This project includes several seismic refraction and wide angle reflection profiles and is called CELEBRATION 2000 (Central European Lithospheric Experiment Based on Refraction 2000). This ambitious project is being carried out during June 2000 and is led by an experiment team from the geophysical and geological communities in Poland, the Slovak Republic, Hungary, the Czech Republic, Austria, and Italy with additional contributions primarily from the geophysical communities in the USA, Denmark, Canada, Germany, Turkey, Finland and Sweden. This large lithospheric seismic experiment will employ about 1100 seismic stations to record shots from about 140 shot points along 5 profiles with a total length of about 3000 km. This project builds on the productive collaborations established during the highly successful POLONAISE'97 project.

16.30

CDP AND DSS DATA FOR KEM-UCHTA PROFILE (THE BALTIC SHIELD)

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The CDP and DSS observations were carried out along W-E Kem-Uchta profile between the White Sea and Russia-Finland boundary. The cross-sections obtained from wide-angle and near-vertical reflections look in different ways. Strong PmP reflections coincide with a boundary between reflective lower crust and the transparent upper mantle at the CDP section (depth of 40 km). The K2 boundary (velocity of 6.8-7.0 km/s, depth of 30 km) also divides crustal layers with different reflectivity pattern. In upper and middle crust such correlation does not observed. In CDP cross-section several inclined boundaries are traced from the surface down to 25-30 km. They trace a well-known fault zone between the Belomorian Mobile Belt and the Korelian Protocraton. The DSS data show several inclined reflectors tracing the faults but they show also the near horizontal K1 boundary (velocity of 6.4-6.5 km/s, depth of 7-10 km). The boundary generates the high amplitude wide-angle reflections, which cross the CDP inclined reflectors. This suggests the near-horizontal crustal layering to be a result of the rock transformation after consolidation of the crust. Tectonic features of orogenic periods were smoothed by metamorphic processes in the high velocity lower crust. In the middle crust a destruction zone and the K1 boundary were created but they preserved the initial tectonic structure of the upper crust.

16.45

IMAGING AND MODELLING A HETEROGENEOUS CRUST MANTLE BOUNDARY: THE CASE OF THE SOUTHERN URALS

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One and two dimensional synthetic seismic modelling of the Moho reflection is carried out to constrain the internal structure of the crust mantle boundary. A reflectivity algorithm was used to calculate the synthetic seismograms for models of Moho consisting of gradient zones and layered sequences. The synthetic seismograms for models of Moho consisting of laterally variable velocity structure were calculated by an explicit finite difference wave equation algorithm.

The laterally heterogeneous models can be achieved by assuming a Moho with different degrees of variable topography or by laterally discontinuous layering. The effects of a low velocity surface cover on the seismic signature of deep events is also analysed. The seismic modelling coupled with stacked images of wide-angle seismic reflection data constrain the Moho beneath the southern Urals. A transitional Moho (gradient velocity-depth profile) does not predict the PmP and Pn features observed in the shot records. The coda of the PmP, the amplitude behavior of this phase with offset and, the existence of a high frequency Pn arrival are modelled with a 6 km thick Moho which consists of approximately 600 m thick, laterally variable layers with a bimodal velocity distribution. The horizontal component stacks of the wide-angle data feature arcuate events suggesting boudin like structures or a boundary with topographic relief. High amplitude sub-Moho reflections support that the structural complexity of the Moho can be followed to the upper mantle, suggesting eastward dipping structures indicating, either, remanents of an old subduction, trapped crustal material within the mantle, or active crust-mantle interactions.

Continental Accretion and Collision II   Tuesday 20th June, Morning

9.00

ARCHEAN ARC-CONTINENT COLLISION IN THE SLAVE PROVINCE, NORTHERN CANADA: A REINTERPRETATION OF LITHOPROBE SNORCLE LINE 1

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Lithoprobe SNORCLE seismic reflection line 1 crosses the southwestern tip of the Archean Slave province in northern Canada. Reflections have been reinterpreted as products of lithospheric wedging using a comparison of the reflection patterns to a Proterozoic analogue, and by correlation of reflection patterns to the known geology. The results provide insights into the evolution of the Slave province at ca. 2.69-2.60 Ga. Reflection patterns in the Yellowknife area consist of (1) east-dipping reflections at 12-14 s that project into the upper mantle, (2) a wedge-shaped body in the lower crust with an east dipping reflection fabric that is truncated on the west by (3) a series of west-dipping reflections in the upper crust. This reflection pattern is similar to that of the Fort Simpson - Hottah collision zone, imaged further to the west on SNORCLE line 1. There, the western plate (Fort Simpson-Nahanni terrane) is interpreted to have been delaminated as the eastern plate (Hottah-Coronation terrane) was inserted into it. This similarity provides support for the interpretation that reflection patterns beneath the Slave province are also products of collisional tectonics. Rocks within the Slave province preserve evidence of a ca. 2.69-2.60 Ga pan-Slave orogenic event, in which the Central Slave Basement Complex, a block of continental crust containing gneisses as old as 4.0 Ga, collided with the ca. 2.7 Ga Hackett River juvenile island arc terrane. The suture between the CSBC and the HR arc is interpreted to be at 4-5 s beneath Yellowknife and to project to the surface east of the data. Beneath the suture, an accretionary wedge and a subduction zone are interpreted. Shear zones at the base of the mafic volcanic sections were active prior to 2.687 Ga, indicating that intervening basins containing greenstone belts collapsed prior to final collision with the HR arc. At the north end of the Slave province, where the arc-continent collision appears narrower and less complicated, the boundary between the arc and the continent has been mapped as a west-dipping suture. The proposed collisional model is similar to that of Kusky, 1989, which also involves delamination of the Central Slave Basement complex; however, in Kusky's model, the accretionary wedge is exposed on the east and the west of the Sleepy dragon complex, whereas in the present model, the accretionary wedge is located in the lower crust. These results provide tantalizing evidence that processes similar to those of modern convergent zones were operational at 2.69-2.60 Ga.

9.15

BASALT UNDERPLATING AND CRUSTAL EXTENSION DURING THE FORMATION OF THE COAST MOUNTAINS BATHOLITH, BRITISH COLUMBIA AND ALASKA

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The Coast Mountains batholith (CMB) is one of the largest batholith complexes of the world and was a target for study by the ACCRETE multidisciplinary project. It is dominated by granodiorite, tonalite, and diorite plutons that intruded between 85 and 50 Ma, with the largest pulse of magmatism occurring between 55 and 50 Ma. Between 55 and 50 Ma, the CMB was also exhumed by 15 - 20 km. The CMB is separated from the terrane to the east (Stikinia) by east-dipping normal shear zones between the migmatites of the footwall and the greenschist to amphibolite facies rocks of the hanging wall; these faults were active during the same 5 Ma time interval. The seismic images show that the normal shear zones can be traced at least to mid-crustal depths. The extension that produced these shear zones resulted in an asymmetric core complex with steep fabrics on its west side and gently east dipping fabrics on the east side. The exhumation of the CMB was due in large part to unroofing during extension. The Vp and Vp/Vs model across the CMB shows that the present CMB crust is comparable in thickness to the average of extended terranes and that the lowest 10 km has seismic properties corresponding to restite and the metamorphic equivalent of gabbro. A model for crustal melting driven by underplated basalt to form the plutons of the batholith is supported by our data; crustal scale extension helped provide space for pluton intrusion into the middle crust.

9.30

BUILDING CONTINENTAL CRUST: THE ACCRETE MODEL

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The ACCRETE project is among the first detailed multidisciplinary studies of a continental arc where new crust has been formed through accretion of exotic terranes and generation of new crust, employing marine wide-angle seismic techniques in a fjord in southeastern Alaska and western British Columbia. A crustal model resulting in Vp/Vs is compared with lab velocity measurements. The crust across ACCRETE profile consists of three units: the Wrangellia-Alexander (WA) far-traveled terrane, the Coast Mountains batholith (CMB), and the Stikinia terrane. The WA is separated from the CMB by the major structural discontinuity called the Coast shear zone (CSZ). The crust under the WA is 23 km thick with high velocity lower crust and *Vp/Vs* appropriate for oceanic crust. The CMB has high average velocity crust and lower crust with *Vp/Vs* of 1.84, compatible with interlayered garnet pyroxene granulite and quartzofeldspathic restite. The crust under Stikinia has a lower average velocity and lower *Vp/Vs*. The crust under the CMB is relatively thin, with the total Moho relief within the ACCRETE seismic section going from 23 to 32 km. Moho is sharp (~200 m), highly reflective and continuous under all terranes with horizontal correlation length on the order of 5-15 km. Low *Pn* velocity (7.9 km/s) indicates anomalously hot mantle and high temperatures of 800+/- 100° C in the lower crust, resulting in garnet granulite facies metamorphism. Geologic and seismic evidence for crustal-scale extension of the CMB and massive intrusion of tonalite and diorite plutons suggests that the lower crust is made of a mafic garnet granulite, the metamorphic product of the mantle-derived basalt that provided the ultimate heat source for driving the extension and the crustal melting. To the SW, the contrast between the crust of the CMB and of the mid-Cretaceous thrust belt, across the CSZ is apparent in the *Vp/Vs* domain and is associated with the difference in their tectonic origin as a crustal suture. Our results suggest that generation of new crust within a former continental arc results in average crustal velocities of about 6.55-6.6 km/s in the lower 3/5 of the crust. This would lead to an average crustal velocity of ~6.4 km/s with 10-15 km of the upper crust restored. Combination of accretion and continental arc magmatism leads to crustal diversity.

9.45

LITHOSPHERIC STRUCTURE ACROSS THE CORDILLERAN OROGEN OF NW BRITISH COLUMBIA, CANADA: LITHOPROBE SEISMIC WIDE-ANGLE AND NEAR-VERTICAL INCIDENCE PROFILING

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The LITHOPROBE Slave-Northern Cordillera Lithospheric Evolution (SNORCLE) transect includes two controlled-source seismic components: 1) a refraction and wide-angle reflection experiment (SNORE) using explosive sources and 2) a vibroseis near-vertical incidence reflection experiment. These coincident datasets were acquired along several corridors crossing the Cordilleran orogen of northwestern Canada. SNORE line 22 traverses the western Cordillera, a complex assemblage of accreted terranes and associated plutonic suture zones, that has been dissected by large-scale fault systems. The refraction/wide-angle reflection (R/WAR) dataset incorporates nine shots and 450 seismographs distributed along the 600 km profile. This coverage is supplemented by the overlapping ACCRETE R/WAR dataset that extends the profile a further 130 km across the Coast belt. P-wave travel time inversion (RAYINVR and FAST) and forward amplitude modeling are employed to model crustal and upper mantle structure. The wide-angle data and associated velocity structural model are compared with coincident near-vertical incidence reflection data acquired in late 1999. Gravity inversion is also incorporated into the analysis. The velocity and density models exhibit a strongly heterogeneous upper crust. Model features include: 1) a crustal-scale transition between the plutonic Coast belt and the accreted Intermontane superterrane to the east, 2) lateral velocity variations consistent with major geologic and terrane elements, 3) velocity contrasts across the Kechika and Tintina fault systems, 4) several wide-angle upper mantle reflectors, and 5) slow (7.85-7.9 km/s) upper mantle velocities consistent with high regional heat flow.

10.00

LITHOPROBE SNORCLE REFLECTION SURVEY 1999-2000: THE NORTHERN CANADIAN CORDILLERA

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The final phase of the SNORCLE reflection program in northwestern Canada acquired ca. 1895 km of vibroseis data along two corridors. From E to SW, Corridor 2 (~1325 km) crosses the western foreland basin, foreland belt, strike-slip Tintina fault, accreted terranes, and ties with the ACCRETE profile at the Alaska coast. Corridor 3 (~570 km) begins in the central Mackenzie Mountains deformed belt, then proceeds SW across the Tintina fault and accreted rocks in the western Cordillera, ending at the Alaska - B.C. border. These results, combined with SNORCLE Corridor 1 data from 1996, provide a nearly continuous transect from the Archean Slave craton to the Modern Canada - Alaska margin.

Acquisition used 576 channels, 50 m station spacing, 75 m VP, 10-80 Hz sweeps, 20 s sweep, 32 s listen, with 8 or 6 sweeps per VP, for 4 or 5 vibrators, respectively. At each source location, stacked and unstacked (no summing) data were recorded to provide flexibility for later processing. Profile 3 has been processed to a preliminary stack. A prominent contrast at 3 - 5 s along the eastern 200 km (to near the Tintina fault) separates upper crust, in which layers generally dip westward and flatten into it, from more reflective mid-to-lower crust. The surface position of the Tintina fault is underlain by westward dipping reflections at ~1.0-1.5 s, but immediately east of the fault and below 4 s lies a 10 km wide non-reflective zone.

10.15

A COMBINED ONSHORE-OFFSHORE WIDE-ANGLE SEISMIC EXPERIMENT IN LABRADOR — APPLICATION OF 2-D FORWARD MODELING, 3-D TOMOGRAPHY AND PRESTACK-DEPTH MIGRATION

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In 1996 a wide-angle reflection and refraction seismic experiment was conducted in Labrador as part of Lithoprobe's Eastern Canadian Shield Onshore-Offshore Transect (ECSOOT). In total, 79 landstations and 35 OBS were deployed to record airgun shots (6000 inch3) along the eight lines. Results from 2-D forward modeling show the existence of a 20-km- thick high-velocity lower crust beneath the NE Grenville Province with a total crustal thickness of 50 km. Farther north, the data revealed the structure of the Mesoproterozoic anorogenic Nain Plutonic Suite, host to the Voisey's Bay ore body. The base of the anorthositic plutons is clearly defined by reflections at a depth of 8 to 11 km. Crustal thickness beneath the plutons is some 5 km less than in the Archean Nain Province not affected by the plutonism. This suggests anatexis of the lowermost crust during the plutonism. A detailed survey was conducted in the Proterozoic Torngat Orogen with the 2-D model showing a 100-km-wide crustal root with a Moho depth of 50 km. Prestack-depth migration of the wide-angle data images the Moho, a midcrustal reflector and some eastward-dipping lower crustal reflectors in the western half of the line. Active seismic tomography shows a correlation of the root with a set of major, late orogenic shear zones and suggests that transpressional shearing focused strain in the region of the root and contributed to the crustal thickening. Detailed information on the project can be found at www.phys.ocean.dal.ca/~tfunck/ecsoot/ecsoot.html.

11.00 **INVITED**

THE SHAPE OF CRATONS

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A number of deep seismic reflection profiles have now surveyed Paleoproterozoic arc-continent collision zones along the margins of several of the world's major cratons. Prominent examples include the 2.0-1.8 Ga Svecofennian terrane boundary with the Baltic craton, the 1.92-1.83 Reindeer zone along the Superior craton and the 1.92-1.90 Hottah terrane along the Slave cratonic margin. Each example reveals variations in the continental accretion process, but the fundamental reflector geometry showing a wedge-shaped older craton flaking off or delaminating the crust of the juvenile terrane emerges in all cases studied to date. The crustal level at which the cratonic wedge causes detachment within the colliding terrane varies from the mid-crust to the Moho. This flaking process builds the craton's superstructure. Underplating of deep crust and mantle portions of colliding terranes (typically intra-oceanic and continental arcs) against the lower cratonic margin represents one possible mechanism for growing the lithospheric roots of cratons and continents. Seismic profiles from the Banda arc of Indonensia provide additional clues about this growth process with the example of a modern juvenile arc along a cratonic margin. Ancient examples indicate that late stage transpression and polarity reversal appear to play a key role and strongly influence the final craton shape defined by the reflector geometry observed in the profiles.

11.30

ONSHORE CRUSTAL REFLECTIVITY OF THE ARCHEAN-PROTEROZOIC BOUNDARY AND COMPARISON WITH BABEL LINES 2 AND 3, NORTHERN SWEDEN

C. Juhlin (1), S.-Å. Elming (2), C. Mellqvist (2,3), B. Öhlander (2), P. Weihed (2,4), A. Wikström (4)
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Sm-Nd isotope ratios of 1.9-1.8 Ga granitoids delineate the Archean-Proterozoic boundary in northern Sweden, one of the most important structures in the Fennoscandian Shield. The boundary strikes WNW-ESE and lies about 100 km northeast of the Skellefte sulfide ore district. Extrapolation of the boundary offshore into the Bothnian Bay and correlation with BABEL lines 2 and 3 indicate the boundary dips to the SSW, consistent with interpretation of the Sm-Nd data. In order to tie the BABEL results with onshore surface geology and obtain detailed images of the uppermost crust a short (30 km long) pilot profile was acquired in the Luleå area of northern Sweden in August 1999. Lower crustal reflectivity patterns on this short profile are similar to those observed on the BABEL data suggesting the same lower crust onshore as offshore. Interpreted Archean reflective upper crust in the NE extends below more transparent Proterozoic crust in the SW. This transparent crust, contains a number of high amplitude reflectors which may represent shear zones or mafic rock within granite intrusions. A marked boundary in the magnetic field in the SW has been interpreted as due to a gently west dipping contact zone between meta-sediments and mafic volcanics, however, the seismic data indicate a near-vertical structure in this area.

11.45

EVIDENCE OF SVECONORWEGIAN OROGENIC STRUCTURES BELOW THE DANISH AREA AND THEIR POSSIBLE INFLUENCE ON THE FORMATION OF OVERLYING PALAEOZOIC SEDIMENTARY BASINS, FROM INTERPRETATION OF COMMERCIAL REFLECTION SEISMIC DATA.

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An extensive net of commercial reflection seismic profiles, down to 6 s twt have been aquired during the last decades for the purpose of hydrocarbon exploration in the Danish area. Together with existing deep seismic data the commercial profiles present a unique oppertunity to investigate the suspected late Proterozoic structures in the upper crystalline crust. The presence of exposed crystalline basement in S Norway and SW Sweden, which mainly belongs to the Grenville-Sveconorwegian Orogen, provides structural control for the seismic interpretations in the eastern part of the Danish area. First results from the interpretation of commercial reflection seismic lines in the Skagerak-Kattegat area and in the SW Baltic Sea shows the reflectivity in the upper part of the crystalline crust as clear sets or bundles of dipping reflections which can be subdivided into two groups; (1) W dipping and (2) SE dipping reflections. We interpret that the W dipping reflections represent the south-westward continuation of the Sveconorwegian ductile shearzones, exposed onshore SW Sweden. The SE dipping reflections represent older, possibly Gothian, compressional structures that became partially overprinted by the later Sveconorwegian Orogeny. The subcrop of some of the prominent bundles of dipping reflections trends close to faults in the sedimentary cover. This may indicate that some of the interpreted late Proterozoic ductile shear zones were reactivated during the subsequent bassin formation in the Danish area.

12.00

NEW SEISMIC IMAGES OF CALEDONIAN COLLISIONSTRUCTURES BENEATH THE NORTH SEA BASEMENT HIGH (DENMARK)

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(2) GeoForschungsZentrum, Telegrafenberg, D-14473 Potsdam, Germany

Upper-crustal structures that may be related to Caledonian collision tectonics in the southeastern North Sea are now imaged in detail by reflection seismic sections of the MONA LISA project. Reprocessing dedicated to enhance the shallow part of deep seismic normal-incidence reflection profiles has included prestack-depth migration. It reveals unexpected structures down to 9 km depth and helps to resolve their geometry (dip, depth and strike). The techniques have been applied on two crossing profiles around the expected location of the Caledonian Deformation Front on the East North Sea Basement High. Below a 2 km thick Mesozoic cover, the section images steep, south-dipping reflectors, interpreted as Caledonian compressive structures. They reach deep into a thick Paleozoic sedimentary succession, assumed to be mainly deposited in the Caledonian foredeep. These reflections down-lap on the south- to west-dipping basement reflector which also appears to have been deformed during compression. By comparison with structures revealed in seismic data from other parts of the area as well as a new gravity map of Europe, these new images provide information for a better understanding of the collision processes involved in this European Paleozoic suture zone between the two plates Baltica and Eastern Avalonia.

The Continental Mantle

Wednesday 21st June, Morning

9.00

CONTINENTAL MANTLE SEISMIC ANISOTROPY: A NEW LOOK AT THE TWIN SISTERS MASSIF

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Recent interpretations of upper continental mantle seismic anisotropy observations often rely on fabric measurements and calculated anisotropies of upper mantle xenoliths. Seismic ray paths of P and S waves, which provide information on azimuthal P wave anisotropy and shear wave splitting, are tens to hundreds of kilometers, whereas xenoliths are usually only a few centimeters in diameter. To place better constraints on field based anisotropy observations and evaluate anisotropy information provided by xenoliths it is important to examine anisotropy in large ultramafic massifs which have originated in the continental upper mantle. One such massif is the Twin Sisters Range located in the western portion of the North Cascades of Washington state USA. The Twin Sisters massif, a slab of unaltered dunite and peridotite, is 16 km in length, 6 km in width and 3 km thick.

Exposed along its south and west sides are mafic granulite facies rocks, which likely represent lower continental crustal fragments. The ultramafic rocks are porphyroclastic in texture, consisting of strained, flattened porphyroclasts of olivine and enstatite and strain-free olivine mosaics. Olivine fabrics are typical of those formed at high temperatures and low strain rates. Petrofabrics and calculated anisotropies of individual samples vary throughout the massif, however overall anisotropy of the body is significant, with P and S waves anisotropies of 5.4% and 3.9%, respectively. The maximum delay time for split shear waves traveling through a 100 km thick slab is 0.8 sec. In general, much higher anisotropies are observed in individual hand samples.

9.15

CONSTRAINTS ON SCATTERING BODIES IN THE 100-200 KM DEPTH RANGE FROM WAVEFORM MODELLING OF PNE SEISMIC PROFILE KRATON

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Scattering bodies embedded in a 75-100 km thick low-velocity zone below the 8° discontinuity at ~100 km depth give rise to a ~5 s long coda of high amplitude trailing the first breaks in the 700-1400 km offset range of the four Peaceful Nuclear Explosion (PNE) seismic sections of Siberian profile Kraton. The scattering bodies are interpreted as pockets of molten or almost molten upper mantle rocks. Estimation of the physical properties of these bodies is important for our understanding of the detailed nature of the lowermost lithosphere and the lithosphere-astenosphere transition. A stochastical approach is used for modelling the scattering bodies. The seismic wavefield is calculated for randomly fluctuating velocity models, which are tested for representing the 75-100 thick inhomogeneous media below the 8° discontinuity. The wavefield computations are based on 1D reflectivity modelling and on a 2D finite-difference scheme. From our modelling studies we conclude that the scatterers are about 5 km thick and probably about 10 to 20 km wide. Velocity contrasts of ±2% of the background velocity are sufficient for the scattering bodies to produce the amplitude characteristics of the observed coda in the 700-1400 km offset range.

9.30

STRUCTURE OF THE LITHOSPHERE IN THE SW UNITED STATES

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We have calculated a new structural model of the lithosphere of the southwestern US through an integrated analysis of gravity, seismic refraction, drill-hole, and geological data. Deviations from the average upper mantle density are as much as ± 3%. A comparison of seismic tomography and gravity inversions indicates that a substantial part (>50%) of these density variations are due to changes in composition rather than temperature. Pronounced mass deficits are found in the upper mantle under the Basin and Range Province and the northern part of the Coast Ranges and adjacent ocean. The seismic, and velocity density structure of the northern and central/southern Sierra Nevada are remarkably different. The central/southern part is anomalous and is characterized by a relatively light crust underlain by a higher-density upper mantle that may be associated with a cold, stalled subducted plate. High densities are also determined within the uppermost mantle beneath the central Transverse Ranges and adjoining continental slope. The average density of the crystalline crust under the Great Valley and western Sierra Nevada is estimated to be up to 200 kg/m^3 higher than the regional average, consistent with tectonic models for the obduction of oceanic crust and uppermost mantle in this region.

9.45

GLOBAL SEISMIC BOUNDARIES AND WEAK ZONES IN THE CRUST AND UPPER MANTLE

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Long range seismic profiling revealed a fine stratification of the crust and upper mantle: high velocity layers alternate with lower velocity ones and strong reflection boundaries often separate the layers. Several such boundaries have a global significance and suggest rheological stratification of the lithosphere (they separate brittle and weak layers). In the continental crust the weak zone is determined at depth of 10-20 km. It is characterized by lower velocities, by higher electrical conductivity, by changes of earthquake distribution and others. Usually it plays role of a detachment zone at crustal block moving. Another week zone is proposed at the Moho level which is very mobile during geological history. A local isostatic equilibrium of the crust is observed at this level. A rheologically weak layer underlined by a global reflection boundary N is distinguished at a depth of 80-100 km. This boundary often underlies low velocity and higher conductivity zones, and it plays an important role in the isostatic equilibrium of the lithosphere. The nature of these boundaries and of velocity inversion zones may be explained by fluids concentration at some critical depths. Together with deep faults they form a channel system for the mantle fluids and matter transportation. During tectonic activation the weak layers were transformed in asthenolites by partial melting and provoked plume tectonics. The crustal weak zones and the plastic flows at the Moho level helped the crustal blocks to move at a local plate tectonics. Such rheological stratification can better explain origin of the observed tectonic pattern than the traditional lithosphere-asthenosphere model.

10.00

ULTRA-DEEP SEISMIC REFLECTIONS: IMAGES FROM THE EARTH'S CORE

<u>Andrew R Ross</u> (1), Hans Thybo(1) & Anatoly Egorkin(2)
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GEON, Chistyi per. 4, Moscow, 119034 Russia

Seismic velocities low enough to suggest partial melt have been previously interpreted from earthquake seismology in a thin ultra-low velocity zone (ULVZ) at the core-mantle boundary (CMB), mainly beneath the oceans. We report high amplitude, laterally coherent seismic phases at exceptionally high frequencies from three nuclear explosions in Siberia. These observations are the first controlled source observations of lower mantle and CMB structures. The seismic phases are internally complex and are consistent with compressional (P-wave) reflections from the CMB and from the top of a ULVZ in a region where no ULVZ has been previously reported. The amplitude ratio of these phases is close to 1, significantly higher than previously reported from earthquakes and most likely the result of the high frequency content of our source, allowing unprecedented resolution at the CMB. The frequency spectra of the two phases is appreciably different, suggestive of hitherto unidentified layering of the ULVZ. The low velocities required to model these phases support the existence of a high percentage of partial melt at the CMB.

10.15

STRUCTURE OF THE UPPER MANTLE TRANSITION ZONE FROM THE PNE DATA

A.V. Egorkin,
The GEON Centre, 4 Chisty per., Moscow 119034, Russia.

During seismic observation on super long-range profiles carried out by Centre GEON, PNE had been used as powerful sources. Some 40 PNE purpose-oriented on Earth's structure study were recorded to the offset of 4000 km. The close spacing (10 km) of the mobile stations allowed high resolution of the upper mantle structure. Refracted and reflected phases associated with the mantle transition zone are recorded. Beyond offset of 2100 km there are three branches with different apparent velocities. Apparent velocity of 10.15 – 10.60 km/s represents the wave refracted below the "400" km discontinuity. From 2350 to 2750 km the first arrivals have an apparent velocity of 10.9 – 11.7 km/s and are caused by wave refracted below the "500" km discontinuity. The first arrivals for distances greater than 2750 km are characterised by apparent velocity exceeded of 12 km/s and represent diving wave which travels below the "660" km discontinuity. Reflections from "400", "500" and "660" are also clearly seen in record sections. Each phase clearly seen before the critical point. Features of these reflections are best modelled by a composite discontinuity in which a sharp velocity jump is overlain by a linear velocity increasing spread over 5-10 km. There is an anti-correlation of the"400" and "660" under kimberlite field.

11.00 **INVITED**

SEISMIC REFLECTIONS ON THE CONTINENTAL MOHO

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The dominant characteristic of the continental Moho is that its seismic reflection response is different from one region to another and also within one region, both at vertical incidence and at wide angles. At vertical incidence, the Moho is characterized by a distinct single reflection, by multi-cyclic reflections (in some cases bright), by weak laterally discontinuous reflections, by termination of strong lower crustal reflections and by gradual disappearance of deep crustal reflections. Many of these characteristics may be found in one region. Reflectivity at wide angles may vary within one region. Possible scenarios for the structure of the Moho zone include gabbro or its metamorphic equivalent against peridotite, interlayered gabbro and peridotite, layered mafic cumulates, and an eclogitized zone. These scenarios are tested by seismic modeling. The often-reported occurrence of eclogite in the lower crust and Moho is complicated because its presence is primarily a question of chemical kinetics. Eclogite at the Moho raises the question of eclogite facies in the lower crust. One model to explain variations in Moho reflectivity with falling temperature involves interlayered basaltic magma and peridotite for bright reflections, crystallizing to interlayered gabbro and peridotite for good reflections, recrystallizing to interlayered eclogite and peridotite for weak to invisible vertical-incidence reflections. With reheating, the reflectivity would increase as eclogite goes to gabbro.

11.30

LINKS BETWEEN WAVE MECHANICS, WAVE FIELD STATISTICS AND THE HETEROGENEITY OF THE CRUST AND UPPER MANTLE

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Seismic reflection data contain a bandlimited representation of the spatial variability and heterogeneity of the illuminated geology. Access to this heterogeneity information is contingent on understanding the links between wave mechanics, wave field statistics and geologic heterogeneity. In the absence of adequate theory, numerical experiments provide partial insight into these relationships and also important insight into the role of noise in modifying the spatial statistics of the wave field. Building on these insights, mapping of local variations in the spatial statistics of reflection data provides a sensitive tool for both qualitative and quantitative assessment of geologic heterogeneity. Due to the selectivity of the reflection method as well as the limited bandwidth, the information provided by statistical mapping is restricted for small geologic features but essentially wide-open for larger features, providing information for geologic heterogeneity ranging over scales of approximately ½ the Fresnel zone to10's of km. In this paper we review the major results of key numerical experiments and demonstrate the use of local statistical mapping of seismic reflection data from several low- and high-grade crustal terrains to investigate the heterogeneity and scaling properties of the crust and upper mantle.

11.45

THE FLANNAN AND W REFLECTORS REVISITED: THE SMOKING GUN OF EARLY TERTIARY LITHOSPHERE-SCALE EXTENSION

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Upper mantle reflectors (Flannan and W) beneath the northwestern British Isles are some of the best-known and most-studied examples of fine-scale heterogeneity within the mantle lithosphere. Significant modification of this lithosphere in early Tertiary time, including dramatic thinning, extensive basaltic intrusion, and regional uplift associated with initiation and development of the Iceland plume, suggests either (1) a Tertiary age for both the sub-horizontal W and the east-dipping Flannan reflectors or (2) preservation of ancient features within the mantle lithosphere despite such pervasive modification. Analysis of existing wide-angle reflection data (LISPB and CSSP) suggests these reflectors continue beneath mainland Scotland, and probably truncate the downward projection of the Great Glen fault and Iapetus suture zone, both lithosphere-scale structures of Paleozoic age. Such a relationship, if correct, would preclude a pre-Paleozoic age for the mantle reflectors. Similarly, basalts of the British Tertiary Province record a rapid (<2-3 Ma) shallowing of the mantle source region which is interpreted as evidence for ~30 km of lithospheric thinning in early Tertiary time, coincident with the locus of the dipping Flannan reflector. These relationships suggest the Flannan reflector might best be interpreted as the down-dip continuation of the Rockall Trough extensional system of latest Cretaceous to earliest Tertiary age.

12.00

SUB-CRUSTAL SEISMIC REFLECTORS BENEATH THE NORTH SEA - RELICT SUBDUCTION AND EXTENSIONAL SHEAR ZONES

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Within the past 10-15 years, several deep seismic profiling projects have been carried out in the North Sea and adjacent areas including the MONA LISA project in the central and southeastern North Sea. These projects have demonstrated the existence of dipping and sub-horizontal seismic reflectors in the mantle lithosphere to a total depth of up to 70-90 km. Two alternative main candidates are present for the interpretation of the sub-crustal dipping reflectors: relict subduction zones and extensional shear zones associated with formation of basins. Examples are presented which are believed to represent both types. South dipping reflectors interpreted to represent oceanic crust of the Tornquist Sea subducted beneath Eastern Avalonia are observed in the southeastern North Sea. Reflectors dipping symmetrically to the west and east away from the Central Graben may originate from extensional shear zones. It is presently difficult to determine to which extent these reflectors may be related to reactivated Caledonian subduction/collision features. Constraints in terms of tectonic setting and other geophysical and geological observations are important for the interpretation of sub-crustal reflectivity.

The Continental Mantle **Wednesday 21st June, Afternoon**

14.15

THE 8° DISCONTINUITY INTERPRETED FROM FENNOLORA P AND S WAVE SEISMIC DATA

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Travel-time modelling of compressional (P) and shear (S) wave data from the long-range Deep Seismic Sounding FENNOLORA profile image the upper mantle beneath the Baltic Shield. Pronounced scattering and delay in travel-times of seismic P and S-waves, and strong attenuation of S-wave phases beyond c. 800 km offset are attributed to a general low-velocity zone below the 8° discontinuity. Tomographic travel-time inversion of first P and S-wave arrivals confirms that the 8° discontinuity represents the top of a zone with negative to zero vertical gradients in the depth range of c. 100 – 150 km. In the P-wave sections, clear, linear refractions are observed at offsets beyond 1100-1300 km, the Lehmann refraction, corresponding to the base of the zero gradient zone is at c. 150 km depth below the cold shield area. However, no S-wave phases are correlated beyond 1200 km offset, which we interpret to be caused by strong S-wave attenuation within the zero gradient zone, which is also characterised by high V_p/V_s ratios (> 1.79). Considering that the shear modulus is very sensitive to the presence of partial melts and free fluids, the V_p/V_s ratio is an apt tool to identify such depth regions. Hence, we attribute the seismic scattering to the presence of partial melts, or possibly free fluids, in the 100-200 km depth interval. Local variations in the V_p/V_s ratios correlate with different Proterozoic terranes, which collided and amalgamated during the Precambrian plate tectonic events that led to the assemblage of the Baltic Shield.

14.30

P-WAVE VELOCITY STRUCTURE OF THE LITHOSPHERE-ASTHENOSPHERE SYSTEM ACROSS THE TESZ IN DENMARK

R. Arlitt (1), H. Shomali (2), E. Kissling (1), J. Ansorge (1), R. Roberts (2) & TOR Working Group
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(2) Department of Earth Sciences, Uppsala

The 900km-long temporary seismic station array TOR with about 30 broadband and 90 short period sensors was designed to study the lithosphere-asthenosphere system (LAS) across the northern part of the Trans-European suture zone (TESZ) by high-resolution teleseismic tomography. This configuration does not allow reliable resolution of 3-D crustal structure. Teleseismic wave fronts, however, are distorted by crustal structure leading to travel time effects of significant amplitude. Based on existing CSS profiles we establish a 3-D crustal model and calculate crustal travel time effects for spherical teleseismic wave fronts using FD methods. After correction for the substantial travel time variation caused by crustal structure across the TESZ, the observed travel time residuals from 46 teleseismic events from all azimuths show great consistency at all stations. Synthetic tests document the high reliability of the tomographic results obtained by non-linear inversion of 3107 high-quality P-wave observations. Three distinctly different lithospheric blocks are found along the TOR profile. South of the Elbe line, the Phanerozoic European lithosphere is only about 70 km thick underlain by a distinct low-velocity asthenosphere. The lithospheric block encompassed by the southern and the northern limits of the TESZ, i.e. the region of the Tornquist fan, is characterized by a 120 km thick lithosphere also overlying a low-velocity asthenosphere. In contrast, no asthenosphere is observed in the North beneath the Baltic shield within the surveyed depth range of about 250 km.The old continental lithosphere reaches a thickness exceeding 200 km.

Continental Rifts and Basins   Wednesday 21st June, Afternoon

14.45

REPROCESSING OF MONALISA DEEP SEISMIC REFLECTION DATA: THE PALEOZOIC RIFT IN THE NORTH SEA.

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The MONALISA deep seismic reflection data, collected in April 1993, were recorded to 26 s to image the deep structures related to Caledonian collision and Paleozoic -Mesozoic rifting and basin formation in the North Sea. Recent pre-stack depth migration of parts of the deep seismic lines has focused on the upper 6 s of the data. The North Sea basin has been well studied, due to economic interest, in the upper Mesozoic series, and with the MONALISA project, into the deep crust and upper mantle. Traditionally, the Paleozoic sequence has been poorly imaged in seismics due to the Mesozoic coverand occurrence of Zechstein salt diapirs, but potential field data have identified a thick Paleozoic sequence. The reprocessing focused on a careful velocity analysis, f-k filtering and pre-stack depth migration. It provides spectacular images of the basins in the North Sea. The resultant profiles show images of basement involvement in the basin formation and has made it possible to discriminate between sedimentary sequences that were deformed and escaped from Caledonian deformation.

15.00

REVIVING DEEP GEOPHYSICS IN THE CENTRAL USA MID-CONTINENT

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Reprocessing of several hundred kilometers of industry seismic reflection data from Illinois, Indiana, and Kentucky, including extended vibroseis correlation, provides high-quality images of the crust and uppermost mantle on records that continue to as much as 16 s travel time. The reprocessing results are highly successful--clear dipping reflections continue right to the bottom of 16-s records. The exciting new images of deep structure, extending at least as deep as about 52 km, now represent one of the largest concentrations of deep seismic profiles between the Appalachians and the Rockies. Perhaps the most remarkable result is the presence of the three highly coherent Precambrian "stratigraphic" sequences beneath the Paleozoic Illinois Basin that continue down to about 17 km depth. 3-D mapping reveals broad "basinal" packages that may be related to a Proterozoic syn-rift and/or volcanic episode. These sequences are possibly analogous to younger Keweenawan-type rift-related volcanism and sedimentation that affected the central USA during the Proterozoic. The reprocessed reflection profiles also suggest that the seismogenic source beneath the seismically active southern Illinois Basin may be related to (1) mid-crustal dipping reflectors associated with thrust-mechanism earthquakes, and (2) seismically imaged steep faults in shallow basement associated with strike-slip-mechanism earthquakes. Extended-correlation vibroseis sections over the central Illinois Basin reveal the first unambiguous dipping mantle reflectors documented from near-normal incidence seismic profiles in the USA since deep reflection profiling began in the 1970's. These mantle reflections can be mapped in 3-D beneath clear Moho reflections that mark the base of a 36-40-km thick crust. The presence of newly observed mantle reflectivity beneath the Illinois Basin may indicate significant upper mantle heterogeneity, relative to other parts of the USA studied using reflection methods. The results of this study clearly indicate the value of "rescuing" geophysical data that might otherwise be permanently lost to the scientific community due to corporate mergers and petroleum companies abandoning a particular geologic province.

15.15

EXTENSION AND STRUCTURAL EVOLUTION OF THE GREAT SALT LAKE, UTAH: A SUBSURFACE VIEW OF THE EASTERN MARGIN OF THE GREAT BASIN, WESTERN U.S.

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Analysis of marine seismic reflection and related data from the Great Salt Lake, Utah provides clues to the nature of crustal extension at the eastern boundary of the Basin and Range Province of the western United States. Interpretations of the data show that the major basin-bounding normal faults beneath the Great Salt Lake generally are listric, becoming subhorizontal at depths of 4-7 km. This rapid decrease in fault dip at depths shallower than the brittle-ductile transition zone in the Basin and Range Province suggests an explanation other than a gradual change of rheology and stress orientations with depth. Our analysis suggests that the Sevier-age Willard thrust probably forms the master detachment into which the Tertiary Carrington normal fault (between Carrington Is. and Promontory Point) soles. Similarly, the Tertiary East Lake normal fault (west of Antelope Island) soles into a footwall imbricate of the Willard thrust. Extension and formation of the major basin-bounding normal faults is accompanied by development of subsidiary faults in the hanging wall. Finite-element modeling of a reactivated thrust-fault surface shows that the first-formed secondary faults will be synthetic to the dip of the old thrust-fault ramp and join it to form a listric normal-fault system. Calculations of fault strike, dip and rake from reflector geometries show that extension generally is east-west, but that significant transverse slip also has occurred; simple cross-section balancing procedures fail to account for the full deformation observed. This data set also yields evidence for an earlier (Eocene) sedimentary basin now unconformably overlain by a greater volume of Miocene and younger strata. The earlier basin indicates that extension in the hinterland of the Sevier foreland fold and thrust belt began almost immediately as compression waned.

16.00 **INVITED**

THE KENYA RIFT AND THE SOUTHERN GREAT BASIN, USA: A COMPARISON OF A NARROW RIFT AND A WIDE RIFT

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Understanding the processes that create the diversity of rifting observed in continental settings is still a major challenge. The relationships between rift morphology and deeper structure are one key piece of the puzzle. The classic Kenya rift is an example of a narrow rift for which the KRISP seismic project has provided much new data. The southern Basin and Range province is a wide rift and has also been the target of several recent seismic experiments. The KRISP results indicate the presence of crustal thickening due to underplating beneath the Kenya dome, thinning of the crust and an increase in crustal extension to the north, and modest crustal thinning associated with the rift to the south. The pre-existing lithospheric contrast between the Archean and Proterozoic basement terranes played a significant role in the location and structural geometry of the rift. In contrast, recent results from the SSCD and DELTA FORCE experiments in the southern Basin and range province show that the crustal thickness is surprisingly uniform. The lower crust does thicken in regions where the extension is greater, but the velocity structure indicates that magmatic underplating is minor. Thus, the main mechanism for maintaining crustal thickness during extension appears to have been lower crustal flow.

16.30

"DOBRE" – DONBAS FOLDBELT (SE UKRAINE) DEEP SEISMIC REFRACTION AND REFLECTION PROFILING

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The Donbas Foldbelt (DF) is the uplifted and deformed part of the Dniepr-Donets Basin that formed as the result of rifting of the East European Craton in the Late Devonian. The thickness of syn-rift and younger strata is in excess of 20 km; coal-bearing Carboniferous rocks are exposed at the surface. A seismic refraction/wide-angle reflection survey was carried out in 1999 to complement existing Deep Seismic Sounding data from the area that, because of their design, did not record significant Pn phase arrivals. The 1999 survey comprised some 245 recording stations along a line of 360 km length, with 11 in-line shotpoints, from the shores of the Asov Sea north to the Ukraine-Russia border. An off-line (fan) profile with some 75 recording stations, including 18 three component stations, was acquired across the rift zone about 100 km north-west of the main profile. Data quality is excellent and preliminary velocity models are presented. Deep CDP profiling – at least 120 km of coincident, 30 s Vibroseis© and 180 s explosive – is planned for the summer of 2000. The seismic data are expected to reveal basin architecture and structural relationships controlling the kinematics of its deformation – as well as other features of the lower crust and upper mantle related to basin formation and inversion.

16.45

FIRST DEEP SEISMIC REFLECTION IMAGE OF THE SOUTH CASPIAN BASIN, CENTRAL EURASIA: EVIDENCE FOR EPISODIC SUBDUCTION

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Two 70-km long profiles in the vicinity of the Absheron Ridge, offshore Azerbaijan, reveal for the first time the crustal scale structure of the South Caspian Basin. These profiles were acquired with the main goal to: (1) elucidate the thickness and nature of the crust, (2) reveal the type of the transition between the South and Central Caspian lithosphere, and (3) provide a full image of the South Caspian sedimentary basin. A bright reflection at 26-28 km depth (12.8-13.0 s) is thought to represent the basement/cover contact. The thick Cenozoic sedimentary section is dominated by a S-vergent fold and thrust system that roots into an intra-sedimentary detachment at ~14 to 20 km. A change in the reflective pattern below 28 km depth, with sub-horizontally layered reflections of noticeably lower frequency reflections, is interpreted as crystalline basement down to the Moho at ~36-40 km (16.0-16.5 s). The ~10 km thick crystalline crust is considered to be of oceanic affinity. Gentle deepening of the crust from south to north is interpreted as evidence for northward subduction of the South Caspian lithosphere beneath the Eurasian continent across the Absheron Ridge. This interpretation is supported by active sub-crustal seismicity which occurs north of the Absheron Ridge. Burial of the fold and thrust system beneath a thick layer (5-10 km) of Plio-Pleistocene sediments as well as an apparent change in the locus of the subsidence in the past 5 Ma suggests the likelihood of episodic subduction of the South Caspian lithosphere.

Integrated Multi-disciplinary Studies   Thursday 22nd June, Morning

9.00 **INVITED**

CRUSTAL STRUCTURE AND TECTONICS ALONG THE LARSE TRANSECTS, SOUTHERN CALIFORNIA, USA

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The Los Angeles Region Seismic Experiment (LARSE) consists of 2 transects (Lines 1 and 2) across southern California, USA, whose chief purposes are to establish fault and sedimentary-basin structure in this region in pursuit of earthquake hazard reduction. Airgun, explosion, and earthquake data were collected onshore on these 2 transects, and are discussed here; airgun data only were collected offshore. Line 1 (1994, 160 km long) crosses the Los Angeles basin, San Gabriel Mts, and Mojave Desert; Line 2 (1999, 150 km long) crosses the San Fernando Valley, western Transverse Ranges, and western Mojave Desert. Chief results from Line 1 are: (1) The (reverse) Sierra Madre fault (SMF) dips northward from the base of the San Gabriel Mts. toward the (strike-slip) San Andreas fault (SAF), but appears to sole into a mid-crustal "master" decollement that terminates northward at the SAF and projects southward beneath the Los Angeles basin to the Whittier Narrows blind thrust fault (WNF). (2) A crustal root 8 km thick is centered below the trace of the SAF. (3) We interpret that, in response to a large component of compression across the SAF, ductile lower crust moves toward the SAF beneath the "master" decollement and a symmetrically located decollement in the mid-crust of the Mojave Desert, causing an accumulation of rock in a crustal root centered below the SAF. Brittle crust above imbricates along compressional faults (e.g., SMF, WNF), and is also offset along strike-slip faults (e.g., SAF). Preliminary results from Line 2 will also be presented.

9.30

THE MULTIDISCIPLINARY EUROBRIDGE: A SEISMIC RECORD OF 2000 MILLION YEARS OF CRUSTAL HISTORY

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The 1500-km long EUROBRIDGE DSS profile in the western part of the East European Craton strikes from the Baltic Shield across a diverse and juvenile Palaeoproterozoic crust to the mostly Archaean Ukrainian Shield. It crosses one major crustal discontinuity of the Craton between its Fennoscandian and Sarmatian crustal segments of different Archaean and Palaeoproterozoic evolution. EUROBRIDGE traverses also the ca. 1.8-1.75-Ga Korosten anorthosite-rapakivi pluton, Meso-Neoproterozoic Volhyn-Orsha aulacogen and the Palaeozoic Pripyat Trough. Each of the tectonic developments somewhat contributed to the lithospheric structure and is recorded in velocity patterns. The 2.0-1.7 Ga subductional/collisional orogenies were most important. The three-layered crystalline crust varies in thickness, seismic velocity values, reflectivity and seismic structure generally corresponding to the geological subdivisions. The crustal structure resembles that in the Palaeoproterozoic crust in Finland, Sweden and Canada.The Moho relief is closely connected with the crustal structures, the higher Moho velocities appear to correlate with older crust. A lower mantle reflector occurs at 65-70 km depth beneath some parts of the profile.

The anorogenic Korosten' pluton in northern Ukraine apparently influenced the velocity distribution in the crust and upper mantle, suggesting magmatic inter- and underplating. However, the Meso-Neoproterozoic and Palaeozoic rifts followed closely the Palaeoproterozoic accretionary tectonics without changing significantly its seismic structure.

9.45

CRUSTAL HETEROGENEITY AND ANISOTROPY OF AN ACTIVE METAMORPHIC MASSIF, NANGA PARBAT, WESTERN HIMALAYA

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Nanga Parbat, in the core of the western syntaxis of the Himalaya, represents a unique exposure of Pre-Cambrian Indian mid-lower continental crust from beneath the collisional orogen. The predominantly quartzofeldspathic gneisses of the Nanga Parbat-Haramosh massif exhibit a polymetamorphic history acquired during Tertiary continental collision between India and Asia. Most recently, pervasive modification of the crust is documented by young (<1-3 Ma) high temperature-low pressure metamorphism and anatexis. Rapid exhumation, the presence of hot springs, young metamorphism, and young intrusive rocks all suggest an anomalous thermal structure lies beneath the massif. Petrophysical measurements on a suite of 30 samples collected in and around the massif provide important insights into the degree of heterogeneity and velocity anisotropy associated with the rocks of Nanga Parbat and the adjacent Kohistan island arc terrane. Mean Vp in three directions ranges from 5.91-6.25 km/s in the Nanga Parbat gneisses. Compressional wave velocity anisotropy in these samples averages 8.4% but anisotropy as high as 12.4% is observed. Mean Vs is 3.4-3.55 km/s. Velocity anisotropy for shear waves averages 12.4% with a maximum of 22.3%. The observed degree of anisotropy is primarily a function of biotite content and rock fabric strength. We note that in some samples, propagation velocities in the foliation plane of the felsic gneisses overlap with mean velocities of the more mafic Kohistan terrane. These results provide important constraints on the interpretation of the velocity structure beneath the massif where in situ velocity variations can be due to both high strain zones in the crust as well as elevated temperature caused by rapid advection of rocks from depth. These results also indicate that crustal anisotropy can be a significant contributing factor to shear wave splitting observations.

10.00

THE NORTHEAST GERMAN BASIN - SEISMIC IMAGING AND DYNAMIC EVOLUTION OF AN INTRACONTINENTAL BASIN

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The intracontinental NE German Basin is of great regional scientific and commercial importance. As part of the Southern Permian Basin it is one of a series of related basins which have been extensively explored, not only for their hydrocarbons, but also for other raw materials and geothermal energy potential. The underlying mechanisms controlling basin formation in the region, however, are poorly understood. Using a variety of methodologies (seismic, sedimentological, modelling) the basin is examined on a variety of scales in order to elucidate its geological development. A 330 km long, NE-SW trending seismic transect across the NE German Basin, combined with a 75 km long, perpendicular cross-line in the basin centre and available industry seismic and well data, reveals the structure of the basin between the stable Precambrian Baltic Shield and the weaker Mid-European Variscides. There is evidence that Baltica crust extends further southwards than previously thought. This is interpreted as an important factor in geothermal distribution patterns observed today. Crustal imaging reveals no evidence of significant Late Carboniferous/Early Permian rifting. This suggests together with the continuous Moho that thermal destabilization of a stressed, inhomogeneous lithosphere, rather than plate-boundary forces, controlled basin evolution. This agrees with recent models suggesting that Upper Rotliegend-Early Triassic subsidence after a period of intense volcanism was predominantly related to thermal cooling of the crust. The deposition of the Zechstein evaporites provided not only an effective seal for underlying hydrocarbons, but they also acted as a zone of decoupling for post-Zechstein basin development.

10.15

MULTIDISCLIPLINARY STUDY OF THE CHICXULUB IMPACT STRUCTURE

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The Chicxulub impact structure, now buried beneath the Yucatan peninsula in Mexico, is widely believed to be the site of the impact that ended the Cretaceous period, and at least partly responsible for the K-T mass extinctions. The crater floor and impact-generated deposits have been penetrated with several deep and shallow boreholes. In September 1996, 650 km of BIRPS deep reflection profile were acquired across the offshore portion of the crater; the 13,000 airgun shots that generated the reflection data were recorded at wide-angle on 35 ocean-bottom and 90 land seismometers. Magnetic, gravity and magnetotelluric data have also been collected across the crater. These data enable us to determine parameters such as the size of the impactor and excavation cavity, the morphology of the impact basin, and the thickness and extent of the impact melt sheet. These parameters enables us to improve estimates of the pollutants released into the atmosphere by the impact, and, ultimately, examine why the impact was so catastrophic. The reflection data provide the first high-resolution image of the third dimension of a pristine large impact crater, providing primary information on the mechanics of crater formation. The initial transient cavity, formed during the compressive stage of impact, appears to collapse along crustal-penetrating faults that offset both the Cretaceous sediments and the Moho. The final crater morphology is sensitive to the conditions of the target planet, in particular the gravity, density and disposition of surface materials. If we can understand crater formation on Earth we will be able to use the morphology of craters on the other planets and moons to learn about their sub-surface rheology.

11.00

25 YEARS OF DEEP SEISMIC PROFILING AT CORNELL

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Year 2000 marks the 25th anniversary of COCORP's first field experiment in deep crustal reflection profiling, ushering in a new era in the exploration of the continental lithosphere. COCORP' success in adapting oil exploration technology to the systematic mapping of deep structure stimulated a number of national programs cored by seismic profiling. A review of COCORP and its progeny at Cornell not only provides a measure of how far we have progressed, but how resistant certain issues have proven to resolution and what strategies are most promising for future discovery. COCORP's original 48-channel recording system contrasts markedly with current 300-500 channel systems coupled with complementary arrays of 3 component recorders to provide simultaneous wide-angle controlled source and broad-band passive data. Tectonically, deep reflection profiles have revolutionized our view of the lower crust. Low-angle megathrusts, mobile Mohos, magma bright spots and deep layered complexes are now standards of the crustal lexicon. Yet interpretational controversy persists: Are bright spots magma or brine? Is deep layering essentially tectonic shear or intrusive in origin? Does the Moho re-equilibrate by mechanical relaxation or phase-change? More compelling answers to these and other questions (many awaiting discovery) *may* arise from new types of experiments, but some will almost certainly find their answer in continued exploration of the majority of the earth that has yet to be probed.

11.15

THE ROLE OF FLUIDS IN THE FORMATION OF REGIONAL-SCALE DETACHMENT SURFACES

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Greenstone supracrustal rocks of the Archaean Eastern Goldfields Province in Western Australia contain numerous gold deposits. Deep seismic reflection imaging shows that regional ENE-WSW D_2 shortening of the supracrustals was delaminated from lower crustal shortening at a detachment surface near the base of the greenstones. Major gold deposits lie close to D_3 strike slip faults that extend through the detachment surface. Previous interpretations of mineralisation models inferred no causal relationship between the detachment surface and fluids that carried the mineralisation. Seismic bright spots at ~6s TWT in Tibet may be caused by fluids ponding in the middle to upper crust (also Chile and western North America). Fluid ponding may therefore be common at depths of 15-20 km in orogens. This depth region correlates loosely with the base of the seismogenic zone in the continental crust. It also corresponds to the transition from an upper crustal hydrostatic fluid pressure regime to a lower crustal suprahydrostatic fluid pressure regimes; the boundary being a low permeability pressure-seal. Fluid pressures near the base of the pressure-seal domain can intermittently exceed lithostatic pressures, leading to hydraulic extension failure. When this occurs over a broad region, as in Tibet, regional detachment surface could nucleate. In orogens, the extension fractures will have poor vertical connectivity and fluids will pond. If faulting subsequently breaks the seal, the fluids will be drained. The interplay of crustal shortening and strike slip faulting, as in the Eastern Goldfields Province, therefore creates an ideal environment in which mineralising fluid paths not only are controlled by regional structure, but also contribute to the formation of the structures.

11.30

DEEP SEISMIC IMAGING OF AN ANCIENT CONVERGENT PLATE MARGIN, EASTERN LACHLAN OROGEN, AUSTRALIA

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The Eastern Belt of the Lachlan Orogen in New South Wales contains major meridional volcanic belts that represent structural remnants of the Ordovician intraoceanic Macquarie Arc. Monzonitic intrusions in this arc host major gold and copper porphyry-type deposits. In 1997 and 1999, the AGCRC acquired refraction (wide-angle) data along one strike-parallel line, and deep seismic reflection (near-normal incidence) data along several strike-normal lines. The reflection lines, mostly oriented east-west and all acquired to 20 s TWT, were designed to examine the dismembered volcanic arc and to test the relationships between the arc rocks, coeval craton-derived quartz-rich turbidites (juxtaposed in a major end-Ordovician collision), and adjacent Silurian-Early Devonian rocks formed during subsequent extension. The refraction profile was oriented north-south and designed to examine the Lachlan Transverse Zone, a major crustal tear that is oblique to the regional grain. The reflection data confirm the presence of major faults cutting the Ordovician volcanics. We interpret the faults as contractional, with some having younger on older (out-of-sequence) relationships. Some of the faults juxtapose Ordovician volcanics above Late Devonian rocks and thus have undergone Carboniferous or later contraction. The seismic data also suggest that Ordovician volcanic rocks underlie the flanking extensional basins.

11.45

THREE-DIMENSIONAL CRUSTAL STRUCTURE FROM DEEP SEISMIC REFLECTION DATA IN THE ARCHAEAN GRANITE-GREENSTONE YILGARN CRATON, WESTERN AUSTRALIA.

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The Archaean granite-greenstones of the Eastern Goldfields, Yilgarn Craton, are one of the largest producers of gold in the world and a knowledge of the tectonic evolution of the region and its mineral systems is fundamental to understanding exploration models. Interpretation of the 1991 Eastern Goldfields deep seismic reflection data have provided images of the internal structure of both the granite-greenstone layers and the upper and middle crust and also provided information on the geometry of the deformational structures. Deformation surfaces were identified using kinematic indicators and unravelling the deformation history indicated the thrust-stack model was the preferred tectonic model. In 1999, we expanded our work with the collection of a grid of deep seismic reflection data within the mineralised Eastern Goldfields region. These new data extend our understanding of the nature of the granite-greenstone detachment surface and the relationships of the major shear zones to the detachment surface. Key economic questions being addressed include the 3D extent and significance of the previously imaged felsic bodies located beneath the greenstone succession and the 3D extent of a 'zone-of-no-reflections' beneath the main mineralised region. One key structural question is whether the emplacement of the granites into the greenstone succession is magmatic or structural in origin. New gravity data and additional geological information along the traverses have further constrained the 3D geometry, resulting in a geological consistent model that can be used as a predictive tool to understand the tectonic evolution and the regions mineral system history.

12.00

SVECONORWEGIAN INTRUSIVES BENEATH THE NORWEGIAN-DANISH BASIN

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The Skagerrak and Silkeborg gravity and magnetic anomalies are situated in the Norwegian-Danish Basin offshore southern Norway and in central Jutland, Denmark, respectively. Most geoscientists have advocated a Permian age for the source rock bodies. A steep upward pointing remanent magnetisation is, however, required to account for the observed negative magnetic anomalies in both areas. We find overwhelming evidence for a Sveconorwegian age (c. 935-1000 Ma) for the source bodies of both anomalies. Permian dykes within the Precambrian of southern Norway carry a flat-lying characteristic remanent magnetisation of reverse polarity (Kiaman superchron). On the other hand, Sveconorwegian intrusive bodies rocks within the Rogaland Igneous Province (RIP), 50 km to the NW of the Skagerrak anomaly, carry a steep upward pointing remanent magnetisation. The eastward extension of the magnetic anomalies caused by the RIP is continuous with the positive part of the Skagerrak anomaly. We suggest that the Skagerrak anomalies are caused by rocks of the RIP and its offshore extension. Both the negative magnetic anomaly and the positive gravity anomaly can be modelled using constraints from seismic reflection lines and available petrophysical data. A 7 km thick complex of ultramafic/mafic intrusives is located below a southward dipping 1-6 km thick section of Mesozoic and Palaeozoic sediments. This body of ultramafic or mafic rocks could be the residue of the parental magma that produced the voluminous Rogaland anorthosites. An inverse modelling of the Silkeborg gravity and magnetic anomalies revealed source depths ranging between 6 and 8 km. The gravity and magnetic anomalies have earlier been attributed to two separate source bodies; a thin layer of magnetic volcanics within the Palaeozoic sedimentary sequence at a depth of c. 7 km and a dense mafic complex at a depth of 11 km. Forward modelling shows that a similar body to that required to account for the Skagerrak anomalies may also be inferred to account for the Silkeborg anomalies (i.e. a steep upward pointing magnetised body situated within a dense, mafic body).

Seismic Techniques Friday 23rd June, Afternoon

9.00 INVITED

ASSESSMENT OF 2D AND 3D VELOCITY MODELS DERIVED FROM WIDE-ANGLE TRAVELTIME DATA

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Nonlinear methods for assessing the reliability of 2D and 3D velocity models derived from wide-angle traveltime data are presented. Deriving alternate models that satisfactorily fit the real data is the best means of estimating the bounds on single model parameters and specific model features, in the case of minimum-parameter and finely-gridded models, respectively. Using a tomographic approach with roughness and perturbation constraints is the most effective way to establish whether particular model features are required by the data or merely consistent with the data. A shortcoming of modeling some datasets is the subjective aspects of identifying and including later phases, assigning specific layers to refracted arrivals, and positioning model nodes when using a minimum-parameter-type approach. The effect of these more subjective choices can be addressed using first-arrival traveltime tomography that seeks a minimum-structure model. Model resolution can be estimated using a tomographic approach and a series of checkerboard tests with a range of anomaly sizes. These techniques are illustrated using real data from central India, southwest British Columbia, the Faeroe Basin, and the Chilean and Iberia margins.

9.30

RAPID AUTOMATIC 2D VELOCITY IMAGES IN DEPTH AND TIME FROM REFRACTED ARRIVALS

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We describe further development of the tau-p velocity imaging method for transforming wide-angle refraction data directly into two-dimensional velocity models. The technique was first developed on ocean bottom seismometer data, but can also be applied to two-ship long-offset multichannel data, in which case the necessary reversal of raypaths is achieved by comparing data in the shot and receiver domains. Despite its large volume, two-ship data is relatively easy to pick because the two-dimensional geometrical density of the data allows automatic picking with the new PickEd routine. Furthermore, as two-ship data is (or can be) spatially sampled equally in the shot and receiver domains, the data is fully reciprocated and there is no requirement for approximating factors to correct apparent velocities into true velocities; instead, the true velocity may be calculated explicitly for each reciprocated path. The densely-sampled tau-velocity-turningpoint image obtained may be converted to depth after filtering to remove points with large uncertainties, and these depth images may be subsequently converted to two-way-time for use with the conventional stack. The long wavelength 2D velocity field is extremely well recovered, but further development of the method is required in order to resolve rapid lateral velocity variations, and to depth-convert in the presence of velocity inversions.

9.45

BROAD UTILIZATION OF SEISMIC DATA FROM LONG-RANGE REFRACTION PROFILES: IMAGING CRUSTAL REVERBERATIONS AND SCATTERING

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Seismic data analysis techniques developed in teleseismic seismology could be efficiently applied to extract additional information from the records from long-range controlled-source profiles. Among these techniques are (1) characterization of crustal attenuation from seismic coda measurements and (2) imaging of the crustal structure using receiver functions. Taking advantage of the density and continuity of the recordings, detailed characterization of crustal properties could be achieved from such analysis of long-range arrivals. We present applications of these methods to three-component recordings of Peaceful Nuclear Explosions (PNE) in ultra-long profile QUARTZ in Russia.

Our resulting estimates of coda Q range between Q=380 near 2 Hz and Q=430 around 5 Hz and can be associated with crustal attenuation. We also "deconvolve" the overlapping coda pattern and derive the true relative amplitudes of the arrivals. In another manifestation of crustal reverberations in long-range PNE arrivals, we show that scattering and P/S conversions within the crust cause pronounced reverberations in the waveforms of P-wave arrivals. Stacking of receiver function sections of first arrivals results in consistent images of the basement along the PNE profiles. Along with an independent way of crustal imaging, our result also indicates that variation of the sediment/basement contact could be a major factor influencing the complexity of long-range arrivals recorded in refraction seismic profiles. Therefore, crustal reverberations should be taken into account in the interpretations of mantle scattering.

10.00

THE HETEREOGENITY OF THE LITHOSPHERE

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Deep crustal seismic reflection and refraction data, teleseismic data, boreholes, and outcrop exposures provide a broad bandwidth look at the heterogeneity of the lithosphere. Unfortunately each sensing method supplies only a subset of the information we desire to characterize the heterogeneity spectrum of the lithosphere, and samples a fraction of the total lithospheric column. Outcrops and borehole data provide scales from sub-meter to a few kilometers. Outcrop data and petrophysical measurements provide cm to kilometer information on vertical and lateral scale parameters and velocity fluctuation intensity. Boreholes generally only provide vertical scales and fluctuation intensity. Reflection data provides lateral scales and some estimates of fluctuation intensity for scales from a few tens of meters to multiple kilometers. Refraction data provides scales from sub-kilometer to multiple kilometers, but often suffer from interpretational biases. Long range refraction data have been used to estimate body size and fluctuation intensity of heterogeneities in the upper mantle. Teleseismic data, particularly high-frequency, high resolution receiver functions, hold the promise of providing kilometer to multiple kilometer direct imaging of S-wave variations throughout the lithosphere. Combined this data allows us to estimate the different scales of heterogeneity of the continental lithosphere.

10.15

WIDE-ANGLE SEISMIC TRAVELTIME INVERSION USING A FRESNEL ZONE BASED PROCEDURE

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Wide angle seismic travel time inversion is commonly performed using ray theory for the computation of arrival times and their sensitivities to the slowness distribution. However, since sound travels as a wavefield, the seismic velocities on the ray are not solely determining the travel time.
A good compromise between computation speed and accuracy in the calculation of forward response as well as inversion estimates is achieved by smoothing the sensitivity kernels as defined by the width of the first Fresnel zone along rays. We define Fresnel zones from travel time residuals efficiently computed by an eikonal equation solver. Synthetic tests demonstrate that ray tracing methods may provide models of an unnecessarily high geological complexity. Furthermore, ray tracers are not always capable of calculating arrivals to all receivers. Using the eikonal solver, we make sure that arrivals are calculated at all receiver positions. For interpretation purposes, Fresnel zone based forward and inverse calculations assure that the obtained models contain only the level of detail warranted by the measurement geometry and the wave equation. The significance and application potential of this approach is demonstrated through realistic synthetic tests and modelling of observed data.

11.00

AUSTRALIAN NORTH WEST SHELF, CRUSTAL REFLECTIVITY AND BULK SEISMIC VELOCITY: A PROBLEM RELATIONSHIP

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Interpretation of the ocean-bottom seismograph data on the Australian North West Shelf suggests that prominent seismic reflectors and changes in reflectivity patterns in conventional reflection data do not necessarily correspond to significant bulk velocity discontinuities. For example, the 6.0 km/s refractor imaged along the Petrel line shows rather poor correlation with the reflectivity of the crust imaged by the conventional reflection data. The velocity model boundaries and iso-velocity lines also do not coincide with the events identified in the reflection section along the Vulcan line. The top of the lower crust is in the vicinity of the prominent reflections at 6 s two way time, but the OBS data show no significant velocity increase at this level. A significant local velocity increase imaged by the OBS data in the depth range 15-23 km, within the lens-shaped lower crustal body detected on the Carnarvon line does not produce any noticeable response in the reflection section. Conventional reflection technology tends to highlight fine seismic stratification of the crust while refraction/wide-angle methods image better the bulk velocity changes in the crust. Only a combination of both techniques provides a clue to a consistent geological interpretation of seismic data.

11.15

THE ORIGIN OF THE INTRA-CRUSTAL DISCONTINUITIES

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It is very puzzling that the intra-crustal discontinuities which are derived from the analysis of seismic crustal refraction/wide-angle reflection data are seldom seen in the complex images derived from coincident near-vertical seismic reflection experiments. This puzzle is addressed in this paper. Heterogeneous Earth models were created in which sets of small sloping reflectors were embedded in a vertical velocity gradient field to create correlatable structures similar to those encountered in the near-vertical reflection experiments. Typical correlation lengths of 5 to 15 km were selected with the reflectors extending from the surface to the Moho. The expected wide-angle reflection field, which was then derived using ray tracing techniques, had many of the characteristics of the observed record sections from many seismic refraction experiments which were recorded over the Canadian Shield during the past 20 years. The numerical experiments predicted the presence of the large Pg coda field and showed that its geometry was related to the velocity contrasts of the reflectors and the surrounding medium. The travel-time curve for the first arrival crustal waves was also broken up into a number of PiP-like wide-angle shingled reflection type travel-time branches giving one the "illusion" that the earth is layered with 1-2 intra-crustal discontinuities. The number of line segments and hence apparent discontinuities is related to the correlation lengths of the geometrical structures of the model.

11.30

SEISMIC IMAGES AND THE GROUND TRUTH

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Our ideas about the evolutionary processes operating in the continental lithosphere are to a large extent derived from the structural information obtained from deep seismic reflection data. Hence the quality and the dependability of the seismic images is a non-trivial issue. The debate relies mostly on indirect arguments though, as there is hardly any direct access to the region below the crystalline basement.
In this context, it is interesting to compare very shallow sub-surface images obtained through different seismic techniques with each other and with the information obtained from CPT and CORES. Both the latter – though "closer to the truth" - do result of course from destructive methods.
Interestingly, even the surface- and the down-hole- seismics feel the medium differently, and therefore yield different views of the same. Differences in wavelength and angle of illumination, effect of lateral heterogeneity and attenuation etc. will be discussed to obtain a better understanding of the information content of reflection seismic data.
Lastly, the availability of co-incident CPT data (resulting from destructive geo-technical testing) offers an extra dimension of comparison, with differences possibly attributable to the different regimes of elasticity (dynamic vs static). Results will be presented from a 50m drill site that was surveyed using the different techniques mentioned here.

11.45

FULL-WAVEFIELD TOMOGRAPHY: THEORY AND PRACTICE

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One of the principal aims of seismology is to determine the elastic properties of the subsurface. In wide-angle seismology, this is done by attempting to find models that successfully reproduce particular aspects of a seismic dataset, most commonly the travel-times of particular phases. Recent advances in computational efficiency, coupled with new algorithmic developments, mean that it is now possible to proceed by finding models that explain a significant fraction of the entire seismic wavefield. In two-dimensions, these techniques are becoming established and are usable on large field datasets; in three-dimensions, full-waveform techniques are being actively developed, but their computational requirements are daunting. Full-waveform tomography offers many advantages: spatial resolution is significantly higher than travel-time methods, imaging is possible with limited spatial and azimuthal coverage, elastic and visco-elastic properties of the subsurface can be recovered, wide-angle and near-normal-incidence data can be imaged with a unified scheme, and these techniques are able to image features with which conventional-reflection and travel-time-tomographic techniques have great difficulty; for example, near-vertical reflectors or velocity structure within sub-horizontal low-velocity zones.

15.15

CRUSTAL STRUCTURE OF AN EXTENDED CONTINENTAL MARGIN NORTHEAST OF NEWFOUNDLAND

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The Orphan Basin is a wide (400 km) zone of thinned and extended continental crust on the rifted continental margin northeast of Newfoundland. It is bounded to seaward by the continental fragment of Orphan Knoll, and to the south by the shelf and basins of the Grand Banks. A wide-angle seismic experiment was run across the basin and the adjacent margin, along an existing deep reflection profile. Data from fifteen ocean bottom seismometers, in combination with a large airgun array, allow the determination of crustal velocity structure over much of the extended continenental crust and the adjacent oceanic region. Prerift metasedimentary rocks, with up to 5 km relief produced by block faulting during extension, are present beneath the synrift and postrift sediments. Crystalline upper and lower crust have a total thickness of typically 10-15 km. Most significant, there is no indication of a high-velocity lower crustal layer (>7 km/s), which might be due to magmatic underplating. The extension of the basin therefore appears to have taken place amagmatically. The continental crust ends abruptly seaward of Orphan Knoll, and the adjacent continent-ocean transition zone shows many of the characteristics of the serpentinized peridotite zones that are seen on some other nonvolcanic margins, suggesting that there may be no actual crust here, and that true igneous oceanic crust may not have been produced until significant continental separation had occurred.

16.00

MODELLING OF WIDE ANGLE SEISMIC DATA FROM OCEAN BOTTOM SEISMOMETERS SOUTHEAST OF SVALBARD: A CALEDONIDE SUTURE RECOGNIZED?

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The assembly of the crystalline basement of the Barents Sea is related to the Caledonian orogeny during the Silurian. Several tectonic phases from the Late Paleozoic to the early Tertiary resulted in deep sedimentary basins in the southwest, but did not greatly affect the platform areas. Southeast of Svalbard conventional seismic reflection data does not provide reliable mapping below the Permian sequence. The modeling of four OBS profiles recorded in 1998 southeast of Svalbard is presented here. Ray-tracing and inversion of the OBS data enable mapping of the depth to crystalline basement and Moho. The depth to top basement varies between 4 and 14 km, and the upper Paleozoic structuring show little correlation with the younger structuring of the area. Several strong reflections originating within the crystalline crust indicate an inhomogeneous basement terrain. Many of these reflections can be modeled with a three-layered crust, but give no velocity information.
Combinations of PmP and Pn arrivals from the Moho constrain the basement velocity to be close to 6.5 km/s on average. The Moho has a strong topography in places, varying from 32 and 38 km, which does not correlate with subsequent basin formation. The thickest crust is associated with top mantle velocities up to 8.5 km/s. Gravity modeling support density variations in the crystalline basement varying between 2800 and 2990 kg/m^3. High basement density accounts for the two major positive gravity anomalies in the area, accentuated by high density upper mantle. This occurs under the Olga Basin, imparting a positive gravity anomaly to the basin. The P- and S-wave modeling indicate a sedimentary section of intermediate clastic content and a felsic crystalline crust. Bodies of more mafic composition are likely at the gravity highs. A geological model that may explain these observations can be found by assuming a pre-Caledonian subduction zone dipping to the southeast, developing into a Caledonian suture zone underneath the present Sentralbanken High. The thickened crust is then caused by partial subduction of continental crust, and the asymmetry between top basement and Moho topography is explained. The high velocity and density anomalies underneath the thickened crust can be caused by an accumulated fraction of eclogitized oceanic crust. High density bodies within the crystalline crust may represent intrusions emplaced above the subduction zone. However, the lateral continuation of the suture zone is unclear, as it is not recognized on one profile as expected.

16.15

DEEP CRUSTAL ARCHITECTURE OF THE VØRING MARGIN, MID-NORWAY

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The evolution of the mid-Norway and conjugate NE-Greenland passive margins includes several distinct episodes of crustal thinning beginning in at least the Permian and ending with breakup in the early Eocene. The final, "successful" rifting episode began in the Late Cretaceous and included significant synrift magmatic activity interpreted to accompany magmatic underplating. Integrating different forms of deep seismic data allows new insight into the structural architecture of the middle to lower crust. These data include industry two-ship multichannel reflection profiles, which show the detailed reflection structure, and and industry/academic wide-angle ocean bottom seismometer reflection-refraction profiles, which delineate the regional velocity structure including the "underplate" and uppermost mantle. These data show the relationship of regional detachment surfaces to the above-lying sedimentary basins, and, below, to the geometry of the "underplate". Progressive changes in upper-crustal extensional style appear to relate well to changes in depth to detachment. Interestingly, some detachment surfaces dip parallel to the margin. In general, deep multichannel reflection data show major basin-bounding normal fault systems to be continuous through relatively transparent middle crust into highly-reflective bands in the lower crust, interpreted as zones of distributed shear within several kilometers of the Moho and underplate

16.30

THE STRUCTURE OF THE IBERIAN MARGIN AT 41 DEGREE 2': MCS AND OBH RESULTS

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West off Iberia, the nonvolcanic rifted continental margin is made up of three main structural segments: the Galicia Bank to the north, the south Iberia Abyssal Plain in the center, and the Tagus Abyssal Plain in the south. The Iberian margin was formed during rifing between Iberia and New Foundland, the breakup propagating northwards, occurring at about 137 Ma, 130 Ma and 114 Ma in the Tagus Abyssal Plain, Iberia Abyssal Plain and Galicia Bank area, respectivley.

During a joint US-German seismic experiment a huge data set of combined multichannel and wide-angle lines were surveyed at the northern Iberian margin (Ewing cruise July to August 1997). Here we present the results of a 300 km long combined MCS/OBH transect across the margin (41 degree 2'N) at the transform zone between the Galicia Bank segment and the Iberia Abyssal Plain segment.

POSTER ABSTRACTS

Active Continental Margins Monday 19th June to Tuesday 20th June

ACM-1

WIDE-ANGLE IMAGING OF THE STRUCTURE OF THE AUSTRALIAN-PACIFIC PLATE BOUNDARY, SOUTH ISLAND, NEW ZEALAND, SIGHT TRANSECT I

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At the South Island, New Zealand, the Pacific-Australian plate boundary, a continental strike-slip zone, as accommodated 80 km of transpression over ~6.4 Myr. Most of the strain is taken up at the Alpine fault at the west coast of the South Island. The mode of shortening in the continental crust and mantle has been the focus of the 1996 SIGHT experiment. The seismic refraction and reflection data collected during SIGHT place good constraints on the deep structure of this orogeny. We have applied reflection tomography and prestack depth migration to image both the long- and short-wavelength seismic structure along the 600 km long SIGHT transect I, which traverses the waist of the South Island along the Whataroa and Rangitata rivers.

Our results show that the largely undeformed Australian crust indents the incoming Pacific plate. Shortening of the Pacific plate forms a crustal root under the Southern Alps. The Mesozoic terranes that make up the bulk of the Pacific crust are partially eroded in the Southern Alps. However, our seismic velocity model indicates that a larger portion of these meta-greywackes form the core of a crustal root that extends to 37 km depth under SIGHT transect I.

Since the Australian lower crust appears to protrude ~15 km beyond the surface expression of the Alpine fault, we infer that both convergence and strike-slip in the upper crust are taken up along an east-dipping fault plane. Strain-partitioning probably occurs deeper in the crustal root, as the convergence becomes more horizontal, while the strike-slip plate boundary extends vertically into the mantle.

ACM-2

CRUSTAL STRUCTURE AND CONTINENTAL COLLISION: SIGHT LINE 2, NEW ZEALAND

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Because of young mountain building and the narrowness of the South Island (160-200 km), the plate boundary through central South Island of New Zealand is a favourable locality to study continental collision with onshore-offshore techniques. Our results from active-source seismic data show lithosphere-wide deformation that manifests itself as abrupt changes in crustal thickness and velocity. We also observe mid-crustal reflectors that are sub-horizontal. In the Pacific plate, lithospheric shortening of about 80 km has been accommodated by uplift and erosion of mid and upper crust and pervasive thickening of lower, old oceanic crust and mantle. Mid crustal velocities are low adjacent to the plate boundary at the Alpine fault. This is attributed to high pressure of fluids whose presence has been independently corroborated from high-conductivity magneto-telluric anomalies. In the Australian plate we observe flexure and faulting. Low upper-crustal velocities may be due to high bending stresses. Asymmetric crustal thickening into a root that isostatically overcompensates the topography can be explained by mantle-pull (Stern et al this conference) and a generally stronger Australian than Pacific plate behaviour during their collision. This study is part of the South Island Geophysical Transect (SIGHT) project, involving US and NZ funds and scientists.

ACM-3

GEOPHYSICAL EVIDENCE FOR CRUSTAL FLUIDS IN A REGION OF ACTIVE CONTINENTAL CONVERGENCE - THE SOUTH ISLAND OF NEW ZEALAND

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A geophysical image of the current deformation of the continental Australian/Pacific plate boundary has been obtained, as part of the continental dynamics project SIGHT (South Island GeopHysical Transects), from refraction/wide-angle reflection seismic data and magnetotelluric data recorded in the central South Island of New Zealand. The transpressive plate boundary is marked by the Alpine Fault along which 480 km of strike-slip motion and 90 km of convergence has occurred over the past 6.4 Ma. On the Pacific plate, where most of the deformation is taken up, the plate boundary is accompanied by low seismic P-wave velocities and high electrical conductivity. Although geologic constraints rule out lithologic variations in the crust, the spatial similarity of the magnetotelluric and seismic velocity anomalies suggests a common origin. A viable explanation is the presence of aqueous fluids. A likely source for these fluids is dehydration of hydrous minerals during metamorphism, and meteoric water may possibly contribute to the observations. Interconnectivity of these fluids could account for the observed high conductivity, and stress in the crust could result in enhanced pore pressures that are sufficient to reduce seismic velocities. The presence and distribution of crustal fluids in this active convergent continental margin may also have important implications for mineralisation in old inactive tectonic regimes.

ACM-4

MARINE GEOPHYSICAL INVESTIGATIONS ACROSS THE CONTINENTAL MARGIN OF PERU: FIRST RESULTS OF THE GEOPECO CRUISE

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The project GEOPECO investigates the Peruvian convergent continental margin by modern geophysical methodes. R/V SONNE cruise SO146 is carried out from 01. March until 04. May offshore Peru. A characteristic feature of the Peruvian continental margin is that for about the last 8 million years the aseismic Nazca Ridge has been subducted, migrating from North to South along the continental margin. The recent intersection with the trench is situated between 15°S and 16°S. Due to the subduction of the ridge, the former accretionary prism was eroded. Afterwards a new accretionary wedge has evolved. Profiles of the continental slope at different latitudes therefore show the developmental history of the accretionary prism at the Peruvian continental margin (von Huene et al., 1996). The region of the continental margin, where the ridge has been subducted, is characterized by absence of recent volcanism, an abnormal geometry of the downgoing plate and extraordinary seismicity (Lindo et al., 1992; Norabuena et al., 1994). Thereby, the nature of mass and fluid transfer into greater depth is influenced in a clearly recognizable way. There possibility of recycling by volcanic transport is missing. The project GEOPECO concentrates on the regions at 9°S and 12°S, where seismic data was collected (Shell, Hawaii Institute of Geophysics (HIG)) and ODP leg 112 was drilled. As Peru is an excellent location to study gas hydrates, another point of emphasis of GEOPECO is the investigation of methane gas hydrates by seismic techniques with high resolution. The project GEOPECO aims at essential improvement and expansion of the already available data of the Peruvian continental slope to get a more detailed image of the structure of the Peruvian continental margin, to enable a better characterization of deeper tectonic-lithological structures, to estimate the amount of material subducted to greater depth, to determine the geometry of the downgoing plate and to identify coupling effects between mechanics at the plate boundary and seismic events by observation of natural seismicity. The heat flow at the lower continental slope is to be determined through the depth of the BSR. A comparison with the heat flow measurements of GEOPECO may give information about efficient advection.

ACM-5

BANGLADESH: EXAMPLE OF AN ONSHORE CONTINENTAL/OCEANIC TRANSITION

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The India plate separated from the Antarctica and Australia plates during the early Cretaceous. After continental breakup, the India plate drifted northwards, colliding with the Burma platelet during the Oligocene and converging against the Tibet plate during the Miocene, forming the Himalayas. Bangladesh is located at the junction of these three plates: India to the west, Tibet to the north, and Burma to the east. Bangladesh therefore has been a passive margin from breakup until Oligocene time when the eastern portion of Bangladesh underwent collision with the Burma Platelet forming a foreland basin (Surma basin). A magnetic map of Bangladesh shows a prominent negative anomaly in Bangladesh oriented southwest-northeast, separating the Indian Shield Platform to the northwest from the Bengal and Surma basins to the southeast. This negative magnetic anomaly corresponds on seismic reflection profiles to a broad tectonic hinge zone, separating shallow continental crust with rift systems to the northwest from deeply buried crust to the southeast. Above the top of the continental crust, there is a wedge of southwest dipping reflectors in the tectonic hinge zone. This wedge is often truncated at its northwestern end, presents mounded features at its top, and has higher amplitude reflectors. It is possible that this wedge represents seaward dipping reflectors (SDRs) characteristic of Initial Oceanic Crust (sensu Talwani and Abreu, 1999). Similar SDRs attached to tectonic hinge zones and coinciding with negative magnetic anomalies are present in the North and South Atlantic. The SDRs wedge would represent the first stage of Oceanic Crust Formation and would be located at the Continental/Oceanic Transition, implying that most of the Bengal and Surma basins would have Oceanic Crust as basement.

ACM-6

SEISMIC IMAGING AND DYNAMIC EVOLUTION OF THE INDIAN PLATE BOUNDARY OFF PAKISTAN

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The NE-SW trending Murray Ridge in the central part of the northern Arabian Sea links the Owen fracture zone to the south with the Ornach-Nal fault to the north. This fault system separates the Indian and Arabian plates, and the Indian and Eurasian plates, respectively. The origin and evolution of the Murray Ridge and the crust beneath the Indus fan to the east is poorly understood. A grid of 2-D seismic profiles obtained by the German R/V SONNE off Pakistan are used to image the crustal structure and to develop a geodynamic model of the Indian plate boundary.

Sequences of dipping reflectors north of the Murray Ridge at the transition to the Oman abyssal plain (reflectors dipping to north) and south of the ridge around 20°30'N/64°30'E (reflectors dipping to SW) are interpreted to consist of flood basalt. They are related to early continental break-up and indicative of the ocean-continent boundary of the Indian paleo-continental margin. The acoustic basement of the Murray Ridge exhibits block faulting typical of thinned and rifted continental margins. Unconformities in the sedimentary pile above the basement indicate multiple phases of uplift.

Transtension along the Murray Ridge led to volcanic activity (Jinnah seamount), and to the development of the NE-SW trending Dalrymple Trough where more than 8 km of clastic sediments have been accumulated in the Neogene. Below the distal part of the Indus fan a basement ridge occur. Its internal reflection pattern and structure support the continental origin of the ridge which is truncated on either side by erosion.

ACM-7

CRUSTAL TYPES IN THE ACTIVE CONTINENTAL MARGINS (OCHOTSK SEA-THE PACIFIC ZONE)

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In the transition zone between the Okhotsk Sea and the Pacific, Deep Seismic Sounding (DSS) data were obtained in the 60-80s and principal differences have been determined in crustal models between the continent, the sea, the volcanic arc and the ocean. But methodological differences in the data interpretation made often impossible to note real differences in the crustal structure. To make the results more objective a reinterpretation of all data were carried out with modern methods. A comparison of the observed wave fields show that in the continental part the thick (30-35 km) crust have three layers with velocities 6.0, 6.5 and 7.0 km/s. In the Okhotsk Sea the crust is thinner (25 km) and has no the lower high velocity layer. In the South Okhotsk basin the sediment thickness reaches 10 km and the consolidated crust with seismic velocities around 7.0 km/s is only 10 km thick. This crust is an intermediate type between the continental and the oceanic ones. In the oceanic area the wave fields have shown three refractions to be clearly identified at the secondary arrivals. Their velocities are the same as of the first arrivals in the continental areas: 6.0, 6.5 and 7.0 km/s. Distinct differences were marked in the Moho wave pattern. In the sea the high amplitude many-phases wide-angle reflections are observed, but the Moho refractions are usually weak and difficult to trace. In the ocean the Moho reflections were found to be very random and of a simple waveform, in the contrary the refractions are of a high amplitude and have long interval of registration (400 km).

ACM-8

CRUSTAL SECTION ACROSS NORTHERN HONSHU AEC AS REVEALED FROM ONSHORE AND OFFSHORE WIDE-ANGLE SEISMIC PROFILES

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An extensive wide-angle seismic experiment across the Northern Honshu Island was conducted in 1997. A 600-km profile line was set from the Japan Trench to the Sea of Japan via northern Honshu. Combined analysis on onshore and offshore seismic data provided a new image of crustal section across the volcanic arc. In the forearc side, the crust is about 20 km in thickness, overlying a uppermost mantle with a Pn velocity of 8 km/s. The subducted Pacific Plate is well imaged down to 20-30 km. The crustal structure under Northern Honshu clearly recorded deformation under the extensional tectonics associated with the Miocene backarc spreading. The eastern part of Northern Honshu, which remains a stable forearc block, has a less deformed upper crust of higher velocity (6.0-6.1 km/s) and a reflective lower crust. The western part of Northern Honshu is covered with highly deformed Tertiary sedimentary layers. The upper and lower crustal velocities are 5.8-5.9 and 6.6-6.8 km/s, respectively. The Pn velocity under the arc is very low (7.5-7.6 km/s). The crustal thickness attains its maximum of 35 km near the present volcanic front, Westward crustal thinning begins at the eastern edge of the backbone range, almost coincident with the eastern limit of Miocene faults. The crustal thickness decreases to 16-17 km at about 250 km west from the volcanic front. The Pn velocity increases to 8.0 km/s in the backarc side. This velocity change occurs in a rather narrow area of 20-30 km width just west of the Honshu Island.

ACM-9

CRUSTAL SECTION OF ARC-ARC COLLISION ZONE, HOKKAIDO, JAPAN, FROM SEISMIC REFLECTION PROFILING

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A seismic reflection survey was conducted in the eastern flank of the Hidaka Mountains under the multidisciplinary project of the 1999 Hokkaido Transect Project. The aim of this survey is to provide deep crustal image of the collision zone, which is an important key for understanding the evolution/deformation process of the island arc crust. On a 43-km profile, 870-channel receivers were deployed and 25 dynamite shots with a charge size of 40 kg were detonated. In addition, 3-channel offline recorders were deployed with 150m-interval on the westward extension of the profile. Preliminary analysis imaged two distinct reflectors forming a wedge-like pattern in t.w.t. of 4-9 sec under the western part of the profile,. The upper reflector, which dips eastward, is probably continued westward to a very strong reflection beneath the Hidata Mountains found in the former experiment by Iwasaki et al. (1999). The lower events, on the other hand, show a flat or gently westward dipping pattern. These two reflections almost merge in the eastern part of our profile to form a single reflective zone in the further east. This image strongly suggests the crustal delamination occurring within the crust of Kuril Forearc.

ACM-10

SEISMIC TOMOGRAPHY BENEATH HIDAKA MOUNTAINS, HOKKAIDO, JAPAN, FROM DENSE SEISMIC NETWORK DATA

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The Hidaka Mountain region in Hokkaido, Japan is characterized by the collision between two island arcs, that is, the Northern Honshu and the Kurile Islands arcs (Kimura, 1981; Seno, 1985; Moriya et al., 1997). Little was known on the processes of uplifting and deformation in and around the mountain region. Dense seismic network was constructed in August 1999 to research the Hidaka Mountain region. The area of this network is 250km X 250km including 130 seismic stations. Each seismic station consists of a 1-Hz seismometer with three components (Up-Down, North-South and East-West). Waveform data are sampled by 100 Hz, transmitted through a communication satellite or a telephone line, and recorded in real-time at one of data center in Hokkaido University. The detection of earthquake, the reading of arrival times of P- and S-waves, and the calculation of hypocenter has been conducted automatically by a computer. After getting the preliminary results from the computer we carefully checked the readings of arrival times and selected only data with a very sharp onset for the seismic tomography. The seismic network has a large potential to give an important key to understanding the seismotectonics for the Hidaka Mountain region. We should investigate accurately the hypocenters and the focal mechanisms, the 3-D P- and S-wave velocity structures and the 3-D Qp and Qs structures. In this study we present a preliminary result from the 3-D seismic tomography for P-wave velocity in and around the Hidaka Mountain region.

ACM-11

SEISMIC REFRACTION/WIDE-ANGLE REFLECTION PROFILING ACROSS ARC-AEC COLLISION ZONE, CENTRAL HOKKAIDO, JAPAN

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In 1999, an extensive seismic refraction/wide-angle experiment was conducted in Hokkaido, Japan. A 227-lm long E-W profile line was set to cross the Hidaka Mountains, which has been formed by the collision between Kuril Forearc and the Northeast Japan Arc since Middle Miocene. This experiment was aimed at elucidating the large-scale crustal deformation associated with this collision process. Six shots with 100-700 kg charges were observed on 297 portable digital recording systems. Preliminary data processing indicates that more than 2-3 km thick sedimentary cover is except under the Hidaka Mountains, where a 6 km/s material is almost outcropped. A very strong later phase observed in eastern part of the profile corresponds to the wide-angle reflection within the colliding Kuril Forearc. A seismic reflection survey performed in the central part of profile shows this reflector can be traced westward to the eastern flank of the Hidaka Mountains to form a wedge-like pattern, indicating the delamination structure associated with the collision. Remarkable seismic attenuation under the Hidaka Mountains also indicates high structural inhomogeneity of the collision zone.

ACM-12

RELATION BETWEEN P-WAVE VELOCITY AND THERMAL STRUCTURES IN THE CRUST BENEATH JAPANESE ISLAND ARC

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P-wave velocity and thermal structures beneath Japanese island arc are compared. P-wave velocity structures were obtained by deep seismic profilings conducted by Research Group for Explosion Seismology (RGES). The thermal distribution in the crust are determined from thermal gradient data which is compiled by Geological Survey of Japan, shows that the temperature of the upper surface of the lower crustal layer correspond to 500° C which is higher than those of continental crust about 200° C. Beneath non-volcanic western Honshu, the temperature of the top of the lower crustal layer is about 300-350° C which is almost the same as those of continental crust. Recently we found crustal intermediate layers of which P-wave velocity is about 6.4 km/s which is intermediate value of those of upper and lower crust, beneath active island arc regions. The intermediate layers are lying in the depth range between 10 and 20 km, just beneath out side regions of the volcanic front of Hokkaido, Northern Honshu and Northern Kanto. The temperatures of upper surface of the intermediate layers take values of about 500 C which are the same as those of lower crust and suggest that the intermediate layer is composed from transient materials in which granitic materials changing into mafic one by hydrothermal and magma processes.

ACM-13

SHALLOW SEISMIC PROFILING IN THE TANAKURA TECTONIC LINE, NORTHEAST HONSHU ARC, JAPAN

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The Tanakura tectonic line (TTL) is a shear zone bounded by two parallel marginal faults 3 km apart and it can be traced for 60 km north-northwest along strike in northeast Honshu arc, Japan. This zone was sheared in pre-Tertiary age by left lateral faults and the reactivation of them in Miocene age developed several sedimentary basins mainly to the west of the zone. Opinions are diverse concerning the formation process of these basins. One is that they are grabens formed by normal faulting under extensional stress field, and the other is that they are strike slip basins formed by left lateral movement of faults.
The seismic source was a Mini-vibrator truck with 16 s of 10-100 Hz sweep at 10 m interval and the seismic data were recorded with 144 channels by 10 m group interval of 10 Hz geophones. The CMP stacked section is 6 km long, covering the Daigo area, the western marginal fault and the shear zone. Basin structures are recognized in the Daigo area and shear zone, whose depths are 2400 m and 1300 m, respectively. Near the western marginal fault, reflectors discontinue and dip gently eastward, but the fault plane is not clear. A flower structure may be imaged there in the seismic section. In this case, lateral movement of the faults in Miocene age is supported and TTL has something with the Japan Sea opening.

ACM-14

LOWER CRUSTAL REFLECTORS AND AN EARTHQUAKE SWARM IN THE NORTHERN MIYAGI AREA, NORTHEASTERN JAPAN: TWO DIFFERENT EFFECTS OF WATER

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The northern Miyagi area is known as one of the most active earthquake swarm areas in the northeastern Japan, where the hazard earthquake "1962 Miyagi-ken Hokubu (Northern Miyagi Prefecture) Earthquake (M6.5)" occurred. We conducted deep seismic profiling experiments to clarify the crustal structure of this seismically active area. The seismic lines are totally 35km long. Sources are 20-30kg explosives and four 17.5-ton vibrators.
The obtained data show clear images of so-called "reflective lower crust" even in shot gathers. This is very rare case, as the lower crust is usually not so reflective in Japan. The reflective lower crust is remarkable to the east of the earthquake swarm area, while it is vague beneath the swarm area. This can be explained by two different effects of water as follows: Remarkable reflectors correspond to trapped water around 450°C isotherm. In the earthquake swarm area, repeated activities like the 1962 earthquake broke this kind of trapping structure, then water can migrate upward. Therefore lower crustal reflectors become vague and the migrated water triggers microearthquakes around the swarm area.

ACM-15

DEEP STRUCTURE BENEATH THE EASTERN SHIKOKU, SW JAPAN, REVEALED BY SEISMIC REFRACTION/WIDE-ANGLE REFLECTION PROFILING

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In the summer of 1999, we conducted a highly dense, onshore-offshore seismic experiment around the eastern Shikoku and the Nankai trough off Shikoku, SW Japan. On shore 93 land seismic stations were deployed on a 165-km-long line in the north-south direction. The interval of the station was about 1-2 km. Three explosives were fired as controlled seismic sources. We obtained high signal-to-noise ratio explosive data along the entire length of the profile. Refracted waves in the curst and wide-angle reflected waves from an intracrustal boundary, subducting Philippine Sea plate and the Moho beneath the northeastern Shikoku can be observed. Analyzing these refracted/wide-angle reflected waves, we could obtain detailed 2-D model beneath the eastern Shikoku. The uppermost crust is covered with a surface layer with velocities of 4.0-5.0 km/s. A velocity of the uppermost crust is 5.7km/s. Beneath the coastline, the top of the subducting Philippine Sea plate is located at a depth of about 20 km and a dip angle is about 14 degree. The island arc Moho is about 30 km deep beneath the northeastern Shikoku.

ACM-16

SEISMIC REFLECTION PROFILINGS FROM THE MEDIAN TECTONIC LINE (MTL) TO THE ACCRETIONARY COMPLEXES, KII PENINSULA, SOUTHW3ST JAPAN

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The typical structure in the outer part of the SW Japan island arc occurs in the Kii peninsula; Cretaceous low P/T metamorphic belt (Ryoke Belt), MTL as a large fault with a long and complicated history, Cretaceous high P/T metamorphic belt (Sambagawa Belt), Jurassic accretionary complexes (Chichibu Belt) and Cretaceous and Paleogene accretionary complexes (Shimanto Belt) from north to south. These belts, except for the Ryoke Belt belonging to the Inner Zone, compose the Outer Zone of SW Japan. Neogene accretionary complexes may occur under the sea further south. The Philippine Sea Plate subducts beneath this arc system along the Nankai trough. For the last ten years, seismic reflection profilings have been made for both shallow and deep targets; Kasahara et al. (1998) for the deep MTL, Yoshikawa et al. (1992) for the shallow MTL, Kawamura (2000) for the very shallow MTL, Matsuoka et al. (2000) and Ito et al. (2000, this symposium) for the accretionary complexes, and Yoshii et al. (1991) for the whole crust and the subducting plate. Although each profile is partial in the whole arc system, they are extremely useful for reconstructing the crustal structure of the Outer Zone from the MTL to the accretionary complexes. In the poster session, we will combine them into a temporary profile of the crustal structure.

ACM-17

SEISMOGENIC LAYER AND CRUSTAL STRUCTURE IN SOUTHWEST JAPAN

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Depths of the seismogenic layer have been well determined from the dense network of microearthquake observations in central Kinki and western Chugoku district, southwest Japan. Whereas, P-wave velocity structure has been derived from refraction and wide-angle reflection explosion experiments along some profiles. The later revealed that the lower crust in the island arc is strongly reflective. Besides, The reflective layer is roughly concordant with those determined from receiver function methods by use of wide-range seismograms. Comparing these results, we found that the lower cutoff depths of seismicity roughly coincide with or slightly deeper than the top of the reflective lower crust in most of the regions. However, below the source area of the 1995 Kobe earthquake and eastern Chugoku district, the cutoff depth crosses the top of the reflective lower crust. This suggests that the lower cutoff of the seismogenic layer is not caused by the velocity structure or the difference of rock types, but other factors, such as temperature and pore pressure.

ACM-18

STRUCTURAL VARIATION ALONG THE JAPAN TRENCH OBTAINED BY MULTICHANNEL AND WIDE-ANGLE ONSHORE-OFFSHORE SEISMIC DATA

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The Japan Trench is a plate convergent zone where the Pacific plate is subducting below the Japan Islands. In northern part of the Japan Trench, horst and graben fault structures are well developed. And there are many seamounts on the Pacific plate in the southern part of the Japan Trench. Many earthquakes are occurred around the Japan Trench caused by plate convergence. Most of these earthquakes are thought to be interplate thrust earthquakes (e.g. Yoshii, 1979). But hypocenters are distributed heterogeneously along the Japan Trench. Earthquakes having magnitude grater than seven were frequently occurred off the Sanriku region, which is northern part of the Japan Trench, but very few large earthquakes happened off the Fukushima region, which is southern part of the Japan Trench. Background seismicity in the Fukushima region is more active than that of the Sanriku region. Since 1997, we have conducted seismic experiments around the Japan Trench to understand the mechanism of large earthquakes using multichannel seismic reflection (MCS) and ocean bottom seismographic (OBS) data. In the Japan Trench fore arc region, two different characteristics are observed between the Sanriku region and the Fukushima region: variation in thickness of interplate subducting sedimentary layer, and P-wave velocity of mantle wedge. The interplate subducting sedimentary layer is observed by the MCS profiles near the trench axis and suggested by the OBS/land data as the low velocity zone. This sedimentary layer is similar to the interplate stratified layer proposed by von Huene et al. (1994). The thickness and velocity is different between the Sanriku and the Fukushima. P-wave velocity of the mantle wedge is 8.0 km/s at the Sanriku region, but 7.4 km/s at the Fukushima region. These characteristics may be related to the heterogeneous hypocenter distribution along the Japan Trench.

ACM-19

CRUSTAL STRUCTURE OF FUJIHASHI - KAMIGORI PROFILE, IN THE WESTERN PART OF HONSYU, JAPAN, BY REFRACTION AND WIDE-ANGLE REFLECTION EXPERIMENT

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Refraction and wide-angle reflection experiment to research the crustal structure of Fujihashi - Kamigori profile, in the central to western part of Japan, was carried out by the Research Group for Explosion Seismology of Honsyu, Japan. The profile was located in E-W direction and in the non-volcanic region. The profile was crossing the Hanaore Fault at the western side of Lake Biwa. The profile was about 220 km in length, and consisted of _$B#4_(B shots and 137 vertical component seismometers. First arrivals of P-wave for all shots are much clear up to about 120 km from each shot. The later phases that reflected from the lower crust were observed clearly. First arrivals of S wave were observed clearly for shot-3 and shot-4. The crustal structure of P wave velocity (Vp) is constructed by using the ray-tracing method. The crust is divided into three parts, and is covered with thin sedimentary. The first layer is about 6 km in thickness and its Vp is 5.6-6.0 km/s. The second layer is 15-19 km in thickness and its Vp is 6.05-6.45 km/s. The third layer is 12-15 km in thickness and its Vp is 6.6-6.8 km/s. The Moho depth is about 37 km and Vp of the upper mantle is 7.85 km/s. It is clarified that the crust of this profile is similar to continental crust and different from the active island arc such as Tohoku and Hokkaido, in the northern part of Japan.

ACM-20

CRUSTAL TRANSECTS OF THE NANKAI TROUGH SEISMOGENIC ZONE - SUMMARY OF RECENT JAMSTEC SEISMIC STUDIES -

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Coseismic rupture zones of great earthquakes along the Nankai Trough have been well studied by many fault models. It is well known that the rupture zone of the 1944 Tonankai earthquake is located southeast off the Kii Peninsula, while the 1946 Nankai earthquake had ruptured westward from south off the Kii Peninsula to off the Shikoku Island. However, little is known about factors that control the size of rupture zone. Structural image of the entire rupture zone gives important and fundamental information to understand the condition of seismogenic zone, because the rupture zone is one of indicators that defines the seismogenic zone of subduction zone. To investigate similarities and differences in deep crustal structures between the different rupture zones of the 1944 and 1946 great earthquakes, and unruptured area where is located just west of the 1946 rupture zone, a wide-angle seismic survey was performed. To obtain the entire image of the seismogenic zone, three profiles was selected to cross or around the presumed coseismic rupture zones from the ocean to the land. We derived crustal structures mainly by using ocean bottom seismographic data. Our crustal models appear characteristic for a subducting oceanic crust, a Neogene-Quaternary accretionary prism bounded by the island arc crust. The subducting oceanic crust traced down to 30-35 km shows that the depth of its surface at the down-dip limit of each rupture area is about 23 km, where does not reach the forearc mantle. However, the subduction angle of the 1944 rupture zone (~11°) is steeper than that of the 1946 rupture zone (~7°). Furthermore the distance of the subducting oceanic crust / Neogene-Quaternary accretionary prism contact zone is proportional to the scale of the presumed rupture area (the 1946 Nankai rupture zone: 70 km, the 1944 Tonankai rupture zone: 50 km, unruptured zone: 20 km).

ACM-21

DEEP TO SHALLOW SEISMIC REFLECTION PROFILING ACROSS THE BACKBONE RANGE OF NORTHERN HONSHU, JAPAN

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Crustal structure, especially the geometry of seismogenic fault is a key to understand on-going active tectonic processes and to estimate the future_$B%f_(Bs destructive earthquakes. A 50-km long deep seismic reflection profiling was carried out across the Ou backbone range in Northern Honshu, which bounded reverse active faults. We successfully obtained the deep crustal image using dynamites (< 500 kg) and vibroseis trucks. The deep geometry of active reverse faults is continuously mapped by shallow to deep seismic reflection profiling down to mid-crustal detachment. The top of reflective lower crust (TWT 4.5 sec) nearly coincidences with the bottom of seismogenic layer and mid-crustal detachment is estimated just below the bottom of seismogenic layer. The backbone range has reflective lower crust similar to continental crust. The seismic reflection profile clearly demonstrates that the 30-km-wide Ou backbone range was produced by reverse faulting bounded both end of the range, and forms a pop-up structure. In the shallow part of the crust revealed by shallow seismic profiling across the active faults, thin-skinned tectonics is dominated and fault-related folds are commonly observed. The analysis using balanced cross section of shallow geologic structure is useful to estimate the deep geometry of seismogenic fault. The estimated dip angle for deeper extension of active fault well accords to the image obtained by deep seismic reflection.

ACM-22

ACTIVE GROWTH FAULT-BEND FOLDING IN THE FRONTAL PART OF HIDAKA THRUST SYSTEM, HOKKAIDO, JAPAN

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Due to the contraction of Eurasian and North American / Okhotsk plates and west ward motion of the Kuril fore arc sliver, a NS trending fold-and-thrust belt was formed in the western part of Hokkaido axial zone. Due to the collision of two plates, crocodile structure associated with the delamination of lower crust in the Kuril arc has been formed since the mid-Tertiary. This movement also produced the west-vergent thrust system in the NE Japan crust associated with the westward migration of thrusting. To reveal the activity of the thrusting in late Quaternary, high resolution shallow seismic reflection profiling was undertaken across the frontal part of the thrust system. With the reprocessed seismic data obtained by oil exploration, the structure of active growth fault-bend fold is clearly demonstrated associated sedimentary structure produced by global sea level change. Using the balanced cross section the evolution of frontal part of the Hisaka thrust system is clearly revealed. Geologically estimated vertical averaged growth rate of the anticline is 0.4 cm/ka for past 3 million years and nearly the same rate is obtained for last 40 thousand years, showing the constant rate of shortening. Thus, the crocodile structure beneath the axial part of Hokkaido is still active.

ACM-23

CRUSTAL STRUCTURE, EVOLUTION AND ACTIVITY OF NORTHERN HONSHU, JAPAN: NORTHERN HONSHU TRANSECT- 97, 98 RESULTS

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The northern Honshu is a classical example of a trench-arc-back arc system. A multidisciplinary project to reveal the crustal structure and activity, including a 600-km long refraction/wide-angle reflection profiling, a 50-km long reflection profiling across the Backbone Range, observation of natural earthquakes by about100 of temporal and permanent seismic stations and morphotectonic research to detect the long-term behavior of crustal movements, was carried out from 1997 to 1998. The resultant crustal structure by wide-angle reflection across the northern Honshu is well explained by the factors of the Miocene crustal stretching associated with the opening of the Sea of Japan and igneous underplating since the late Miocene. Deep seismic profiling across the Backbone Range revealed the pop-up structure bounded by reverse active faults, which are produced by the subsequent EW compression since the late Pliocene. Detailed image of seismic tomography using natural micro-earthquakes suggests that the deeper extensions of active faults are demonstrated as zones showing lower P-wave velocity. General structure and active tectonics are strongly controlled by the Miocene back arc spreading and inversion tectonics; Miocene normal faults reactivated as reverse faults.

ACM-24

CRUSTAL STRUCTURE ALONG THE CENTRAL SUNDA ARC

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A series of geoscientific investigations on the Sunda Arc off Indonesia contributes new insights into the structure and geodynamics of the subduction zone at the transition from frontal to oblique collision. The Sunda Arc plate boundary is characterized by the variation of different geophysical parameters, most strikingly the relative direction of kinematic motion of the Indian plate as it subducts beneath Eurasia. A grid of marine seismic wide-angle profiles including four wide-angle strike lines were acquired in 1999. The main profiles coincide with multichannel lines across the subduction complex. Initial traveltime analysis on the wide-angle data reveal rather high upper crustal velocities within the outer arc high. Lateral velocity variations across the wedge are significant, though the velocity field is generally smoother on profiles characterized by oblique collision. The Moho reflection of the downgoing slab is present on most of the data and could be verified to a depth of more than 25 km underneath the accretionary complex. The high quality multichannel data displays a coverage of 3000%. Despite the extremely rough seafloor topography, reflectivity is high. Initial results from a combined interpretation of the reflection and refraction data is presented which constrain the crustal structure along the central Sunda Arc subduction zone.

ACM-25

VELOCITY INHOMOGENEITIES OF EARTH'S CRUST AND UPPER MANTLE IN KAMCHATKA REGION

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The 3-D velocity model of Earth's crust and upper mantle was constructed by one of the seismic tomography methods. 600 regional events since 1992 to 1998 with high accuracy epicenter coordinates estimation and very clearly detected first arrivals of P and S waves were chosen. The main regularities in distribution of velocity inhomogeneities in Earth's crust and upper mantle for the region of eastern Kamchatka and Avachi, Cronodsky and Kamchatsky bays were determined on the base of velocity delays distribution of Vp and Vs and relation Vp/Vs for 3 layers model of lithosphere (0-20, 20-35, 35-90 km). The Earth's crust faults are determined, their spreading and depth is shown. The great difference between deep structures of southern and northern parts of Kamchatka in the area of contact with Aleutskaya arc is established.

ACM-26

UNDERPLATING AND DEWATERING IN THE NANKAI SEISMOGENIC ZONE

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We have conducted extensive seismic experiments composed of multichannel seismic reflection (MCS) and ocean bottom seismographic (OBS) studies to understand the nature of the Nankai seismogenic zone off Shikoku since 1997. In this paper, we would like to present the MCS data and discuss tectonics, hydrogeology, and furthermore implication on the updip limit to the seismogenic zone in the Nankai convergent margin off Shikoku. Based on reflection characteristics, we could identify three major seismic reflection units which are denoted "A", "B", and "C" from top to bottom: Unit A (post-Miocene accretionary units and the sedimentary cover), Unit B (Miocene to Pliocene Shikoku Basin sediments), Unit C (pre-Miocene basaltic rocks of the Shikoku Basin oceanic crust). It is remarkable that Unit B appears to thicken landward; 200-300 m seaward to 1000-2000 m landward. We interpret this unit as an underplated layer which may be formed by duplexing related to decollement step-down. The topmost reflector of this unit, which actually corresponds to interface between overriding Unit A and Unit B, shows a variety of amplitude change along the MCS profile normal to trench axis. Therefore, we can divide the accretionary wedge into three different zones from deformation front, according to amplitude character of the reflector; apparent decollement reflector (ADR) zone, low amplitude reflector (LAR) zone, and deep-seated strong reflector (DSR) zone. Especially, we could observe very strong, deep-seated reflector with positive polarity along the basal decollement in the DSR zone. One possible explanation for origin of the DSR is diffusive flow model to be associated with dewatering of clay minerals that occupy most of Unit B, during smectite-to-illite transformation (e.g., Hyndman et al., 1997). Fluid derived from the dewatering, may migrate upward as diffusive flow, leading to density reduction of accretionary sediments immediately above the DSR and thus forming the DSR. We propose that position of the DSR is apparently related to the updip limit to the seismogenic zone.

ACM-27

DEEP SEISMIC REFLECTION EXPERIMENT WITH A HIGHLY DENSE ARRAY OF SEISMOGRAMS, NORTH OF THE MEDIAN TECTONIC LINE (MTL), SHIKOKU, JAPAN

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A 12-km long deep seismic reflection experiment was successfully conducted for the Median Tectonic Line (MTL) and its underlying structures with the following unconventional specifications. (1) Sparse shot spacing: 2 shot points located at both terminations of the seismic line. (2) Relatively strong shots: 500- and 100-kg dynamites. (3) A highly dense array of seismograms: 50-m interval. The result exhibits prominent imaging of deep events: N-dipping events at about 3.0 and 4.5 sec. at the southern end of the line, and 6.5 sec., and the Moho (?) at 11.5 sec. The shallower and the deeper events of the former are continuously connected with the MTL and the fault between the Sambagawa metamorphic rocks and the Cretaceous Shimanto group, respectively, in the profile across the MTL by conventional specifications (Ito et al., 1996). This result gives us the convincing evidence that the MTL dips at about 40 to 50 degrees northward at depth. Even such unconventional specifications as this experiment, if a highly dense array of seismograms is equipped, can produce scientifically significant results. Thus this experiment also provides useful information for preparing less expensive profilings.

Continental Accretion and Collision Monday 19th to Tuesday 20th June

CAC-1

IMAGING AN EVOLVING THRUST SHEET IN THE BOLIVIAN OROCLINE: FROM 2-D SEISMIC LINES TO A 3-D MODEL OF AN OBLIQUE DEFORMATION FRONT

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The Central Andes are part of an active continental margin system, though the style of deformation on their eastern front resembles a foreland fold-and-thrust belt, as in continental collision zones. In the Bolivian Orocline the general Andean structural strike turns from NW-SE to N-S. Also, the northern limb of the bend comprises a WNW-ESE to E-W trending segment, commonly explained by thrusting on an oblique ramp. There, the structure of the youngest, most recently detached thrust sheet is analyzed in detail to unravel the kinematic evolution of this economically important area, and to enlighten the deformation processes at an oblique deformation front. A dense grid of 2-D seismic lines from hydrocarbon exploration industry is used to develop a 3-D structural model allowing the spatial resolution of key structures.

The south-dipping Brazilian Shield provides a quasi-oblique ramp for the onlapping wedge of sediments, which are thrusted NE-wards. Along the WSW-ENE trending deformation front, the structural style varies between two end members. The eastern tip of the thrust sheet is dominated by reverse faults with associated folds while the main part of the thrust boundary resembles a transfer zone comprising WSW-ENE trending small-scale folds and minor strike-slip faults. This deformation pattern indicates an intensified strain partitioning caused by the interaction of contraction direction and basement topography. Thus, the shape of the Brazilian Shield seems to control the structural evolution of the Bolivian Orocline.

CAC-2

DEEP SEISMIC REFRACTION EXPERIMENTS IN 1999 ON THE MIZUHO PLATEAU, EAST ANTARCTICA: THE SEAL PROJECT

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"Structure and Evolution of the East Antarctic Lithosphere (SEAL) Geotransect Project" have been caring out from 1996-1997 austral summer season in a framework of the Japanese Antarctic Research Expedition (JARE). The main target of the project is to obtain crustal section in the different geological terrain from the Archean to the early-Paleozoic ages by deep seismic refraction/reflection probing between the Western Enderby Land and the East Queen Maud Land, East Antarctica. From the east to the west, several crustal structure and evolution process are to be compiled from the Napier Complex (Archean) , the Rayner Complex (late-Preterozoic), the Lutzow-Holm Complex (Paleozoic), the Yamato-Belgica Complex (Paleozoic) and the Sor-Rondane Mountains (late-Preterozoic) by both geophysical and geological surveys. In the austral summer season on 2000, deep seismic refraction/reflectio!!JARE-41 as the first explosive experiment. More than 160 plant-type 2 Hz geophones were set along the Mizuho route 200 km in length. A total amount of 3,300 kg dynamite charge at 7 explosives along the route give the information concerning the deep velocity structure of a continental margin in the Pareozoic Luztow-Holm Complex. The investigation revealed that the Moho depth was about 40 km with the velocity of the surface layer, middle crust, lower crust and mantle, about 6.0, 6.4, 6.9 and 7.9 km/s, respectively. Reflective layers in the lower crust as pointed out by JARE-21 seismic data are also able to be detected by wide-angle reflection analysis. The depth patterns of reflective layers on the Plateau can be related to the Bouguer gravity anomalies and are useful for studying evolution of the Lutzow-Holm Complex. In this presentation, we will give the outline and scientifi

CAC-3

HISTORY OF THE TRANS-HUDSON OROGEN FROM SEISMIC SIGNATURES

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Integrated analyses of the 2000 km reflection and comparable length refraction data of the THO reveal complex laterally changing convergence processes along the western margin of the orogen. In the south and west, the patterns of reflectivity, which permeates the entire crust, outline cratonward thrusting and prominently brittle deformation characteristics of low temperature thermal regimes. To the north-northwest, the reflection architecture is indicative of lithospheric deformations associated with higher crustal temperatures, indentation and more progressive subduction. The most northerly reflection profile exhibits the remnant of the latest stages of the convergence and subduction, suggesting a time variant south to north drifting convergence process. The involvement of the Moho as a major basal decollement zone, in the final stages of the collision, is demonstrated through its spacial variant seismic signal characteristics. The structural variations on this crust-mantle interface mark the remnant of intra-oceanic subducting plates.

CAC-4

THREE-COMPONENT RECORDING OVER THE CHEYENNE BELT, SE WYOMING

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The Cheyenne belt is an ancient crustal-scale shear zone separating Archean Wyoming craton to the north from accreted Proterozoic arc terranes to the south. For the past two years, a multidisciplinary study of the area was undertaken with the goal of imaging Proterozoic accretion boundaries and creating a well-constrained model of tectonic evolution of the region. As a part of the CDROM project (Continental Dynamics Rocky Mountains Transect), an industry seismic crew acquired vertical-component 2D seismic data covering the area from near Rawlins, WY to south of Steamboat Springs, CO. They also acquired three-component 2D seismic data for the second half of the line. For every shot, vertical-component data were recorded on 1000 stations with 25-meter spacing. However, the three-component data were recorded only on 12 three-component stations with 50-meter spacing, and data collected by University of Arizona as a piggy-back experiment were recorded on 20 three-component stations with 25-meter spacing. Since the three-component spreads were not moved often and consisted of a small number of stations, the multicomponent data do not provide continuous coverage of the subsurface and have low fold. However, these data provide the only shear-wave information along the main line, and the opportunity to analyze Poisson's ratios and compositions. As the first stage of processing and interpretation, a P-wave velocity model for the subsurface was created based on the vertical-component data recorded by the industry crew. Since these data are more complete and provide a continuous coverage of the subsurface the P-wave velocity model was used as a reference. Also, P- and S-wave velocity models were created based on the multicomponent data. Three-component recording captured the complete wave field including P-, SV-, SH-, and PS-waves. Analysis of these arrivals permits evaluation of crustal anisotropy and rock properties.

CAC-5

CONTINENTAL DYNAMICS - ROCKY MOUNTAIN PROJECT (CD-ROM): DEEP SEISMIC REFLECTION PROFILING EXPERIMENTS IN THE WESTERN U. S.

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A major element of the Continental Dynamics - Rocky Mountain Project (CD-ROM) is two ~200 km long deep seismic reflection profiles that were recorded during the fall of 1999. The northern profile targets the Cheyenne belt, a Proterozoic suture that lies approximately along the Colorado/Wyoming border. The southern profile targets the Jemez lineament in northern New Mexico. This enigmatic feature may also be related to a major Proterozoic tectonic boundary. A contract crew was employed and provided data acquisition parameters that included Vibroseis sources with a minimum total peak force of 200,000 lbs., 1000 active recording channels, 25 s records, 25 m group intervals, and 100 m source intervals. Long offset recordings were independently obtained by our group.

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CONTINENTAL DYNAMICS - ROCKY MOUNTAIN PROJECT (CD-ROM): DEEP SEISMIC REFLECTION PROFILING EXPERIMENTS IN NORTHERN NEW MEXICO, UNITED STATES

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One component of the Continental Dynamics - Rocky Mountain Project (CD-ROM) included the acquisition of a ca. 200 km long deep seismic reflection profile adjacent to the Rocky Mountains Front in northern New Mexico. The profile is targeted at studying Proterozoic accretion of the North American continent and its influence on Phanerozoic tectonics. In particular, the profile targets the Jemez lineament of northern New Mexico, an enigmatic feature associated with Cenozoic volcanism which may also be related to a major Proterozoic tectonic boundary. The seismic reflection data were acquired in November 1999 with Vibroseis sources with a minimum total peak force of 200,000 lbs., 1000 active recording channels, 25 s records, 25 m group intervals, and 100 m source intervals. In addition, wide-angle recordings of the Vibroseis source were obtained for a portion of the line. Here we present preliminary stacked record sections of the results.

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POSSIBLE ORIGINS FOR SEISMIC REFLECTIONS IN THE PROTEROZOIC SOUTHERN GRANITE-RHYOLITE PROVINCE OF TEXAS AND NEW MEXICO, USA

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The question of how the southern margin of the North American craton grew and developed remains essentially unanswered, because Precambrian rocks are buried beneath Phanerozoic strata. Existing studies of the geology and geochronology of the Precambrian subcrop suggest that amalgamation of the southern mid-continent took place 1.8 - 1.6 Ga, and that accretion was followed by intrusion and burial of these terranes by huge volumes of granitic and rhyolitic rocks 1.4 - 1.34 Ga. Regional extension appears to have occurred ~1.25 Ga and then again at ~1.1 Ga, contemporaneous with the Grenville orogeny. Here we present results from reprocessing and interpretation of industry seismic reflection data from the southern granite-rhyolite province of Texas and New Mexico. A major south-dipping structure is associated with the southern edge of the Sierra Grande uplift, and may be related to 1.8 - 1.6 Ga accretion. To the east, abundant high-amplitude reflectors that extend for tens of km and are strongly reminiscent of reflectors interpreted to be mafic sills in the Precambrian shield of Canada are found. Cross-cutting relationships suggest multiple episodes of sill injection.

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SEISMIC REFLECTION PROFILING OF THE CENTRAL ROCKIES FOR CRUSTAL EVOLUTION AND CRUSTAL STRUCTURE: THE CD-ROM PROJECT

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The CD-ROM project involves seismic reflection and refraction profiling, structural geology and geochemistry along the strike of the Rocky Mountains from southern Wyoming to southern New Mexico for crustal evolution from the Archean to the Cenozoic. We report on a 250-km crustal seismic reflection profile recorded in fall 1999 across southern Wyoming and northern Colorado. This represents the first crustal reflection profiling on land in the U.S. in recent years. The target of the profile include the Archean craton of the Wyoming Province on the North; the Cheyenne Belt, a 7-km-thick shear zone marking a crustal suture between Archean and Proterozoic; and several Proterozoic island arc terranes. N-S Laramide structures responsible for the Rocky Mountains are superposed followed by a thermal event and crustal thickening in Cenozoic. Crustal thickness increases from 38 km in the Wyoming province to about 54 km in north central Colorado. The seismic profile was recorded with a 1000-channel system and a 20-km spread. At the north end, abundant reflections are found throughout the crust down to the Moho at 13 s.

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NEW REFLECTION SEISMIC DATA IMAGE THE CRUST AND MOHO UNDER WESTERN SIBERIA

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New deep (20s TWT) near vertical reflection seismic data image the crustal structure and Moho underneath the western margin of the West Siberian Basin. The 100 km long survey runs from near the Ural mountains in the west towards the central part of the basin in the east. This data set is the eastward continuation of a series of reflection seismic profiles shot across the entire exposed part of the Urals orogen at a latitude c. 58°N. Combined analysis of current and previous data shows that the basin deepens eastward from less than 100m, adjacent to the Ural Mountains, to 1 km at the eastern end of the profile. The upper crust below the basin is transparent, but the middle crust shows predominantly W-dipping reflections some of which are traceable into the lower crust. Pronounced sub-horizontal reflectivity (between 10 and 13 s TWT) identified beneath the Urals continues on the new data and we interpret the Moho to be at the base of this reflective package. The data indicate that the Moho starts to become more shallow at the eastern end of the profile.

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THE CRUSTAL ARCHITECTURE OF THE SOUTHERN AND MIDDLE URALS FROM THE URSEIS, ESRU, AND ALAPAEV REFLECTION SEISMIC PROFILES

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The Paleozoic Uralide orogen of Russia is an example of an intact collisional orogenic belt preserved within the Eurasian plate. Although much of the eastern part of the orogen is buried beneath the West Siberian Basin, the URSEIS, ESRU, and reprocessed Russian reflection/refraction profiles, have nevertheless shown the Uralides to be bivergent, with a crustal root along the central axis of the orogen. In the Southern (URSEIS) and Middle (ESRU and Alapaev) Urals, the East European Craton continental crust thickens eastward from ~40 km's to ~48 km's, and is imaged as sub-horizontal to east-dipping reflectivity that can be related to its Paleozoic and older evolution. The suture zone between the East European Craton and the eastern terranes, the Main Uralian fault, is poorly imaged in the URSEIS profile, but in the ESRU and Alapaev profiles it is imaged as a wide zone of east-dipping reflectivity that extends from the surface into the middle and lower crust. The differences in the reflection pattern of the Main Uralian fault between the Southern and Middle Urals may be related to tectonic reworking of the original suture in the Middle Urals. East of the Main Uralian fault, the Magnitogorsk (Southern Urals) and the Tagil (Middle Urals) volcanic arcs show a similar reflectivity pattern in all profiles, in which the upper crust is moderately to weakly reflective, and the middle to lower crust appears as a cloud of diffuse reflectivity with weak west-dipping events in the Tagil arc lower crust. The Moho beneath both arc complexes is poorly imaged in the reflection data, but based on refraction data is thought to reach a depth of 50 to 55 km's. East of the arc complexes, the Uralian structural architecture is dominated by a wide zone of anastomosing strike-slip faulting into which numerous syntectonic Late Carboniferous and Permian granitoids intruded. This area is imaged in the seismic profiles as clouds of diffuse reflectivity interspersed with, or cut by sharp, predominantly west-dipping reflections. In the Southern Urals, the west-dipping Kartaly reflection sequence extends from the middle crust into the lower crust where it appears to merge with the Moho. The boundaries and internal faults of the strike-slip fault system are well marked by aeromagnetic anomalies, allowing them to be correlated between the seismic profiles. We suggest that the Uralide orogen was affected by a significant amount of strike-slip faulting during the Permian that overprinted the earlier collisional features, making it difficult to correlate individual geological units in the reflection seismic profiles from the Southern Urals to the Middle Urals.

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CRUSTAL STRUCTURE AT THE KARELIAN-BELOMORIAN BOUNDARY, BALTIC SHIELD

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In 1999 the CDP observations were carried out along 270 km profile Kem-Uchta, (E-W profile from the White Sea to the Russia-Finland boundary). The profile coincides with a line of the old DSS observations and crosses remarkable tectonic units of the Baltic Shield - a junction zone between the Karelian Protecraton and the Belomorian Mobile Belt. The observation scheme: 100-fold Vibroseis utilizing five vibrators 50 ton in total, by linear array of 10 km length, 100 m spacing for the vibrators and 50 m spacing for receivers, up to 25 s two-way travel time. The CDP cross-section shows several principal features of the crustal structure. Thickness of the crust is 40 km. The Moho is traced as a boundary between the reflective lower crust and the transparent upper mantle. It is a flat near horizontal boundary without any disturbances. In contrary the upper and middle crust have complicate structure: several strong reflectors are dipping to the east. They are of listric forms and flatted out at a depth of 25-30 km. These reflectors outlines a wide (~100 km) suture zone at which the Belomorian Mobile Belt over trusted on the Karelian Protecraton. These two tectonic units differ in the reflectivity pattern of the lower crust: it is strong reflective beneath the Karelian Protocraton and more transparent beneath the Belomorian Belt.

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3-D CRUSTAL VELOCITY MODEL OF THE BALTIC SHIELD

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The 3-D crustal model of the Baltic Shield was constructed from the DSS data. The data were obtained during last 50 year with different equipment, methods of observation and of interpretation. That is why we start our modeling with comparison of the observed wave-fields and construction of time maps for the first arrivals and for the Moho reflections. The time maps confirm the Moho depth map by U.Luosto (1997) and show very smooth changes of crustal structure. The comparison of the travel-time curves revealed several regular velocity layers which are possible to trace along the most of the profiles. Two upper layers with velocities 6.0-6.4 and 6.5-6.6 are divided by reflection boundary K1 which is the most stable boundary along all profiles. Very often the K1 boundary underlines a velocity inversion zone. The depth to the boundary increases from 9-10 km in the Kola Province to 16-18 km in the South Finland. The boundary K2 (top of the lower crustal layer with velocities 6.8-7.0 km/c) is clearly determined from the first arrival velocities. The K2 depths are very stable in the area (27-30 km). In the South Finland the layer with velocities 7.2-7.4 km/s fills in the deep depression of the Moho.

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CRUSTAL REFLECTIVITY UNDERNEATH THE CENTRAL SCANDINAVIAN CALEDONIDES

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We have studied data from a ~160 km long dynamite/vibroseis reflection seismic profile, part of the Central Caledonian Transect (CCT), acquired in the Central Scandinavian Caledonides between 1988 and 1992. Extended correlation has been used to increase the record length to 20 s for the vibroseis component. The reflectivity, interpreted as due to dolerites, is high at depths <15 km in the Precambrian basement, throughout the profile. These Precambrian rocks are largely covered by thin sedimentary thrust sheets, transported by the Caledonian orogeny. Aeromagnetic surveying shows a large positive anomaly in this area, suggesting that the dolerites are located in a homogeneous, highly magnetized, Rätan type granite, a granite belonging to the Transscandinavian Igneous Belt (TIB). In the middle/lower crust, weak east-dipping reflectivity is observed. To the east, partly in the Svecofennian Domain (SD), a ~60 km segment of subhorizontal reflectivity at 14-15 s suggests a flat Moho at a depth of ~50 km. Underneath the central part of the profile, coinciding with the location of the TIB granite, the Moho appears to shallow to ~42 km, and to be less well defined, while further west it appears to again deepen to ~50 km. In order to verify that these variations in Moho topography and deep reflectivity are real, we have estimated the signal penetration depth and studied variations in fold. Except for localized parts of the profile, we believe that the entire crust has been imaged. We propose that much of the deep reflectivity was erased during emplacement of the TIB granite at 1.85-1.65 Ga. Extension at ~1.0 Ga led to the thinning of the crust and allowed dolerites to intrude the granitic upper/middle crust. Later Caledonian compression sheared this granite-dolerite system.

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MONA LISA: A SEISMIC KEY TO NORTH SEA TECTONIC EVOLUTION

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Seismic profiles from the south-eastern North Sea around the deep seismic MONA LISA lines show structures inherited from Caledonian collisional processes, late Palaeozoic extension and magmatism, and Mesozoic graben formation. The 1993-95 MONA LISA project involved acquisition of 1112 km seismic normal-incidence reflection data recorded to 26 s TWT along four profiles, together with coincident wide-angle reflection/refraction data recorded by offshore OBHs along profiles 1,2 and 3. Integrated interpretation of the deep seismic wide-angle and normal-incidence data along profiles 1, 2 and 3 has focussed on the crust and upper mantle velocity structure. The SW-dipping Baltica-E. Avalonia suture zone separates 38-35 km thick, high velocity shield type Baltica crust in the northern and eastern parts of ML1, 2 and 3 from a 25-28 km thick, low velocity crust of Caledonian origin to the south and west. New seismic reprocessing of the upper 7 s TWT of selected target areas along ML2, 3 and 4, show new aspects of the sedimentary evolution, the occurrence of down-faulted, presumably Palaeozoic strata, and spectacular images of the effects of Caledonian deformation. Additionally, the wide-angle refraction data reveals substantial occurrences of lower and upper Palaeozoic strata in the area.

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COLLISIONAL CRUSTAL STRUCTURES FROM THE WESTERN PYRENEES TO THE CANTABRIAN MOUNTAINS AND THE IBERIAN CHAIN

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A new insight on the crustal structure of North Iberia, between the western Pyrenees, the Cantabrian Mountains, and the Iberian Chain is achieved from the interpretation of a seismic refraction / wide angle reflection data set acquired in 1997. The area exhibits a complex 3D structure, with perpendicular to oblique Variscan and Alpine-Pyrenean strikes and the imprints of the Mesozoic crustal extension related to the opening of the Bay of Biscay. Important variations in crustal thickness and velocity distribution are inferred from a 550 km-long E-W transect, along strike of Alpine structures, from the Cantabrian Mountains to the western Pyrenees. One of the most outstanding features is the presence of a continuous Alpine crustal root along this transect. On average, the Moho depths are 45-48 km, being 5-7 km shallower beneath the Basque-Cantabrian Basin, a wide zone of lower relief where the Mesozoic extension was mainly focussed. Also remarkable is the presence of a high velocity layer (~6.45 km s^{-1}) at mid-crustal depths beneath the Cantabrian Mountains and the Basque-Cantabrian Basin. A number of geophysical and geological constraints suggest that this layer could be the present signature of the lower crust of the Cantabrian Margin indenting the Iberian crust during the alpine compression. Below this wedge, the crustal root was formed by the northward underthrusting of the lower part of the Iberian crust. Three other profiles, running from the western Pyrenees northeastwards to the Aquitaine Basin and southwards to the Iberian Chain, helped to complete this picture. An Alpine crustal thickening of the middle crust with Moho depths of 39-43 km is also inferred beneath the Iberian Chain.

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INDEPTH III, A WIDE-ANGLE PROFILE ACROSS THE BANGGONG-NUIJANG SUTURE, SOUTHERN TIBET

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In summer 1998, a seismic wide-angle profile (INDEPTH III = GEDEPTH II) with a total length of 400km was observed in southern Tibet. In total, 14 short period and 35 broad-band seismometers recorded signals from 14 shot points yielding a dense network of overlapping travel time branches. In the centre of the profile, the Bangong-Nuijang Suture (BNS) is crossed which is clearly observed by large delay times and diffractions. The BNS stands out as a broad zone of low velocities down to a depth of at least 25 km. Based on velocities below 6.5 km/s, we modelled a sialic upper crust down to 30 to 35 km, underlain by a 7.0 km/s lower crust down to about 60 km in the northern Chantang Block and about 70 km in the southern Tibet block. These data are compatible with those of the INDEPTH II studies in the Tibet Block further south. However, no low velocity layer was detected along our profile. In spite of our high quality recordings no reliable Moho events could be observed (except from one shot-point). For our model low frequency signals of Pn waves from nearby earthquakes had to be added. It seems doubtful whether the BNS is still connected to the deep subcrustal lithosphere, seen in the recent recordings of receiver functions.

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ARCHEAN ARC-CONTINENT COLLISION IN THE SLAVE PROVINCE, NORTHERN CANADA: A REINTERPRETATION OF LITHOPROBE SNORCLE LINE 1

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Lithoprobe SNORCLE seismic reflection line 1 crosses the southwestern tip of the Archean Slave province in northern Canada. Reflections have been reinterpreted as products of lithospheric wedging using a comparison of the reflection patterns to a Proterozoic analogue, and by correlation of reflection patterns to the known geology. The results provide insights into the evolution of the Slave province at ca. 2.69-2.60 Ga. Reflection patterns in the Yellowknife area consist of (1) east-dipping reflections at 12-14 s that project into the upper mantle, (2) a wedge-shaped body in the lower crust with an east dipping reflection fabric that is truncated on the west by (3) a series of west-dipping reflections in the upper crust. This reflection pattern is similar to that of the Fort Simpson - Hottah collision zone, imaged further to the west on SNORCLE line 1. There, the western plate (Fort Simpson-Nahanni terrane) is interpreted to have been delaminated as the eastern plate (Hottah-Coronation terrane) was inserted into it. This similarity provides support for the interpretation that reflection patterns beneath the Slave province are also products of collisional tectonics.

Rocks within the Slave province preserve evidence of a ca. 2.69-2.60 Ga pan-Slave orogenic event, in which the Central Slave Basement Complex, a block of continental crust containing gneisses as old as 4.0 Ga, collided with the ca. 2.7 Ga Hackett River juvenile island arc terrane. The suture between the CSBC and the HR arc is interpreted to be at 4-5 s beneath Yellowknife and to project to the surface east of the data. Beneath the suture, an accretionary wedge and a subduction zone are interpreted. Shear zones at the base of the mafic volcanic sections were active prior to 2.687 Ga, indicating that intervening basins containing greenstone belts collapsed prior to final collision with the HR arc. At the north end of the Slave province, where the arc-continent collision appears narrower and less complicated, the boundary between the arc and the continent has been mapped as a west-dipping suture. The proposed collisional model is similar to that of Kusky, 1989, which also involves delamination of the Central Slave Basement complex; however, in Kusky's model, the accretionary wedge is exposed on the east and the west of the Sleepy dragon complex, whereas in the present model, the accretionary wedge is located in the lower crust. These results provide tantalizing evidence that processes similar to those of modern convergent zones were operational at 2.69-2.60 Ga

CAC-22

A COMBINED ONSHORE-OFFSHORE WIDE-ANGLE SEISMIC EXPERIMENT IN LABRADOR — APPLICATION OF 2-D FORWARD MODELING, 3-D TOMOGRAPHY AND PRESTACK-DEPTH MIGRATION

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In 1996 a wide-angle reflection and refraction seismic experiment was conducted in Labrador as part of Lithoprobe's Eastern Canadian Shield Onshore-Offshore Transect (ECSOOT). In total, 79 landstations and 35 OBS were deployed to record airgun shots (6000 inch3) along the eight lines. Results from 2-D forward modeling show the existence of a 20-km- thick high-velocity lower crust beneath the NE Grenville Province with a total crustal thickness of 50 km. Farther north, the data revealed the structure of the Mesoproterozoic anorogenic Nain Plutonic Suite, host to the Voisey's Bay ore body. The base of the anorthositic plutons is clearly defined by reflections at a depth of 8 to 11 km. Crustal thickness beneath the plutons is some 5 km less than in the Archean Nain Province not affected by the plutonism. This suggests anatexis of the lowermost crust during the plutonism. A detailed survey was conducted in the Proterozoic Torngat Orogen with the 2-D model showing a 100-km-wide crustal root with a Moho depth of 50 km. Prestack-depth migration of the wide-angle data images the Moho, a midcrustal reflector and some eastward-dipping lower crustal reflectors in the western half of the line. Active seismic tomography shows a correlation of the root with a set of major, late orogenic shear zones and suggests that transpressional shearing focused strain in the region of the root and contributed to the crustal thickening. Detailed information on the project can be found at www.phys.ocean.dal.ca/~tfunck/ecsoot/ecsoot.html.

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VERTICAL SEISMIC PROFILING TO 8550 M DEPTH - NEW RESULTS FROM THE CONTINENTAL DEEP DRILLHOLE KTB (S GERMANY)

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A comprehensive program of seismic borehole measurements comprising Vertical Seismic Profiling and Moving Source Profiling is performed in the superdeep borehole of the Continental Deep Drilling Program (KTB), Germany. The deepest part of this borehole (from 6000 m to 8500 m) has now been sampled for the first time by Vertical Seismic Profiling applying a newly developed HP/HT-borehole-geophone. The most important targets are: a major thrust-related fault intersecting the well at 7 km depth (so-called SE1 reflection), stacks of steeply inclined deformed felsic and mafic layers, fluid filled fractures of varying spatial density and orientation, and the so-called Erbendorf body, a highly reflective mid-crustal layer 2 km below the end of the borehole. The three-component records of the VSP show compressional, shear and converted waves, both in transmission and reflection. The seismic arrivals carry signal energy between 10 and 250 Hz imaging geological structure at scale lengths between some 100 m and some 5 m, respectively. Amphibolite units show an average P-wave velocity of 6500 m/s with local variation of 10% caused by fractures and anisotropy. The influence of anisotropy is also observed in a Gneiss sequence where changes in the dip of foliation create a low velocity layer of 5500 m/s between 8000 and 8500 m depth. Measurements will be completed in May 2000. The project is funded by DFG, ICDP, and NSF. Further significant financial, personnel and technical support has been provided by the GFZ Potsdam and GGA Hannover.

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THE CONFIGURATION CHARACTERISTICS OF MOHO INTERPRETED FROM THE DEEP SEISMIC DATA IN ANDA-ZHAOZHOU ZONE, NE CHINA

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The area of the Anda-Zhaodong-Zhaozhou (for short A-Z-Z) had been studied two times using vertical seismic reflection and some records were achieved. Processing these records, we got five stack profiles. Firstly, the Moho phase was identified in the five profiles. Secondly, t_0 was closed at crossing of section. At last, we got top (t_0) depth and (t_0) thickness of the Moho every kilometer and drew isoline. The Moho top shows "river bend shape" blowups between the Anda and the Zhaozhou, where the (t_0) depth changes from 9.9 seconds to 10.25 seconds. The change of (t_0) depth is complex along any direction. It is different from traditional understand. In the district of the A-Z-Z, the change of the Moho thickness is simple in middle part and complex in the south part and the north part. The thickest location is located at about 10 kilometers to the south of the Anda, where the (t_0) depth value is 110 ms. The thinnest location is located at the Zhaozhou segment and the east part of the Anda segment, where the (t_0) depth value is about 30 ms. In the Zhaozhou segment there is a wide range of (t_0) depth, from 9.9 seconds to 10.75 seconds, but the (t_0) thickness is thin. The axial direction of thickness isoline is primarily northwest direction. It is give that formative factor and influential factor of the Moho includes mantle convection, phase transformation, differentiation, rotation of the earth, tectonic action, etc. Through the complicated modality of the Moho of the A-Z-Z region, we can infer that the effect and process of influential factor of Moho is complicated and variable.

The Continental Mantle — Wednesday 19th to Thursday 20th June

TCM-1

CRUSTAL AND UPPER MANTLE STRUCTURE OF NORTH AMERICA AND RUSSIA

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We present new contour maps of the seismic structure of the crust and upper mantle of North America and Russia. These maps incorporate nearly all information that is available from the regional seismic reflection and refraction profiles that were recorded over the past forty years. Our depth-to-basement map shows vast portions of the European and East Siberian platforms are covered by 2-10 km of Late Proterozoic and younger sediments. The West Siberian platform is covered mainly by Mesozoic sediments. Depth-to-basement in excess of 10 km is found in the Peri-Caspian Depression, in the north section of the West Siberian platform (south of the Kara Sea) and in the north and east of the Siberian platform. Crustal thickness has been mapped by more than 100,000 km of long-range seismic profiles, including those that used powerful Peaceful Nuclear Explosions (PNEs) as seismic sources. The crust within stable shields and platforms is 32-50 km thick and averages 42 km. The seismic velocity of the upper-most mantle (Pn velocity) is 7.8 – 8.5 km/s with an average value of 8.15 km/s. Values of 7.8 – 8.0 km/s are evident beneath rifts in West Siberia and beneath regions that were tectonically active during the Mesozoic and Cenozoic. Pn velocities in excess of 8.4 km/s are found on either side of the north-south trending Urals and in several regions of Siberia, including areas where diamonds have been found. These results are compared with those of North America. These two continental regions consist of ancient cratons and stable younger platforms, and these seismic observations are an important constraint on the evolution and stabilization of cratonic crust.

TCM-2

LOW VELOCITIES AND STRONG SCATTERING BELOW THE 8° DISCONTINUITY ALONG PNE PROFILE KRATON IN SIBERIA

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Delayed and scattered first arrivals with a strong coda of ~5 s duration are observed in the 700-1400 km offset range in the four Peaceful Nuclear Explosion (PNE) seismic sections of the 3500 km long profile Kraton in Siberia. The traveltime delays constrain a ~100 km thick zone of reduced velocity below the 8° discontinuity at ~100 km depth. This zone is clearly imaged by first arrival traveltime tomography. The strong coda is consistent with scattering produced by bodies imbedded in a 75-100 km thick low-velocity zone below the 8° discontinuity. Waveform modelling studies show that velocity contrasts of about 2% of the background velocity are sufficient in order for the scattering bodies to produce the amplitude characteristics of the observed ~5 s coda. Between ~100 and ~200 km depth a generalised shield geotherm lies close to or above the solidus curve for peridotite containing small amounts of C-H-O. As the temperature gets close to the solidus the seismic velocity of mantle peridotite drops significantly. A gradual decrease in P-wave velocity of up to 6% is expected even at high sub-solidus temperatures. The scattering bodies below the 8° discontinuity are interpreted as pockets of molten or almost molten material.

TCM-3

CRUST-UPPER MANTLE COUPLING FROM PROFILE QUARTZ IN RUSSIA

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The long-range, PNE-sourced profile QUARTZ extends NW-SE from the Baltic shield across the Pechora Basin, the Ural Mountains and the West Siberian Basin to the Altai Mountains. Three PNEs and 48 chemical explosions are shot into 400 3-component recorders giving continuous reversed coverage of the crust and upper mantle. Such dense seismic coverage on long profiles reveals strong heterogeneity in the upper mantle. Some of these features can be related to crustal structures, and other regional interfaces seem to be unrelated to surface structures. High-velocity uppermost mantle on the east flank of the Urals is ascribed to garnet peredotite brought up along the Main Uralian Fault imaged in a reflection profile. A zone of low velocity and increased attenuation is found in the lower lithosphere. This zone may be related to 3-dimensional convection flow during the propagation of the failed West Siberian Rift and formation of the vast West Siberian Basin. The most dramatic example of the crust-mantle coupling occurs in the thinning of the lithosphere, SE dip of 410-discontinuity, and increased attenuation in the asthenosphere to the SE toward the Altai Mountains in the Himalayan hinterland. Modern seismic studies of the upper mantle are showing great complexity and are in a stage of development similar to the reflection studies of the crust 20 years ago.

TCM-4

CRUST AND UPPER MANTLE STRUCTURE ALONG "RIFT" PROFILE (SIBERIAN CRATON)

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The long-range profile RIFT which was carried out with nuclear explosions, crosses several large geostructures: the Siberian cratons, rifts of the West-Siberian young plate and the Baikal Rift Zone. A combine interpretation of the record-sections, obtained from chemical and nuclear explosions allowed to determined some new peculiarities in the lithosphere structure of these areas. In the rift zones the high velocity intrusions in the middle and lower crust and lower mantle velocities are observed. In the Siberian craton, which is one of the largest area of the continental plateau-basalts , two anomalous high velocity blocks (8.5-8.6 km/s) were outlined beneath the Moho. They penetrate down to the depth of 100 km. Deeper a near horizontal layering is more pronounced and an inversion zone is distinguished. Between these two lithosphere blocks several specific features are observed in the crust and upper mantle structure: decreasing of seismic velocities in the middle crust, inclined crustal and uppermost mantle reflectors dipping to the north, a high velocity gradient zone at a depth of 100-150 km, a reflectivity zone (bright spot) at depth of 300-350 km. These structural peculiarities suggest an old suture zone divided the Siberian Carton into two microplates with subduction of the southern plate beneath the northern one.

TCM-5

THE MOHO AS A DETACHMENT SURFACE

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In seismic reflection sections, the Moho is usually interpreted either as the base of a zone of reflectivity in the lower crust or as a discrete zone of reflectivity, in both cases overlying the generally non-reflective uppermost mantle. Reflectivity in the lower crust has been attributed to a number of causes, such as shear zones and highly deformed, perhaps anisotropic rocks, fluid filled cracks, and sills, whereas the non-reflective nature of the uppermost mantle is attributed to low impedance contrasts between the rock types that constitute the mantle. Examples abound where the Moho has been affected by tectonics, for example where it is offset by crustal faults. We have also identified examples where the Moho exerts a strong control on tectonic processes. One example is a series of inverted extensional faults that extend from upper crustal levels in eastern Tasmania to sole into the Moho, indicating that the Moho behaved as a detachment surface. The fault geometry appears unaffected by compositional-based changes in crustal rheology. In northwest Tasmania, the Moho has a similar reflection character, implying it may also have been a detachment surface, but at least one other level of detachment exists a few kilometres above the Moho. These structures were probably emplaced in the Neoproterozoic. Examples exist from provinces of other ages, for example on the present day northwest continental margin off Western Australia. In the Archaean Yilgarn Block, the detachment at the Moho formed across a much thicker ductile zone. The rheological change at the Moho, from quartz-dominated above to olivine-dominated below, is greater than others encountered in the crust and upper mantle. The Moho should therefore play a significant role in controlling tectonic processes, rather than simply reacting to them. This is what deep seismic data are showing.

TCM-6

UPPER MANTLE OF THE ALTAI-SAYAN FOLD AREA FROM DATA OF AREAL SEISMOLOGICAL OBSERVATIONS

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Results of interpretation of the Moho refractions (Pn) recorded from earthquakes and industrial explosions by areal seismological network of stations within the Altai-Sayan region are represented. It is shown, that the use of specific processing methods allows us to obtain the reliable information on the Moho structure from the data of irregular and enough sparse network of stations (with average spacing of about 100-200 km). Within the central part of the Altai-Sayan fold zone for the territory of 250 thousands of square kilometers, the Moho surface was imaged and the distribution of compressional wave boundary velocities was obtained in terms of isotropic and anisotropic models of media. The areas with relatively decreased and increased values of P-wave boundary velocities were distinguished. The depths of Moho surface, varying in this region between 40 km and 55 km, were determined. At the interpretation of data in terms of anisitropic model of the upper mantle in Altai-Sayan region, the nearly isotropic areas were distinguished (with anisotropy ratios lesser than 1-3%) along with zones of well-marked anisotropy of elastic properties (to 10-12 %). For particular sections of upper mantle, the distinctions in principal orientation of peak values of boundary velocity ellipses were established. Obtained results give new constraints on the upper mantle structure of the Altai-Sayan seismically active zone and the mechanisms of processes occurring there.

Continental Rifts and Basins

Wednesday 21st to Thursday 22nd June

CRB-1

P-WAVE MODELING OF WIDE ANGLE SEISMIC DATA FROM OCEAN BOTTOM SEISMOMETERS SOUTHEAST OF SVALBARD

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Several tectonic phases during the Late Paleozoic, Mesozoic, and early Tertiary resulted in deep sedimentary basins in the southwestern Barents Sea, but did not greatly affect the platform areas. Here, reliable mapping of Paleozoic structure and stratigraphy below the high seismic velocity Permian sequence is problematic with conventional seismic reflection data, and the early post-Caledonian development of the region is largely unknown. This led in 1998 to the acquisition of a survey of ten OBS profiles southwest to southeast of Svalbard. The P-wave data from the four easternmost profiles are presented here. The survey was acquired in a widely-spaced grid, allowing several ties between the different profiles. Ray-tracing and inversion of the interpreted OBS data agree well with the shallow stratigraphy mapped from reflection seismic data. Below the Permian section, the data permit mapping of the depth to crystalline basement as well as crustal thickness. Large variations in the depth to top basement show upper Paleozoic sedimentary basins and structural highs which are not always recognized in the younger structuring of the area. The early basin formation may be analogous to the development of the Devonian basin on the adjacent island of Spitsbergen through post-Caledonian orogenic collapse, though a mid-Carboniferous rift event recognized to the south may have affected the area. However, the depth to Moho shows a strong relief ranging from 32 to 38 km not corresponding to the early basins, suggesting a complex geological development of the area. The thickest crust is also associated with high top mantle velocities (8.1- 8.5 km/s). A number of reflected arrivals originate within the crystalline crust and partly fit with an internal layering of the basement. Even if large acoustic impedance contrasts may occur locally, combinations of PmP and Pn arrivals from the Moho constrain the basement velocity to be low, close to 6.5 km/s on average. Some of the intra-basement structures may have governed the location of Mesozoic faults.

CRB-2

S-WAVE AND GRAVITY MODELING BASED ON P-WAVE MODELS OF WIDE ANGLE SEISMIC DATA FROM OCEAN BOTTOM SEISMOMETERS SOUTHEAST OF SVALBARD

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Southeast of Svalbard no reliable mapping below the Permian sequence from conventional seismic reflection data exists, and the early post-Caledonian development is largely unknown. The modeling of four OBS profiles acquired in 1998 southeast of Svalbard is presented here. Based on earlier P-wave modeling of these profiles, S-wave and gravity modeling give new constraints on the structure and lithology of the area. The S-wave recordings enable direct and indirect estimates of the S-wave velocity of the sedimentary and crystalline units. The Vp/Vs ratios of the sedimentary units indicate a mixed lithology of sand and clay, and possibly carbonates. An increase of the Vp/Vs ratio with depth agrees with a reduction in porosity with increasing overburden. Very high values seen where sedimentary units gets thin is likely due to the development of cracks as a response to erosional unloading. Top crystalline basement uniformly shows a Vp of 6.3 km/s and a Vp/Vs ratio of 1.69, indicating a quartz rich igneous or metamorphic lithology compatible with granite or felsic gneiss. S-waves converted at and reflected off the Moho indicate that this value is representative for the bulk of the crystalline crust. There are indications of a higher ratio at the southwestern part of the area, and bodies of intermediate to mafic composition may be present here. There is little correlation between observed gravity and the depth to crystalline crust and to Moho. The gravity modeling suggests that the observed field is dominated by density variations between 2800 and 2990 kg/m^3 in the crystalline crust. High basement densities account for the two major positive gravity anomalies in the area, augmented by high density in the upper mantle. This occurs under the Olga Basin, imparting a positive gravity anomaly to the basin. Only one major anomaly corresponds to a top basement feature; a low located between the Sentralbanken High and the Olga Basin. The high density body in the southwest correlates with the area of possibly increased Vp/Vs ratios, compatible with a more mafic composition here.

CRB-3

THE LAPTEV SEA RIFT

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The interaction of the active Arctic mid-oceanic ridge with the north-eastern Siberian continent since the Late Cretaceous resulted in a complex horst and graben system on the Laptev Sea shelf. About 4000 km of seismic (MCS) data and additional refraction seismic data made a conclusive interpretation of the main structural elements possible. The basins, showing a Cenozoic sedimentary cover of up to 14 km presumably have formed as linked half-grabens, accompanied by the development of a major fault which is interpreted to represent a hinge zone. The mapped depth of the Cenozoic sediments and the Moho will be discussed as well as models for the rift structure. It is likely that the Arctic mid-oceanic ridge terminates at the shelf edge and a further development of the Laptev Sea rift as a future oceanic basin is not expected.

CRB-4

IMAGING THE THICKEST (?) SEDIMENTARY BASIN IN EARTH HISTORY: DEEP SEISMIC REFLECTION PROFILING OF THE SOUTH CASPIAN BASIN

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New deep seismic reflection data provide the first normal-incidence image of the thickest (?) sedimentary basin in Earth history, the South Caspian Basin. Significant features imaged with the seismic data are: (1) a series of high-amplitude folds, developed within a thick Cenozoic sedimentary section, (2) a prominent deep reflector at 26-28 km depth (12.8-13.0 s) with a gentle northward dip, (3) an underlying layered interval with discernibly lower frequency reflections down to ~36-40 km (16.0-16.5 s), and (4) a noticeable decrease in reflectivity below ~36 km. We interpret the bright reflection at ~26-28 km depth as the basement/cover contact, making this the deepest sedimentary basin in Earth history, to our knowledge. This interpretation is consistent with previous velocity models from both seismic refraction and teleseismic studies in the South Caspian region, which suggest a minimum sedimentary thickness of 20 km. The underlying, more highly reflective portion of the section below 28 km is interpreted as the crystalline basement. Downward termination of reflectivity at ~36-40 km is thought to represent the Moho, despite the absence of a clearly reflective horizon. The apparent ~10 km thickness of the South Caspian crystalline crust suggests an oceanic affinity for this part of the basin.

CRB-5

FORMATION OF THE BALTIC SEA PALEORIFT - IMPLICATIONS OF THE BABEL PROFILES

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The Baltic Sea has many characteristic features of failed rifts: topographic low (now under water), thinner crust with large crustal gradients and the products of voluminous bimodal magmatism; the rapakivi granites and associated gabbro-anorthosites and mafic dykes and sedimentary basins. The crustal columns hosting the rapakivi granites are characterised by ovoid crustal thickness and Bouguer anomaly minima.

BABEL lines B,1, 6, 7, and C image well crustal structures associated with the large rapakivi batholiths Landsortdjupet (B), Åland (C, 1 ,7) and Bothnian rapakivi (1, 6). The rapakivi granites are imaged as unreflective blocks delineated by listric and normal faults. The crustal structure is characterised by extensional listric shear zones that flatten out either at the lower to middle crustal boundary or at the Moho boundary. The band of lower crustal reflectors is upward concave and is underlain by less reflective crust and a well-defined reflective Moho (line 1, 7). High reflective structures within the batholiths are related to contacts between mafic dykes or intrusions and rapakivi granites. The lower crustal structures are interpreted to result from mafic under- and intraplating. The intraplating provided energy source for partial melting that resulted in the rapakivi magmatism and the cooling underplated material crystallised as mafic unreflective lowermost crust and produced a new Moho boundary.

The large granite laccoliths are not structurally connected to each other but seem to be separated by thick and rigid crustal blocks (line 1, 6, B). The growing age zonation of the rapakivi granites in Fennoscandia is interpreted to reflect a spreading plume-head underneath the lithosphere. The lack of fertile lithologies and/or net strengthening and of thinned crust led to cessation of extension and spreading of deformation to adjacent areas of weaker crust. Thin-skin sedimentary basins developed on and around the rapakivi granites.

CRB-6

SEISMIC REFLECTION AND REFRACTION EVIDENCE FOR CRUSTAL THINNING BENEATH THE CENTRAL GRABEN, NORTH SEA

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Coincident high resolution near-normal incidence and wide-angle seismic profiling have been carried out across the Central Graben in the North Sea as part of the MONA LISA deep seismic experiment. High quality seismic reflection and refraction data permit generation of well-defined reflectivity and P-wave velocity models for the crust, including deep graben sediments, the crust-mantle boundary and the uppermost mantle. Beneath the Central Graben, with up to about 10 km of sedimentary units, the Moho is uplifted to about 25 km as compared to a depth of 32-36 km west and east of the Graben. Lateral variation in lower crustal reflectivity and velocity structure is observed with Moho at the base of a zone of increased reflectivity. Graben formation is found to be associated with crustal thinning by a factor of up to 2-2.5. Spectacular reflectors dipping, generally, away from the Graben are observed in the mantle lithosphere to a depth of about 70 km. Lithospheric extension is concluded to be the main mechanism for graben formation. The sub-crustal dipping reflectors may represent zones of localized shear.

CRB-7

NEW IMAGES FROM THE MONALISA DEEP SEISMIC DATA: REPROCESSING AND PRE-STACK DEPTH MIGRATION OF SELECTED AREAS.

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The MONALISA collaborative project was designed to provide detailed structural information about the thick sedimentary cover, crust and upper mantle, in the south eastern North Sea, related to Caledonian collision and Late Paleozoic to Mesozoic rifting and basin formation. Seismic normal-incidence reflection data were collected along four profiles together with coincident wide angle data for three of them.
Parts of the deep seismic lines were selected for reprocessing of the upper 6 s to better image the sedimentary sequences and the basement, specially the areas close to the Caledonian front where the transition between Caledonian and Precambrian basement is inferred based on available boreholes.
The processing sequence focused mainly on deconvolution, a very careful velocity analysis, f-k filtering and pre-stack depth migration. The results are very successful and show images of the Paleozoic sequences between the Mesozoic and the basement. Some sequences seem to be affected by Caledonian deformation while others appear as a rift sequence without signs of compressional tectonics.

CRB-8

THE ELBE FAULT SYSTEM IN THE NE-GERMAN BASIN - A BASEMENT-CONTROLLED WEAKNESS ZONE?

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During the Permian-Cenozoic history of the North German Basin the Elbe Fault System (EFS) was repeatedly reactivated as a zone of weakness along its southern margin. Starting with post-Variscan wrenching and volcanic activity in Late Carboniferous this area was subject to differential subsidence and inversion during Mesozoic times. In the present-day basin structure the EFS encloses an area of strong salt-tectonic deformation and basement faulting. In contrast, the northern part of the basin has a shallow slope and deformation intensity is small. The deep seismic data of DEKORP BASIN'96, results from gravity modelling and thermo-mechanical models indicate the presence of a lower crustal block with high seismic velocities, high density and a high integrated strength below the northern (rather stable) part of the basin. The southern edge of this block bounds the EFS in the north in the area of the river Elbe. South of this block, a crustal unit characterized by low seismic velocities, a lower average density and of weaker rheology follows correlating spatially with the EFS in the sedimentary fill along the southern basin margin. The comparison of major structural trends in the basin with the characteristics of crustal structure suggests a causal relationship between a younger and weaker crust and strong Mesozoic-Cenozoic deformation in the south of the basin, while an older and stronger crust correlates with minor Mesozoic-Cenozoic deformation in the north. The presence of similar structures along the EGT and MONALISA2 lines farther west and along the POLONAISE P4 lines farther east imply a lateral continuity of this crustal structure.

CRB-9

"DOBRE" – DONBAS FOLDBELT (SE UKRAINE) DEEP SEISMIC REFRACTION AND REFLECTION PROFILING

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The Donbas Foldbelt (DF) is the uplifted and deformed part of the Dniepr-Donets Basin that formed as the result of rifting of the East European Craton in the Late Devonian. The thickness of syn-rift and younger strata is in excess of 20 km; coal-bearing Carboniferous rocks are exposed at the surface. A seismic refraction/wide-angle reflection survey was carried out in 1999 to complement existing Deep Seismic Sounding data from the area that, because of their design, did not record significant Pn phase arrivals. The 1999 survey comprised some 245 recording stations along a line of 360 km length, with 11 in-line shotpoints, from the shores of the Asov Sea north to the Ukraine-Russia border. An off-line (fan) profile with some 75 recording stations, including 18 three component stations, was acquired across the rift zone about 100 km north-west of the main profile. Data quality is excellent and preliminary velocity models are presented. Deep CDP profiling – at least 120 km of coincident, 30 s Vibroseis© and 180 s explosive – is planned for the summer of 2000. The seismic data are expected to reveal basin architecture and structural relationships controlling the kinematics of its deformation – as well as other features of the lower crust and upper mantle related to basin formation and inversion.

CRB-10

A NEW PRECAMBRIAN GEOLOGIC PROVINCE BENEATH THE ILLINOIS BASIN, USA

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Surprisingly little is known of the deeply buried Precambrian rocks of the Illinois Basin, despite the fact that it is one of the world's most intensively studied intracratonic basins. Since the initial discovery of petroleum here in 1886, the Illinois Basin has produced over 4 billion barrels of oil and an estimated 4 trillion cubic feet of associated dissolved natural gas. Production shot up rapidly beginning in 1937 as a result of the application of a new technique called seismic reflection shooting. Until now, almost none of the resulting reflection data have been available to academic researchers. A spectacular first-order result from newly released and reprocessed seismic profiles is that the reflectivity of Precambrian upper crust is richly coherent and widespread. Long regional profiles reveal vertically stacked, broad basinal "seismic stratigraphic" sequences beneath the Paleozoic basin. The internal structure of the sequences is marked by dipping and offset reflectors, and by extensive apparent angular unconformities, all of which give the impression of a sedimentary (or volcani-clastic) succession. The regional structure of the sequences is well developed with discrete boundaries along which the sequences "pinch out" beneath the base of the basin's Paleozoic sediments. For many years we have known that an areally extensive granite-rhyolite terrane (~ 1.5 Ga) lies beneath much of the Paleozoic strata of the basin based on a few scattered drill holes that just penetrate the top of the Precambrian. This terrane, however, is thought to only represent a thin veneer (a "few kilometers thick") or isolated igneous intrusions—what lies beneath, or within, the granite-rhyolite rocks has remained a mystery but might correspond, at least in part, to the sub-basin reflection sequences. The newly mapped "basement" reflectivity could represent extensive remnants of Proterozoic continental rifting that have not yet been drilled. This reflectivity therefore indicates a new geologic province beneath the Illinois Basin whose economic potential remains to be tested. Perhaps we are seeing an older analogy of the Keweenawan rift-related volcanic and sedimentary rocks deposited during Proterozoic rifting elsewhere in the central USA.

CRB-11

CRUSTAL STRUCTURE OF MORAY FIRTH BASIN, NORTH SEA, FROM DEEP SEISMIC REFLECTION, SUBSIDENCE MODELING, AND GRAVITY

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The Moray Firth basin (MFB), offshore northeastern Scotland, is the shortest and least understood of the three arms of the North Sea Mesozoic-Tertiary rift system. The interpretation of three regional 2-D deep (15-s) reflection profiles across the MFB is integrated with the results of subsidence analysis of the sedimentary section and gravity modeling. Our results reveal a strongly asymmetric basin developed over a crust where the depth to the Moho usually varies locally by no more than a few kilometers along a profile. No dramatic shallowing of the Moho is observed below the axis of the MFB as seen in other parts of the North Sea rift. The structural asymmetry of the crust beneath the MFB is accentuated by the configuration of the parallel ENE-striking margins of the basin, which consists of a shallow-dipping normal fault on the north, in contrast to a steeply dipping fault to the south. Along the north margin, the border fault produces a fault-plane reflection in the upper crust that is in places collinear with S-dipping reflections in the lower crust; however, these reflections do not appear to penetrate the Moho. Elsewhere below the basin interior, the prominent Moho reflector passes smoothly beneath intrabasin faults and depocenters with no obvious structural correlation. A "layered" lower crust is generally not observed as described for other North Sea rifts and often attributed to rifting processes. Our observations provide the first deep reflection constraints that Permo-Triassic and late Jurassic stretching was less advanced in the MFB than in the other two arms of the North Sea rift. Strain rate inversion of subsidence data show that stretching factors are in the range 1.2-1.5. These data demonstrate that two phases of rifting occurred. The first phase was in the Permo-Triassic and is poorly constrained. The second phase is centered on 150 million years. A period of anomalous subsidence is evident during the Early Cenozoic and is probably associated with movement way from the Iceland plume.

CRB-12

MUST MAGMATIC ADDITION TO THE LOWER CRUST PRODUCE REFLECTIVITY?

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The Færoe-Iceland Ridge (FIR) is an ideal laboratory to investigate the reflectivity and velocity structure of a thick crust generated above a mantle plume in order to constrain models of underplating and the origins of lower crustal layering in an environment dominated by young igneous processes. Over 600 km of common depth-point (CDP) data were collected using a 153-l airgun array with a 6-km streamer (240 channels) and a 75-m shot spacing. The interpretation of these data has been integrated with a detailed velocity model of the crust and upper mantle along the FIR. Due to the intermediate water depths and the presence of basalt near the water bottom, specialized processing steps were required for the CDP data. A wave equation-based multiple attenuation scheme was applied to the pre-stack data, which used a forward model of the multiple series to predict the actual multiple energy at greater traveltimes. Array simulations were applied in the shot and receiver domains in order to minimize spatial aliasing and attenuate low apparent-velocity noise. Most of the sections over the oceanic portion of the FIR show no pronounced reflectivity, although occasional Moho and/or lower crustal reflections are observed. We believe the poor reflectivity implies a lack of physical properties contrast rather than an effect of acquisition or processing. Amplitude decay and reflection strength vary along the FIR, but generally persist to traveltimes of at least 9 s (i.e., into the lower crust), indicating that the reduced reflectivity is not an artifact. The principal result from the CDP data is that the addition of melt to the lower crust along the trace of the plume apparently did not produce strong physical property contrasts in the lower crust. Perhaps this was because the entire crust was hot at the time of formation. In contrast, igneous intrusion into pre-existing continental crust is capable of producing significant reflectivity such as that seen near the Færoe Islands at the eastern end of the FIR, and elsewhere beneath the northwestern European continental margins.

CRB-13

UPPERMOST MANTLE BENEATH THE EASTERN PART OF SIBERIAN CRATON AND ADJACENT FOLD AREAS

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Seismic data about the Moho topography and velocity distribution are considered. The area of about 2,5 million sq. km has been studied with different density of observations: the most detailed DSS data are obtained in the Yakutian kimberlite province (YKP) and the Baikal-Vitim fold system; there are available only local earthquake data in the Aldan shield and Verkcho-Jansk orogenic belt (VJOB). Composite travel time curves of the seismic phases observed in the first arrivals up to offsets of 300-400 km and the PmP phase are shown from DSS data. Those from seismological data were used up to offsets of 800 km. Crustal thickness over this area changes from 30-35 km (beneath the VJOB, Vilyui basin and the Baikal Lake) up to 50-60 km (beneath Aldan shield, south-western part of the Baikal rift zone and central part of the YKP). Pn-wave velocity changes over a wide range of values. The least values of 7,7-7,8 km/s are observed beneath the Baikal rift zone and Vilyui basin. The highest of them are found under diamond-bearing regions of the YKP. The velocity at the Moho is characterized by values 8,0-8,2 km/s beneath the VJOB that has a decreased crustal thickness and elevated relief level. So we may assume that the crust can be not in isostatic equilibrium. As we can see the crust and uppermost mantle in areas of location of different geological structures can exhibit the similar seismic properties. So it's very important to find integrated multidisciplinary geophysical features of the crust and mantle to explain the origin and evolution of geological structures.

STE-11

ANISOTROPY OF SCHISTS: CONTRIBUTION OF CRUSTAL ANISOTROPY TO ACTIVE-SOURCE SEISMIC EXPERIMENTS AND SHEAR-WAVE SPLITTING OBSERVATIONS

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We have made five, independent compressional and shear wave velocity measurements to completely characterize transverse isotropy for samples from four metamorphic belts; the Haast schist terrane (South Island, New Zealand), Poultney slate, Chugach phyllite, Coldfoot schist and Pelonaschist (USA). These measurements include compressional wave velocities for propagation parallel, perpendicular and at 45° to the symmetry axis (perpendicular to foliation), shear wave velocity for propagation and particle motion perpendicular to the symmetry axis and shear wave velocity for propagation parallel to the symmetry axis. Along with density, these five velocities characterize the transverse isotropy exhibited by these rocks. Velocity measurements were made up to pressures of 1 GPa (about 30-km depth) where microcracks are closed and anisotropy is due to preferred mineral orientation. Our samples exhibit compressional wave anisotropy of 6 - 20 % as well as significant shear-wave splitting. Metamorphic terranes that are anisotropic to ultrasonic waves may also be anisotropic at the scale of active and passive seismic experiments. If the magnitude of crustal anisotropy is significant and if the anisotropy is appropriately oriented, it may contribute to observed shear-wave splitting values. Our dataset can also be used to model the effects of crustal anisotropy for active-source seismic experiments in order to determine if the anisotropy of the terrane is significant and needs to be taken into account during processing and modeling of the data. We generate synthetic seismic data for isotropic and anisotropic models representing South Island New Zealand to investigate the kinds of errors introduced when anisotropic seismic data is modeled assuming an isotropic medium.

STE-12

ELASTIC WAVE PROPAGATION IN ANISOTROPIC MATERIAL POSSESSING ARBITRARY INTERNAL TILT: HAAST SCHIST TERRANE, SOUTH ISLAND, NEW ZEALAND

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Laboratory petrophysical measurements of field samples representative of the Southern Alps orogen of the South Island, New Zealand, reveal geological terranes of isotropic to severely anisotropic compositional and textural fabrics. Within the Southern Alps (Indo-Australian/Pacific transpressional plate boundary), the originally deep-seated Haast schist terrane is upturned and exposed by uplift along the Alpine (plate boundary) fault. This terrane has measured P-wave anisotropy of up to 17% at confining pressures of up to 10 kbars. Overlying the schist terrane is the isotropic Torlesse greywacke terrane (6.0-6.1 km/s). Active- and passive-source seismic experiments were conducted in 1996 and 1998 producing 3-component data imaging or propagating through the anisotropic schist terrane.

In order to analyze the seismological data sets, we have developed 3D full wavefield finite difference code to create three-component synthetic seismograms incorporating anisotropic wave propagation. We allow each node point to have its own geological dip (tilt of anisotropy symmetry axes) in addition to its own values of velocities and density. We present calibration models of flat layers with internally dipping fabrics plus the effects of hetergeneous earth structure whose internally dipping fabrics are not necessarily parallel to layer boundaries. We then present synthetic seismograms simulating the seismological field experiments across the Southern Alps orogen.

STE-13

WIDE-ANGLE SEISMIC TRAVELTIME INVERSION USING A FRESNEL ZONE BASED PROCEDURE

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Wide-angle seismic travel time inversion is commonly performed using ray theory for the computation of arrival times and their sensitivities to the slowness distribution. However, since sound travels as a wavefield, the seismic velocities on the ray are not solely determining the travel time.
A good compromise between computation speed and accuracy in the calculation of forward response as well as inversion estimates is achieved by smoothing the sensitivity kernels as defined by the width of the first Fresnel zone along rays. We define Fresnel zones from travel time residuals efficiently computed by an eikonal equation solver.
Synthetic tests demonstrate that ray tracing methods may provide models of an unnecessarily high geological complexity. Furthermore, ray tracers are not always capable of calculating arrivals to all receivers. Using the eikonal solver, we make sure that arrivals are calculated at all receiver positions. For interpretation purposes, Fresnel zone based forward and inverse calculations assure that the obtained models contain only the level of detail warranted by the measurement geometry and the wave equation. The significance and application potential of this approach is demonstrated through realistic synthetic tests and modelling of observed data.

STE-14

PROCESSING OF HEAD WAVES FOR SYSTEM OF OBSERVATIONS WITH MULTIPLE OVERLAPPINGS.

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The construction of time (stack) sections of head waves is carried out on the basis dynamic conversion in traces of a time section. For deriving time sections two variants of algorithms with use of one-channel and multichannel filters of the Wiener are considered on the basis dynamic conversions. The conversions of head waves was applied to the data of seismic exploration by a method CDS (common depth site), obtained on the Siberian platform and to deep materials CDP (common depth point)-DSS (deep seismic sounding). By results of processing the series of refracting horizons is investigated. It is shown that the given method of processing realizes suppression of all types of waves except for head and improves signal-to-noise ratio, automizes the process.

STE-15

ON TECHNIQUE FOR OCEAN-BOTTOM SEISMIC DATA PROCESSING: INVESIGATIONS ON BARENTS SEA SHELF

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The report is devoted to OBS 4C data processing for investigations on the base profile in the Barentz Sea performed in 1995 and 1998. We consider kinematic data processing, i.e. study of the seismic wave arrivals, which is crucial for OBS data analysis. The task comprises two stages: kinematic data acquisition and interpretation. The profile Kinematic Data Bank (KDB) was formed by picking first and later wave arrival times from complicated multi-wave field with low signal/noise ratio at large offsets. Special processing of KDB data resulted in delineation of the first arrivals, refraction and reflection traveltime curves. The approach to kinematic interpretation was based on two interpretation models: thick-layered model and continuous 2D velocity distribution. The first one was used for plotting the continuously traced refracting and reflecting horizons and rough velocity estimation; the second – for detailed study of V(x,z). Each model suggested the relevant methods of getting solution to kinematic inverse problem. Both approaches were applied concurrently, implementing the two independent ways of imaging the same media section. That allowed, through several iteration, to minimize discrepancy in results of both methods and get the optimal seismic section. The branching of the interpretation process occurs when crude velocity estimates at OBS points produced by refraction traveltime inversion is used as initial approximation to V(x, z) for first arrivals tomography. The original software was applied for all processing phases, from interactive arrival picking to plotting boundaries and tomography computations. It provided for technological level permitting simultaneous processing of large amounts of field data acquired in different seismic investigations. The resulting seismic section images the crust structure along the 1400 km profile down to depth of 40 km. The report presents the details of the interpretation technique, intermediate and final results.

STE-16

3D SEISMIC TOMOGRAPHY BY USING TRAVELTIME AND WAVEFORM OF MULTIPHASE AND APPLICATION TO CRUSTAL STRUCTURE IN THE NORTHERN MARGIN OF QINGHAI-TIBET PLATEAU

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A new technique of simultaneous inversion for 3D seismic velocity structure by using directed, reflected and refracted waves was applied to the Northern margin of Qinghai-Tibet Plateau. The inversion results were improved with five practical new methods. (1) The Pg, Sg, Pm, Sm, Pn and Sn are applied; (2) The velocity inverted by DSS was applied to constrained to improve the accuracy; (3) The model was modified by waveform inversion; (4) The genetic algorithm applied to location, traveltime inversion and waveform inversion was adopted to optimized; (5) The velocity sections for any depth and velocity-distance-depth profiles from surface to Moho were got to analyze the crustal characteristics.
The general crustal structure for research area was got, the deep structure difference including basin and folding area for different geological province can be found, the deep structure features in earthquake areas of Gulang M8.0, Shandan M7.3, Menyuan M6.4, Jingtai M6.8 were got.

STE-17

DEEP VIBROSEISMIC SOUNDING IN SIBERIA

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Results of long-term researches conducted by scientists of the Siberian Branch of the Russian Academy of Sciences on the development of powerful and ecologically safe vibroseismic sources are represented. The vibrators are designated for deep seismic sounding and provide high-stability seismic wave generation (regarding amplitude, phase, frequency and orientation). As a result of experimental and methodical works, executed in various regions, the monochromatic signals from powerful vibrators were recorded at distances up to 1500 km, and good-quality vibroseismic records comparable in quality with records from explosions in water basins and boreholes were obtained at distances out to 350 km. Direct experiments show that a forty-minute work of 100-ton powerful vibrator is equal in seismic energy to explosion of 4-5 tons of trotyl, and the 40-minute operating of a 40-ton collapsible vibrator is 3-4 times weaker than the explosion of a 1.5 ton trotyl charge distributed in 1.5-2.5-m-deep water basin. With researches at the Baikal and Bystrovka vibroseismic test sites, the high stability and recurrence of vibration effects being equal to a decimal fraction of a millisecond was shown. The carried out experimental research with powerful vibrators of various design convincingly prove their effective use in deep seismic sounding and vibroseismic monitoring of a medium. The results of vibroseismic studying the earth's crust and upper mantle in Altai-Sayan region and Baikal rift zone and the detailed analysis of wave field from powerful vibrator at various distances are presented in the paper. Vibroseismic observations substantially supplement the data of previous deep seismic investigations in these regions and make justified setting up of seismological observations and active vibroseismic monitoring of seismically dangerous sites of these regions.

STE-18

IMAGING BASEMENT FAULT BLOCKS WITH WIDE-ANGLE MULTI-CHANNEL DATA

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We present a new method to image basement structure from long-offset data acquired by Veritas DGC in 1998 in the Faroes-Shetland Basin. Over 200 km of data was collected by using a single streamer of 12 km and a second streamer of 5km, giving a maximum offset of 18km. The survey has produced a densely sampled dataset of very high quality which has allowed us to view the data in the common-offset domain and to trace weak events across individual shot records at the full range of offsets. These events, seen in common-offset sections, represent wide-angle reflections returning from beneath a high velocity basalt layer and show basement topography to consist of fault blocks on a 5-10 km scale, while also showing deeper structure below this. A 2D tau-p mapping technique has been used to determine a large scale velocity model suitable for use with travel-time inversion and pre-stack depth

STE-19

DEPTH FOCUSING AND PRE-STACK MIGRATION OF WIDE-ANGLE CRUSTAL AND SHALLOW SEISMIC RECORDS

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At large offsets typical for both crustal-scale and near-surface seismic exploration, the performance of prestack migration algorithms critically depends on depth focusing which is their ability to determine an accurate background velocity model. In our new prestack migration package, detailed wide-angle depth focusing is achieved (1) by interactive analysis of common-image gathers and (2) by estimating coherency attributes of the wavefield in the pre-stack domain. Both of these methods are used for refining the velocity model for a family of travel-time map-based pre-stack depth migration algorithms, such as diffraction-stack, Kirchhoff, Kirchhoff-reciprocal- Kirchhoff (KRK), and asymptotic inversion.
In the first of these techniques, we generate a series of Common-Image gathers and use an interactive program to identify and pick the residual reflection moveouts due to errors in the background velocity model. The resulting picks are directly projected back into the velocity model making our wide-angle depth focusing similar to conventional CMP stacking velocity analysis.
Our second method utilizes the entire midpoint-offset-depth data volume to measure the coherency within the migrated common-image gathers. In a single pass through the processing tool, seismic records are migrated into each imaging point for a range of background velocities, and the regions of the maximum coherency are identified. The coherency can be estimated using traditional semblance methods or by a high-resolution measure based on phase statistics. The resulting coherency panels are then picked and used in tomographic velocity updating.
We apply these techniques to 2-D shallow seismic data acquired by Rice University team at Hill Air Force base, Utah. The results show that our approach is capable of resolving overburden velocity variations above the target horizon at 6 - 15 m depths thus providing the necessary focusing for a reliable high-resolution reflection depth image of the target horizon.

STE-20

ASSESSMENT OF 2D AND 3D VELOCITY MODELS DERIVED FROM WIDE-ANGLE TRAVELTIME DATA

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Nonlinear methods for assessing the reliability of 2D and 3D velocity models derived from wide-angle traveltime data are presented. Deriving alternate models that satisfactorily fit the real data is the best means of estimating the bounds on single model parameters and specific model features, in the case of minimum-parameter and finely-gridded models, respectively. Using a tomographic approach with roughness and perturbation constraints is the most effective way to establish whether particular model features are required by the data or merely consistent with the data. A shortcoming of modeling some datasets is the subjective aspects of identifying and including later phases, assigning specific layers to refracted arrivals, and positioning model nodes when using a minimum-parameter-type approach. The effect of these more subjective choices can be addressed using first-arrival traveltime tomography that seeks a minimum-structure model. Model resolution can be estimated using a tomographic approach and a series of checkerboard tests with a range of anomaly sizes. These techniques are illustrated using real data from central India, southwest British Columbia, the Faeroe Basin, and the Chilean and Iberia margins.

Passive Continental Margins Wed. 21st to Thurs. 22nd June

PCM-1

SIMULTANEOUS WIDE-ANGLE AND ZERO-OFFSET TRAVELTIME INVERSION FOR 2D VELOCITY STRUCTURE OF THE IBERIA MARGIN

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We present an analysis of wide-angle and MCS data from the Iberia margin along a 335 km dip profile over the Galicia Interior Basin (GIB), Galicia Bank (GB), S reflector, and Peridotite Ridge. The MCS data provide a detailed image of the margin sediments and basement. The wide-angle data constrain the sub-sedimentary velocity structure. Zero-offset reflection times from the sediments, basement and S reflector were inverted simultaneously with the deeper refraction/wide-angle phases to account for the complex shallow structure on the deeper raypaths. A model satisfying all the data was obtained which includes subjective features considered geologically reasonable. To objectively assess this model, the first arrival data were inverted using a tomographic approach. The isovelocity contours representing the Moho in the final tomographic model agree well with the Moho derived from the inversion of the complete set of traveltimes using the subjective approach. The S reflector appears to be the Moho just 3-5 km beneath the seafloor and its seaward dip suggests it is a detachment fault. Landward of the S reflector, the correlation between crustal thickness, water depth and sediment thickness is typical for a rifted margin. Crustal thickness variations suggest the margin extended in two phases spatially separated by about 100 km, with stretching factors of 2.5-3 and nearly infinite implied for the early and late (preceding seafloor spreading) stages of rifting beneath the GIB and GB basin.

PCM-2

CRUSTAL IMAGES OF MESOZOIC EXTENSION AND ALPINE COMPRESSION AT THE NORTH IBERIAN MARGIN

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The North Iberian Margin (NIM) at the southern part of the Bay of Biscay, separated from the Armorican conjugate margin since the Mesozoic opening of the Atlantic Ocean, has been affected by successive tectonic episodes of rifting, passive margin and shortening from Permo-Triassic to Later-Tertiary times. A crustal cross section of the NIM, from the abyssal plain to the coastline has been established by combining commercial seismic reflection profiling at the platform, the deep profile ESCIN-4 and gravity modelling. The detailed cross section of the Iberian continental shelf reveals structures from all three tectonic events: a) normal faults and asymmetric basins from the Permian to lower Cretaceous extensional stage. b) Upper Cretaceous sediments deposited under stable conditions during the passive margin period. c) Inverted faults, thrusts and folds related to the Tertiary compression that led to a remarkably steep (17°) continental slope. Tertiary deformation is particularly intense at the foot of the continental slope where uppermost Cretaceous to Lower Miocene sediments are deformed and thrusted northwards. The deep structure was constrained from the ESCIN-4 vertical and wide-angle seismic data. A conspicuous reflective lower crust and Moho deepening landwards are imaged together with reflections from a second deeper Moho that suggest a duplicated lower crust forming a crustal root under the Cantabrian Mountains and subducting to the North. Features interpreted as crustal scale Mesozoic detachments could be the weakness zones that allowed the Margin's lower crust to "slide" southwards and split the Iberian crust, forcing the subduction of the Iberian lower crust northwards.

PCM-3

THE STRUCTURE OF THE IBERIAN MARGIN AT 41 DEGREE 2': MCS AND OBH RESULTS

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West off Iberia, the nonvolcanic rifted continental margin is made up of three main structural segments: the Galicia Bank to the north, the south Iberia Abyssal Plain in the center, and the Tagus Abyssal Plain in the south. The Iberian margin was formed during rifing between Iberia and New Foundland, the breakup propagating northwards, occurring at about 137 Ma, 130 Ma and 114 Ma in the Tagus Abyssal Plain, Iberia Abyssal Plain and Galicia Bank area, respectivley.
During a joint US-German seismic experiment a huge data set of combined multichannel and wide-angle lines were surveyed at the northern Iberian margin (Ewing cruise July to August 1997). Here we present the results of a 300 km long combined MCS/OBH transect across the margin (41 degree 2'N) at the transform zone between the Galicia Bank segment and the Iberia Abyssal Plain segment.

PCM-4

THE INITIAL PHASE OF THE SOUTH ATLANTIC RIFT -- NEW SEISMIC DATA OF THE ARGENTINE PASSIVE CONTINENTAL MARGIN

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The study area of the BGR98-cruise is located offshore Argentina. It comprises the outermost shelf, the slope, the rise and even the abyssal plain, and includes the seaward extension of the Colorado Basin. Approximately 12.000 km of multichannel deep seismic lines, mostly traversing across the Argentine continental margin, were acquired by the BGR. In the Late Jurassic / Early Cretaceous times, continental break up of Gondwana led to the opening and northward propagating of the South Atlantic. Since 135Ma, the Paranà-Etendeka continental flood basalt provinces were emplaced, associated with multiple series of seaward-dipping reflectors (SDRS), possibly related to the Tristan da Cunha hot spot. Up to five distinct zones of SDRS reaching down to more than 13s TWT could be mapped trending parallel to the Argentine continental margin. Transform faults were interpreted on strike lines and across some of them the SDRS show lateral displacement or even disappear. The angles of dipping of the individual SDRS vary reflecting different phases of their emplacement for which a model is proposed. Very few extensional tectonic features could be found affecting the continental crust within the study area. Normal faulting is concentrated on one zone parallel to the margin wherein small grabens were formed, west of an outer margin high. Prior to the break-up, sedimentation has started most probably with a lacustrine facies interfingering with the SDRS (most likely to consist of basalt and volcanoclastic sediments). Below the break-up unconformity, synrift sediments are found within the marginal basins and time equivalent deposits overly the SDRS and the associated interbedded lacustrine sediments. After break-up, the continental margin was affected by thermal subsidence, especially along the elongated SDRS zones. A thick sedimentary column (up to 6000 m in the southern pqrt) was deposited onto the transition zone between the continental and the oceanic crust during the period of thermal sag. On top of the break-up unconformity 4 progradational phases were deposited during the cretaceous followed by an erosion (End Cretaceous / Early Tertiary). This has formed a widespread erosional surface on which a thick aggradational sedimentary wedge was then deposited and strongly affected by gravity faulting related to detachment layers formed by the underlying erosional surface. The most recent sedimentation started with a prominent onlap horizon (Paleogene) and drift structures were deposited forming giant dunes. Based on the seismic interpretation, IFP softwares GENEX / DIONISOS were used, to model the subsidence of and the sedimentary processes within the transition zone, in order to establish the thermal history, the tectonic evolution as well as the sedimentary distribution taking into account decompaction and erosion processes.

PCM-5

EARLY OPENING--INFERENCES FROM U.S. EAST COAST MARGIN AND SOUTH ATLANTIC CONJUGATE MARGINS

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Highly reflecting continental crust off the U.S. east coast terminates abruptly against an interface that dips steeply landwards. We believe that Initial Oceanic Crust lies seaward of this boundary. This crust consists of intrusives overlain by extrusives ; the latter appear in seismic reflection records as characteristic seaward dipping reflectors. The continental crust undergoes only moderate thinning prior to an apparently abrupt breakup.
Seaward dipping reflectors (SDR's) also characterize the Pelotas Basin in the western South Atlantic and the conjugate Walvis basin in the eastern South Atlantic. Under the feather edge of the SDR's rifted continental crust is seen in the reflection records; while the crust underlying the major part of the SDR's is devoid of reflectors and presumably represents Initial Oceanic Crust. A number of adjacent lines in both margins show the along strike variations in the SDR's. Also notable in these sections is the presence of antithetic faults.

PCM-6

IMAGING CRUSTAL STRUCTURE ON THE EUROPEAN CONTINENTAL MARGIN IN THE PRESENCE OF SIGNIFICANT BASALT FLOWS AND SILLS

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Thick basalt flows and multiple sill injections are endemic on the northwest European continental margin. The strong impedance contrasts generated by these basalt layers severely hinder imaging of the underlying crustal structure, both by reflecting much of the seismic energy and by generating many strong inter-bed multiples. We discuss a variety of techniques which can help overcome some of these problems, using as examples seismic data acquired in the Faeroe-Shetland Trough. Four-component, sea-bed data acquired using a cable-mounted array of three-component geophones plus hydrophones allow direct recording of S-waves at the seabed. Even with airgun sources, locally strong P-to-S conversions create prominent S-wave phases and allow us to determine the S-wave velocity structure of the lava flows. Two-ship synthetic aperture seismic profiles with offsets of up to 38 km acquired in the same location as the 4C data allow the deeper sedimentary and basement structure to be determined. Finally, even larger offsets of up to 110 km have been recorded by deploying three-component seismometers on land on the island of Suduroy, Faeroe Islands, at one end of the offshore synthetic aperture profiles. These recorded clear Moho reflections, thus constraining the crustal structure to a depth of 25 km.

PCM-7

CRUSTAL STRUCTURE OF AN EXTENDED CONTINENTAL MARGIN NORTHEAST OF NEWFOUNDLAND

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The Orphan Basin is a wide (400 km) zone of thinned and extended continental crust on the rifted continental margin northeast of Newfoundland. It is bounded to seaward by the continental fragment of Orphan Knoll, and to the south by the shelf and basins of the Grand Banks. A wide-angle seismic experiment was run across the basin and the adjacent margin, along an existing deep reflection profile. Data from fifteen ocean bottom seismometers, in combination with a large airgun array, allow the determination of crustal velocity structure over much of the extended continenental crust and the adjacent oceanic region. Prerift metasedimentary rocks, with up to 5 km relief produced by block faulting during extension, are present beneath the synrift and postrift sediments. Crystalline upper and lower crust have a total thickness of typically 10-15 km. Most significant, there is no indication of a high-velocity lower crustal layer (>7 km/s), which might be due to magmatic underplating. The extension of the basin therefore appears to have taken place amagmatically. The continental crust ends abruptly seaward of Orphan Knoll, and the adjacent continent-ocean transition zone shows many of the characteristics of the serpentinized peridotite zones that are seen on some other nonvolcanic margins, suggesting that there may be no actual crust here, and that true igneous oceanic crust may not have been produced until significant continental separation had occurred.

PCM-8

COMBINED NEAR-VERTICAL AND WIDE-ANGLE REFLECTION AND REFRACTION STUDIES OF THE AUSTRALIAN NORTH WEST SHELF

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Wide-angle reflection and refraction data were used in this study to supplement conventional CDP (near-vertical reflection) data. The wide-angle data were recorded by ocean-bottom (OBS) seismographs on the Australian North West Shelf during a survey undertaken by AGSO along 5 profiles of total length 2764 km. Velocity information can now be derived from two independent data sets: CDP and OBS data. Residual (difference between these two velocity data sets) velocity images can be produced and analysed. Even within the top 5 km of the section, residuals between the OBS- and CDP-derived interval velocities vary from –0.5 to +3.5 km/s and increase further with depth. Consequently, the depth equivalent of 4 s two-way time will vary by up to 1.2 km or 10%. OBS-derived velocity model enables depth migration of refraction/wide-angle seismic data thus presenting them in the same style as the conventional reflection data and extending seismic image into the lower crust where the CDP data lacks detail.

PCM-9

DEEP SEISMIC REFECTION PROFILING OF THE PROTEROZOIC HAMERSLEY PROVINCE, WESTERN AUSTRALIA

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Images from two seismic reflection profiles of the Hamersley Province foreland fold-and-thrust belt in the Pilbara region of Western Australia reveal a complex Archaean/Proterozoic tectonic history. The Ophthalmian (~2.3 Ga) and Ashburton orogenies (~1.7 Ga) are recognised tectonic events, which resulted in significant crustal shortening and formed the regional EW-trending fold belts in the Hamersley Basin. The seismic data provide some clear evidence for thrusting in the upper crust that formed during the Ophthalmian orogeny. However, prominent shallow reflections, which define the Archaean mafic volcanic and volcaniclastic rocks of the Fortescue group that overlie the granitic basement, show surprisingly little collisional deformation characteristics. The basal contact is mainly subhorizontal with a slight increase in thickness to the south and has probably served as a decollement surface for at least one of the main orogenic events. The upper crust is about 10 km thick (1.5 - 5 s twt) and consists of Archaean granite and greenstones. This part of the crust exhibits significant lateral variations in reflectivity that are probably manifestations of remnant Archaean deformations. A transition from upper to mid and lower crust is marked by strong reflections at about 5 s twt. A generally highly reflective imbricated mid and lower crust consists presumably of higher grade metamorphic laminae. Discontinuous reflections with dips of up to 20 degrees in opposite directions exists in this part of the crust. Reflectivity tapers off at 11 to 11.5 s twt indicating that the Moho is not a first-order discontinuity. Estimates of crustal thickness, using velocity information from earlier refraction studies, indicate a depth to Moho from 34 in the north to 37 km in the south, which is in agreement with prediction based on the regional Bouguer gravity anomaly. It is anticipated that the seismic images help address questions regarding the diagenesis of the economically significant iron-ore deposits in the Hamersley Basin.

PCM-10

S-WAVE AND GRAVITY MODELING BASED ON P-WAVE MODELS OF WIDE ANGLE SEISMIC DATA FROM OCEAN BOTTOM SEISMOMETERS SOUTHEAST OF SVALBARD

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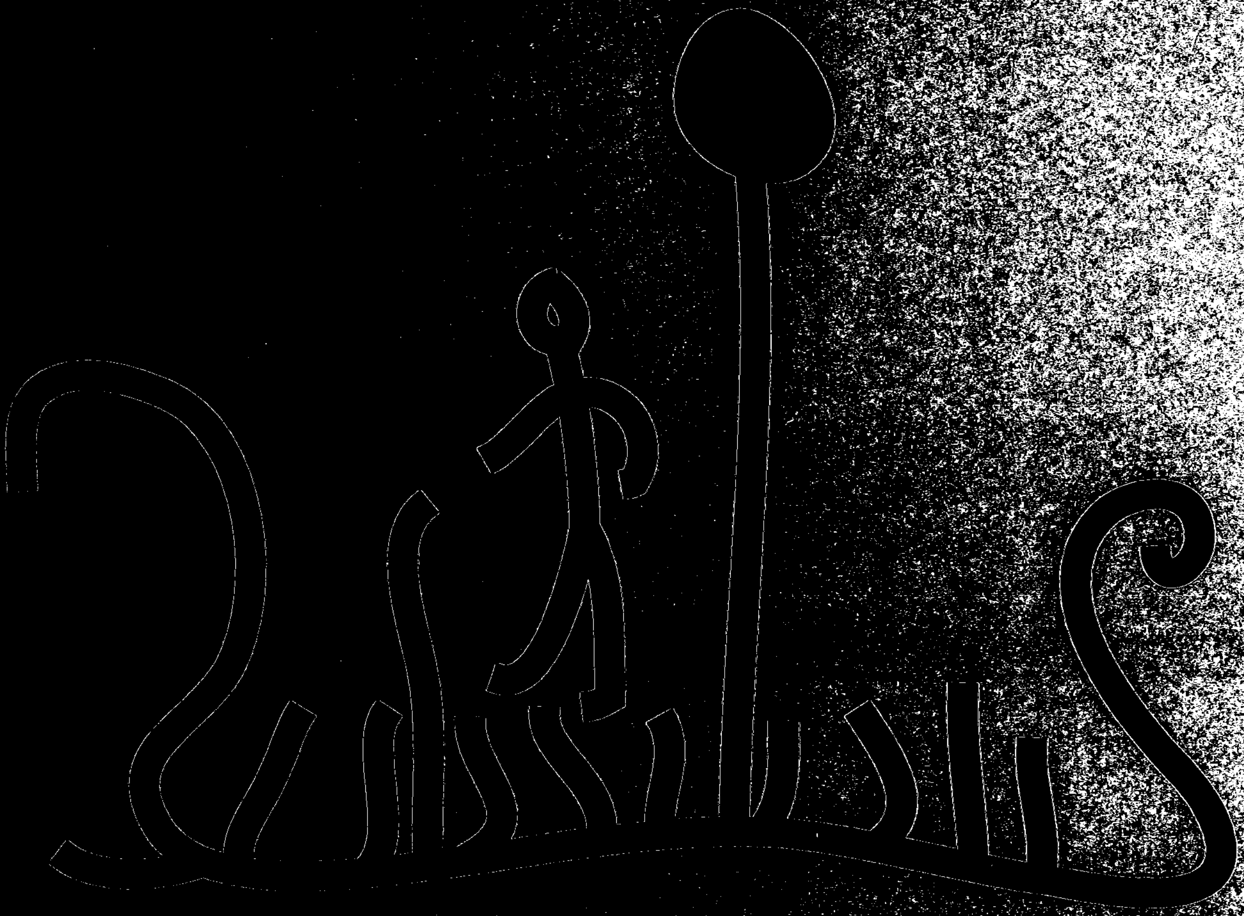
Southeast of Svalbard no reliable mapping below the Permian sequence from conventional seismic reflection data exists, and the early post-Caledonian development is largely unknown. The modeling of four OBS profiles acquired in 1998 southeast of Svalbard is presented here. Based on earlier P-wave modeling of these profiles, S-wave and gravity modeling give new constraints on the structure and lithology of the area. The S-wave recordings enable direct and indirect estimates of the S-wave velocity of the sedimentary and crystalline units. The Vp/Vs ratios of the sedimentary units indicate a mixed lithology of sand and clay, and possibly carbonates. An increase of the Vp/Vs ratio with depth agrees with a reduction in porosity with increasing overburden. Very high values seen where sedimentary units gets thin is likely due to the development of cracks as a response to erosional unloading. Top crystalline basement uniformly shows a Vp of 6.3 km/s and a Vp/Vs ratio of 1.69, indicating a quartz rich igneous or metamorphic lithology compatible with granite or felsic gneiss. S-waves converted at and reflected off the Moho indicate that this value is representative for the bulk of the crystalline crust. There are indications of a higher ratio at the southwestern part of the area, and bodies of intermediate to mafic composition may be present here.

There is little correlation between observed gravity and the depth to crystalline crust and to Moho. The gravity modeling suggests that the observed field is dominated by density variations between 2800 and 2990 kg/m^3 in the crystalline crust. High basement densities account for the two major positive gravity anomalies in the area, augmented by high density in the upper mantle. This occurs under the Olga Basin, imparting a positive gravity anomaly to the basin. Only one major anomaly corresponds to a top basement feature; a low located between the Sentralbanken High and the Olga Basin. The high density body in the southwest correlates with the area of possibly increased Vp/Vs ratios, compatible with a more mafic composition here.



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