6th International Symposium on

# SEISMIC REFLECTION PROBING OF THE CONTINENTS AND THEIR MARGINS

## Program & Abstracts

Budapest, Hungary
12-17 September 1994

# Sponsors

The Local Organizing Committee would like to thank the following organizations for their generous support:

**ACCORD:** Assistance of the Community in Co-operation in R&D
**ELGA:** Eötvös Loránd Geofizikai Alapítvány (Eötvös Loránd Geophysical Foundation)
**IASPEI:** International Association of Seismology and Physics of the Earth's Interior
**ILP:** International Lithosphere Program
**ISF:** International Science Foundation Travel Grant Program
**Lithoprobe**
**MOL Rt:** Magyar Olaj- és Gázipari Rt. (Hungarian Oil and Gas Co.)
**OMFB:** Országos Műszaki Fejlesztési Bizottság (National Committee for Technological Development)
**PACE** Foundation: Programme for Association on Co-operation in Earth Sciences

## INTRODUCTION AND WELCOME

The Symposium Organizing Committee extends a hearty welcome to all participants to the 6th International Symposium on 'Seismic Reflection Probing of the Continents and Their Margins' being held in Budapest. The choice of Budapest as the venue for this event meant both pleasure and responsibility for Hungarian geophysicists and geologists. Through your contribution we hope the symposium will be a scientific success and a rewarding experience.

The Symposium is held in the Agro Hotel which is located in one of the most delightful spots of Budapest, high on a hill, with a glorious view. Budapest also offers many cultural opportunities which are worth taking advantage of.

In conclusion let we thank you for coming, wish you a successful conference and a pleasant stay in Budapest.

## SPECIAL EVENTS PROGRAM

***Sunday, 11 September***
19.30 - 21.00 Welcoming Icebraker (Agro Hotel)

***Tuesday, 13 September***
19.00 - Organ Concert (Matthias Church)

***Friday, 16 September***
19.30 - Conference Banquet (Agro Hotel)

## SYMPOSIUM ORGANIZING COMMITTEE

Károly POSGAY, (Chairman) Eötvös Loránd Geophysical Institute of Hungary
Tamás BODOKY, Eötvös Loránd Geophysical Institute of Hungary
Zoltán NAGY, MOL Rt/Hungarian Oil and Gas Co.
Endre HEGEDŰS, Eötvös Loránd Geophysical Institute of Hungary
István KÉSMÁRKY, MOL Rt/Hungarian Oil and Gas Co.
Ernő TAKÁCS, Eötvös Loránd Geophysical Institute of Hungary

## SECRETARIAT

Éva BELLÉR, Association of Hungarian Geophysicists
Lajos TÓTH, Eötvös Loránd Geophysical Institute of Hungary

## ADDITIONAL INFORMATION

*Mounting of Posters*

Poster presentations may be mounted after 9.00 on Monday, September 12 in the poster room. Each poster presentation has been assigned a numeric identification. See the detailed 'Poster Presentation Program', to find the identification for your poster. For example, one poster is designated 3/2, indicating scientific Theme 3 and poster 2 within that theme. Poster boards are labelled in the same way. Mount your poster on the board that has your poster identification from the detailed program. Poster may remain on display throughout the Symposium. All posters must be removed no later than 10.00 am Friday, 16 September.

*Audio-Visual Equipment*

The Auditorium is equipped with two 35 mm slide projectors, two overhead projectors and two screens.

*Carousels and Previewing of Slides*

Carousels for your slides and projectors for previewing of oral presentations are available in a separate room. Please empty and return your carousel(s) to this room at the Lunch or Diner break following your presentation.

*Languages*

Papers will be presented in English and no simultaneous interpretation will be provided.

## PROCEEDINGS VOLUME

The Organizing Committee has made preliminary arrangements with the publishers of the Elsevier journal Tectonophysics for a special issue in which the proceedings will be published. This will be similar to the special issue in which the proceedings of the 5th International Symposium held in Banff (1992) were published [Tectonophysics, Vol. 232, Nos. 1-4, 1994].

All those, who have ticked the 'Yes' box on the Conference Registration Form are kindly asked to confirm their intention by leaving the title and the author(s) name in the 'Tectonophysics' box on the Registration desk. The Committee on publication, appointed by the Editor-in-chief, will decide on the content of the special issue. Manuscripts will undergo the usual rigorous review process of the journal.

In order to avoid major delays between the meeting and the publication of the proceedings, three copies of the manuscripts with all illustrations must be received by 31 December, 1994 on the following address:

Dr. Károly Posgay
Eötvös Loránd Geophysical Institute of Hungary
POB 35
H-1440 Budapest

Papers arriving later will not be considered for publication in the proceedings of the conference.
A short Guide for Authors can be found at the end of each copy of Tectonophysics, a detailed one is published in Vol. 227, Nos. 1-4. You are kindly asked to consult this guide.

## OPENING EVENTS

*Monday, 12 September*

9.00 — 9.30 Welcoming Addresses:
K. POSGAY, Chairman of the Organizing Committee
I. KÉSMÁRKY, Vicepresident of the Association of Hungarian Geophysicists
T. BODOKY, Director of the Eötvös Loránd Geophysical Institute of Hungary; President of the European Association of Exploration Geophysicists

## SCIENTIFIC PROGRAM

## ORAL PRESENTATION PROGRAM

### *Monday, 12 September, Morning Session*

**Theme: Potential of deep seismic reflection profiling for hydrocarbon exploration**

Chairman: T. BODOKY (9.30 — 12.00)

| | |
|---|---|
| 9.30 — 10.00 | *I. BÉRCZI* (invited speaker): Application of Deep Seismic surveys in Oil and Gas exploration in the Hungarian Part of the Pannonian Basin |
| 10.00 — 10.30 | *D. M. FINLAYSON* (invited speaker), D. W. JOHNSTONE, A. J. OWEN, K. D. WAKE-DYSTER: Deep Seismic Images of Early Rifting Processes in the Otway Basin, Australian Southern Margin |
| 10.30 — 11.00 | COFFEE BREAK |
| 11.00 — 11.20 | K. BADDARI, M. DJEDDI, *R. BAOUCHE*: Physico-Geological Statistical Model of South-Eastern Constantinois Carbonated Reservoirs of Algeria |
| 11.20 — 11.40 | *D. EATON*, B. MILKEREIT, G. ROSS, E. KANASEWICH: Seismic Evidence for Basement Controls on Sedimentation in the Western Canada Sedimentary Basin |
| 11.40 — 12.00 | |

### *Monday, 12 September, Afternoon Session*

**Theme: Deep seismic reflection profiling results and techniques**

Chairman: R. MEISSNER (14.00 — 15.40)

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|---|---|
| 14.00 — 14.20 | *L. D. BROWN* and Cornell Deep Seismic Research Group: COCORP and Global Deep Seismic Profiling |
| 14.20 — 14.40 | *S.P.LARKIN*, A. LEVANDER, D. OKAYA, K. HOLLIGER: Three-Component Seismic Imaging of the Basin Range/Salton Trough Transition Zone in South-eastern California, USA |

14.40 — 15.00 *E. S.WISSINGER*, A. LEVANDER, J. S. OLDOW, G. S. FUIS, W. J. LUTTER: Seismic Images of the Brooks Range Fold and Thrust Belt, Alaska, from an Integrated Seismic Reflection/Refraction Experiment

15.00 — 15.20 *I. KÉSMÁRKY*, Z. HAJNAL: LITHOPROBE, Vancouver Island Interval Velocity Case Study — a Retrospective View

15.20 — 15.40 *J. H. MCBRIDE*, R. W. HOBBS, R. S. WHITE: Whole-Crustal Normal Faults? — Oceanic Deep Reflection Evidence

15.40 — 16.10 COFFEE BREAK

Chairman: L. STEGENA (16.10 — 17.50)

16.10 — 16.30 *M. TORNE* and IAM Group: E. BANDA, R. LONG, L. MENDES-VICTOR, L. SENOS, J. C. SIBUET, A. B. WATTS: A Seismic Image of the Iberian Atlantic Margins: The IAM Project

16.30 — 16.50 *J. ALVAREZ-MARRÓN*, J. J. DAÑOBEITIA, A. PÉREZ-ESTAÚN, J. A. PULGAR: Seismic Structure of the Northern Continental Margin of Spain

16.50 — 17.10 *R. CARBONELL*, M. TORNE, E. BANDA: Lateral Heterogeneous Velocity Model for the Betics Cordillera: Results from Migration Moveout Velocity Analysis

17.10 — 17.30 *M. SIMON*, H. GEBRANDE, M. BOPP: Pre-Stack Migration and True-Amplitude Processing of DEKORP Steep- and Wide-Angle Reflection Measurements

17.30 — 17.50 *Č. TOMEK*, S. VRANA: Deep Seismic Transect Through West Bohemia and its Significance for the Interpretation of Variscan Continental Collision

## *Tuesday, 13 September, Morning Session*

**Theme: Deep seismic reflection profiling results and techniques**

Chairman: St. MUELLER (8.30 — 10.00)

8.30 — 9.00 *Z. HAJNAL* (invited speaker), B. REILKOFF, K. POSGAY, E. HEGEDŰ S, E. TAKÁCS, I. ASUDEH, St. MUELLER, J. ANSORGE, R. DELACO: Crustal Scale Extension in the Central Pannonian Basin

9.00 — 9.20 *F. HORVÁTH*, G. TARI, L. CSONTOS, P. SZAFIÁN: Crustal Structure and Mechanism of Extension in the Pannonian Basin

9.20 — 9.40 *A. HIRN*, F. AVEDIK, E. BANDA, D. BLUNDELL, M. LOUCOYANNAKIS, J. DRAKOPOULOS, R. NICOLICH, J. MCBRIDE, L. A. MENDES-VICTOR, M. SACHPAZI: Deep Structure of Ionian and Aegean Basins and Margins: Streamers Multichannel and Wide Angle Seismics

9.40 — 10.00 *M. SACHPAZI*, A. HIRN, A. NERCESSIAN, J. DRAKOPOULOS, J. DIAZ, M. LOUCOYANNAKIS and STREAMERS Group: Wide Angle Images of Aegean Crusts

10.00 — 10.30 COFFEE BREAK

Chairman: T. ITO (10.30 — 12.10)

10.30 — 10.50 *P. BANKWITZ*, H.-J. BEHR, H.-J. DÜRBAUM: The DEKORP MVE-90 Profile and its Geological Consequences

10.50 — 11.10 *P. SADOWIAK*, G. HIRSCHMANN, H. WIEDERHOLD: Seismic Reflections from the Crystalline Crust at the KTB Site (Germany)

11.10 — 11.30 *S. V. SOBOLEV*, A.Yu. BABEYKO, E. LÜSCHEN, K. FUCHS: Nature of Seismic Reflections at KTB Borehole in Germany: Modeling Based on Rocks Composition, Fabrics and Borehole Measurements

11.30 — 11.50 *M. KÖRBE*, H. HORSTMEYER, Th. RÜHL: Three-Dimensional Migration of the 3D Deep-Seismic Reflection Survey at the KTB Location, Oberpfalz, FRG

11.50 — 12.10 *W. RABBEL*, E. LÜSCHEN: Shearwave Anisotropy of Laminated Lower Crust

## *Wednesday, 14 September, Morning Session*

**Theme: Deep seismic reflection profiling results and techniques**

Chairman: Z. HAJNAL (8.30 — 10.40)

8.30 — 8.50 MONA LISA WORKING GROUP (*H. THYBO*, L. B. PEDERSEN, E. R. FLUEH, R. ENGLAND, N. BALLING): Mona Lisa — Deep Seismic Profiling in the South-Eastern North Sea

8.50 — 9.10 *S. KODAIRA*, H. SHIMAMURA, H. B. HIRSCHLEBER, R. MJELDE: Crustal Structure of the Ocean-Continental Transition Zone of the Lofoten Margin, off N. Norway by OBS Refraction and Wide-Angle Reflection Studies

9.10 — 9.30 *R. MJELDE*, M. A. SELLEVOLL, S. KODAIRA: Crustal Structure of the Volcanic Margin off Lofoten, N. Norway, from Multichannel Reflection and Wide-Angle OBS-Data

9.30 — 9.50 *M. MCCAUGHEY*, S. C. SINGH: A Simultaneous Inversion of Both Reflection and Wide-Angle Seismic Data

9.50 — 10.10 *S. C. SINGH* and the BIRPS Core Group, P. J. BARTON, T. A. OWEN, J. J. DOODY: Wide-Angle and Broad-Band Seismic Investigation of the Continental Crust

10.10 — 10.40 COFFEE BREAK

Chairman: R. CLOWES (10.40 — 12.00)

10.40 — 11.00 *R. W. ENGLAND*, N. J. SOPER, P. D. RYAN and the BIRPS Core Group: Identification of Terranes Using Deep Seismic Data from Offshore Britain and Ireland

11.00 — 11.20 *R. HOBBS*, BIRPS Core Group, A. ZIOLKOWSKI, R. JOHNSTON: Multiple Suppression Techniques and their Application to Deep Seismic Reflection Data

11.20 — 11.40 V. S. DRUZHININ, *S. N. KASHUBIN*, T.V. KASHUBINA, V. A. KOLMOGOROVA, G.V. PARYGIN, A.V. RYBALKA, A. M. TIUNOVA: The Main Features of the Interface between the Crust and the Upper Mantle in the Middle Urals (in the vicinity of the deep drillhole SG-4)

11.40 — 12.00 *J. H. KNAPP*, M. A. BADER, D. N. STEER, L. D. BROWN: COCORP and Seismic Reflection Profiling of the Uralian Orogen, Russia

## *Wednesday, 14 September, Afternoon Session*

**Theme: Seismic reflection studies of the Precambrian crust**

Chairman: D. FINLAYSON (14.00 — 16.30)

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| 14.00 — 14.30 | *R. M. CLOWES* (invited speaker): Lithoprobe Reflection Studies of Archean and Proterozoic Crust in Canada |
| 14.30 — 14.50 | *J. HALL*, R. WARDLE, C. GOWER, A. KERR, K. COFLIN, C. KEEN, P. CARROLL: Reflection Seismic Images of Proterozoic Orogens of the Northeastern Canadian Shield |
| 14.50 — 15.10 | *S. B. LUCAS*, Z. HAJNAL, J. LEWRY, D. WHITE: Seismic Reflection Record of a Transition from Collisional to Post-Collisional Tectonics: Trans-Hudson Orogen (Canada) |
| 15.10 — 15.30 | *D. J. WHITE*, S. B. LUCAS: Ancient Continental Collision: Variations in Response of the Northwestern Superior Crust to Terrane Impingement |
| 15.30 — 15.50 | *C. JUHLIN*, J. H. KNAPP, S. KASHUBIN, M. BLIZNETSOV: New Deep Seismic Reflection Data from the Urals — the ESRU Profile |
| 15.50 — 16.10 | *D. SNYDER*, H. PRASETYO: Deep Seismic Reflection Profiles of an Archean Craton Becoming a Modern Mountain Belt, The Banda Arc |
| 16.10 — 16.30 | *S. BEZDÁN*, Z. HAJNAL: Seismic Ivestigation along the Western Flank of the Trans-Hudson Orogen Transect |
| 16.30 — 17.00 | COFFEE BREAK |
| 17.00 — 19.00 | **Special Poster Session 1** |

## *Thursday, 15 September, Morning Session*

**Theme: Long-range seismic profiles using nuclear sources. Earthquake (teleseismic) data**

Chairman: A. ÁDÁM (8.30 — 10.10)

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| 8.30 — 9.00 | *St. MUELLER* (invited speaker): The Lithosphere-Asthenosphere System in the Mediterranean-Alpine Region |
| 9.00 — 9.30 | *A.V. EGORKIN* (invited speaker): Features of the Mantle Structure Beneath Northern Eurasia from Long-Range Recodings |
| 9.30 — 9.50 | *E. S. HUSEBYE*, B. O. RUUD, Y. GRUNDT: Finite Difference Modelling of Elastic Wave Propagation in Perturbed Media: Seismic Processing and Interpretation |
| 9.50 — 10.10 | *F. A. NEVES*, S. C. SINGH, K. F. PRIESTLEY: Velocity Structure of the Upper Mantle Transition Zones from Waveform Inversion of Seismic Refraction Data Using Genetic Algorithm |
| 10.10 — 10.40 | COFFEE BREAK |

Chairman: Č. TOMEK (10.40 — 12.20)

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| 10.40 — 11.10 | *N. I. PAVLENKOVA* (invited speaker): Structure of Upper Mantle from Long-Range Seismic Profiles in Eurasia |

**Theme: Seismic reflection studies of the sub-crustal lithosphere and the asthenosphere**

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| 11.10 — 11.40 | *J. ANSORGE* (invited speaker): The Structure of the Lower Lithospere as Derived from Seismic Reflection and Refraction Surveys |
| 11.40 — 12.00 | *J. H. MCBRIDE*, D. B. SNYDER, R. W. ENGLAND: Upper-Mantle Reflector Structure Beneath Scottish Caledonides |
| 12.00 — 12.20 | *B. YANG*, C. LIU, M. LI, H. ZHOU: Study of Moho Characters Using VRSM |

## *Thursday, 15 September, Afternoon Session*

**Theme: Deep seismic reflection profiling results and techniques**

Chairman: J. ANSORGE (14.00 — 15.40)

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| 14.00 — 14.20 | *E. SHEIKH-ZADE*: Results of Seismic Reflection Profiling in the Turanian Platform |
| 14.20 — 14.40 | *K. D. NELSON*, W. ZHAO and Project Indepth Team: Indepth Deep Profiling of the Himalayan Collision Zone |
| 14.40 — 15.00 | *X. WU*, G. WU, C. WU, J. LU: Structure of the Northern Boundary of Qinghai-Tibetan Plateau: A View from Seismic Reflection Probing |
| 15.00 — 15.20 | *G. WU*: Golmud-Ejinaqi Geoscience Transect (GEGT) in China |
| 15.20 — 15.40 | *T. ITO*, T. IKAWA, S. YAMAKITA, T. MAEDA: Gently N-Dipping Median Tectonic Line (MTL) Transformed into the Deep-Seated Subhorizontal Detachment, Japan |
| 15.40 — 16.10 | COFFEE BREAK |
| 16.10 — 19.00 | **Special Poster Session 2** |

## *Friday, 16 September, Morning Session*

**Theme: Modelling deep reflections, results of bore hole studies, laboratory results and integrated models**

Chairman: L. BROWN (8.30 — 10.00)

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| 8.30 — 9.00 | *R. MEISSNER* (invited speaker): Faulting and Folding; Fact and Fiction |
| 9.00 — 9.20 | *J. BRITTAN*, M. WARNER: Seismic Velocities from Heterogeneous Crust |
| 9.20 — 9.40 | *L. LEVATO*, R. OLIVIER, S. SELLAMI, J.-J. WAGNER, J.-L. EPARD, H. MASSON: Seismic Interpretation and Modelling in the Western Swiss Alps Using Velocity and Density Laboratory Measurements |
| 9.40 — 10.00 | A. LAW, *D. SNYDER*: Velocity Extrapolations from Hand Sample to Deep Seismic Reflection Profiles |
| 10.00 — 10.30 | COFFEE BREAK |

Chairman: S. KLEMPERER (10.30 — 12.10)

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| 10.30 — 10.50 | *C. A. HURICH*: Extracting More Information from Deep Seismic Data |

10.50 — 11.10 *E. S. HUSEBYE*, S. O. HESTHOLM, B. O. RUUD: Synthesizing 2D FD Seismic Wave Propagation in Heterogeneous Lithosphere

11.10 — 11.30 *L. ENGELL-SØRENSEN*, G. RYZHIKOV, M. BIRYULINA: Global Optimization in 3D Reflection Seismics

11.30 — 11.50 *B. MILKEREIT*, M. SALISBURY, D. EATON: Crustal Reflectivity — The Density Connection

11.50 — 12.10 *P. MORGAN*, P. BARTON, M. WARNER, K. JONES, J. MORGAN, C. PRICE: Modelling the Crust and Upper Mantle Reflections of Northern Scotland

***Friday, 16 September 16, Afternoon Session***

Chairman: I. KÉSMÁRKY (14.00 — 16.50)

14.00 — 14.20 *E. LÜSCHEN*, K. BRAM, W. SÖLLNER, S. SOBOLEV: Nature of Seismic Reflections and Velocities from VSP-Experiments and Borehole Measurements at the KTB-Deep Drilling Site in SE-Germany

14.20 — 14.40 *G. HIRSCHMANN*: KTB — The Crustal Structure of a Variscan Terrane Boundary: Seismic Investigation — Drilling — Models

14.40 — 15.00 *K. HOLLIGER*, W. ALBERT, P. BIRKHÄUSER, P. BLÜMLING, B. MILKEREIT: Detailed Structure of the Upper Crust from Borehole Data

15.00 — 15.20 *B. J. CARR*, S. B. SMITHSON, V. GARIPOV, N. KARAEV, Y. KRISTOFFERSON, P. DIGRANES, D. SMYTHE, C. GILLEN: Vertical Seismic Profile Results from the Kola Superdeep Borehole, Russia

15.20 — 15.50 COFFEE BREAK

15.50 — 16.10 *K. BADDARI*, M. DJEDDI, M. AKKOUCHE: Model of the Earth' crust of the North of Algeria Based on the Data of Complex Geophysical Investigation

7 16.10 — 16.30 *K. BADDARI*, A. D. FROLOV: Seismic Anisotropy Observed During the Process of Deformation and Failure of Large Scale Rock Blocks

16.30 — 16.50 *J. A. PULGAR*, J. GALLASTEGUI, A. PÉREZ-ESTAÚN, J. ALVAREZ-MARRÓN: Interpretation and Seismic Modeling of the Variscan Foreland Thrust and Fold Belt (NW Spain) from ESCIN-1 Deep Seismic Reflection Data

Speakers didn't turn up.

## POSTER PRESENTATION PROGRAM

**Theme: Deep seismic reflection profiling results and techniques**

1/1. J. ANSORGE, R. DE IACO, St. MUELLER, K. POSGAY, E. HEGEDÜS, E. TAKÁCS, Z. HAJNAL, B. REILKOFF, I. ASUDEH: High Density Crustal Wide-Angle Reflections in the Pannonian Basin of Southern Hungary

1/2. S. SÜLE, E. TAKÁCS, E. HEGEDŰS, K. POSGAY, J. SÍPOS, Z. TÍMÁR, G. VARGA, Z. HAJNAL, B. REILKOFF, I. ASUDEH, ST. MUELLER, J. ANSORGE, R. DEIACO: Deep Structure of the Lithospere along the Hungarian Geotraverse between two Subbasins of the Pannonian Basin

1/3. W. RABBEL, H. STEENTOFT: Conflicting Dips and the Transparency of the Upper Crust — a DEKORP 2S Case History

1/4. V. RAILEANU, C. DIACONESCU, E. SUCIU: Deep Seismic Reflection Results from the SW of the Moesian Platform Romania

1/5. R. NICOLICH, M. ROMANELLI, J. McBRIDE, A. HIRN, B. DE VOOGD, E. BANDA, STREAMERS Group: Crustal Image of the Ionian Basin and its Calabrian Margins

1/6. M. LOUCOYANNAKIS, E. KAMBERIS, F. MALTEZOU, A. HIRN, M. SACHPAZI: Ionian Basin Interaction with the Western Hellenides: A Normal Incidence and Wide Angle Reflection Line

1/7. L. CERNOBORI, R. NICOLICH, M. ROMANELLI, A. HIRN, M. SACHPAZI, F. AVEDIK, J. GALLART, ETNASEIS Group: The Sicilian Margin to the Ionian Basin and Mt Etna

1/8. F. AVEDIK, R. NICOLICH, A. HIRN, F. MALTEZOU, J. McBRIDE, STREAMERS Group: Appraisal of a New Low Frequency Seismic Pulse Generating Method on a Deep Seismic Reflection Profile in the Central Mediterranean Sea

1/9. P. FABRETTI, R. SARTORI, L. TORELLI, N. ZITELLINI: A Crustal Section Across Sardinia Continental Margin, Southern Tyrhenian Sea

1/10. N. VIDAL, J. GALLART, J. J. DAÑOBEITIA: The Iberia—Western Mediterranean Continent—Ocean Transition Revealed by Composite Steep and Wide-Angle Reflection Seismic Sections

1/11. J. A. PULGAR, J. ALVAREZ-MARRÓN, J. GALLART, G. FERNÁNDEZ, A. PEREZ-ESTAÚN, D. CÓRDOBA, ESCI-N Group: Seismic Image of the Cantabrian Mountains Uplift in the Western Ending on the Pyrenean Belt from Integrated ESCI-N Reflection and Refraction Data

1/12. J. H. McBRIDE: Does the Great Glen Strike-Slip Fault Really Offset Lower Crustal and Upper Mantle Structure?

1/13. P. HAGUE, S. C. SINGH: Crustal Velocity Structure off the North East Coast of England from Wide-Angle Multi-Channel Seismic Data

1/14. D. DYRELIUS, H. PALM: Seismic Reflection Images of Deep Basement Deformation beneath the Caledonian Foreland in the Central Scandes

1/15. J. H. KNAPP, D. N. STEER, M. A. BADER, L. D. BROWN, A. V. RYBALKA, V. B. SOKOLOV: A Seismic Reflection (CDP) Transect of the Middle Urals, Central Russia

1/16. S. L. KLEMPERER, Bering-Chukchi Working Group: Preliminary Results of Deep Seismic Reflection Profiling between Alaska and Russia, Bering Shelf — Chukchi Sea

1/17. INDEPTH Research Group (c/o L. BROWN): Reflection Imaging of Continental Underthrusting beneath the Himalayas, Tibet: Lessons from INDEPTH I

1/18. T. MIYAZAKI, T. YOKOKURA, N. KANO, K. YAMAGUCHI, Y. KUWAHARA: Experiments on Deep Seismic Profiling in Japan: Tohoku-I Section

1/19. T. MAEDA, T. ITO, T. IKAWA, S. YAMAKITA: Deep Structure of the Median Tectonic Line (MTL) and Its Relate Microseismicity, Southwest Japan

1/20. D. M. FINLAYSON, H. M. J. STAGG, B. J. DRUMMOND, G. O'BRIEN, B. R. GOLEBY: National Geoscience Programs in Australia — the Role of Deep Seismic Profiling

1/21. C. D. N. COLLINS, P. A. SYMONDS: Reflection Data Recorded by Land Stations during a Marine Seismic Survey on the Northwest shelf, Australia: Constraints on the Interpretation of Deep Reflection Data

1/22. B. J. DRUMMOND, B. R. GOLEBY, C. D. N. COLLINS: Minaral System Models Based on Deep Seismic Reflection Data

1/23. J. H. LEVEN, J. F. LINDSAY, T. J. BARTON, A. J. OWEN, C. D. N. COLLINS: Crustal Structure beneath the Late Proterozoic Officer Basin, Central Australia

1/24. F. DAVEY, S. HENRYS, E. LODOLO: Crustal Seismic Measurements across a Fore-Arc Basin

1/25. J. WU, B. MILKEREIT: Pseudo-3D Processing of the Sudbury Seismic Reflection Data

1/26. S. BEZDAN, Z. HAJNAL: Crustal Velocity Estimates Taking Advantage of Long Offset Recording

1/27. K. VASUDEVAN, F. A. COOK: Three Dimensional Seismic Crustal Structure of a Hinterland Core Complex on the Lithoprobe Southern Canadian Cordillera Transect

1/28. Q. LI, K. VASUDEVAN, F. A. COOK: Seismic Skeletonization and Event Classification: A New Approach for Crustal Seismic Interpretation

1/29 D. EATON: Is Proterozoic Crust Less Reflective than Phanerozoic Crust?

1/30 A. S. MELTZER and the Mendocino Working Group: Crustal Structure and Triple Junction Migration: Seismic Images of the Mendocino Triple Junction

1/31. B. C. BEAUDOIN, Mendocino'93 Working Group: Lithospheric Images of the Mendocino Triple Junction Region

1/32. S. BANNISTER, U. TEN BRINK, T. STERN, B. BEAUDOIN: MOHO Transition between East and West Antarctica from Seris Reflection Profile Data

**Theme: Seismic reflection studies of the Precambrian crust**

2/1. T. ABRAMOVITZ, H. THYBO, A. BERTHELSEN: Proterozoic Terrane Sutures in the Southern Baltic Shield along Babel Lines B and A

2/2. N. V. SHAROV, A. VINOGRADOV: The Mozaic-Inhomogeneous Seismic Models of the Baltic Shield Lithosphere: A Fractal Assumption

2/3. E. C. HAUSER: Project Craton: Exploration of the Structure and Evolution of the Precambrian of the U.S. Continental Interior

2/4. D. J. BAIRD, J. H. KNAPP, D. N. STEER, K. D. NELSON, L. D. BROWN, A. CALVERT: COCORP Profiling of the Trans-Hudson Orogen, Montana and N. Dakota

2/5. B. MILKEREIT, J. WU: Seismic Image of an Early Proterozoic Rift Basin

2/6. R. F. MEREU, S. WINARDHI, B. ROY: The Structure and Nature of the Greenville Front under the Canadian Shield: Results from the 1992 LITHOPROBE Abitibi-Grenville Seismic Refraction Experiment

2/7. B. NÉMETH, Z. HAJNAL: MOHO Signature from Wide Angle Reflections

2/8. J. WU, B. MILKEREIT, D. E. BOERNER: Seismic Cross-Section of the Enigmatic Sudbury Structure

**Theme: Seismic reflection studies of the sub-crustal lithosphere and the asthenosphere**

3/1. K. POSGAY, T. BODOKY, E. HEGEDÜS, S. KOVÁCSVÖLGYI, E. TAKÁCS, Z. TÍMÁR, G. VARGA, F. HORVÁTH, L. LENKEY, P. SZAFIÁN: Lithospheric-Asthenospheric Structure beneath the Békés Basin

3/2. R. MARCHANT, G. STAMPFLI: From Deep Seismic Reflection Profiling to Tomografic Images in the Western Alps

3/3 K. A. JONES, M. R. WARNER, C. E. PRICE, J. V. MORGAN, R. P. LL. MORGAN, P. A. BARTON: Crustal Anisotropy and Mantle Reflector Polarity from Deep Seismic Normal Incidence and Wide Angle Reflections

3/4. I. YU. KULAKOV, S. A. TYCHKOV, S. I. KESELMAN: Three-Dimensional Structure of Lateral Heterogeneities in P-Velocities in the Upper Mantle of the Southern Margin of Siberian Plate

3/5. K. F. TYAPKIN: The Role of Faults in the Tectonosphere's Seismogeological model

**Theme: Potential of deep seismic reflection profiling for hydrocarbon exploration**

5/1. S. HUGHES, P. J. BARTON, C. A. ZELT: Combined Seismic Reflection and Refraction Data in the Faeroe Basin, offshore NW Scotland

5/2. V. TROFIMOV: Seismic Investigations of the Pre-Cambrian Basement in Tatarstan (Eastern Part of Russian Platform)

**Theme: Modelling deep reflections, results of bore hole studies, laboratory results and integrated models**

6/1. T. S. LEBEDEV, V. A. KORCHIN, P. A. BURTNY: Seeting up Deep Regional Petrovelocity Models of the Lithosphere Based on a System Analysis of Experimental PT-Data and Geologic-Geophysical Information

6/2. P. DIGRANES, Y. KRISTOFFERSEN, V. GARIPOV, N. KARAEV, B. J. CARR, S. SMITHSON, Kola Working Group: Offset VSP Data from the Kola Superdeep Borehole, with Emphasis on Anisotropy

6/3. V. SOKOLOV: Deep Structure of the Crust and the Mineral Prognostication as the Results of the Composite Geophysical Research of the Urals

6/4. N. PAPASIKAS, C. JUHLIN: Interpretation of Reflections from the Central Part of the Siljan Ring Impact Structure Based on Results from the Stenberg-1 Borehole

6/5. M. A. RIAHI, C. JUHLIN: Reflectivity Characteristics of the Crust from Modelling Refraction/Wide-Angle Reflection and Normal-Incidence Reflection Data on BABEL Line 1

6/6. S. O. HESTHOLM, B. O. RUUD, J. PETERSEN, E. S. HUSEBYE: Visualizing Seismic Wave Propagation in the Lithosphere

6/7. A. S. LONG, M. C. DENTITH: Deep Seismic Reflection Profiling of the Pinjarra Orogen and Adjacent Yilgarn Craton, Western Australia

# ORAL PRESENTATION PROGRAM

# ABSTRACTS

9.30

## Application of Deep Seismic Surveys in Oil and Gas Exploration in the Hungarian Part of the Pannonian Basin

L.Bérczi (MOL Rt., Hungarian Oil and Gas Co. Ltd. H-1502, Budapest, Pf. 22.)

The Hungarian part of the Pannonian Basin is a matured petroleum province with thousands of water, oil and gas wells. The approximately 60 years of oil and gas exploration focussed predominantly on the Neogene sedimentary infill of the Basin. Recently, the inner-structure of the pre-Neogene Basement has become the object of pre-eminent geological speculations as a possible new petroleum system containing additional recoverable oil and gas reserves.

With their low frequency (2-35 Hz) method, the deep seismic reflection surveys focussed originally on lithosphere studies, have significantly contributed to revealing the inner structure of the pre-Neogene Basement. The consistent and integrated geophysical and geological interpretation of these regional profiles has indicated that the inner structure of the Basement involved is more complicated than had anticipated earlier.

The deep reflection seismic profiles of regional extension (over 100 km) have revealed, that:
- the compressive tectonic elements are as important as the well known extensional ones had been known earlier
- the inner structure of the deep lying sedimentary rocks can be appropriately interpreted with this method:
- the combination of this method with results of the basic research on the Earth-Crust and the Upper Mantle provides a new tool to describe the fundamentals of the evolution of the Pannonian Basin.

10.00

## DEEP SEISMIC IMAGES OF EARLY RIFTING PROCESSES IN THE OTWAY BASIN, AUSTRALIAN SOUTHERN MARGIN

D. M. Finlayson, D. W. Johnstone, A. J. Owen and K. D. Wake-Dyster
Australian Geological Survey Organisation, GPO Box 378, Canberra A.C.T. 2601, Australia

The Otway Basin is one of a number of prospective basins formed along Australia's southern margin during the Jurassic-Early Cretaceous rifting of Australia from Antarctica. It lies on what we have termed the Otway-Sorell microplate, a transitional region between the margin to the west where continental separation took place quite close to the Australian craton, and the region to the east where separation failed to develop in the Bass Strait area but instead switched to the south of Tasmania.

AGSO deep seismic profiling during 1992 across four targets in the onshore part of the Otway Basin aimed to improve our knowledge of early basin rift geometry and crustal processes, and hence improve our understanding of hydrocarbon prospectivity. Pre-Aptian rift segments with half-graben geometry have a variety of trends. The bounding faults dip predominantly, but not exclusively, towards the continent. The basin sequences in these half-graben are imaged at greater than 4 s two-way time in places and the bounding faults sole along detachments with ramp and flat geometry at mid-crustal levels. The trend variations indicate that extensional strain direction varied along the rift system, probably controlled by pre-existing Palaeozoic geology. Basement highs between some of the rift segments are interpreted as accommodation zones. Multiple basin-bounding faults in some places mirror features within basement and probably indicate a component of strike-slip during early rifting. Various play concepts are associated with all these rift features.

Crustal thickness is interpreted to be 31 km (10.3-10.5 s TWT) near Lake Bullen Merri, an area of recent volcanism where prolific crustal and upper mantle xenoliths provide geological control on the interpretation of intra-crustal reflections. Towards the south, crustal thinning (to about 9 s TWT) seaward of a major fault zone coincides with a significant increase in post-Albian deposition and is interpreted to be the landward limit of rifting along a lower plate margin which ultimately separated Australia from Antarctica.



11.00

## PHYSICO-GEOLOGICAL STATISTICAL MODEL OF SOUTH-EASTERN CONSTANTINOIS CARBONATED RESERVOIRS OF ALGERIA

K BADDARI , M DJEDDI , R BAOUCHE.
(INH - BOUMERDES ALGERIA).

Séismic studies carried out in the south-eastern constantinois (Algeria) have helped to demarcate the surface containing oil which corresponds to the area as a carbonic barrier of Cenomano-Turonian.

The results obtained from these studies have helped to define the physical characteristics of the reservoirs as well as the stratigraphy and the sequences of the rocks.Drilling results carried out in the field of Ras-Toumb confirm the seismic studies and indicate that a tectonic synsedimentary existed during the superior cretaceous.

The physical characteristics of Cenomano-Turonian reservoirs obtained after the geological and geophysical studies were not able to define which are productive or not.

Results obtained after study of these reservoirs have demonstrated that variations of facies are present mainly at the formation level of Ras-Toumb.The variations don't create barriers of permeability and don't seem to play a fundamental role in the migration and accumulation of hydrocarbons.

Therefore,a statistical study by the discriminating function, applied for all the lithological units of Cenomano-Turonian which are in the wells in the area of Cherguit-el-Kihal,has permitted to put into evidence the petrophysical parameters of two groups of layers :those which are productive and others that are dry.To this end,a discriminating equation has been established to approach the type of the layers concerned so as to avoid tests of productivity which are useless.

11.20

## SEISMIC EVIDENCE FOR BASEMENT CONTROLS ON SEDIMENTATION IN THE WESTERN CANADA SEDIMENTARY BASIN

D. Eaton, B. Milkereit (Geological Survey of Canada, Ottawa, Canada, K1A 0Y3)
G. Ross (Geological Survey of Canada, Calgary, Canada) and E. Kanasewich (Department of Physics, University of Alberta, Edmonton, Canada)

Multichannel seismic reflection data acquired by LITHOPROBE in the Western Canada Sedimentary Basin (WCSB) provide dramatic evidence for a previously unrecognized thick-skinned fold-thrust belt in the Precambrian crust underlying the Phanerozoic cover in east-central Alberta. The orogen formed during oblique convergence between the Archean Hearne craton and a collage of crustal domains, and is interpreted to be coeval with the Early Proterozoic Trans-Hudson orogen to the east. Structures developed in the basement appear to have exerted a subtle, but significant, influence on patterns of sedimentation in the sedimentary basin. Three styles of basement-cover interaction are recognized: drape of sediments over paleotopographic highs, discrete faulting, and "tectonic inheritance" (*i.e.* coincidence of sedimentary facies transitions with an underlying Precambrian tectonic domain boundary). The latter style of interaction, perhaps the most important in terms of hydrocarbon exploration in the WCSB, is documented using compressed seismic displays across an Upper Devonian reef trend in the basin. The reef trend overlies an Early Proterozoic magmatic arc (Rimbey Arc) and hosts very significant reserves of oil and gas. The seismic data show that the intervening Cambrian to Middle Devonian stratigraphy undergoes an abrupt lateral facies transition immediately above the Rimbey Arc, providing the first direct evidence for basement controls on the inception of reef growth. We speculate that basement structures may have provided a conduit (or barrier) that influenced the circulation of crustal fluids during episodes of Paleozoic subsidence.

11.40

14.00 COCORP AND GLOBAL DEEP SEISMIC PROFILING

L. D. Brown and Cornell Deep Seismic Research Group (Department of Geological Sciences and Institute for the Study of the Continents, Cornell University, Ithaca NY 14853)

The past several years have witnessed the transition of deep seismic profiling at Cornell from a national program of reconnaissance profiling in the US (COCORP) into a collage of multi-technique collaborations addressing major features of the continental crust on a global basis. The term "COCORP" itself has become as much a generic term representing a specific style of lithospheric exploration as it is a particular program of activity. Highlights of COCORP research over the past two years include:

**Project CRATON:** COCORP vibroseis and explosive source surveys have mapped new details of Proterozoic deformation at lower crustal and upper mantle depths associated with the buried Trans-Hudson orogen. Reprocessing of COCORP data from the Grenville Front reveal a complex splay zone of faulting that overthrusts a Precambrian sedimentary sequence that may be Keweenawan in age.
**Project INDEPTH:** A multinational initiative, organized in cooperation with the Ministry of Geology and Mineral Resources of China, to profile the Himalayas and Tibetan Plateau. The results of this effort, still in its early stages, have already demonstrated the viability of reflection profiling through ultra-thick crust, and provided new constraints on the deep geometry of continent-continental collision.
**Project URSEIS:** This collaboration with EUROPROBE to carry out a deep seismic profile across the southern Urals will test models for orogenic collapse, Moho re equilibration, and the origin of layering in the lower crust. Reprocessing of existing Russian data has already revealed new aspects of upper crustal structure in this Paleozoic compressional belt. A deep test survey (ESRU) demonstrated the presence of key marker reflections in the lower crust.
**COCORP Superdeep:** A theme common to all of COCORP's recent activities is the need to probe deeper, to image mantle as well as crustal structures. This has led to new evaluations of vibroseis vs. explosive sources and development of new processing techniques to extract very low S/N energy.
**COCORP In Hyperspace:** Easy access to a variety of datasets is the key to quantitative synthesis. COCORP has moved to exploit GIS and the INTERNET to facilitate retrieval of COCORP data and establish a model for a global Deep Seismic Meta-Database.
**COCORP In 3D:** 3D modeling of deep reflection datasets and exposed lower crustal sections is being used to evaluate the viability of 3D acquisition to address significant issues of deep exploration.





14.20 THREE-COMPONENT SEISMIC IMAGING OF THE BASIN AND RANGE/SALTON TROUGH TRANSITION ZONE IN SOUTHEASTERN CALIFORNIA, USA

Larkin, S. P., Levander, A. (Department of Geology and Geophysics, Rice University, Houston, Texas, USA)
Okaya, D. (Department of Geological Sciences, University of Southern California, Los Angeles, California, USA)
Holliger, K (Institut für Geophysik, ETH-Hönggerberg, Zürich, Switzerland)

The RISC (RIce/uSC) deep crustal seismic reflection experiment, a piggyback on PACE92, was located across the Chocolate Mountains in the transition zone between the southern Basin and Range Province and the Salton Trough in southeastern California, USA. The geology of southeastern California reflects a complicated juxtaposition of tectonic events over time. These events include Paleozoic passive margin sedimentation, Mesozoic arc magmatism and mountain building, and Tertiary Basin and Range extension followed by the development of the San Andreas Transform/Salton Trough system. A single-fold vertical component CMP energy display has been created which delineates the major structural features of the transition zone. This section shows two main levels of reflectivity, one between 5 and 6 s and one between 8 and 9 s. The latter zone is interpreted to be the Moho discontinuity, with crustal thickness of 26-29 km. The midcrustal zone can be modeled as a change in fabric orientation from predominantly vertically oriented structures to predominantly horizontally oriented structures, with no change in average velocity. Elastic finite-difference simulations of such a crustal fabric reproduce the observed data remarkably well. Connecting these two levels of reflectivity is a zone of reflections dipping to the northeast. These reflections correspond to the northeastern lateral extent of a high velocity body observed beneath the Salton Trough in PACE92 refraction data. In addition, wide-angle vertical and horizontal shot gathers contain a high-amplitude diffraction event (P to P and P to S) originating from the point where these dipping reflectors intersect the Moho.
To remove effects due to irregular topography and near-surface velocity heterogeneity, we have employed a wave-equation datuming technique to downward continue the recorded wavefield from the recording surface to the basement interface using a velocity model obtained from a traveltime inversion of Pg arrivals. We then upward continue this extrapolated wavefield to a flat datum surface using the basement velocity as the replacement velocity. The result is a properly datumed shot gather with surface waves removed. Reflector continuity is increased, thus enhancing the recorded image.

14.40 SEISMIC IMAGES OF THE BROOKS RANGE FOLD AND THRUST BELT, ALASKA, FROM AN INTEGRATED SEISMIC REFLECTION/REFRACTION EXPERIMENT

E.S. Wissinger, A. Levander, and J.S. Oldow (Geology & Geophysics, Rice University, P.O. Box 1892, Houston, Texas, USA)
G.S. Fuis, and W.J. Lutter (US Geological Survey, 345 Middlefield Road, Menlo Park, California, USA)

The Brooks Range, Arctic Alaska, is a north vergent, intact fold and thrust belt of the western North American Cordillera, whose Mesozoic-Cenozoic development is roughly contemporaneous with that of the Rocky Mountains. In 1990 Rice University and the U.S. Geological Survey acquired an integrated reflection/refraction dataset across the Brooks Range and the flanking geologic provinces. The data were collected with a 700 channel seismograph system recording data from 0 to 250km offsets. The seismic data have been processed and interpreted using conventional and unconventional methods. Low fold conventionally processed reflection images show a remarkably clear, but complicated upper and midcrustal section from the unmetamorphosed Endicott Mountains allochthon at the front of the Brooks Range into the metamorphic belts in the southern Brooks Range. Clear lower crustal and Moho reflections are visible intermittently across the 300 km long profile. Single-fold CMP images made from signal enhanced data with offsets as great as 30km show pronounced reflectivity in lower crust, and at the Moho, and provide additional detail in the midde crust. The data establish that an exposure of Paleozoic basement rocks, the Doonerak window, is part of a crustal scale duplex. The reflection images also show a highly reflective north-dipping Moho at 35-50km depth, and a ~190km long master decollement soling to Moho depths (~30km) at the southern end of the range. A 50km thick root is present near the front of the range. In the southern and central range the Moho is characterized by a 1s thick band of reflection which appear to thicken and shallow abruptly from 15s to 13s twt near the range front.
A seismic velocity model for the Brooks Range has been developed from wide-angle reflections and refractions at intermediate to long offsets, using travel-time inversion methods. The seismic velocity model is generally compatible with the seismic reflection images, and shows generally high crustal velocities throughout the Brooks Range.
The Brooks Range seismic data have been used to constrain four possible balanced cross-sections for development of the range. Estimates of crustal shortening are in excess of 250km.

12 September

15.00

## LITHOPROBE, VANCOUVER ISLAND INTERVAL VELOCITY CASE STUDY - A RETROSPECTIVE VIEW

I. Késmárky* and Z. Hajnal*

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Interval velocity estimates were computed from seismic data sets collected along Line 1 of the Lithoprobe Vancouver Island experiment. Independently of standard methods, we concentrated on a more accurate estimation of the velocity from high signal level segments of the subduction zone.

The central scheme of our approach was to carry out high precision stacking velocity analyses which included generalized "vertical stacking" procedures. In all aspects of our computations consideration was given to the dips ,and curvatures observable on the time section. The interval velocity calculations were based on a 2D model, containing plane and curved dipping interfaces.

Besides the interval velocity calculation, the reliability (standard deviation) of the estimates were also strictly controlled. Considering the arrival time uncertainties of the individual traces, the reliability of the estimated parameters were calculated via the error propagation law. This theoretical model showed that in spite of the relatively small normal moveouts, consistent interval velocities could be estimated if 50-150 neighbouring CDPs were considered simultaneously.

The velocity-depth function derived through this analysis appears to enhance recent concepts derived from geologic investigations about the nature of the subducted rock mass.

15.20

## WHOLE-CRUSTAL NORMAL FAULTS?-OCEANIC DEEP REFLECTION EVIDENCE

I. H. McBride, R. W. Hobbs, and R. S. White (BIRPS, Bullard Labs, Madingley Rd., Cambridge CB3 0EZ, UK)

Observations of normal faults, associated with major extension, that penetrate the entire thickness of continental crust remain inconclusive. In order to view this problem another way, BIRPS acquired closely spaced (4000 m) deep reflection profiles along and across a portion of the Early Cretaceous mid-Atlantic ridge off the coast of west Africa. Along profiles parallel to the seafloor spreading direction, we can observe the net effects of axial ridge extension of the crust that developed as the two lithospheric plates moved apart. After applying time and depth migrations, the profiles show west-dipping (towards the spreading ridge axis) apparently planar normal fault reflectors in the upper igneous crust, continuing down in places to the Moho where they are abruptly truncated. Studies of seismicity over the active mid-Atlantic ridge and results from rheological modelling, which suggest that much or all of the oceanic crust deforms brittly, are consistent with our interpretation of crustal-penetrating faults. That the faults do not cut or extend beyond the Moho reflection implies that they pre-date the formation of the Moho surface unless the Moho acted as a detachment. The "preservation" of this relationship in Early Cretaceous crust implies that active faulting at the ridge crest rapidly dies out as crust spreads away from the ridge. We suggest that the faults developed initially at or near the spreading ridge before the process of igneous crustal accumulation was complete.

12 September

16.10

## A SEISMIC IMAGE OF THE IBERIAN ATLANTIC MARGINS: THE IAM PROJECT

*Torne, M., and IAM Group, Institute of Earth Sciences, Consejo Superior de Investigaciones Cientificas (CSIC), Marti I Franques s/n, 08028 Barcelona, Spain IAM Group: E. Banda (Inst. of Earth Sciences, CSIC, Spain), R. Long (University of Durham, UK), L. Mendes-Victor (University of Lisbon, Portugal), L. Senos (I.M., Lisbon, Portugal), J.C. Sibuet (IFREMER, Brest, France), and A.B. Watts (University of Oxford, UK).*

*The Iberian Atlantic Margins Project (IAM), financed by the European Community within its JOULE Programme, was designed to study the nature of the deep continental and oceanic crust in selected areas of the Atlantic Margins of Iberia for a better understanding of the processes governing the formation of these margins. A total of 20 near-vertical deep seismic reflection profiles (about 3800 km) were recorded along the North Iberian Margin (Cantabrian margin), Iberia and Tagus Abyssal Plain, Gorringe Bank region, and Gulf of Cadiz. This together with refraction/wide-angle reflection data recorded by land stations and Ocean Bottom Seismometers provides a large amount of knowledge in terms of crustal structure and velocity information of the Iberian Atlantic Margins. Lines were shot at a shotpoint interval of 75 m with a recording window of 25 s. The analog streamer used was 4.8 km long -with 192 channels organised into 25 m groups- towed at a depth of 15 m. The airgun array (BOLT) consisted of 36 guns arranged in 6 identical sub-strings and towed at a depth of 10 m. The guns were fired at a nominal pressure of 2000 psi. Comercial processing started shortly after the end of the cruise. As a result the stacks for some lines are now available. Preliminary outstanding results are: the imaging of deep reflections in both oceanic and continental crust; prominent basement faults in the area of the Gulf of Cadiz; the presence of a multicycle-high amplitude-low frequency reflector in the eastern part of the Horseshoe Abyssal Plain; and the presence of a weekly reflective lower crustal zone in some areas of the continental shelf.*

16.30

## SEISMIC STRUCTURE OF THE NORTHERN CONTINENTAL MARGIN OF SPAIN

J. Alvarez-Marrón (Geology Department, Oviedo University, 33005 Oviedo, Spain)
J.J. Dañobeitia (Institute of Earth Sciences, CSIC, 08028 Barcelona, Spain)
A. Pérez-Estaún (Institute of Earth Sciences, CSIC, 08028 Barcelona, Spain)
J.A. Pulgar (Geology Department, Oviedo University, 33005 Oviedo, Spain) and ESCI-N Research Group.

The continental margin of northern Spain was rifted during Late Jurassic-Early Cretaceous times and subsequently reactivated during the north-south convergence of Eurasia and Iberia in the Tertiary. A multichanel seismic experiment was designed to study the structure of this margin. Two profiles, one north-south in front of Asturias (ESCIN-4) and the other to the nortwest of Galicia (north of the Galicia Bank; ESCIN-3) were adquired. The ESCIN-4 stacked section images inverted structures in the upper crust within Le Danois Basin. A thick sedimentary package can be recognised from 6 to 9.5 s (TWT) to the north of the steep continental slope, and a 40 km long north tapered wedge of inclined, mainly south dipping reflections is imaged within this package. In the northwestern part of the ESCIN-3 stacked line, horizontal reflections from 6.5 to 8.5 s correspond to an undisturbed package of sediments lying above an oceanic-type basement. A few kilometers long strong horizontal reflection at 11.2 s within the basement may represent a Moho reflection. Two bands of reflections dip shallowly towards the south-east from the base of the gently dipping continental slope. The part of the line that runs parallel to the coast is characterised by bright, continuous lower crustal reflections from 8 to 10 s. It also images a band of strong reflections that dip gently towards the south-west from 10 to 13.5 s.

12 September

16.50 *LATERAL HETEROGENEOUS VELOCITY MODEL FOR THE BETICS CORDILLERA: RESULTS FROM MIGRATION MOVEOUT VELOCITY ANALYSIS*

*Carbonell, R., Torne, M., Banda, E., Institute of Earth Sciences, Consejo Superior de Investigaciones Cientificas, Marti I Franques s/n, 08028 Barcelona, Spain*

*We dervied a laterally heterogeneous velocity model for the Betics with a high velocity layer at
the base of the crust which might explain differences between refraction and reflection
interpretations. We use an iterative pre-stack Kirchoff depth migration algorithm coupled with a
migration moveout velocity analysis to obtain a velocity model for the Betics cordillera. The
pre-stack depth migration algorithm appropriately migrates data recorded with significant
topographic relief and to which no datum static correction have been applied. We use
synthetic seismic reflection data to demonstrate that areas characterized with high topography
and lateral velocity variations, can be properly imaged with this algorithm. This algorithm is
also able to recover the correct velocity models. The area of the Betics cordillera with its
complex tectonic history is characterized by significant topographic relief and strong lateral
velocity variations. The surface expression of these velocity changes can be observed in the
geology of the area, for example the low velocities of the sedimentary basins contrast with the
high velocities of the Betics core complexes. The Pre-Stack depth migration algorithm consist
of two steps: 1) travel time calculation; a ray tracing algorithm or a finite difference scheme
used to evaluate the travel time from the actual source and receiver positions to all the points
in the velocity grid, 2) imaging; the amplitudes corresponding to a particular time are posted at
the point of the image grid from which they would have been reflected according to the
modeling (step 1). This migration scheme produces not only the migrated image but common
image gathers (CIG) or common reflection gathers, which can be interpreted as migrated
CDP's. A correction to the velocity model is derived from the event moveout in the CIG's. By
successive or iterative migrations we improve the image as well as obtaining an improved
velocity model. The fact that a ray tracing or a finite difference travel time simulator is used
assures the physical significance of the velocity model.*

17.10 PRE-STACK MIGRATION AND TRUE-AMPLITUDE PROCESSING OF DEKORP STEEP- AND WIDE-ANGLE REFLECTION MEASUREMENTS

M. Simon, H. Gebrande and M. Bopp (Institut für Allgemeine und Angewandte Geophysik, University of Munich, Theresienstr. 41, D-80333 Munich, Germany)

An alternative to the CMP-processing will be presented, which seems to be more appropriate to
crustal seismics. It has been developed originally for wide-angle seismics but can also be applied
to steep-angle seismic data.

The essential points of this processing sequence are:
- Single shot processing instead of CMP-processing
- True amplitudes instead of automatic gain control (AGC)
- Pre-stack migration instead of CMP-stacking and poststack migration

For the purpose of true amplitude processing a very accurate editing is needed. In addition, the
individual coupling of sources and receivers to the ground must be taken into acount by multiply-
ing each trace with two scalars, one depending on the source and another on the receiver point.
The subsequent process of prestack migration is the most time consuming. Although the isochrone
migration applied is based on kinematic principles, the amplitude distribution may be regarded
qualitatively as an image of the reflectivity. The method can resolve very steeply dipping reflectors
and works with physically meaningful migration velocities, not with dip-dependent processing
velocities like CMP-stacking. The migration velocities are computed prior to migration by ray
tracing from a macro velocity model. Robustness of the method can be increased by forming
envelopes after single shot migration and stacking them up to a final image.
Applied to DEKORP-Data from the surroundings of the German Continental Deep Drilling Project
(KTB) the Franconian fault zone - dipping with about 55° - has been imaged very well, in addi-
tion to many other reflectors througout the whole crust.



12 September

17.30 Č. TOMEK, S. VRANA: Deep Seismic Transect Through West Bohemia and its Significance for the Interpretation of Variscan Continental Collision

13 September

8.30 CRUSTAL SCALE EXTENSION IN THE CENTRAL PANNONIAN BASIN

Z. Hajnal, B. Reilkoff (Department of Geological Sciences, University
of Saskatchewan, Saskatoon, SK S7N OWO, Canada), K. Posgay, E.
Hegedüs, E. Takács (Eötvös Loránd Geophysical Institute, Budapest,
Hungary-1145), I. Asudeh (Geological Survey of Canada, Ottawa, ON, K1A
OY3, Canada), St. Mueller, J. Ansorge, R. DeIaco (Institute of
Geophysics, ETH-Hönggerberg, Zürich CH-8093, Switzerland)

The 1992 international crustal seismic program of the Hungarian
Geotraverse collected low frequency vertical incidence and wide-angle
reflection data, using the properties of a variety of refraction
recording systems. The northeast trending 95 km long multifold
reflection survey crosses a number of dominant Neogene structural
features of the Central Pannonian Basin: the Makó-Hódmezővásárhely
Trough (MHT), the Battonya-Pusztaföldvár High (BPH) and the Békés
Subbasin (BSB). The unconformal basin-basement contacts at variable
travel times of two to four seconds are marked by strong and distinct
seismic signatures. The uppermost segment of the basement, within the
region of the central high is marked by zones of locally subparallel,
but regionally fragmented characteristic patterns of reflectivity. The
western margin of the MHT is defined by a gently northeast dipping
normal fault extending throughout the entire crust. A distinct set of
subparallel reflections, beneath this fault, indicates crustal scale
mylonitization. The hanging wall is associated with the tilted,
seismically transparent, crustal block of the BTH. A comparable low
angle extensional fault outlines the northeastern limit of this
crustal block. Within the footwall of this fault, seismic reflections
imaged an additional similarly subparallel zone of reflectivity. Both
master faults merge into the Moho which is characterized with a zone
of complex reflectivity. The lower lithosphere is illuminated by short
reflective segments which may be related to large scale regional
tectonics.

9.00 CRUSTAL STRUCTURE AND MECHANISM OF EXTENSION IN THE PANNONIAN BASIN

F. HORVÁTH (Eötvös University, Budapest, Ludovika tér 2, H-1083), G. TARI (Amoco
Production Company, Houston), L. CSONTOS and P. SZAFIÁN (Eötvös University,
Budapest)

Regional interpreted seismic sections across the Pannonian basin will be presented to show
the structural style of the Neogene basin fill, and the underlying "basement" rocks of
Paleozoic, Mesozoic and locally of Paleogene age. Major tectonic phases include: (1) Middle
to Late Cretaceous compressions and nappe formation; (2) Late Oligocene/earliest Miocene
large-scale strike-slip faulting; (3) Middle Miocene extension and differential block
movements; (4) Late Miocene, and Late Pliocene through Quaternary episodes of
compression and basin inversion. The different tectonic features are strongly inter-related:
older structures influence younger structures.
Most obviously, Middle Miocene low-angle normal faults usually root in Cretaceous
compressional detachment planes. Interestingly enough normal displacement can occur
either along dip or strike of the former detachment, and amount to a few tens of kms.
Detachment planes can be traced down to the lower crust, where the extensional deformation
appears to be ductile shear. A model is presented to explain occasional lower crustal
lamination and unflat Moho in the Pannonian basin. It is derived from shallow and deep
crustal seismics, magnetotelluric data and compatible with gravity and geothermal
observations.

13 September

9.20 DEEP STRUCTURE OF IONIAN AND AEGEAN BASINS AND MARGINS :
STREAMERS MULTICHANNEL AND WIDE ANGLE SEISMICS

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(Univ. London), M. Loucoyannakis (DEP-EKY, Athens), J. Drakopoulos (Univ. Athens),
R. Nicolich, (DINMA, Univ. Trieste), J. McBride (Univ. Cambridge) L.A. Mendes-Victor
(Univ. Lisbon) and M. Sachpazi (Univ. Athens)

STREAMERS, sponsored by the European Community programme JOULE is a reconnaissance
survey with state of the art deep seismics of the relation between sedimentary basin and deep
crustal structure in parts of the Mediterranean.
Over 700 km of profiles were recorded in the Ionian with a tuned air gun array of over 7000
cubic inches and about 1000 km in the Aegean with an array of less that 1500 cubic inches
operated in "single-bubble" array mode for low-frequency generation. Both setups were efficient
enough to penetrate to Moho depth, at vertical incidence with a 180 respectively 96 channels
streamer and wide-angle with land stations.
In the Ionian basin imaging reaches under Messinian salt and carbonates platform to the lower
crust - upper mantle. Across its western margins deep topography is very diverse across the Malta
escarpment, Sicily and the Calabrian accretionary prism. Basins of the Western Hellenides zone
of convergence are well imaged but the deeper crustal images are blurred, possibly in part due to
extreme sediment thickness and tectonics.
Wide angle seimics image the lower crust across the margins of the Cretan extensional basin, for
which the normal incidence is still in processing stage.
Strong reflectivity at depth characterises the Cyclades massif. Combining vertical and wide angle
shall result in a complete crustal section across the North Aegean trough illustrating lower crustal
structure related to extensional sedimentary basin formation.

9.40 WIDE ANGLE IMAGES OF AEGEAN CRUSTS

M. Sachpazi, A. Hirn, A. Nercessian (IPG Paris), J. Drakopoulos (Univ. Athens),
J. Diaz (CSIC, Barcelona), M. Loucoyannakis (DEP-EKY Athens) and
STREAMERS Group.

An array of 8 GI air guns of 840 c. i. total generator volume was operated in the
Aegean at a 20 s interval by O/V Le Nadir in the single-bubble mode (Avedik et
al.,Geophysics 1993). This method gave this apparently small source a crustal scale
penetration for the 96 channels streamer at normal incidence and for land station-
based wide angle coverage. On Crete a relatively narrow band of strong subcritical
to wide angle reflections is observed from below 24 km depth under the southern
margin of the Sea of Crete supposed to be stretching towards a continental margin
structure. Recording on several of the Cyclades islands highlights an area where a
strongly reflective unit occupies the large thickness of the whole lower half of the
crust in the region of the metamorphic core complexes. The base of the upper crust
or the Moho itself are occasionally seen as a single thin reflection in addition or in
place of the lower crustal response. Moho reflections may be traced in the North
Aegean domain to provide constraints on modes of crustal thinning.

10.30

## THE DEKORP MVE-90 PROFILE AND ITS GEOLOGICAL CONSEQUENCES

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The MVE 90 profile follows about 200 km in NE-SW direction the Saxothuringian Zone, mostly without platform cover sediments, and reveals some characteristics of the crust. These insights allow new models on the development of this area. It reflects (1) indications of a pre-Variscan subduction zone at the southern flank of the Mid German Crystalline Zone, and shows the upthrusted Schwarzburg anticlinorium with its deep-rooting Proterozoic core; (2) the lower Carboniferous flysch basin in Thuringia, where reflector bands from Devonian limestones and diabases mark the lower boundary; (3) the earthquake swarm sources in the upper crustal anomaly of the Vogtland area represented as two reflector lamellae beneath and above of 10 km depth; (4) antiforms of the Proterozoic crystalline in the Erzgebirge block; (5) the deep structure of the Elbe Zone with fault extension down to the lower crust; (6) compressional fold (?stack) features in the Lausitz block with a seismic pattern different from the west-Elbian area. (7) The lower crust of the Erzgebirge is characterized by a layer with many inclined reflectors: either a shear band originated by late Palaeozoic extension tectonics or a much older relic of the pre-Cadomian crust.

The MVE 90 data offers the possibility of new concepts of the crustal evolution. The hitherto unknown feature of a west dipping seismic anomaly at the SE flank of the Crystalline Zone coincides with a linear magnetic anomaly of Central Europe and represents probably a relic of an Early Palaeozoic subduction zone. Furthermore, the internal structure (gravimetric and magnetic anomalies) strikes oblique to the boundaries of the Saxothuringian and other Variscan zones. This hints to a transpressive collision mechanism. Taken this into account the Mid German Crystalline Zone had originated in Lower Palaeozoic and has broadened in Upper Palaeozoic time along the NW flank of the closed suture.
The profile has initiated a new discussion on origin of granites which are common in the Erzgebirge related to the negative gravimetric anomaly of 50 mgal. Erzgebirge, that means ore province + granite province. The profile should give answers concerning this combination. Despite of the gravimetric minimum some antagonism requires alternative interpretations. At several locations petrological results indicate a primary crustal thickness of more than 80 km (today less than 30 km). Hence it follows that crustal thinning took place. Consequences for the interpretation of the seismic crustal pattern will be discussed.

10.50

## SEISMIC REFLECTIONS FROM THE CRYSTALLINE CRUST AT THE KTB SITE (GERMANY)

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In the area of the German Continental Deep Drilling Program KTB several seismic data have been collected by the DEKORP group: A network of 2D deep seismic reflection profiles and wide-angle measurements are available as pre-site investigations. In 1989 comprehensive seismic studies (ISO89) were carried out at the KTB that started in 1987 in the Oberpfalz, NE Bavaria. Since the turn of the year 1992/93 it is the deepest borehole in crystalline rock in western and central Europe. At present the KTB-Hauptbohrung (HB) has just passed the depth of 8700 m. The deep borehole is located in the European Variscides at the western edge of the Bohemian Massif at the Saxothuringian/Moldanubian suture. The Franconian Line, a NW-SE striking post-Variscan fault system, separates the uplifted crystalline complexes of the Bohemian Massif in the east from the Mesozoic sediments of the South German Platform in the west. The principal experiment of the ISO89 seismic survey (Integrated Seismics Oberpfalz) was a 3D seismic reflection study covering an area of 18 * 19 $km^2$ with a bin spacing of 50 m. In the beginning a temporary envelope-stacked data set was performed by the DEKORP Processing Center at Clausthal due to processing problems. The data exhibit several strong reflection events. The improved phase-stacked data show higher resolution and a more detailed image of the reflections than the envelope-stacked data. Especially a group of steeply dipping reflections (SE) is striking. The prominent SE1 reflector dips with about 55° to the NE representing the Franconian line. It was penetrated by KTB-HB between 6865 and 7260 m depth. The strong slightly curved flat reflections between 11 and 13 km depth can be correlated to the high-velocity Erbendorf Body. The object of special interest is the immediate surroundings of the drillhole. In addition to the reflections mentioned above some other reflections that might be significant for the drilling are observed: West of KTB-HB a strong bundle of SW dipping reflections meeting with the SE1 reflections is present in the middle crust. Further down reflection elements with less amplitudes can be observed between 8 and 9 km depth (H, L1,L2). The reflections have been mapped in 3D. Their location after migration will be shown and correlations with drilling results will be discussed.



11.10

## NATURE OF SEISMIC REFLECTIONS AT KTB BOREHOLE IN GERMANY: MODELING BASED ON ROCKS COMPOSITION, FABRICS AND BOREHOLE MEASUREMENTS

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Using the technique of petrophysical modeling we separate the effects of lithology, rock matrix fabric and fluid-filled cracks on elastic wave velocities and density of the rocks from KTB Pilot borehole. Our modeling consists of 4 steps.
(1) We calculate equilibrium compositions and volume proportions of minerals from bulk chemical compositions of cuttings and rock-flour available every 2 m along borehole. For that we use the data on pressures and temperatures of last equilibrium and thermodynamic modeling approach.
(2) We calculate density and isotropic seismic velocities from mineralogical composition and experimental data on elastic properties of single crystals. While calculated density fits density (gamma-gamma) log data and density laboratory measurements almost perfectly the isotropic seismic velocities significantly differ from sonic log and VSP observations. The difference remarkably correlates with dip of foliation plane demonstrating clear anisotropic effect.
(3) Introduction of matrix anisotropy due to orientation of mica crystals parallel to foliation plain only partially accounts for this difference, the calculated velocities being up to 6 % too high.
(4) The best fit is achieved if the combination of matrix anisotropy and the brine-filled cracks is considered. The orientation of cracks does not correlate with the orientation of foliation plane in rocks. Several intervals of relatively high crack aspect ratio and porosity are defined.
The following reasons for seismic reflections at KTB are most likely: (I) - fracture zones with high crack density and relatively high cracks aspect ratio, (II) - zones of high anisotropy due to alignment of mica crystals. The lithological contrasts are apparently less significant.

11.30

## THREE-DIMENSIONAL MIGRATION OF THE 3D DEEP-SEISMIC REFLECTION SURVEY AT THE KTB LOCATION, OBERPFALZ, FRG

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The 3D steep-angle deep-seismic survey had been measured as the main part of the project ISO 89 (Integrated Seismics Oberpfalz 1989) covering an area of about 17.85 x 19.1 km. The processing of this data had been done at the DEKORP Processing Center (DPC) at the Institute for Geophysics of the Technical University Clausthal. The three-dimensional post-stack migration of this dataset has been faced with two major problems. Firstly, the survey includes areas with a strong lateral velocity gradient (3000 m/s (sedimentary rocks) -- 5500 m/s (crystalline rocks)). Secondly, the data is sparsely sampled in spatial direction (50 x 50 m binning) but includes steeply dipping events with a true dip up to 60 degrees. It seemed to be necessary to use different kinds of migration algorithms to be aware of the problems and advantages of the distinct methods and to select the best one. Therefore, other research institutes were asked to give support with the 3D-migration algorithms available at the institutes. The dataset had been migrated with a one-pass 3D-FD-migration by GEOMAR, Kiel. At the ETH Zürich an one-pass phase-shift algorithm was used to migrate the data. Both institutes used commercial software packages. At the DPC, Clausthal an algorithm has been developed for a 2 x 2D and an one-pass migration using the summation- or Kirchhoff-technique. The results of the different approaches of three-dimensional migration will be presented and discussed in this paper.

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11.50

## SHEARWAVE ANISOTROPY OF LAMINATED LOWER CRUST

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Deep seismic reflection studies have shown that "lamellae" are a widespread reflectivity pattern of the lower crust of the central European Variscan belt. It has been interpreted, inter alia, as alternating subhorizontal layering of mafic and felsic rocks implying a tectonic process of structural and textural ordering. Consequently, lower crust lamellae should be seismically anisotropic. The specific type of anisotropy should provide some insight into their mineral composition, the prefered orientation of minerals, and the stress system causing the ordering of minerals. We investigated this problem in the area of the Urach geothermal anomaly (S Germany) known as a "classical" example of lower crust lamellae. A restricted range of subsurface points was probed in an expanding spread experiment with two orthogonal azimuths of observation until 90 km source-geophone-offset. Both P- and S-waves were recorded with densely spaced 3-component geophones. Based on polarization analysis and traveltime interpretation the following results were obtained: (1) S-wave splitting is observed only for $S_mS$-arrivals implying that the lower crust is anisotropic. (2) The type of anisotropy is quasi-hexagonal (tranverse isotropic). (3) The coefficient of S-wave anisotropy is about 6-13 %. (4) The observed relation between direction and velocity of S-wave propagation is typical for horizontally ordered mafic minerals (here: orthopyroxene in a pure shear stress system).



14 September

8.30

## MONA LISA - DEEP SEISMIC PROFILING IN THE SOUTH-EASTERN NORTH SEA.

MONA LISA WORKING GROUP (Reporters: H. Thybo, Copenhagen; L. B. Pedersen, Uppsala; E. R. Flueh, Kiel; R. England, Cambridge; and N. Balling, Aarhus).

The MONA LISA (Marine and Onshore North Sea Acquisition for Lithospheric Seismic Analysis) collaborative project has collected 1158 km of seismic near-normal-incidence data, recorded to 26 s, and wide-angle data from 26 onshore stations and 3 OBS stations along 4 profiles in the Danish and German sectors of the North Sea. The profiles cross the Caledonian Front and the SW border of the Baltic Shield west of Denmark in the area where Avalonia, Laurentia and Baltica meet. Two E-W profiles cross the Central Graben between the Ringkobing-Fyn and the Mid-North Sea highs. The near-normal-incidence data clearly image crustal and upper mantle structures that may be related to the above tectonic features. The sections show strong similarities with the BABEL profile crossing the Caledonian Front in the southern Baltic Sea, suggesting that structures may be correlated beneath Denmark, but are remarkably different from the NEC and MOBIL profiles which image a northward dipping Iapetus suture in the western North Sea. The wide-angle data are of high quality despite the thick sedimentary sequence in the area and even show sub-critical Moho reflections to near-vertical incidence. Preliminary interpretations show thick crust beneath the Ringkobing-Fyn High and that the southern North Sea is underlain by thinner Avalonian crust. The numerous reflections from the crust and upper mantle require careful interpretation of their geometry which may give clues as to their age and origin.

8.50

## CRUSTAL STRUCTURE OF THE OCEAN-CONTINENTAL TRANSITION ZONE OF THE LOFOTEN MARGIN, OFF N. NORWAY BY OBS REFRACTION AND WIDE-ANGLE REFLECTION STUDIES.

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During the past decade we have concentrated the crustal structure study of the Lofoten margin by means of Ocean Bottom Seismographic refraction and wide-angle reflection studies. In this paper we present the recent results of the crustal structure on the transition from the ocean to the continent, i.e. from the Lofoten basin to the area covered by the flood basalt. We divided this area into three segments: the seaward side of the magnetic anomaly 21 (A), between magnetic anomaly 21 and seaward dipping reflectors (SDR) (B), and from SDR to the escarpment high (C). In the region A, we obtained a typical oceanic crust, which consists of sediments, the oceanic layer 2 (4.9 - 5.5 km/s), layer 3A (6.3 - 6.8 km/s) and layer 3B (7.0 - 7.1 km/s). In the region B, the layers are identical to those in the region A, however, the oceanic layer 3B becomes up to 5 km thick towards the continent. We also found a high velocity layer (7.3 km/s) in the lower crust, beneath the layer 3B. We interpreted that the crust beneath SDR was originally typical oceanic crust, however the layer 3B was thickened, and the crust was underplated by the high velocity body. We interpreted region C as the ocean-continental transition crust. The velocity of the layer 3B gradually decreases down to 6.8 km/s, which is identical to that of the lower crust beneath the Lofoten islands. We identified several clear wide-angle reflection phases reflected from the lower crust in the region C. We believe that the phases are reflections from sills of the oceanic material intruded into the continental lower crust.

9.10 CRUSTAL STRUCTURE OF THE VOLCANIC MARGIN OFF LOFOTEN, N. NORWAY, FROM MULTICHANNEL REFLECTION AND WIDE-ANGLE OBS-DATA

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The crustal structure of the volcanic passive margin off Lofoten, N. Norway, is at present relatively well known, mainly as a result of extensive experiments using both the multichannel reflection technique and 3-C Ocean Bottom Seismographs (wide-angle data). The crystalline crust beneath the continental shelf is inferred to consist of Precambrian rocks ranging from granulite to amphibolite facies, probably reflecting an uplift of the shelf and the Lofoten islands from lower crustal levels. In this area a three-layered crust is observed with velocities ranging from 6.0 - 6.8 km/s. The thickness of the lower crust decreases from a maximum thickness of about 12 km beneath the shelf to almost zero thickness beneath the Lofoten islands, probably as a result of ductile properties of the lower crust combined with large scale tectonism. The strong shallowing of the Moho beneath the Lofoten islands, as well as a bright wide-angle upper mantle reflection might be explained by inferring a master-fault penetrating into the mantle. The area from the ocean/continent transition to the shelf edge about 100 km landwards is almost entirely covered with an up to 2.5 km thick flood-basalt extruded during the break-up between Norway and Greenland in early Eocene. The basalt is opaque with regard to the multichannel reflection technique, but sub-basalt structures can be mapped from the OBS-data. An up to 4 km thick sedimentary basin is inferred below the basalt, and the low velocities in the crystalline crust (6.0 - 6.8 km/s) confirm that the crust on the landward side of the Lofoten escarpment represents strongly thinned continental crust. A high-velocity body in the lower crust (7.3 km/s) that extends from the seaward dipping reflectors and almost to the Lofoten escarpment, is believed to represent a magmatic underplated body.

9.30 A SIMULTANEOUS INVERSION OF BOTH REFLECTION AND WIDE-ANGLE SEISMIC DATA

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S.C.Singh (BIRPS, Madingley Road, Cambridge, CB3 0EZ, UK)

One of the problems with standard seismic reflection data is that it provides very poor constraints on seismic velocity at depth, since at depth the rays are all vertical. Combining the normal-incidence data with wide-angle data, which contains rays at all angles, provides a dataset which can constrain crustal velocities and interfaces very effectively. We have developed a travel-time tomographic technique to invert such a combined dataset. We invert for a model of the crust which consists of layers of 2-dimensional, smoothly varying velocity separated by interfaces. To obtain a high resolution but stable solution from noisy data the model is over-parameterised and a smoothing regularisation is imposed on the resulting set of equations. Synthetic studies demonstrate the efficiency and stability of this approach and show the desirability of combining the two experimental geometries. This technique has been applied to the SWABS dataset which was collected off the north-east coast of England by BIRPS in 1992, with the aim of characterising the seismic properties of the lower crust. Travel-times from the reflection profile, and from 7 digital ocean bottom seismometers, were simultaneously inverted to provide a well constrained velocity and interface model of the crust.



9.50 WIDE-ANGLE AND BROAD-BAND SEISMIC INVESTIGATION OF THE CONTINENTAL CRUST

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J. J. Doody (Department of Geology and Applied Geology, University of Glasgow, Glasgow. Scotland)

In August 1992, the British Institutions Reflection Profiling Syndicate (BIRPS) conducted an integrated deep seismic experiment around the northeast coast of England. It consisted of a series of various seismic acquisition techniques all focused on the same target, lower crust, allowing the estimation of different length scale of velocity and reflectivity structures. A 100 km long expanding spread profile (ESP) allowed the estimation of 1-D average velocity structure of the whole crystalline crust using a non-linear global waveform inversion scheme. This velocity was used to obtain 2-D velocity structure from travel-times inversion of reflection/refraction arrivals of seven ocean bottom seismometers along the profile. The 2-D velocity information was then used to obtain medium scale reflectivity structure of the lower crust from a critical angle profile (CAP) in which the receiving ship was placed at the critical distance for the lower crust from the shooting ship. The conventional reflection survey provided 2-D seismic image of the crust along the profile which shows that lower crust is strongly reflective. This seismic image was further enhanced using a dual streamer (over/under) configuration where energy up to 75 Hz were recorded from the lower crust indicating that the reflectors have sharp boundaries and could be very thin, order of 10s of metres. The frequency vs amplitude analysis of the broad-band data, 5–75 Hz, gives an improved estimate over previous determination of attenuation of seismic waves, $Q = 1000$ for the lower crust. The simultaneous recording of the airgun shots by a 192-channel 3 km land array shows strong reflected shear energy from the lower crust.

10.40 IDENTIFICATION OF TERRANES USING DEEP SEISMIC DATA FROM OFFSHORE BRITAIN AND IRELAND

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If terranes have different geological histories from their surroundings differences in their structure should be discernible on deep seismic profiles, providing the structures in question have length scales (100's to 1000's m) which can be resolved by the seismic method. A review of deep seismic profiles crossing Caledonian terranes in the UK and Ireland reveals that this approach is not always possible. The Iapetus Suture can be clearly delineated on this basis beneath northern England but locating terrane boundaries west of Ireland is more difficult. Terranes west of Ireland are significantly narrower and it is probable that otherwise characteristic reflection patterns are overprinted by the deformation suffered during collision, or by post collision structural reactivation. In such areas the location of terrane boundaries relies on, and is driven by, integration of surface geology and potential field data with seismic interpretation. The identification of reflectors beneath the Moho also provide an insight into the origin and extent of Caledonian terranes. The Flannan reflector appears to be displaced by the Great Glen Fault system. The Moho parallel W reflector, first seen north of Scotland on the DRUM and GRID data can be traced on the LISB-B refraction profile and the WIRELINES and recently acquired WESTLINE near normal incidence profiles, as far south as the surface trace of the Highland Boundary fault, where it appears to terminate abruptly. It is disrupted beneath the surface traces of terrane boundaries in western Ireland. These observations suggest that terranes north of the Highland Boundary Fault consist of both crust and a keel of lithospheric mantle and were derived from the same source of continental (Laurentian) crust. The Midland Valley and terranes to the south do not show significant sub-Moho reflectivity. This may indicate a different derivation for these terranes or destruction of mantle features during subduction of Iapetus oceanic crust.

11.00

## MULTIPLE SUPPRESSION TECHNIQUES AND THEIR APPLICATION TO DEEP SEISMIC REFLECTION DATA.

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Marine deep seismic reflection data is being used extensively to map the continental margins, in particular to try to image the structures related to the rifting and eventual onset of oceanic spreading. All these data have one thing in common: the lower crustal image is degraded by the presence of multiple energy. Free-surface reflections at the sea surface, coupled with the increasing water depth, as the profile moves across the continental shelf edge towards the continent ocean boundary, produces a complex long-period multiple. This multiple is not a simple mimic of the sea-bed reflection series but grows in complexity at each period by repeated convolution so the energy becomes delayed into the peg-leg multiples. Hence, the appearance of severe multiple contamination is highly dependent on the presence of strong impedance contrasts within the near-surface sediments
The talk will present a review of the current techniques and their application to seismic data. Examples will be taken from the BIRPS WESTLINE profile that crosses the Rockall trough to the west of Ireland. The profile crosses two conjugate margins and a section of highly stretched continental crust. State-of-the-art multiple suppression techniques, e.g. pre-stack F/K, Radon transform, and methods based on the wave-equation, will be compared to novel methods being developed that use a far-field source wavelet recorded on a shot-to-shot basis during the acquisition of the reflection data. The measurement of the source wavelet should enable the exact "removal" of the free-surface from the data along with all the multiple energy, thus allowing confident interpretation of the lower crustal reflection data.

11.20

## THE MAIN FEATURES OF THE INTERFACE BETWEEN THE CRUST AND THE UPPER MANTLE IN THE MIDDLE URALS (in the vicinity of the deep drillhole SG-4)

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Reflection and refraction as well as DSS data obtained in the Middle Urals are represented. Particular attention was paid to the seismic image of the lower crust and the upper mantle. Both boundaries geometry anomalies in the lower crust and P- and S-waves velocity and polarisation anomalies obtained with 3-component geophones are considered. Analysis of available seismic materials indicates considerable deepening of the main interface between the crust and the upper mantle beneath the central part of the Urals and presence of the peculiar complicated transitional complex above it. Thickness of the crust reaches 55-60 km in the vicinity of super deep drilling SG-4. In the area of SG-4 location Moho boundary trough widens from Tagil zone far to the west to Central Urals uplift and Western Urals folding zone. Velocity along the main interface within this trough is about 8.5 km/s. Transitional complex consists of the relatively thin layers (thickness 3-5 km) with increased or decreased velocities. Average velocity for the whole transition zone changes from 7.3 to 7.8 km/s and depends on the prevalence of the complexes. Thus the complex was determined in the lower crust beneath the Urals using seismic data. There are some peculiarities in its structure, that allow to consider it as an original structural and tectonic crust stage. There are upper mantle complexes with relatively high velocity parameters beneath it.

14 September

11.40

## COCORP AND SEISMIC REFLECTION PROFILING OF THE URALIAN OROGEN, RUSSIA

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The Uralian orogen of central Russia forms the principal tectonic and geographic boundary between Europe and Asia, and unlike the other major Paleozoic orogens (Appalachians, Variscides, Caledonides), is characterized by a pronounced crustal root (based on Soviet DSS data) and an apparent lack of syn- or post-orogenic collapse. In this respect, the Urals provide a special opportunity to test modern hypotheses concerning nature of the lower crust, mobility of the Moho, and the role of orogenic collapse in evolution of the continental lithosphere. As part of a multinational effort to study the crustal structure and tectonic evolution of the Uralian orogen, COCORP has joined with European colleagues within the framework of EUROPROBE in (1) reprocessing of existing Russian seismic reflection data, (2) acquisition of the ESRU (EUROPROBE Seismic Reflection Profiling in the Urals) profile in the Middle Urals, and (3) planning for a 500-km deep reflection transect of the Southern Urals (Project URSEIS) in 1995. Reprocessing (with CDP techniques) and interpretation of existing shallow (< 8 sec. TWTT) reflection datasets (Aramashevskii, Alapaevskii, and Chernoistochinskii) has provided an important calibration for understanding of previous Russian processing and interpretation. The CDP processing reproduces the general distribution of reflectivity seen on earlier versions, but provides greater detail in the geometric relationships of tectonic features, including the trajectory of the Main Uralian fault (suture zone), and the presence of a mid-crustal detachment within the Uralian hinterland. Collaboration with Swedish, Russian, and German scientists on the ESRU Project in the summer of 1993 led to acquisition of the first deep CMP reflection data in the Urals (Juhlin et al 1994). Combined with the reprocessing work, these data provide an ~190 km transect through the Middle Urals. Deep structure of the Urals imaged on the ESRU data can be interpreted as evidence for either large-scale imbrication of the Moho and lower crust beneath the axis of the orogen, or intercalation of East European crust with exotic (oceanic and island-arc) terranes to the east. Preparations are now under way for Project URSEIS (Urals Reflection Seismic Experiment and Integrated Studies), a multinational seismic experiment cored by a hybrid-source, deep seismic reflection profile, targeted for 1995. These new data should provide the first complete seismic image of the crustal and upper mantle architecture of an intact Paleozoic orogen, and contribute potentially fundamental new insight into the processes of continental collision and subsequent orogenic evolution.

14.00

## LITHOPROBE REFLECTION STUDIES OF ARCHEAN AND PROTEROZOIC CRUST IN CANADA

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LITHOPROBE's multidisciplinary earth science research program is spearheaded by seismic reflection studies. Funding agencies recently approved our 10-year plan to continue existing studies, carry out significant new ones and bring the full project to a planned conclusion. Most of the recent and new studies are focusing on Precambrian regions. In 1992, 520 km of 18 s data were acquired across central Alberta to investigate the series of Archean and Paleoproterozoic domains below the sediments of the W. Canada sedimentary basin. Seismic sections show thrust stacking at crustal scale and dramatic imbrication of the Archean Hearne craton. Images of similar collisional features to the east were obtained from earlier work in the Trans-Hudson Orogen Transect. Available geochronologic constraints indicate contemporaneity of tectonic activity between the two regions at 1.8 Ga. These results suggest that collisional tectonic activity was coeval over a broad crustal region, ca. 1000 km across strike. Also in 1992, 1280 km of marine data were recorded across the Paleoproterozoic Makkovik & Labrador and Mesoproterozoic Grenville orogens off S.E. Labrador, and across the Proterozoic Torngat orogen and bounding Archean Nain and Rae cratons off N.E. Labrador. Images in the south show characteristic crustal features associated with the different Proterozoic tectonic domains. Images in the north are of lesser quality but indicate differences between the two Archean cratons with some distinctive features for the Torngat. Studies of the Grenville continued on land in 1993 with lines of 250 and 410 km across the eastern and central parts showing extensive reflectivity throughout the crust. In the Archean Superior craton, a 250 km line extending north from earlier work in the Abitibi greenstone belt across the Opatica plutonic belt shows spectacular crustal reflectivity, perhaps indicating continent-continent collision, and a mantle reflector that may extend to 21 s. During 1994, an additional 600 km of data in the Alberta Basement Transect will extend previous coverage northwest across a series of Paleoproterozoic domains and a further 1000 km of data in the Trans-Hudson Orogen Transect will help determine the 3-dimensional structure of the region.

14.30

## REFLECTION SEISMIC IMAGES OF PROTEROZOIC OROGENS OF THE NORTHEASTERN CANADIAN SHIELD

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As part of LITHOPROBE's Eastern Canadian Onshore-Offshore Transect (ECSOOT), 1270 km of marine reflection profile were collected in 1992 along the Labrador coast and across Ungava bay to image the crustal structures associated with several Proterozoic events of crustal accretion onto Archean cratons. The resultant images show varying styles of crustal structure. The crust is generally dominated by whole-crustal dipping reflection fabrics which, in some cases, extend from the sediment/basement unconformity down to the base of the crust. In these cases, there is no sign of a tendency for the dipping reflectors to flatten in the deep crust. The lower crust has various styles: while often characterised by low reflectivity, it occasionally shows quite strong reflectivity, with some instances of a strong (?Moho) reflector at its base. Reflection times to the base of the crust are estimated to lie in the range 10-14 s. The mantle shows several zones of dipping reflectivity, with dip direction often opposite to that in the overlying crust. Combining the crustal fabrics with surface geology and information from isotope studies is underway, but not completed. In at least one instance, an external thin-skinned fold thrust belt appears to be associated with an interior, thick-skinned fabric, which itself may root into the mantle. The range of Proterozoic structures observed appears similar to that observed in younger collisional orogens.

14.50

## SEISMIC REFLECTION RECORD OF A TRANSITION FROM COLLISIONAL TO POST-COLLISONAL TECTONICS: TRANS-HUDSON OROGEN (CANADA)

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Seismic reflection data from a LITHOPROBE transect of the Trans-Hudson Orogen (THO) suggest that the crustal architecture was largely shaped during collisional deformation and post-collisional (intracontinental) transpression. The 1.9-1.7 Ga tectonic history records the interaction of three Archean continents (Superior, Hearne and an 'exotic', largely buried microcontinent) and Proterozoic arcs/accretionary collages developed outboard of these continents. Three fundamental stages in orogenic evolution are captured in the seismic images: (1) crustal-scale overthrusting associated with progressive westward accretion of arcs/accretionary collages against the Hearne margin (>1.85-1.83 Ga), (2) terminal collision involving crustal-scale (northward) underthrusting of the Archean microcontinent and southward translation of the allochthonous Proterozoic accretionary stack (1.83-1.80 Ga), and (3) intracontinental transpression involving a shift to less oblique relative motion between Superior craton and the rest of THO to the west (1.80-1.70 Ga). Imaged post-collisional features include a crustal-scale culmination cored by the microcontinent (to 15 s), regional-scale domes and basins and steep faults in the upper crust (<8 s), and low-angle reflections that appear to truncate dipping reflections in the lower crust (to 12-14 s). These features indicate decoupling between an upper crustal domain of strike-slip faulting and folding and a deep crustal domain of ductile flow beneath major low-angle detachments, which may include the Moho. The transition from collisional to post-collisional tectonics thus records a change from orogen-parallel thrusting in response to impingement of the Archean microcontinent to transpression and longitudinal 'escape' of THO crust away from the converging Superior craton. Most reflectors are probably associated with peak metamorphic collisional deformation, whereas the overall geometry of reflectors is principally controlled by the boundary conditions (Archean crust/lithosphere) and post-collisional deformation.



15.10

## ANCIENT CONTINENTAL COLLISION: VARIATIONS IN RESPONSE OF THE NORTHWESTERN SUPERIOR CRUST TO TERRANE IMPINGEMENT

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The Archean Superior craton was juxtaposed against a collage of juvenile arc and oceanic Proterozoic terranes during the ca. 1.8-1.9 Ga Hudsonian orogeny. Comparison of seismic reflection and geological data sets from different corridors across the 'suture zone' separating the Superior craton from the accreted juvenile terranes indicates that the mechanical response of the craton to collision varied significantly along the margin. In the northern corridor (Cape Smith Belt, Ungava orogen), geological mapping clearly demonstrates that the Superior craton formed the underthrust plate during collisional tectonics. However, seismic results from two LITHOPROBE corridors in the Trans-Hudson Orogen (THO) to the southwest indicate that juvenile Proterozoic rocks project beneath the craton margin. We propose a tectonic model that accommodates both the surface geology and the seismic results. The collisional history of the margin initiated with Superior craton forming the lower plate, eventually colliding with juvenile terrane(s) to form craton-verging fold and thrust belts. High-resolution seismic profiles in the THO segment image early thrust-nappe structures related to this early deformation. Further evolution within the THO segment appears to have resulted in a major vergence reversal, with Proterozoic terranes wedging into the Superior craton. Wedging is observed at both mid-crustal levels and at deeper levels where Superior crust may have delaminated at or near the Moho. Wedging and back-thrusting are related to post-collisional, intracontinental deformation in THO, and were coeval with strike-slip faulting along the suture zone. In contrast, post-collisional deformation in the Ungava Orogen is characterized by folding of Superior basement and the allochthonous terranes.

15.30

## NEW DEEP SEISMIC REFLECTION DATA FROM THE URALS - THE ESRU PROFILE

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Recent cooperation between western and Russian scientists has resulted in acquisition of the first deep CDP reflection data from the Ural orogen, as well as reprocessing of existing seismic reflection datasets. The ESRU (EUROPROBE Seismic Reflection Profiling in the Urals) profile, collected near the SG-4 Superdeep borehole in the Middle Urals, is a 56-km long CDP line recorded to 35 sec. TWTT over the Main Uralian fault (MUF) in the summer of 1993. These data provide the basis for a more detailed interpretation of crustal structure in this part of the orogen than has previously been possible, particularly with respect to the deep crust. The main features imaged on the ESRU profile are (1) a steeply-dipping (45°E) ~5-km thick package of high reflectivity in the east, the base of which corresponds to the surface trace of the MUF, (2) a thick (~4 km) package of sub-horizontal reflectivity in the west which appears to dip below a major structural ramp in the Uralian foreland, and (3) a thick zone of relatively strong reflectivity which characterizes the lower crust along the entire profile, but is considerably shallower to the east (8-12 sec.) than in the west (10-14 sec.). The apparent offset in this zone of reflectivity (directly below the east-dipping MUF) suggests either (1) imbrication of the Moho and lower crust on a steep west-vergent fault or (2) intercalation of Asian and East European lower crust during Uralian orogeny. Reprocessing of 20 sec. records from Profile R-17 in the West Siberian basin, ~300 km to the NNE of the ESRU profile, reveals pronounced lower-crustal reflectivity between 11-14 sec., suggesting that the "shallow" zone of lower crustal reflectivity in the Middle Urals (coincident with a crustal root inferred from refraction data) may be anomalous. Future deep reflection profiling will be critical to address this question.

14 September

15.50 DEEP SEISMIC REFLECTION PROFILES OF AN ARCHEAN CRATON BECOMING A MODERN MOUNTAIN BELT, THE BANDA ARC

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Mountain building is widely considered to result from the collision of a volcanic island arc with a continental margin and the convergence of the Banda Arc with Australia is often cited as an example of this process. Eastern Timor represents the most advanced stage of arc-continent convergence along the Banda Arc and thus can also be regarded as a first stage of collisional orogenesis. Based on observations within the topmost few kilometres of the crust, Timor has previously been interpreted geologically as a subduction zone melange or accretionary prism, the overthrusting margin of the Australian continental shelf, rifted Australian basement, and a young fold and thrust belt. The first deep seismic reflection profiles from this type convergence zone have revealed both N- and S-dipping structures throughout most of the uppermost 50 km of the 200 kilometre-wide arc. These structures have a geometry that is consistent with orogenic processes uplifting the arc on large deep-seated shear zones and smaller-scale thrust and fold structures, a geometry both predicted by numerical models and observed in mature continental collision zones. Pronounced reflectivity in the lower crust of the Australian shelf, probably dating to Jurassic extension, is apparently destroyed by deformation and possibly metamorphism at 40 km depths beneath the Timor Trough. Evidence of horizontal shortening is observed at all levels of the crust in the vicinity of the trough. The continental crust of Australia appears to have thickened beneath the Banda Arc whereas the oceanic lithosphere of the Banda Sea has remained relatively rigid and deformed largely by brittle failure and earthquakes.

16.10 SEISMIC INVESTIGATION ALONG THE WESTERN FLANK OF THE TRANS-HUDSON OROGEN TRANSECT

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Coincidental dynamite and vibroseis reflection surveys, along a 200 km segment of the Trans-Hudson Orogen Transect, generated comparable seismic signals from different sources. The amplitudes of the explosive generated signals are at least 60 dB higher than the analogous vibroseis events. The equivalent final stacks exhibit only comparable signal to noise ratios due to the difference in data acquisition folds of the two surveys. Detailed velocity analysis was accommodated by the expanding spread surveys. On the western end of the profile the dominant westerly dipping horizons and a 3-sec offset of the Moho are clearly visible on both sections. The advantages of the dynamite source include deeper penetration and mapping of zones of subcrustal reflectivity. Moreover, the dynamite data indicate that the diffraction patterns generated at lower crustal and Moho depths can extend to 17-19 sec TWT. Thus, proper migration at lower crustal depth ranges requires observation of greater travel times than followed by the presently accepted standard data acquisition procedures.

15 September

8.30 THE LITHOSPHERE-ASTHENOSPHERE SYSTEM IN THE MEDITERRANEAN-ALPINE REGION

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In plate-tectonic terms the Mediterranean-Alpine region can be characterized as a broad and complex transition zone between the African and Eurasian lithospheric plates. The present crust-mantle structure is the result of a dramatic evolution since the early Cretaceous with dynamic processes mainly governed by the counterclockwise rotation of Africa versus Europe which has led to an increasing lithospheric shortening from west to east. Superimposed on this large-scale dominant motion are regional tectonic deformations which are associated with compressive, strike-slip and extensional structures. The observational data available indicate that most of these features reach deeply into mantle and can only be understood as manifestations of processes involving the entire lithosphere-asthenosphere system.

Examples of regional cross-sections are briefly discussed starting from the Eastern through the Central to the Western Mediterranean. Lateral variations of the upper-mantle structure are derived from the dispersion analysis of seismic surface-waves, the tomographic inversion of P- and S-wave traveltimes, long-range seismic refraction experiments and deep-reaching near-vertical reflection surveys. Beneath a highly differentiated crustal structure pronounced lateral variations of seismic wave velocities are indicative of rapidly changing heterogeneities in the upper mantle. Finally, it will be shown that decoupling and wedging phenomena, differential rotations and strongly variable deformation rates have shaped the present tectonic appearance of the Mediterranean-Alpine realm.

9.00 FEATURES OF THE MANTLE STRUCTURE BENEATH NORTHERN EURASIA FROM LONG-RANGE RECODINGS

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Deep seismic studies with a network of long-range profiles transecting ancient Precambrian platforms,young Paleozoic plates and Caledonian and Hercynian orogenic belts were carried out across former Soviet Union during the last 20 years. These DSS have included recordings from 60 Peaceful Nuclear Explosions (PNE) along various geotraverses out to distances in excess of 3500 km. Combine interpretation of kinematic and dynamic parametrs of different types of waves (P,S,reflected,refracted) was undertaken to determine two-dimensional velocity variations in the upper mantle. Seismic Sounding of the mantle in northern Eurasia using PNE reveal vertical and lateral mantle inhomogeneities. In contrast to standard seismological earth models such as PREM and IASP91 three,rather than two,mantle discontinuities are found between 400 and 700 km. depth.They are located at about 400-420,510-550 and 660-680 km.depth.In the upper mantle the uppermost layer through which Pn propagates extends down to about 70-100 km.depth and is divided into blocks with velocities from 7.9 to 8.6 km.s .The mantle below this depth,but above 400 km. discontinuity,is characterized by alternating high and low body-wave velocities. The velocity fluctuates between 8.1 and 8.8 kms .Average velocities are higher than standard seismological reference models. The most pronounced low-velocity zone is between about 200 and 270 km.depth. This channel displays substantial lateral variation in thickness and velocity. The quality factor (Qp) in high-velocity upper mantle layers changes from 200 (depth 40-70 km) to 470 (depth 510-670 km).In low-velocity layers Qp is much less and fluctuates between 40 and 90.

## 15 September

### 9.30 FINITE DIFFERENCE MODELLING OF ELASTIC WAVE PROPAGATION IN PERTURBED MEDIA: SEISMIC PROCESSING AND INTERPRETATION

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A principal tool in interpretation of crustal refraction and wide-angle reflection profiles is forward modelling using dynamic ray-tracing. A potential flaw of this approach is that a dominant observational feature, namely the P-coda waves are not accounted for. Also, in many cases it is not obvious that the phase identifications, as presented by the analyst, is valid. Often stringent criteria like apparent phase velocities, signal correlation and so forth are not used as guide for identifying signals embedded in P-coda waves and subsequently objectively recognizing specific phase arrivals. Our approach to this problem is to compute 2D finite difference synthetics for crustal models derived from ray-tracing, but allowing for random, small-scale velocity and density perturbations within the crust. Such inhomogeneous media with RMS perturbations of the order of 2 to 4 per cent is a basic requirement for P-coda excitation. The synthetic records are then subject to commercial processing techniques like f-k filtering, p-tau mapping and inversion using the ProMAX software package. The main outcome of our synthetic exercise so far is that very simple crustal models overlaying a halfspace, but subject to randomized small-scale velocity perturbations, produce synthetic records which are surprisingly similar to the observational ones. Also, the crustal velocity distribution is not well constrained as for 'perturbed' models we could not recover accurately the original velocity model.

### 9.50 VELOCITY STRUCTURE OF THE UPPER MANTLE TRANSITION ZONES FROM WAVEFORM INVERSION OF SEISMIC REFRACTION DATA USING GENETIC ALGORITHM

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We present new velocity models for the 410 and 670 km transition zones beneath central Siberia based upon observations of the 1982 "RIFT" Deep Seismic Sounding (DSS) profile. A Peaceful Nuclear Explosion (PNE) was detonated to provide energy for the 2600-km long profile extending from the Yamal Peninsula to the Mongolian border SE of Lake Baikal. The unambiguous arrivals from these upper mantle transition zones were inverted. We use a hybrid inversion scheme which combines the Maslov synthetic seismogram theory for 2-D forward modelling and an 1-D inversion using a genetic algorithm for optimization. The inversion result shows that the 410 km transition zone has a two-step velocity gradient structure. This model would satisfy and explain both seismological (sharper, less than 4km thick) and mineral physics (more than 20 km thick) estimates for the sharpness of this upper mantle discontinuity.



### 10.40 STRUCTURE OF UPPER MANTLE FROM LONG-RANGE SEISMIC PROFILES IN EURASIA

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Long-range seismic profiles carried out in Russia with nuclear explosions show regular stratification of the upper mantle. Several boundaries were traced from refractions and wide-angle reflections which were correlated at the same time-distance intervals in different tectonic areas. The first boundary (N) with velocity 8.4-8.5 km/s is located at a depth of 90-110 km inside the thermal lithosphere. It underlines horizontally inhomogeneous and anisotropic uppermost mantle and in many cases is covered by a zone of velocity inversion. In West Europe and in the Mediterranean the N-boundary was traced by intensive reflections inside the thermal asthenosphere. Another boundary is located at a depth of 180-220 km (L-boundary?). It generates strong but unstable reflections and looks like a high velocity (8.5 km/s) lamellar zone located between two lower (or normal) velocity layers. Sometimes the boundary shows distinct inclination, for instance, it dips from the Baikal Rift to the Siberian Craton and from the Urals to the West-Siberian platform. Three boundaries are observed in the transition zone between the upper and lower mantle at depths 410, 520 and 680 km.

### 11.10 THE STRUCTURE OF THE LOWER LITHOSPHERE AS DERIVED FROM SEISMIC REFLECTION AND REFRACTION SURVEYS

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Most of our knowledge about the structure of the lithosphere-asthenosphere system pertains to the internal structure of the crust. This allows to understand the tectonic evolution and structural changes with time and to make quantitative comparisons between crustal structures from different areas. However, we are still far from properly understanding the role of the subcrustal lithosphere in processes leading to mountain building, basin formation etc. Structural information about the lower lithosphere is inferred from near-vertical and long-range wide-angle reflection and refraction profiles. A seemingly consistent pattern of consecutive traveltime branches leads to mostly horizontal alternating high- and low-velocity layers. Differences persist between the models derived from the same data by different authors with respect to the number of layers, velocities, velocity gradients and velocity contrasts, as well as thickness of layers. These differences arise from the insufficient quality of data, different approaches of the interpreters and ambiguity caused by lateral inhomogeneities. A fair number of high-quality near-vertical reflection surveys in western Europe shows consistent reflections from the subcrustal lithosphere. In most cases these signals are steeply dipping, are attached to the crust-mantle boundary and can be interpreted as relics of old tectonic processes. The few subhorizontal reflectors do not prove the reality of the mostly 1-D velocity-depth distributions which are derived from long-range seismic data over distances of several hundred kilometers. Therefore, before comparing structures from different tectonic realms and ages, data and interpretations in one single area should be improved. Models have to be verified rigorously with other techniques.

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11.40

UPPER-MANTLE REFLECTOR STRUCTURE BENEATH SCOTTISH CALEDONIDES

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The Flannan reflector beneath the Scottish and Irish Caledonides is perhaps the most widely studied discrete structure in the uppermost mantle beneath the continents. Previous investigations have proposed differing interpretations for the reflector as a thrust related to the Caledonian orogeny (Silurian-Early Devonian) or as a normal fault or shear zone reactivated during post-Caledonian (e.g., Devonian or Permo-Triassic) extension. Our study uses all of the presently available deep seismic reflection data (including proprietary data) to further map mantle reflector structure along the Caledonian orogen and to better constrain the geometrical and tectonic relation of this structure to regional upper crustal geology. The regional distribution of the mantle reflector shows that it is not spatially related to either Caledonian compressional or subsequent basin extensional structures in a simple way. A structural contour map clearly shows two distinct discontinuous surfaces consisting of a steeply plunging antiform-synform pair beneath the West Orkney basin (north of the Scottish mainland) and beneath the Færoe -Shetland basin west of Shetland, respectively. We suggest that these two surfaces were once part of a continuous, more or less planar surface that has been offset and deformed by either (or perhaps a combination) of two processes: (1) by differential extension of the crust that was at least partially coupled to the uppermost mantle beneath the West Orkney and Færoe-Shetland basins; (2) by a broad, approximately east-west trending zone of sinistral simple shear that was largely confined to the upper mantle but later reactivated to deform the crust. This study implies a linkage between upper crust and upper mantle deformation. The results of this study also suggest that the Flannan mantle structure may be a feature inherited from a ca. 1.9-Ga old subduction event that affected the southern margin of the Laurentia-Baltica supercontinent.

12.00

STUDY OF MOHO CHARACTERS USING VRSM

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Liu Cai, Li Min and Zhou Hui (ditto)

Study of VRSM ( Vertical Reflection Seismic Method ) has been done successfully in north-east Asia and Tibet plateau. The study has an important function for the study of pacific plate subduction effect on continent margin of northeast Asia since Mesozoic era and the rise mechanism of Tibet plateau since Neozoic era. The paper studies emphatically Moho's characters and the study methods are special processing techniques, including instantaneous data, time—frequency analysis and modeling, etc, besides some normal techniques such as stack, migration and filtering, etc. After studying we discover that the Moho of northeast Asia and Tibet plateau keep obvious common characters, e. g. , Moho appears the model of transition zone, change in both directions is complex, Moho contains interior structures and faults, etc. The paper also discusses the mechanism of the characters. Under the background of T, P, the mantle convection and the earth rotation togather cause Moho's stratification. We can see that the subduction of India plate into beneath Tibet plateau produced MHT, the oblique subduction of Kula plate led to the development of a series of NNE or NE trending structures and partly rise of Moho in northeast Asia. The 50s's records of northeast Asia prove clearly that the asthenosphere has stratification structure. The heat convection is the main reason of the phenomenon.

15 September

14.00

RESULTS OF SEISMIC REFLECTION PROFILING IN THE TURANIAN PLATFORM

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The Turanian platform, including the Kazakhstan fold belt, is one of the most studyed young inner-continental platforms using seismic reflection methods. For more than 15 years numerous seismic profiles, including deep CDP profiles, single-fold near-vertical reflection data, and also wide-angle reflected data have been collected, and reveal a good qualitive similarity of the results of these different seismic methods. These data have led to the following conclusions. The depressions, or basins, of the Turanian platform are characterized by substantial changes of crustal reflection character, and complex structure of the Moho surface, which primary is marked by subhorizontal reflectors. Clear reflections are seen in the upper crust on the seismic section in the Amu-Darya basin, but beneath the Usturt and Aral Sea basins the majority of reflectivity is concentrated in the lower crust. This predominance of subhorizontal reflections is the most general symptom of the crust beneath basins. However, this sharply differs from that of the Kazakhstan shield, where the main part of the entire crustal section is highly reflective with abundant inclined reflections, but containing local "transparent" zones likely representing intrusive bodies. These differences are the consequence of important tectonic and geological processes. In contrast with the Kazakhstan fold belt, which formed as a result of Paleozoic overthrusting of thin-skinned nappes, the crust of the basins consist of monolithic massifs of ancient cratonic fragments (micro-continents) divided by narrow suture zones.

14.20

INDEPTH DEEP PROFILING OF THE HIMALAYAN COLLISION ZONE

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Project INDEPTH (INternational DEep Profiling of Tibet and the Himalaya) is a cooperative geoscience program being undertaken by the Chinese Academy of Geological Sciences of the Ministry of Geology and Mineral Resources of China (MGMR) and several North American and European institutions. The goal of INDEPTH is to image the large-scale structure of the crust beneath the Himalaya/Tibet Plateau and thereby contribute to the understanding of the mechanics of continent/continent collision.

Data acquisition for the pilot phase of INDEPTH took place during the summer of 1992 south of Kangmar, within the Tethyan Himalaya in southern Tibet. Approximately 100 km of explosive-source common midpoint (CMP) deep reflection profile together with complimentary wide-angle and off-line reflection data were acquired. Additionally, MGMR investigators collected gravity and magnetic data along the survey route.

The top of the Indian continental crust underthrusting the Tethyan Himalaya is clearly imaged on both the CMP profile and wide-angle data between about 25 and 41 km depth, dipping gently to the north. The Indian Moho is intermittently imaged at ~75 km depth - the deepest Moho yet traced by CMP profiling. Numerous generally north-dipping reflections above the main thrust decollement are consistent with thrust imbrication of the upper crust within the Tethyan Himalaya. One of these reflections is also a candidate for the extensional South Tibetan Detachment that bounds the north flank of the High Himalaya.

The new INDEPTH results substantially extend the "known" northward extent of underthrust Indian continental crust beneath Tibet and demonstrates that crustal doubling beneath at least the southernmost part of the Tibet Plateau has been accomplished by the wholesale underthrusting of Indian continental crust beneath a structurally imbricated upper crust.

Data acquisition for INDEPTH II will take place during May-October, 94, with preliminary results to be reported at the Budapest meeting. The field program will include CMP deep profiling, wide-angle and "off-line" recording with portable REFTEKs, field geological investigation, and broadband teleseismic recording. Principal geologic goals are to track the top of underthrust Indian crust northward beneath the Tibet Plateau or downward into the mantle, examine crustal structure in the vicinity of the Tsangpo suture, and determine the relationship between the South Tibetan Detachment and deeper compressional structures within the crust.

14.40

## STRUCTURE OF THE NORTHERN BOUNDARY OF QINGHAI-TIBETAN PLATEAU: A VIEW FROM SEISMIC REFLECTION PROBING

Xuanzhi Wu, Gongjian Wu, Cunling Wu, and Jie Lu (Lithosphere Research Center, Chinese Academy of Geological Sciences, Beijing 100037, China)

The Qinghai-Tibetan plateau, constituting earth's largest region of elevated topography and anomalously thick crust, is considerd a good field laboratory of the continent-continent collision. 94 km CMP deep reflection data was collected in autumn, 1993, along a NNE trending profile across the North Qilian Front Thrust, which is widely thought to be the northern boundary of the Qinghai-Tibet plateau. The goal of this program was to image the fine crustal structure of this area. The source consisted of six 18-ton vibrators generating a 8- to 40-Hz linear sweep lasting 20 seconds. The spread was 9.5 km long with a 100 m trace spacing and 200 to 1000 m nearest source-receiver offsets. In spite of the strong noise and the highly variable and difficult near-surface geology of mountainous region and gobi, the stacked section still provided new crustal-scale information on Moho, the lower crust and the deep extension of the known North Qilian Front Thrust. In the northern portion of the section, a band of south-dipping continuous reflections was traced to at least 8s twt and clearly demonstrated the extention of the Chijinpu-Jinta fault zone which was maped by the drillings and surface geology. The great deep extention of this fault zone supports the idea that Chijinpu-Jinta fault zone is the eastern extention of the well known Altun fault belt, a major strike-slip fault belt in Asia, which mark the boundary between the Qinling-Qilian fold system and Tarim-Beishan continental block.

15.00

## GOLMUD-EJINAQI GEOSCIENCE TRANSECT (GEGT) IN CHINA

Gongjian Wu (Lithosphere Research Center, CAGS, Beijing 100037, China)

GEGT is the extension, northward to the Sino-Mongolian boundary, of Yadong-Golmud Geoscience Transect (YGGT) in Qinghai-Tibetan plateau, GGT-No.3 editted by ICL and AGU. Together with the YGGT, it forms a nearly 2400 km long interior continental transect in China and in connection with Indian Geoscience Transect in the south, Mongolian-Siberian Geoscience Transect in the north. From south to north it goes through three orogenic belts: Kulun orogenic belt, Qilian belt and Beishan belt, two basins: Qaidam basin and Corridor basin.

Using reflection and refraction seismic, earthquake, geomagnetic, gravity, heat flow, remote sensing and MT investigations, and combining geological and paleomagnetic information, we devided GEGT into 7 terrances bounded by 6 fault zones. Seismic investigation shows that depth of Moho in GEGT is 40-60km, dipping southward. the Moho of the basins along the two sides of the Qilian orogenic belt is shallower. A low-velocity layer exists generally in the crust, 16-22km deep, 10-14 km thick. MT data suggest that the electrical lithosphere is 145-160 km thick, and the heat flow data also show in Qilian orogenic belt the structure of "thick crust - thin lithospheric mantle" and "hot crust - hot lithospheric mantle". The north part of Qilian orogenic belt overthrusts northward and is guessed to be a form of "bottle neck". Thickening and uplift of the crust have been caused by compression due to northward movement of the Indian plat and southward movement of the Siberian plate. Qilian orogenic belt is probably in a "front" position between the two plates. The work of GEGT is continued.



15.20

## GENTLY N-DIPPING MEDIAN TECTONIC LINE (MTL) TRANSFORMED INTO THE DEEP-SEATED SUBHORIZONTAL DETACHMENT, JAPAN

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MTL is the most striking fault in Japan, which is running from southwest to central Japan. The total length of its trace exceeds 1,000km. It is world-widely famous, because (1) it jaxtaposed the high-P/T Sambagawa with the low-P/T Ryoke metamorphic belts in Late Cretaceous (Paleogene?), and (2)its western segment is still active in a right-lateral motion. In spite of its significance, its deep-seated structure was not clear. The attitude of MTL fault plane had been believed to be vertical for a long time, only based on its nearly straight trace. This vague, but traditional thought on MTL has been completely defeated by the recent seismic reflection studies of MTL (Yoshikawa et al., 1987; Yusa et al., 1992; Ito et al., 1993, 1994). The studies have revealed that (1)MTL fault plane is not vertical, but gently (at about 30-40 degrees) dips northward. (2) It must transform into the deep-seated subhorizontal detachment. (3)The active MTL which is almost vertical is a near-surface short-cut fault branching off from the N-dipping MTL associated with a present right-lateral strike-slip motion. The slab, the hanging wall of MTL, which was originally formed by the low-angle thrusting along MTL, is now moving nearly parallel to the strike of MTL in a fault-reactivation process.

## 16 September

### 8.30 FAULTING AND FOLDING; FACT AND FICTION

Meissner, Institut für Geophysik, Kiel-University, Germany

Faulting and folding in the lithosphere are reactions to global, regional, or local stresses. Rheological and mechanical conditions, either locally along faults or more regionally along lithospheric structures, determine the mechanism of stress accumulation and stress release. Temperature, creep rate, pore pressure, lithospheric and grain size, are the most important boundary conditions for producing the many features of observable faults and folds. Most sediments show brittle behaviour with strongly reduced viscosity and impedance along faults; but also ductile behaviour of young and weak sediments is observed. The upper crystalline crust is the home of brittle behaviour and widespread seismicity, mostly along faults, observable by reflection seismics down to the lower continental crust. Here, ductile behaviour without seismicity dominates, sometimes folding can be recognized. Based on rheological arguments shear faults are not possible in the ductile lower crust and so far have never been observed. Thrust with oceanic or strain-hardened material however, are rheologically possible and are observed in suture zones. The uppermost mantle may occasionally act again in a brittle way, showing faults and seismicity. Various suggestions for mapping faults have been made, many of them violating elementary rheological conditions, none of them matching the direct confirmation of faults by seismic reflections.

### 9.00 SEISMIC VELOCITIES FROM HETEROGENEOUS CRUST

John Brittan and Mike Warner, Department of Geology, Imperial College, London, England, SW7 2BP.

Deep near-normal-incidence seismic data recorded during the past decade suggest a widely-varying and highly-complex pattern of lower-crustal heterogeneity. Many wide-angle seismic experiments performed over such crust have attempted to constrain lower-crustal seismic velocity and thus composition. It is therefore important to investigate the effect of crustal heterogeneity upon the seismic velocities measured from such experiments. Lower crusts with similar compositions but arranged in different structures have been modelled. Our results suggest that the velocities measured by a surface observer may depend significantly upon the geometrical arrangement of the heterogeneities.

Heterogeneity can bias velocities to both high and low values. For example: a lower crust composed of thick (i.e., width > seismic wavelength) layers with random high and low velocity materials will appear to have a significantly faster seismic velocity than one comprised of a homogenous mixture of the two materials; whereas a lower crust composed of thin layers can lead to significantly lower, measured seismic velocities. The effects of layered sequences on seismic velocities may be particularly relevant in areas where crust has been formed by the underplating and intrusion of melts. The presence of heterogeneity and an accurate compilation of mineral elasticity data can be used to reconcile seismic velocities measured on volcanic continental margins with petrological models of melting in the mantle.



## 16 September

### 9.20 SEISMIC INTERPRETATION AND MODELLING IN THE WESTERN SWISS PS USING VELOCITY AND DENSITY LABORATORY MEASUREMENTS.

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S. Sellami, J.-J. Wagner (Laboratoire de Pétrophysique, Dpt. de Minéralogie, Université de Genève, Genève 4, Switzerland CH-1211)
J.-L. Epard and H. Masson (Institut de Géologie, Université de Lausanne, Lausanne, Switzerland CH-1015)

We have used measurements of P-wave velocities and densities on rock samples to help the interpretation of NFP/PNR20 line W1 located in a structural depression in the western Swiss Alps. The samples were collected up-dip from the different geologic units crossed by the seismic profile. Three mutually perpendicular cores were drilled in each block of rocks and the velocities were measured in the three directions. The measurements were done at room temperature and, for the velocities, under confining pressures up to 400 MPa, which corresponds approximately to lithostatic pressure at 12 km depth. We performed a reflectivity analysis by computing the normal incidence reflection coefficients for the lithologic boundaries expected to be imaged beneath the seismic profile, using average velocities at 300 MPa, where the velocities tend to asymptotic values. This "quick" evaluation was sufficient to provide a scale for the analysis of most of the reflections observed. However the interpretation of a prominent reflection at the southern end of the section was controversial due to alternative projections of surface geology. We therefore applied a "preserved amplitude" processing sequence to analyse the strength of the reflections in this area and we performed a more detailed reflectivity analysis which took into account velocity anisotropy and variations with pressure. The correlation of the reflectivity analysis with the strength of the observed reflections allowed the identification of the probable stratigraphic sequence responsible for the prominent reflection. Massive limestone embedded in shaly layers can be the source of very strong reflections, depending on the orientation of the shales which are highly anisotropic. The reflection coefficient of the shale/limestone boundary, can be as high as 0.2.

We propose a 2-D model whose seismic response shows reflection patterns very similar to the observed ones.

### 9.40 VELOCITY EXTRAPOLATIONS FROM HAND SAMPLE TO DEEP SEISMIC REFLECTION PROFILES

Adam Law and Dave Snyder (BIRPS, Bullard Laboratories, Madingley Road, Cambridge CB3 0EZ, UK)

Traditionally velocity models used to create synthetic seismograms are compiled from laboratory measurements of the propagation of high frequency seismic energy through rock core samples at large confining pressures. The high pressures are required to avoid the effects of weathering or rock fracture near the surface, but the change in scale and interogating frequencies between these laboratory measurements and regional seismic profiling makes extrapolations tenuous. This problem has been addressed in a field area along the coast of central Sweden containing a well-studied mylonite zone, the Singö shear zone. Hand samples were collected across the zone, high-pressure velocities were determined in the laboratory, and point counts were made of the rock mineralogy with which to estimate velocities by averaging individual grain velocities. The resulting velocities showed similar trends across the shear zone and agreed to within 10%. In situ velocity measurements were made on two scales using field ultrasonic and shallow refraction equipment, the former using 54 kHz frequency, the latter 300–350 Hz frequencies. Although the ultrasonic field measurements apparently recorded S-wave arrivals, these can be correlated with S-wave measurements made in the lab to provide a study of velocity on scales ranging from 1 cm cores to 2 m outcrops to 50 m refraction spreads to tens of kilometres of crust sampled by the main BABEL experiment using offsets of 100–600,000 m. At all scales, velocities were observed to increase within the shear zone and correlated with an increase in mafic mineral content. The composite thickness of the mylonitized zone is ~300 m and could successfully modelled to produce reflections observed on the BABEL seismic sections.

16 September

10.30 EXTRACTING MORE INFORMATION FROM DEEP SEISMIC DATA

C. A. Hurich (Earth Science Dept. Memorial Univesrity, St.John's, Newfoundland, Canada, A1B 3X5)

Seismic reflection data have provided a wealth of information on the tectonic architecture of the continents but much of the potential information content of the data is yet to be exploited because of our lack of understanding of the physics of the complex reflection wavefields and the lack of a methodology to analyse the wavefield. Several workers have recently demonstrated that the reflection wavefield may often be dominated by scattering rather than specular reflection. Scattering theory for heterogeneous media suggests that the scattered wavefield is best understood in the form of a statistical description. On the other hand, it is imperative to derive information from the wavefield in a form that can be directly related to the geology. Our approach to investigating the properties of complex reflection wavefileds is presently focused on generation of large numbers of seismic models and statistical description of the the synthetic seismograms. The objective of the modeling is to identify and calibrate parameters of the wavefield that correlate with the original model and provide useful geologic information. Initial results of our experiments suggest that the reflection wavefield can be decomposed into subsets dominated by either scattered components or specular components that may carry separate and complimentary geologic information.

10.50 SYNTHESIZING 2D FD SEISMIC WAVE PROPAGATION IN HETEROGENEOUS LITHOSPHERE

E.S. Husebye (Institute of Solid Earth Physics, Allégaten 41, Bergen, Norway)
S.O. Hestholm (Institute of Solid Earth Physics, Allégaten 41, Bergen, Norway)
B.O. Ruud (Institute of Solid Earth Physics, Allégaten 41, Bergen, Norway)

A description is given of the numerical finite difference (FD) scheme used to solve the elastodynamic wave equation, including a few remarks on the source functions used. Our FD method has been used for computing synthetic seismograms for 2-D crust/upper mantle models of size 150x400 $km^2$, with options for free-surface topography. The strategy was to introduce successively more complex lithosphere models for generating the synthetics: the reference model was a laterally homogeneous lithosphere. The interface scattering was visualized through displays of synthetic waveforms and snapshots for models with a corrugated Moho only and free surface topography only. Near the free surface the latter seems to dominate, in the form of P-to-Rg and S-to-Rg conversions. Lithosphere randomizations were introduced through von Karman functions of order $\nu = 0.3$, with rms velocity fluctuations of 3-4 per cent and correlation distances (horizontal and vertical) at 2.5 and/or 10 $km$. In case of a medium of only sub-Moho heterogeneities, those with horizontal anisotropy ($a_x = 10$ $km$; $a_z = 2.5$ $km$) produced relatively strong Pn and Sn phases. For full scale lithosphere models, characteristic features of the synthetics were qualitative similar to observational records of local events. Dominant attributes were a pronounced P coda consisting mainly of P- and Rg-scattered wavelets, and a relatively strong S coda consisting mainly of P-to-S and S-to-S scattered wavelets. The P and S waveforms are severely distorted pointing to the futility of reliably picking secondary arrivals in profiling and local event recordings. The above schemes are now being adapted to mimic reflection profiling surveys with an option for ProMax data processing.

16 September

11.10 GLOBAL OPTIMIZATION IN 3D REFLECTION SEISMICS

L. Engell-Sørensen, G. Ryzhikov and M. Biryulina (Institute of Solid Earth Physics, University of Bergen, Bergen N-5007, Norway)

In order to recover the velocity in nonhomogeneous media Global Optimization (GO) of the seismogram agreement is applied. Compared to the wavelength low and high spatial frequencies are represented by the background model and the laterally slowly varying reflecting boundary, respectively. The purpose of this work is to solve the high and low frequency problem simultaneously.

The GO algorithms used for inverting the reflection seismic data in 3D do not need other information than the seismic data (e.g. *a priori*). The algorithms allow localization of the problem, and hence to use data corresponding to this location only.

The main purpose of this work is to apply the object function: Entrophy of Image Contrast (EnIC) and analyse GO by the use of GA and Simulated Annealing (SA). EnIC assumes that the reflection response is generated by objects which are located in space.

The image is obtained by a 3D-linear inversion algorithm, which corresponds to full-waveform inversion. For global optimization is was necessary to use GA and SA applied on simplified models. This first approach gives the opportunity to deal with 3D velocity analysis and gives the first step of the reconstruction of a real image by comparing the sharp boundaries in a recovered difference object (a 2D manyfold in a 3D medium).

Future approaches would be to include *a priori* information about the geometric structure or lithology, angle dependence of the response, both Kirchoff-type and Born formalism in the linear inversion, and the second time-derivative in the Born inversion. Also the problem of a subsurface and not a subreflector must be treated in the future.

11.30 CRUSTAL REFLECTIVITY – THE DENSITY CONNECTION

B. Milkereit, M. Salisbury and D. Eaton (Geological Survey of Canada, Canada K1A 0Y3)

Groundtruth or physical testing of seismic images is an important element of the validation of results from earth science investigations. Such tests can be achieved through deep "boreholes of opportunity" and comprehensive physical rock property studies. During the past decades, the acquisition of crustal seismic reflection data has led to considerable speculation and controversy about the origin of crustal reflectivity. Seismic reflections occur at changes in compressional and shear wave velocity, velocity anisotropy and/or density. Documented sources of such changes include intrusive and compositional layering, detachment surfaces of various types, magmas, mylonites, cataclastic zones, fluid-filled fractures, and porosity changes. The most important factor controlling the magnitude of seismic reflections is impedance, the product of density and compressional wave velocity. In the past, very little attention has been paid to the presence of high density mineralization in the crystaline crust. High density minerals, such as magnetite, exhibit high seismic impedance values and in contact with most crustal rocks could yield normal incidence reflection coefficients of 0.15 to 0.2. We will review the results from laboratory physical rock property studies, integrated seismic and borehole geophysical surveys, and 3D forward modeling. The physical rock property studies are important for the development and application of seismic profiling techniques for mineral exploration. On a larger scale, the abundance of high density/magnetic susceptibility minerals in the crystalline crust may hold the key for a better correlation of seismic reflectors and prominent magnetic and gravity anomalies.

16 September

11.50

## Modelling the Crust and Upper Mantle Reflections of Northern Scotland

Peter Morgan and Penny Barton (Bullard Labs, Cambridge, U.K.)
Mike Warner and Kevin Jones (Imperial College, London, U.K.)
Jo Morgan, and Claire Price (Kingston University, U.K.)

The crust of off-shore northern Scotland is well-known from many BIRPS deep re-
flection surveys such as DRUM and SLAVE. These lines also show reflectors in the
mantle, known as the Flannan and W-reflectors. We present results from a marine
refraction experiment, shot off northern Scotland in June 1992, in which data from
zero offset to wide-angle were collected with a mid-point about the W-reflector, a
bright sub-horizontal mantle reflector. This is the first experiment to collect coin-
cident normal incidence reflections, wide-angle reflections and refractions from this
feature.

A crustal model, including Moho topography, has been derived for the region.
Detailed modelling of wide-angle reflection amplitudes show that the W-reflector is a
positive impedance feature in the mantle at 45 km depth. Knowing the polarity and
high impedance contrast of this reflector indicates a layer of high velocity material,
probably eclogite, in peridotite mantle.

14.00

## NATURE OF SEISMIC REFLECTIONS AND VELOCITIES FROM VSP-EXPERIMENTS AND BOREHOLE MEASUREMENTS AT THE KTB-DEEP DRILLING SITE IN SE-GERMANY

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The 1989 VSP program at the KTB Pilot Hole (0-3600 m, KTB-ISO89) was complemented in 1992 by
a standard VSP (zero-offset, vibrator source, 8-123 Hz, 12.5 m 3-component receiver spacing) in the
Main Hole from 3600 to 6000 m. P-wave velocities oscillate around 6 km/s in the upper 3200 m in
accordance with sonic log velocities and correlate with paragneisses which prevail in this depth range.
At about 3200 m depth velocities increase to 6.4 km/s correlating with metabasites which dominate in
the depth range 3200 to 7500 m (below 7500 m : paragneisses). Pronounced P-wave reflections,
accompanied by P- to S-wave conversions and a lack of S-wave reflections, occur in the lower depth
range only (3000-6000 m) and correlate with fluid-filled fracture systems, rather than with lithological
contrasts (gneiss-amphibolite). Subvertical dip (50-70°) in structures and textures prevails down to the
maximum depth of 8730 m, causing about 10 % S-wave anisotropy as an average, indicated by direct
observations of S-wave splitting. Lithological and depth predictions ahead of the drillbit (P-wave
reflections and missing S-wave reflections at 8.3 km, fracture zone, anisotropy or composition effects ?)
are being tested by recent borehole measurements.



14.20

## KTB - THE CRUSTAL STRUCTURE OF A VARISCAN TERRANE BOUNDARY: SEISMIC INVESTIGATION - DRILLING - MODELS

G. HIRSCHMANN (Geological Survey of Lower Saxony, Stilleweg 2, D-30655 Hannover, Germany)

One of the principal scientific targets of the German Continental Deep Drilling Program (KTB) is to investigate the architecture of a Variscan collision zone. The location at the western edge of the Bohemian Massif is characterized by the juxtaposition of three terranes involved in the Variscan collision (Saxothuringicum, Moldanubicum, Bohemicum). According to the geological and seismic pre-site investigation it had been expected to drill through a MP-metamorphic nappe unit (Zone Erbendorf-Vohenstrauss - ZEV) into the cryptic suture characterized by large-scale underthrusting of the Saxothuringian under the Moldanubian units. The geological results of the KTB Hauptbohrung are contradictory to this initial structural model. The improved processing of 2D-seismic data, and the results of a 3D-seismic survey and of a wide-angle experiment (Integrated Seismics Oberpfalz 1989) supplied further valuable structural information. The following conclusions may be drawn: (1) The ZEV is a deep reaching and steeply inclined MP-metamorphic unit implanted into the boundary zone between the LP-metamorphic Moldanubian und Saxothuringian units. Probably it is in connection with the highly reflective, high velocity "Erbendorf Body" in the middle crust. (2) The ZEV is derived from subducted parts of the Bohemicum. (3) The emplacement of the ZEV in the upper crust can be explained rather by upthrusting of subducted Bohemicum in a transpressional system (parautochthonous model) than by intracrustal nappe transport and stacking (modified allochthonous model). (4) A steeply dipping lower crustal reflector may represent the actual terrane boundary. (5) Major seismic reflections of the upper crust are caused by late- and post-Variscan fault zones at the western boundary of the Bohemian Massif.

14.40

## DETAILED STRUCTURE OF THE UPPER CRUST FROM BOREHOLE DATA

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Wilfried Albert, Philip Birkhäuser, Peter Blümling (NAGRA, 5430 Wettingen, Switzerland)
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High-resolution seismic probing of the upper crystalline crust has shown considerable potential for
environmental, engineering, and mining applications. For the interpretation of deterministic features
targeted, such as lithological boundaries and fault zones, some *a priori* knowledge of the small-scale
stochastic heterogeneity, which is primarily responsible for the scattered seismic "background noise", is
critical. Borehole data provide detailed 1-dimensional *in situ* information on the elastic properties of the
upper crystalline crust at a scale ranging from less than one meter up to several kilometres. This
information, combined with site-specific seismic and geological data and existing generic models of
crustal heterogeneity, is valuable for the planning and interpretation of high-resolution seismic surveys
of the upper crystalline crust. We present results from the stochastic analysis of sonic and density
borehole measurements from northern Switzerland, from the German deep drill site (KTB) in south-
eastern Germany, and from the north range of the Sudbury impact structure in Canada. The boreholes in
northern Switzerland and south-eastern Germany penetrate Variscan basement consisting of granites
and gneisses of variable composition, whereas the Canadian data sample layered mafic intrusion and
impact breccias of early Proterozoic age. Lithological control within the borehole and surface seismic
measurements are available for all datasets. Preliminary results suggest that despite significant
differences in age and geological setting there are some notable similarities between the datasets: after
removing the deterministic large-scale trend, the stochastic small-scale seismic heterogeneity of all
datasets can be characterised by autocovariance functions/power spectra corresponding to bandlimited
fractal (von Karman) media with quasi-Gaussian probability density functions. The purpose of this
paper is to discuss these new results in light of existing models of the seismic structure of the upper
continental crust, and to evaluate implications for seismic exploration.

15.00

## VERTICAL SEISMIC PROFILE RESULTS FROM THE KOLA SUPERDEEP BOREHOLE, RUSSIA

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During the spring of 1992, Vertical Seismic Profiles (VSP's) were collected in the Kola Superdeep
Borehole as part of a larger seismic study of the Kola region. The VSP data provides insight into the
seismic wavefield, calibration for the surface seismic studies, and a more reliable basis for interpreting
anisotropic effects. The multicomponent VSP's were recorded from 2.1 km to 6.0 km and the surface to
500 m in the Superdeep Borehole and a nearby satellite borehole respectively. The 1992 VSP's are
sampling the Proterozoic Pechenga complex. The Pechenga complex consists of alternating
metasedimentary and metavolcanic layers that range from greenschist to amphibolite grade facies, dip 20-
50 degrees to the southwest, and contain a shear zone at 4.5 km. The structure and lithology provide a
complex seismic wavefield response that is recorded on the VSP's. The Kola VSP's display: 1. abundant
transmitted and reflected mode converted energy, 2. P and S-wave reflections from lithologic and
structural boundaries, 3. fracture and mineral fabric induced seismic anisotropy at the near surface and
deeper in the Superdeep borehole. Seismic boundaries are defined by reflected primary phases, reflected
converted phases, and transmitted conversions. The mode conversions are seen at vertical incidence due
to the dip of the Pechenga sequence. Forward modeling and P-S separation filtering were implemented to
aid in phase identification due to the interference of all these phases. Near surface (< 500 m) velocity
anisotropy is detected by the direct P and S-waves with the fast direction roughly N 30 E which is
constrained by surface strike measurements of mafic dikes. Notable polarization changes, in the vertically
incident direct shear wave, correspond to mapped shear zones in the borehole indicative of mineral fabric
anisotropy. Due to 15 seconds of recording, deeper reflection events are detected. This includes an event
from Moho depths. The Kola VSP data gives a view into the nature of seismic wave propagation in
Precambrian crust that can be used with both past and present seismic investigations in crystalline terrains.

15.50

## MODEL OF THE EARTH'S CRUST OF THE NORTH OF ALGERIA BASED ON THE DATA OF COMPLEX GEOPHYSICAL INVESTIGATION.

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The North of Algeria, like other sectors of the western mediterranean region has significant quaternary tectonic mouvement. Several desctructive earthquakes take place in this erea. This seismic activity in due to collision movement of the african plate with the europian plate.

We have established a model of this seismoactive block earth layers of the north of Algeria by the complex interpretation of seismic and the potentiel methods data.

This model has permitted to define different blocks of the crust earth layers, the repartition of seismogenic faults delimiting the blocks and participing in the seismic process.

The most active fault is that of El Asnam which has happened on october 10,1980 ($M_s$=7,3) the powerfull earthquake never recorded in the western mediterranean region.

This model, allow describle the seismogenic process and evaluate the seismic risk and better understand the physical process of seismic sources.



16.10

## SEISMIC ANISOTROPY OBSERVED DURING THE PROCESS OF DEFORMATION AND FAILURE OF LARGE SCALE ROCK BLOCKS.

K.BADDARI ( Lab. of Physics of the Earth INH , Boumerdes , Algeria )
A.D FROLOV ( RGGU , Moscow )

Seismic anisotropy in deformed rock massif reflects one of the
principal properties of the medium - the existence of some order in
it . This order is differently reflected in seismic wave field .
We have studied the evolution of seismiv anisotropy during the
deformation and destruction of large rock samples under various
thermodynamic conditions. It has been found that the average velocity
increases in a nonlinear manner from the load of about 0.45 - 0.5 to
that of failure . The velocity then decresed , this being due to a
developing dilatancy . At the time , dispersion of the velocities has
significantly incresead begining from about 0.8 - 0.85 load to
that of failure .
To evaluate the evolution of velocity in homogeneities in the bloc
, it was partitioned into elemenyary volumes . An analysis shown
that seismic anisotropy increases before the main rupture . The
peak of the increase coinciding with the dynamic propagation of
rupture . On the character of the seismic anisotropy evolution ,
the rock block is divided in the zones of the incrased and decreased
danger of the brittle failure .
The seismic anisotropy provide information about the physical
process in the stress strained rock and may help in solution of
reveling the early stages of fracturing and predicting catastrophic
phenomena ( earthquake , rock burst , carry collapses etc ... )

16.30

## INTERPRETATION AND SEISMIC MODELING OF THE VARISCAN FORELAND THRUST AND FOLD BELT (NW SPAIN) FROM ESCIN-1 DEEP SEISMIC REFLECTION DATA

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The ESCIN-1 deep seismic reflection profile has provided a good seismic image of the foreland thrust
and fold belt (Cantabrian Zone) of the Variscan Belt in NW Spain and the transition to the hinterland
(Westasturian-leonese Zone). This area has been the focus of much geological study for a long time and a
high degree of knowledge has been achieved about its surface geology, complemented by data obtained
from ESCIN-1 and various high-density wide angle data sets. Two different zones can be seen in the first
12 seconds (TWT) of the unmigrated line. A moderately reflective to highly reflective upper zone of
materials deformed during the Variscan Orogeny and a lower, almost transparent, undeformed basement.
Both areas are bounded by a slightly west-dipping, higly reflective band of discontinuous reflectors which
lies at 5 sec. (TWT) in the easternmost part and 6 seconds in the transition to the hinterland. This band
increases its dip and reaches 9 sec. (TWT) in the westernmost part of the line. It has been interpreted as
the basal decollement surface of the Variscan Foreland Trust and Fold Belt in this area. The interpretation
and seismic modeling of the reflective interface between the cover and the basement was made
integrating available geological and geophysical data: velocity data from refraction and wide angle,
reflection seismic data from ESCIN-1 and the surface geology. All this data allowed us to propose a
geological model of the crust which was tested obtaining synthetic seismograms and can be correlated
with surface geology.

# POSTER PRESENTATION PROGRAM

# ABSTRACTS

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## HIGH DENSITY CRUSTAL WIDE-ANGLE REFLECTIONS IN THE PANNONIAN BASIN OF SOUTHERN HUNGARY

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High density vertical and wide-angle seismic reflection and refraction data were recorded along a 120 km long profile in a Hungarian-Canadian-Swiss cooperative project in 1992. The SW-NE oriented profile traverses the Neogene sedimentary Mako trough and Békés basin. In addition to a moving array of 195 2Hz recording instruments along the reflection profile, 14 fixed three-component 2Hz recorders were deployed at the SW and 3 at the NE end of the line at 100 m interval. 288 shots were fired in 70 m deep boreholes at 300 m interval. The shot size was 50 kg of explosives. The wide-angle data were despiked, bandpass filtered with 4 to 30 Hz, sorted according to distance from the individual station, and stacked. The stacking of traces with equal distances provided dense record sections of excellent quality with a clear difference between the compilations from twelve southwestern stations and those from three northeastern stations. First arrival phases propagating through the sediments are followed by a clear Pg phase. Nearvertical incidence reflections from the Moho are clearly visible from the shortest offset distance at 23 km and continue as wide-angle reflections to the end of the profile. Prominent secondary phases stand out at larger traveltimes as free surface multiples refracted in the high-velocity gradient zone of the sediments.

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## DEEP STRUCTURE OF THE LITHOSPHERE ALONG THE HUNGARIAN GEOTRAVERSE BETWEEN TWO SUBBASINS OF THE PANNONIAN BASIN

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In the framework of the Hungarian Geotraverse Project performed in Hungarian-Canadian-Swiss cooperation, a deep seismic profile about 100 km long was run along a trace connecting two subbasins of the Pannonian basin. The thickness of Neogene sediments in these subbasins reaches 6000 to 7000 meters. Data is being processed in parallel at the University of Saskatchewan, the Swiss Federal Institute of Technology and the Eötvös Loránd Geophysical Institute of Hungary. To render more reliable interpretation of deep structures, magnetotelluric measurements were also carried out along the seismic profile.
Presented in our paper, are the results of deep seismic processing which include signal/noise ratio improvement (f-k filtering, f-x deconvolution, weighted median trace mixing), as well as the use of various migration algorithms (Stolt f-k method, stable explicit finite-difference and steep-dip explicit finite-difference time migration and Gazdag's phase shift method).
In the course of the geological interpretation of deep structures flatly dipping surfaces reflecting the covering structure of the Battonya-Pusztaföldvár anticline, which separates the two subbasins, as well as a deep fault penetrating the whole Earth's crust under the Makó graben were detected. Magnetotelluric investigations support our assumptions that the Earth's crust is thinning out beneath the Békés basin.



## CONFLICTING DIPS AND THE TRANSPARENCY OF THE UPPER CRUST - A DEKORP 2S CASE HISTORY 1/3

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The DEKORP 2S deep reflection profile crosses the Saxthurigian and Moldanubian units of the central European Variscides in southern Germany. It has been regarded as a classical example of highly reflective lower crust overlain by a transparent upper crust. A closer inspection of single shot records, however, showed that a lot of reflected and/or diffracted arrivals are found also at travel-times corresponding to upper crustal levels. They display a complex pattern of conflicting dips and were formerly suppressed as a consequence of Common Midpoint (CMP) stacking focussing on subhorizontal arrivals. We applied the following data processing techniques in order to enhance dipping arrivals as well: CMP-stacking with high RMS-velocities, Dip Moveout (DMO), and the Common Reflecting Element (CRE) method. All these approaches were successful in creating more or less coherent reflection/diffraction images of the upper crust although the corresponding sections differ remarkably in detail. These differences are caused by different dip sensitivities of the applied methods. Even with the help of a single covered near-offset-section, a final decision on the most appropriate processing algorithm cannot be found. Nevertheless, the basic conclusion of our investigation is that the upper crust along the DEKORP 2S profile is not as transparent as it appeared to be so far. The tectonic implications of this finding are still under discussion.

## DEEP SEISMIC REFLECTION RESULTS FROM THE SW OF THE MOESIAN PLATFORM ROMANIA 1/4

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A 38 km seismic reflection line and 17 s TWT was recorded in the SW extremity of the Moesian Platform . It crosses the Vidin-Strehaia uplift and the Lom-Craiova Depression on a NW-SE direction.A reflective sedimentary cover sinks from -3 s at NW to -4 s at SE. The upper crust and the top of the lower crust are poorly reflective and show some short and subhorizontal events as well as diffractions suggesting a brittle medium.More many reflection groups extended over 3-4 km length and 1.5- 2.5 s depth intervals appear at the base of crust, between about 8-12 s, as a cruste-mantle transition zone. This transition zone could be an effect either of a possible Palaeozoic extention whom relicts was partly conserved as reflective layers or of a magmatic underplating. The whole crust shows a slightly thickening from 10.5 s (NW) to 11.5 s (SE). A few subcrustal reflections can be seen in the central part of the seismic section, maybe as a consequence of a isostatic balancing.

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## CRUSTAL IMAGE OF THE IONIAN BASIN AND ITS CALABRIAN MARGINS

R. Nicolich, M. Romanelli (DINMA, Univ. Trieste), J. Mc Bride (BIRPS, Cambridge), A. Hirn, B. de Voogd (ECORS, Paris), E. Banda (CSIC Barcelona) and STREAMERS Group.

From the Spartivento bassin off the SE coast of Calabria, two 200 km long MCS lines were recorded towards S and SE, into the Ionian basin with a large, 7200 c. i., tuned array and a 180 channels, 4.5 km long streamer. Good penetration indicates at places a thick layered sequence of sediments beneath the Messinian salt. Beneath that, existence of only a reduced thickness of crust, as inferred previously from DSS and ESP is confirmed. The crust-mantle transition is marked by a 0.5 to over 1 s TWT (i. e. up to 4 km) thick stack of monochromatic low-frequency reflections.
The long lasting comparative discussion of the Ionian with oceanic and continental crusts may now take into account not only depths and velocities but also the peculiar reflection image of the lower crust-mantle and its variation in topography suggested as a result of profiling long traverses. With the addition of wide angle land-recording of these lines and of other surveys onshore, the prolongation of Calabria can be recognized in the structures of the basement and the base of the crust above the flexed Ionian crust.

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## IONIAN BASIN INTERACTION WITH THE WESTERN HELLENIDES : A NORMAL INCIDENCE AND WIDE ANGLE REFLECTION LINE

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A line from the deep Ionian basin, through the channel between Kefallinia and Zakyntos islands and to near Missolonghi was shot with a large tuned array of 36 air guns with 7200 c. i. total source volume. It was recorded with a 180 channels, 4.5 km long streamer, as well as at variable offset by land stations on both islands and either side of the Gulf of Patras. The Ionian thrust as well as deformation within the External Hellenides are imaged into the basement by normal incidence data. Ray-tracing through this heterogeneous upper crust allows to use wide angle data to validate the section to lower crustal depth. Structural elements may be related to the overriding of the Hellenides on Ionian crust.

## THE SICILIAN MARGIN TO THE IONIAN BASIN AND MT ETNA

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L. Cernobori, R. Nicolich, M. Romanelli (DINMA Univ. Trieste), A. Hirn, M. Sachpazi (IPG Paris), F. Avedik (IFREMER, Brest) , J. Gallart (CSIC , Barcelona) and ETNASEIS Group

An array of 8 GI air guns totalling only 840 c. i. volume was directed to a rather low frequency band useful for deep penetration by using the "single bubble" method. A 96 channels streamer was used with a 24 fold coverage. Two profiles were recorded near to M[t] Etna, one along the coast an other from the Ionian deep basin to Catania.
With respect to the oceanic-like crust of the Ionian basin, the E coast of Sicily is traditionally considered as its extensional continental margin. A reference profile we recorded across the Malta escarpment south of Siracusa is in keeping with such belief but such an image does not show up on the profile reaching the vicinity of M[t] Etna,off Catania. In the shallower part of the section, tilted basement blocks can be seen, but their faults appear to be active more recently than the supposed formation of the Ionian basin. Also, at variance with the structure of continental margin formed by pure shear the crust-mantle boundary deepens seawards under the tilted blocks, in the time-section. Migration and water layer replacement will quantify the degree of crustal upwarp and advection of magmatic or mantle material.

## APPRAISAL OF A NEW LOW FREQUENCY SEISMIC PULSE GENERATING METHOD ON A DEEP SEISMIC REFLECTION PROFILE IN THE CENTRAL MEDITERRANEAN SEA

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The large tuned air gun arrays used in off-shore petroleum exploration are also the most frequently employed seismic sources for executing deep crust-mantle surveys. However, the signal output of these arrays is reduced to about 1/5 of its original value on the 0-256 Hz frequency band when we consider only the 10-40 Hz frequency band which is relevant to deep seismic surveys. To try improve on this, a low frequency seismic pulse generating method was developed within the Ifremer Earth Science Group.
The standard tuned air gun array output produces a bubble-pulse-free signal centred on the primary pulse. Considering that the first bubble pulse contains the major portion of the low-frequency acoustic energy present in the gun's pressure signature, the new method concentrates the array's output on the first bubble pulse instead of on the primary pulse and in addition cancels the following bubble pulses
In 1993, part of the STREAMERS international deep seismic profiling programme sponsored by the European Community was executed in the Aegean sea using an academic research vessel and a "single bubble" air gun array. The array, composed of 8 GI air guns had a total, generator plus injector, volume of 23.3 l (1425 cubic inches).The air pressure for the guns was 1.5 MPa ( 2100 p.s.i.). The tow depth of the streamer and that of the gun array were kept closely identical at approximately 20 meters.
In order to evaluate the performance of the new method, we re-shot a profile previously run in 1992 during an earlier part of the STREAMERS programme, in the Western Ionian sea by a commercial seismic vessel equipped with a large, 36 guns, 117 l (7118 cubic inches) tuned air gun array. Results of the comparison will be presented

## 1/9 A CRUSTAL SECTION ACROSS SARDINIA CONTINENTAL MARGIN, SOUTHERN TYRRHENIAN SEA.

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We present a crustal section derived from a multichannel seismic reflection line shot offshore eastern Sardinia. This line was acquired during 1989 by R/V OGS Explora using a sound source produced by 32 air guns (total 80 lt) and a 120 channels, 3.0 km long, receiving streamer with 25m group interval and record length of 14s. The section is oriented NW-SE across the Western Tyrrhenian passive margin developed, since Miocene time, as an extensional area back of Appennine and Calabrian arc. The seismic line shows evidence of an intracrustal detachment horizon above which brittle deformation accommodated stretching during rifting of the Tyrrhenian basin. This deformation is expressed by a major listric normal fault which produced an asymmetric graben; evidences of normal and reverse faults are detected at the hangingwall rollover anticline. Moving SE, toward more thinned and stretched crust, a deeper reflector that rise from 8 to 6s, marks an abrupt change in the amount of extension of the continental crust.

## 1/10 THE IBERIA-WESTERN MEDITERRANEAN CONTINENT-OCEAN TRANSITION REVEALED BY COMPOSITE STEEP AND WIDE-ANGLE REFLECTION SEISMIC SECTIONS

N. Vidal, J. Gallart and J.J. Dañobeitia (Institute of Earth Sciences-CSIC, Barcelona, Spain)

Seismic reflection profilings of the ESCI experiment at the Iberia-Western Mediterranean transition were designed to image the structural features at depth in an area affected by successive compressional and extensional tectonics since Cenozoic times. The ECORS and ESCI profiles altogether provide a 700 km-long crustal transect mapping the lateral evolution between a thickened continental crust (Pyrenees), a thinned continental crust (Valencia trough) and an oceanic-type crust (South Balearic basin). Strong crustal depth variations associated with the onshore/offshore transition could not be resolved from the near-vertical land and marine sections but from dense-spaced wide-angle data, due to more favourable Moho-energy returns and sampling offsets involved. A thorough processing of the wide-angle data in terms of conventional reflection seismics leads to composite steep and large aperture stacked and migrated sections revealing a strong but continuous thinning of the crust. In the Catalan and Balearic flanks of the Valencia trough, a thinning of at least 10 km in the lower crust takes place in around 30 km horizontal distances. A significant change in the reflectivity pattern is observed in the South Balearic basin.

## SEISMIC IMAGE OF THE CANTABRIAN MOUNTAINS UPLIFT IN THE WESTERN ENDING OF THE PYRENEAN BELT FROM INTEGRATED ESCI-N REFLECTION AND REFRACTION DATA 1/11

J.A. Pulgar and J. Alvarez-Marrón (Dep. Geología, Universidad de Oviedo, Spain), J. Gallart, G. Fernández and A. Pérez-Estaún (Inst. Earth Sciences-CSIC, Barcelona, Spain), D. Córdoba (Dep. Geofísica, Universidad Complutense, Madrid, Spain) and ESCI-N Group.

The seismic signature and lateral variations of the crust across the Cantabrian Mountains (N Spain) are examined on a N-S crustal transect lying around the highest topographic elevations. The Cantabrian Mountains constitute the western extension of the Pyrenees and are formed by Paleozoic basement uplifted during the Alpine orogeny over the Cenozoic Duero basin. An Alpine reworking and thickening of the Variscan crust is supported from different seismic data sets. The 65 km-long ESCIN-2 steep reflection profile, between the Duero basin and the Cantabrian zone (foreland of the Variscan chain), displays a northward-dipping crustal reflectivity pattern. The Moho is clearly identified at the bottom of the reflective lower crust, and deepens from 11 to 15 s TWT at the northern end of the profile, about 30 km inland. Crustal velocities are constrained by a 200 km-long reversed refraction profile from explosive sources at both ends, which confirms the thickening of the crust beneath the Picos de Europa unit, where the Moho depth reaches almost 50 km. The thick crust is characterized, on average, by velocities lower than those on the Variscan domain westwards. The Moho at the continent-ocean transition is revealed on a stacked section after multichannel processing of the piggy-back wide-angle recordings on land of the marine ESCIN-4 profile. The section covers 15 km inland and 60 km seawards, and shows a continuous, moderate thinning of the crust northward, along the Cantabrian platform.

## DOES THE GREAT GLEN STRIKE-SLIP FAULT REALLY OFFSET LOWER CRUSTAL AND UPPER MANTLE STRUCTURE? 1/12

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Previous interpretations of deep seismic reflection profiles across the Great Glen fault system have postulated that the fault penetrates the crust and upper mantle as a vertical plane that offsets the Moho discontinuity. This interpretation has become a general feature of regional syntheses of the deep geology of the British Isles. Reprocessing of portions of several profiles across the fault improves the resolution of lower crustal and upper mantle structure and calls into question the "Moho step" interpretation. Diffraction analysis and experimentation with migration applied to reflection data north of Shetland across the northward continuation of the Great Glen fault (Walls Boundary fault) indicate a narrow synform or 'keel' developed on the Moho directly beneath the fault. North and west of Ireland, analyses of amplitudes, frequencies, and the geometrical behavior of reflections upon migration show that structures previously interpreted as Moho steps may be better explained as distinct packages of reflectivity that are uppermost mantle in origin. In one location north of Ireland where three-dimensional control exists, the vertical downward projection of the Great Glen fault intersects, without disrupting, dipping structure in the upper mantle. This observation leads to a model for displacement on the fault system in which motion is laterally transferred along a dipping ramp (or blind thrust) in the uppermost mantle, analogous to models developed for the San Andreas fault that indicate displacement along the fault to be laterally offset within the middle crust. One of the principal conclusions of this study—that major vertical steps on the Moho beneath the Great Glen fault is difficult to support from the available seismic data—is consistent with rheologically based studies which predict that Moho 'topography' such as vertical steps is unlikely to be preserved over long periods of geologic time.

## 1/13 CRUSTAL VELOCITY STRUCTURE OFF THE NORTH EAST COAST OF ENGLAND FROM WIDE-ANGLE MULTI-CHANNEL SEISMIC DATA

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Results of the inversion and modelling of an expanding spread profile are presented. The ESP data were collected as just one component of the BIRPS Seismic Wide Angle Broadband Survey, an experiment designed to yield information on physical properties of the continental crust off the North East coast of England.
One dimensional waveform inversion has been performed on the first arrivals of the dataset, turning rays sampling the crust to a depth of approximately 20km. A genetic algorithm has been used to tackle the non-linear global optimisation problem. The algorithm rapidly samples the model space of interest and, in conjunction with a graph binning technique, determines the posterior probability distribution of each parameter within the model space. This allows a quantification of errors associated with velocity down to the top of the lower crust.
The velocity structure of the remainder of the continental crust is recovered by a combination of forward modelling and inversion. Features of this one-dimensional velocity-depth profile are tied in with reflecting events observed on the coincident deep reflection profile.

## 1/14 SEISMIC REFLECTION IMAGES OF DEEP BASEMENT DEFORMATION BENEATH THE CALEDONIAN FORELAND IN THE CENTRAL SCANDES

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A recently acquired, more than 160 km long, continuous seismic reflection profile across the Caledonian
terrain in Jämtland is presented. It runs eastwards from the national border between Norway and Sweden
and ends in the Svecofennian domain, about 20 km beyond the Caledonian thrust front.
The data provide excellent images of the structures in the upper crust, where Caledonian nappe
geometry can be easily correlated with the geological mapping. Below the nappes, the structures are
dominated by alternating antiformal stacks of deformed crystalline crust and areas of less deformed crust.
The seismic section shows that the crustal thickening at these stacks is of an order that implies that the
underlying middle crust has been deformed. Antiformal stacks can be found all the way out to the
Caledonian front even though their magnitudes diminish to the east. With a model in which these stacks
form progressively during the Caledonian deformation, it is possible to explain several observed
characteristics of the Caledonian nappes, e.g. the existence of both thrusts and extensional deformation.
Beneath the Caledonian thrust front, a change of style of structure and deformation is observed to occur
across a prominent, deeply based antiformal structure in the basement, - probably of pre-Caledonian
(Precambrian) origin.
Clear reflections from the lower crust and Moho are very sparse on the vertical incidence data, but are
well recorded at wider angles, as can be seen in the data from some far offset experiments, carried out in
connection to the seismic reflection field campaign.

## A SEISMIC REFLECTION (CDP) TRANSECT OF THE MIDDLE URALS, CENTRAL RUSSIA 1/15

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Reprocessing of existing data (Chernoistochinskii, Alapaevskii, and Aramashevskii profiles), combined
with the first deep CDP reflection data (ESRU Profile) from the Urals, provides an ~190-km transect of
the crust in the Middle Urals of central Russia. Major features of the shallow crust include, from W to E:
(1) a foreland fold-thrust belt characterized by a steep frontal ramp (centered beneath the axis of the
regional Kvarkush anticline) and a deep (>10 km), basement-involved(?) detachment, (2) the steeply E-
dipping Main Uralian fault (MUF; suture zone), (3) a series of large-scale antiforms and associated W-
dipping (E-vergent?) shear zones in the Uralian hinterland that appear to be truncated at depth by (4) a
zone of sub-horizontal reflectivity (5-8 sec. TWTT), which we interpret as a mid-crustal detachment
within the hinterland of the Urals, and (5) a major, high-angle strike-slip fault (the Febralski fault) in the
eastern Urals, identified by correlation of the seismic data with surface geology. The geometric, and
accordingly kinematic, relationships of the MUF with both the foreland and hinterland zones of
detachment remain unclear on the basis of these data. The MUF *may* truncate the foreland detachment at
the latitude of the ESRU profile, and appears to penetrate to mid-crustal depths (minimum of 22 km) at a
steep (45°E), essentially constant (i.e. non-listric) dip on the basis of the Chernoistochinskii-Alapaevskii
profiles. From these relationships, we conclude that the East European basement extends a minimum of
25 km in the subsurface to the E of the exposed trace of the MUF, and probably constitutes the material
which makes up the pronounced crustal root in the Urals beneath the Tagil zone. Truncation of
detachment surfaces in both the foreland and hinterland may provide evidence for late-stage (normal?)
displacement on the MUF. Overlap along strike of the ESRU and Chernoistochinskii profiles provides
3-D control on the geometry of the foreland detachment and the Tagil island-arc terrane. The foreland
detachment shallows to the S, attains a more pronounced eastward dip, and appears to merge with the
MUF. The Tagil zone, which narrows considerably to the S, appears also to thin dramatically above the
W-dipping Serov-Mauk fault. An image of deep crustal structure, based on distribution of lower-crustal
reflectivity, is limited to the ESRU profile and may be interpreted as evidence for either (1) W-vergent
imbrication of the Moho and lower crust, or (2) intercalation of East European and island-arc crust of the
Tagil zone (Juhlin et al 1994).

## PRELIMINARY RESULTS OF DEEP SEISMIC REFLECTION PROFILING BETWEEN ALASKA AND RUSSIA, BERING SHELF-CHUKCHI SEA 1/16

Simon L. Klemperer (Department of Geophysics, Stanford University, Stanford CA 94305-2215, USA) and the Bering-Chukchi Working Group.

In August 1994 the R/V Ewing will be used to acquire about 3000 km of new deep-crustal MCS reflection profiles using a 20-gun, 8400 c.i. airgun array fired every 50 m into a 160-channel, 25-m receiver spacing cable to give a 40-fold common mid-point (CMP) section to 18 seconds travel-time sampled every 4 ms. We plan to acquire two separate profiles through the Bering Straits, each completely crossing the entire Cordilleran orogen from the Chukchi Shelf edge in the north to the Bering Shelf edge in the south, forming a crustal transect entirely across the continental connection between Eurasia and North America, and crossing all its fundamental structures, the boundaries between different crustal types, and several of its large sedimentary basins. We hope that the seismic profiles will address the nature of the different types of continental crust making up the Bering and Chukchi shelves, and the boundaries between these crustal blocks; and will allow study of mechanisms for formation of deep sedimentary basins (the profiles will cross four major petroliferous basins, the Navarin, Norton, Hope and Chukchi), and of the disappearance of the Brooks Range, a significant mountain range onshore in Alaska which disappears into the low topography of the Bering Straits, possibly related to the appearance of low-angle normal faults onshore in the Seward peninsula.

We plan to display preliminary brute stacks from this new survey.

## 1/17 REFLECTION IMAGING OF CONTINENTAL UNDERTHRUSTING BENEATH THE HIMALAYAS, TIBET: LESSONS FROM INDEPTH I

Project INDEPTH Research Group (c/o Larry Brown (brown@geology.cornell.edu), Dept. of Geological Sciences and INSTOC, Cornell University, Ithaca, New York, USA, 14850)

Project INDEPTH, a collaborative effort of U.S. and Chinese institutions, collected 100 km of deep reflection profiles in the Tethyan Himalaya of the Tibet region during the summer of 1992. The remote operating environment and ultra-deep targets of Project INDEPTH presented a special challenge for deep seismic profiling. The most serious technical problems encountered with INDEPTH I were wind noise, variation in shot-energy coupling, cross-feed from radio "bursts", strong ground roll from the explosive sources, and poorly constrained shot statics. Wind noise in particular may mask lower crustal and mantle reflections on the north end of the survey. The difficulty in consistently drilling to the nominal shot depth of 50 m was a major variable in signal penetration. FX-deconvolution and correlation coefficient filtering proved effective in mitigating this noise to a certain degree; however, whether the Moho's reflectivity varies laterally or is merely lost beneath the noise on parts of the line remains in question.
The most prominent features revealed by the profile are: (1) A mid-crustal reflection that marks the Main Himalayan Thrust (MHT), the active fault along which the Indian plate is underthrusting southern Tibet. The MHT exhibits a ramp and flat geometry that truncates underlying reflections in the Indian crust. (2) Lower crustal and Moho reflections (with surprisingly broad bandwidth) at 75 km depth beneath the southern end of the survey. (3) A "bright spot" at sub-Moho travel times that is demonstrated by a cross-line to be a steep, eastward dipping structure in the lower crust or Moho west of the survey. (4) A pervasive north-dipping reflection "fabric" at mantle travel times. Although noise levels at mantle travel times are high, frequency-dependent correlation coefficient filtering helps reveal this fabric. Although side-swipe has not been ruled out, this reflectivity may result from shearing of the mantle "lid" during underthrusting. Ctherwise, there appears to be little evidence of massive deformation of the Indian crust as it passes beneath the Tethyan thrust belts. Analysis of these results emphasizes the importance in ultra-deep reflection profiling of adequate drilling supplies for consistent shot placement, rigorous radio protocols, shooting to a wind-minimal schedule, and field processing capabilities.

## 1/18 EXPERIMENTS ON DEEP SEISMIC PROFILING IN JAPAN: TOHOKU-I SECTION

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We are conducting a program "Study on Deep Crust" funded by Science and Technology Agancy of Japan, to elucidate deep crustal structures under the Tohoku Arc, a northeast part of the Japanese Islands. By the end of 1993, three segments of seismic reflection profiling were acquired in the westernmost part of the Tohoku Arc. Two of those segments covers 16 km length in the Shonai Plain using explosive sources, and the other does 11 km length in the Shinjo Basin using vibrator sources. Another reflection profile, about 18 km long, was reproduced from a refraction record in the Ou backbone ranges. Those segments show shallow to middle crustal structures of the backarc margin side and the volcanic zone of the Tohoku Arc, although a poor S/N ratio of records sometimes makes interpretation difficult especially in the deeper part of the records.
The profile in the Shonai Plain shows gently waved reflections in shallow, which correspond to middle Miocene to Pleistocene sediments and volcanics. The Sakata thrust zone is found at the middle of the profile and can be traced downward to the east. The Sakata thrust zone and deep reflectiors subparallel to it seem to have controlled the uplifting of the Dewa Hills originated by E-W shortening of the Arc. Continuation of those structures in the Shonai profile is not clear now.
The profile at the active volcanic area shows a mid-crustal reflector, which is just above where low frequency earthquakes occur in the lower crust. This implies that the reflector represents a thermal structure under the active arc.

## Deep structure of the Median Tectonic Line (MTL) and its relate microseismicity, southwest Japan 1/19

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MTL is the most significant fault in Japan and has been playing an important role in the structrural development of Japanese island arc since Late Cretaceous (Paleogene?). According to the traditional model on MTL, MTL fault plane must be vertical to the deeper part. The model, however, was based on no evidence of deep structures of MTL. We made the first exploration of deep seismic reflection across MTL in eastern Shikoku in 1992. The tentative processing has shown that MTL fault plane is not vertical but N dipping at 30 degrees to at least 5 km depth (Ito et al., 1993). This is also supported by both the gravity and MT surveys. As the tentative processing was done within TWT 3.0sec, the deeper structure was not revealed. Therefore, we have tried to reprocess full data(TWT=5.0sec) of the 1992 exploration performing lower-frequency filtering, prestack migrations etc. Here we reach a clearer imaging of deeper structure of N-dipping MTL. Our result has defeated the traditional(vertical MTL) model. The northern boundary of microseismicity associated with active MTL right-lateral motion is dipping northward. The boundary corresponds to the N-dipping MTL fault plane revealed by our studies. The traditional model could not explain the N-dipping boundary, and gave a difficulty to us. The result of the deep seismic reflection studies must solve the difficulty.

## NATIONAL GEOSCIENCE PROGRAMS IN AUSTRALIA - THE ROLE OF DEEP SEISMIC PROFILING 1/20

D.M. Finlayson, H.M.J. Stagg, B.J. Drummond, G. O'Brien, B.R. Goleby (Australian Geological Survey Organisation, Canberra, ACT, Australia)

Regional deep seismic profiling by the Australian Geological Survey Organisation (AGSO) now plays a major role in three national geoscience programs in Australia.

Management of Australia's offshore resources is underpinned by research carried out through the Continental Margins Program. In recent years the emphasis has been on the acquisition of approximately 25,000 km of regional deep seismic reflection data (16 s record length) on a regional grid, primarily on the 2000 km long North West Shelf, but also including the southeast margin. Recording of refraction data will become a major priority in 1995. The acquisition of deep reflection data is taking place at the rate of about 10,000 per year. Interpretation of these data are yielding a new understanding of the regional tectonic framework, the basin-forming processes of these margins, and the origins of the structures that underpin many of the hydrocarbon fields.

Onshore, AGSO has entered into a National Geoscience Mapping Accord (NGMA) with each of the State and Territory Governments to re-map Australia's geology. Carefully placed regional deep seismic profiles are used to provide 3 dimensional control of the areas being mapped. Australia now has over 5,600 km of 20 s reflection data available to constrain its onshore regional mapping, with several hundred kilometres planned for each of the next few years.

The Australian Geodynamics Cooperative Research Centre (AGCRC) was recently established by AGSO and several other Australian research bodies to study the role of geodynamic processes on the formation of large ore bodies and petroleum provinces. The seven year research program will include several regional seismic profiles. The first to be undertaken was a 250 km transect of the Proterozoic Mount Isa Inlier, presently one of the most intensively explored mineral provinces in the world, in mid 1994.

1/21 REFRACTION DATA RECORDED BY LAND STATIONS DURING A MARINE SEISMIC SURVEY ON THE NORTHWEST SHELF, AUSTRALIA: CONSTRAINTS ON THE INTERPRETATION OF DEEP REFLECTION DATA.

C.D.N. Collins and P.A. Symonds (Australian Geological Survey Organisation, Canberra, ACT, Australia)

Seismic recording stations were deployed on the mainland and on islands off northwest Australia during a marine seismic survey of the Browse Basin by the Australian Geological Survey Organisation (AGSO). The stations recorded long-offset wide-angle reflection and refraction data from the routine air-gun shots. The purpose of recording the data was to obtain deep velocities and regional structure, to map variations of crustal thickness, and to provide a link between onshore and offshore crustal data. Because of the relatively low power of the source and noisy site conditions, it was necessary to enhance the data at large offsets by filtering and stacking. Ocean wave noise was a major problem, but stations deployed on islands adjacent to the mainland recorded arrivals out to offsets of approximately 250 km.

The velocities interpreted from the long-offset data constrain the interpretation of deep reflectors and allow accurate depth conversion of the reflection profiles. They also provide some constraints on the petrological interpretation of reflection features. An unusual zone of prominent reflectors within the lower crust under the eastern margin of the Browse Basin appears to disrupt the Moho, and is associated with high refraction velocities. These reflectors may represent mafic intrusives injected into the lower crust during crustal thinning associated with basin formation. The deep basement geometry and crustal structure along several traverses were interpreted from the onshore data, in conjunction with the vertical incidence reflection data. Considerable thinning of the original crust occurs beneath the basin sediments. The velocity data allow this to be quantified, and stretching factors of 3.0 - 3.5 have been deduced. The velocity data also permit an estimate to be made of the relative thinning that has occurred between the upper and lower crust during extension.

1/22 MINERAL SYSTEM MODELS BASED ON DEEP SEISMIC REFLECTION DATA

B.J. Drummond, B.R. Goleby and C.D.N. Collins (Australian Geological Survey Organisation, Canberra, ACT, Australia)

Mineral systems are defined as the combination of fluid source, migration pathway and host rock that led to the formation of a mineral deposit. Mineral system models play a fundamental role in the strategies of mineral exploration companies by constraining the way they use information about the regional geology and known ore deposits to form a predictive approach to their exploration. Two recent studies by the Australian Geological Survey Organisation (AGSO) directly constrained mineral systems models by mapping the distribution of crust-penetrating fault systems.

A network of profiles in the Devonian Cobar Basin in central New South Wales mapped in 3 dimensions a mid-crustal detachment over which the upper crustal plate slid to create the basin. The net displacement vector was 24 km to the northeast. Fault systems within the basin are either transfer faults parallel to or normal extensional faults orthogonal to the upper plate vector. Faults bounding the basin margin parallel the top or bottom of a ramp in the mid crustal-detachment. Gold mineralisation lies along the basin margin, and is therefore controlled by mid-crustal structures, whereas the largest silver-lead-zinc ore body in the basin lies on a transfer fault that probably penetrates only to the bottom of the basin, at about 6 km.

Gold mineralisation in the Eastern Goldfields in Western Australia occurs in greenstone supracrustals in second and higher order splays off major shear zones. The largest deposits are in the hanging wall of the Bardoc Shear. Reflection data mapped the Bardoc Shear from its surface outcrop to its intersection at 15 km depth with the Ida Fault. The Ida Fault can in turn be followed to depths of 25-30 km. These shear zones therefore provide a direct fluid migration pathway from the lower crust into the supracrustals. The Bardoc Shear cuts a regional detachment at the base of the greenstones at 6-7 km depth. Other shear zones in the region are also mineralised, but they sole onto the detachment. The fluid migration pathway into these shears is therefore less direct than into the Bardoc Shear.

CRUSTAL STRUCTURE BENEATH THE LATE PROTEROZOIC OFFICER BASIN, CENTRAL AUSTRALIA 1/23

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The Officer Basin is one of the least explored of a series of related broad intracratonic basins which formed on the Australian craton during the Neoproterozoic and early Palaeozoic (800 - 360 Ma). In 1993 the Australian Geological Survey Organisation (AGSO) and South Australian Department of Mines & Energy (MESA) undertook a major seismic survey in the central Officer Basin, recording 550 km of 10 fold 20 s data using explosive sources.

The basin sediments in the central Officer Basin shallow from up to 7 km in the sub-basins near the northern edge to around 3 km on the southern platform area, and are for the most part remarkably undeformed except at the northern margin. The deeper seismic data show that a series of prominent north dipping structures pervade the crust beneath the central Officer Basin extending to around 12 s two-way-time. Most of these Proterozoic basement structures are truncated at the base of the Officer Basin sequence by an erosional event which peneplaned basement before the Willouran deposition of the regionally extensive basal units (Pindyin Sandstone and Alinya Formation).

During the last major orogeny to affect the basin (the Carboniferous Alice Springs Orogeny) some of these structures were reactivated, forming a thrust-controlled homoclinal upturn of the basin sediments at the northern basin margin. At approximately 17 km from the basin margin a set of these faults bifurcate. The upper branch steepen at depths less the 9 km, and are directed towards the surface to the north of the basin margin. The lower branch of these thrusts soles into the base of the sedimentary sequence - most probably into the evaporitic Alinya Formation.

CRUSTAL SEISMIC MEASUREMENTS ACROSS A FORE-ARC BASIN 1/24

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The fore-arc basin region of the Pacific-Australian convergent plate boundary off northeastern New Zealand is marked by a conspicuous local negative gravity anomaly exceeding 60 mgal in amplitude. Crustal seismic reflection data were recorded to 16 s TWT over this feature and imaged a deep sedimentary basin about 80 km wide containing a thick, well stratified, sequence (at least 7 s TWT). The basin is downwarped on its western flank and apparently fault controlled along its eastern margin. Flanking the edges of the basin appear to be older sequences of igneous or volcanic character. The origin of these units and indeed the mechanism for the formation of this deepened fore-arc basin is unknown. The lower crust- upper mantle is not well imaged on the data, presumably due to loss of energy in the shallow reflective layers, but the data appears to indicate little or no crustal thinning under the basin, consistent with the gravity data. Further south, along eastern New Zealand, a crustal downwarp of the back-arc region is ascribed to the locking of the subducting Pacific plate against the Australian plate and pulling it down. The extreme local nature of the gravity anomaly off northeastern New Zealand indicates that this is unlikely there. The profile runs along the boundary between oceanic (north) and continental (south) crust on the Australian plate and this boundary, the major strike slip faulting through eastern New Zealand with offsets of several hundred kilometres over the past 5 Ma and the subduction of a thick oceanic plateau (the Hikurangi plateau) have probably had a major influence on the formation of the basin.

1/25

## PSEUDO-3D PROCESSING OF THE SUDBURY SEISMIC REFLECTION DATA

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Innovative reprocessing of Lithoprobe broad-band seismic reflection data (30-140 Hz sweep) has been conducted to optimize the seismic image of the enigmatic Sudbury Structure of the Canadian Shield. In response to the challenge of crooked survey lines, we have developed straight-line CMP binning strategy. This approach has several advantages over the conventional slalom-line CMP binning: (1) substantially reducing crooked-line effects; (2) improving the lateral continuity of seismic reflections; (3) producing a less distorted seismic image; (4) enabling a better correlation with the surface map pattern. With the straight-line binning, cross-dip analysis and corrections become more meaningful and more effective. Together, they reveal the lateral dips of reflection events, valuable information for geological interpretation. 3D CMP binning has also been applied to highly crooked portions of the survey lines to pinpoint seismic reflections. These pseudo-3D seismic processing techniques, in conjunction with refraction statics, surface-consistent residual statics, and spectral balancing, have overcome limitations associated with conventional 2D seismic data processing and produced a remarkably clear seismic image across the Sudbury Structure, warranting a new, more detailed, structural interpretation.

1/26

## CRUSTAL VELOCITY ESTIMATES TAKING ADVANTAGE OF LONG OFFSET RECORDING

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Four expanding spread profiles with a maximum offset of 20.4 km were collected along the Trans-Hudson Orogen Transect. The small stepout distance (100 m) provides high fold (>30) data. Velocity analysis is carried out both in the CMP and in the super shot gather domains. It is well known that the second order hyperbolic time-distance relationship has limited validity as a function of the offset. As synthetic examples demonstrate, higher order moveout equations exhibit less departure from the actual traveltimes than the standard second order approximation. Both coherency-based and linear techniques of velocity analysis were tested on the data taking advantage of the long offset recording. The coherency-based methods have higher velocity resolution and high noise suppression, while the linear techniques are superior in time the resolution.

1/27

## THREE DIMENSIONAL SEISMIC CRUSTAL STRUCTURE OF A HINTERLAND CORE COMPLEX ON THE LITHOPROBE SOUTHERN CANADIAN CORDILLERA TRANSECT

Kris Vasudevan and Frederick A. Cook (LITHOPROBE Seismic Processing Facility, Department of Geology and Geophysics, The University of Calgary, Calgary, Alberta, T2N 1N4, CANADA)

The Monashee complex is an elongate north-south exposure of high grade rocks in the south-central Canadian Cordillera that is flanked by middle Eocene extensional faults, and that is cored by Cretaceous to Paleocene contractional faults. Structures wrap around its southern flank to give the appearance of a crustal-scale lateral ramp that is analogous to lateral ramps in foreland thrust belts. LITHOPROBE regional reflection profiles were fortuitously recorded with a north-south profile (line 6) oriented along the strike of the complex, and an east-west profile (lines 7-8-9) crossing its strike. The intersection of the two profiles afforded an opportunity to acquire an areal (3-D) survey in the region of southwestward plunge of the complex, and thus to delineate its three dimensional subsurface structure in the vicinity of the lateral ramp. Vibroseis data were obtained with 50 m receiver point spacing, and 100 m source point spacing over an area of about 12 x 12 km for a total of about 115,200 traces with a correlated listening time of 18.0 s. We have processed the data to optimize signal in 100 m x 100 m bins for a nominal 6-fold coverage. Initial results allow us to map structures in the hangingwall of the contractional Paleocene Monashee decollement and to delineate the relative strikes of layers in the subsurface beneath the coverage area.

1/28

## SEISMIC SKELETONIZATION AND EVENT CLASSIFICATION: A NEW APPROACH FOR CRUSTAL SEISMIC INTERPRETATION

Qing Li, Kris Vasudevan and Frederick A. Cook (LITHOPROBE Seismic Processing Facility, Department of Geology and Geophysics, The University of Calgary, Calgary, Alberta T2N 1N4, CANADA)

Seismic skeletonization is a syntactic pattern recognition technique to automatically identify coherent arrivals on a seismic reflection profile. If arrivals can be automatically recognized, a variety of descriptive attributes can be incorporated into a relational database to provide new approaches to interpretation. The skeletonization method we use retains the main features of an approach previously described by Lu and Cheng (Geophysics, Vol. 55, No. 10 1990), with the introduction of two modifications to reduce misconnections among seismic cycles from three neighbouring traces (triplets) and to improve the efficiency of the iterative procedure in the identification of seismic events. In the first we modify the cost function for non-neighbour trace-cycle correlations, and in the second we alter the triplet-configuration optimization procedure to include singlets, doublets and triplets. Application of the modified pattern recognition method to skeletonize deep crustal reflection profiles from the LITHOPROBE Southern Canadian Cordillera transect faithfully reproduces the geometry of reflection events and represents a major first step in this new approach to interpretation of crustal reflection data.

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## IS PROTEROZOIC CRUST LESS REFLECTIVE THAN PHANEROZOIC CRUST?

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In 1992, LITHOPROBE acquired 500 km of multichannel seismic reflection data across the Western Canada Sedimentary Basin and its underlying Archean to Early Proterozoic basement. Conventional (AGC) processing of the data yielded migrated stacks that featured a reflective lower crust, similar in appearance to "typical" lower crust observed in Phanerozoic regions worldwide. However, subsequent processing, using relative-amplitude preserving techniques, provides evidence that lower crustal reflectors are characterized by reflection coefficients that are about an order of magnitude smaller than those present in the overlying sedimentary basin, and considerably smaller than r.c.'s reported for the lower crust in other regions. The processing scheme consists of surface-consistent trace amplitude analysis, NMO and static correction, regression stack, Q estimation and compensation, coherency filtering and geometrical spreading correction. Each step in the procedure is carefully monitored to ensure that relative amplitude information is preserved, thus permitting amplitude anaysis to be performed using stacked data. Our results imply possible temporal constraints on processes responsible for structures leading to enhanced lower crustal reflectivity; either the processes were fundamentally different in the Precambrian, or the intrinsic reflectivity must decay with time.

1/30

## CRUSTAL STRUCTURE AND TRIPLE JUNCTION MIGRATION: SEISMIC IMAGES OF THE MENDOCINO TRIPLE JUNCTION

A.S. Melzer (Dept. of Earth & Environmental Sciences, Lehigh University, Bethlehem, PA 18015)
and the Mendocino Working Group†

The Mendocino Triple Junction Seismic Experiment is a multi-institutional effort to study the crust and
upper mantle of the western margin of North America where the Gorda, North American, and Pacific plates
come in contact forming a triple junction. Over a two year time period we have collected an integrated
seismic dataset including: deep marine multichannel seismic (MCS) and ocean bottom seismometer (OBS)
profiles, onshore wide-aperture reflection-refraction dynamite profiles, and combined offshore-onshore
wide-aperture profiles. The Mendocino Triple Junction (MTJ) has been migrating along the western margin
of North America through time. Our study exploits the well defined triple junction region as an in-situ
laboratory to study tectonic accretion and crustal deformation before and after it is modified by thermal and
magmatic processes associated with passage of the triple junction, and to evaluate the implications of these
processes for continental growth and evolution. The seismic dataset consists of two main east-west
transects, one to the north of the triple junction (~40°45'N) where the Gorda Plate is subducting beneath
North America and one to the south (~39°30'N) where the Pacific and North American Plate are in strike-
slip contact providing data that sample the crust and upper mantle before and after the passage of the MTJ
respectively. Additional north-south transects, provide an image of the transition between the subduction
margin north of the MTJ and the strike-slip margin to the south. In this poster, we discuss initial results
from the second year of our work which focuses on the offshore component of our experiment. Sixteen
seconds of MCS data were collected with a 160 channel system having a 25m group interval and a
maximum offset of 4 km. The source was an 8300 cubic inch airgun array fired every 50m. CMP gathers
are nominally 40 fold with midpoints spaced every 12.5 m. The offshore MCS program was complemented
by large-aperture recording of airgun shots on ocean-bottom and onshore seismographs. The MCS data
provide structural images while the large aperture datasets provide velocity control on deep crustal
reflections and in addition, because of the dense shot spacing will allow for wide-aperture imaging.

†The Mendocino Working Group includes representatives from : Lehigh University, Oregon State University, Stanford University, Rice University, Penn State University, Humboldt State University and the U.S. Geological Survey.

## LITHOSPHERIC IMAGES OF THE MENDOCINO TRIPLE JUNCTION REGION

1/31

Bruce C Beaudoin (Department of Geophysics, Stanford University, Stanford,
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The tectonics of northern California are governed by the interactions of the Pacific, Juan de Fuca, and
North American plates and their junction, the Mendocino Triple junction (MTJ). The present day system
formed 25-30 my ago when a Pacific spreading center collided with the North America establishing two
triple junctions, the Rivera and Mendocino, that diverged along the continental margin. One consequence of
this migration, in a rigid plate model, is that the North American plate slides off of the Gorda plate leaving
in its wake a void that is filled by upwelling asthenosphere: the slabless window as first presented by
Dickinson and Snyder in 1979. Supporting evidence for a slabless window exists from heat flow, gravity,
telescismic P-wave delay studies, and geochemical considerations.
The Mendocino Triple Junction Seismic Experiment, is a multi-year, multi-institutional effort to
study the crust and upper mantle of the North American margin before and after it is modified by passage of
the Mendocino Triple Junction. The first phase of this study was during August, 1993 when we collected
650 km of onshore seismic refraction/wide-angle reflection data to characterize the subduction and
transform regimes and the transition between them. The second phase of this study was during June, 1994
when we collected over 900 km of offshore MCS data and recorded the airgun shots along linear extensions
of the offshore lines onshore, along offshore OBS profiles, and with a 3-D array designed to focus on the
triple junction.
An unexpected result from our 1993 onshore study are single-fold reflection sections that show
prominent images of the subducting Gorda plate, the transition from subduction zone tectonics to transform
margin tectonics, and the region of the slab window. Within the region of the proposed slab window
unusually high amplitude near-vertical reflections define the base of north America at 7-8 seconds at the
coast to 10 seconds 75 km inboard. At this point the strong reflection terminates and is replaced by a series
of bright reflectors in the lower crust/upper mantle that are suggestive of partial melt. These images and
preliminary sections from the 1994 offshore work will be presented.

†(The Mendocino 93 working group includes representatives from Stanford Univ., Oregon State Univ.,
Rice Univ., Lehigh Univ., the U.S. Geological Survey, the Geological Survey of Canada, Penn State
Univ., Humboldt State Univ., the University of Texas Institute for Geophysics, and the Dublin Institute for
Advanced Studies.)

## MOHO TRANSITION BETWEEN EAST AND WEST ANTARCTICA FROM SERIS REFLECTION PROFILE DATA

1/32

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Uri ten Brink (United States of Geological Survey, Woods Hole, USA)
Tim Stern (Research School of Earth Sciences, Victoria University of Wellington, New Zealand)
Bruce Beaudoin (Stanford University, USA)

Data from a wide angle seismic reflection profile, SERIS, over the eastern front of the Trans-
Antarctic mountains has revealed a strong clear dipping band of reflections which is
interpreted as the Moho ramp between the (~ 22 km thick) crust of Ross Embayment (West
Antarctica) and the (~34-40 km thick) crust of the East Antarctic craton. The reflection band
beneath the mountains appears to be remarkably continuous on individual shot gathers and
appears unfaulted while, in contrast, Moho reflections beneath the Ross Embayment appear
to be weaker and less laminated. The nature of the Moho ramp, and its lateral position, east
of the Trans-Antarctic mountain front, have important implications for models of the uplift
of the 5000m high mountain range.

## 2/1 PROTEROZOIC TERRANE SUTURES IN THE SOUTHERN BALTIC SHIELD ALONG BABEL LINES B AND A

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In the southern Baltic Shield along BABEL profiles B and A, crustal reflectivity is dominated by a fabric of NE-dipping reflections and the crust/mantle boundary is in general non-reflective. A prominent, almost continuous reflection can be correlated from 3.5 s TWT in the upper crust below the southernmost part of the island of Öland to 14 s TWT, corresponding to the base of the lower crustal reflectivity, north of Öland. It may extend north of the island of Gotland at 23.4 s TWT where a relatively strong, NE-dipping reflection is observed in the otherwise transparent upper mantle. Moho depths determined from wide-angle data coincide with the termination of crustal reflectivity, except in an almost transparent zone where the upper mantle velocity changes over short distance from 8.2 to 7.8 km/s (+/- 0.2) and a prominent NE-dipping reflection truncates the Moho and continues into the upper mantle, separating a wedge of low velocity upper mantle (7.8 km/s) to the northeast from high velocity upper mantle to the southwest (8.2 km/s). We interpret the NE-dipping reflection as a relict Proterozoic suture originating from a collision between two Svecofennian juvenile arc terranes, the Svealand Terrane to the northeast above the suture and a subducted and more reflective Svecofennian suspect arc terrane to the southwest. The Trans-Scandinavian Igneous Belt developed as an I-type granitic batholith above the collision zone in the crust of the Svealand Terrane between 1.84-1.76 Ga. The pervasive N-dipping reflections within the crust are interpreted as shear zones developed during collision, subsequently reactivated by Gothian collision and later post-orogenic extensional events. Further south, a strong SW-dipping reflection is interpreted as a suture, the *Gothian Deformation Front*, along which the relatively seismically transparent Gothian terrane of the Blekinge-Bornholm Block was overthrust to the northeast concealing the more reflective Svecofennian suspect arc terrane. Since the arc terrane was also subducted northward beneath the present-day Svealand Terrane, it is not exposed in the basement surface in the southern part of the Baltic Shield and its presence can only be infered by its geophysical expression.

## 2/2 THE MOZAIC-INHOMOGENEOUS SEISMIC MODELS OF THE BALTIC SHIELD LITHOSPHERE: A FRACTAL ASSUMPTION

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The integration both DSS and CDP data together with seismological records of local and remote earthquakes for the last 30 years was made and main parameters of lateral and vertical inhomonetics in the Baltic Shield lithosphere were evaluated. 3D seismogeological models and seismic ones for different terrains were desighned. As a result it was proven that any persistent seismic surfaces penetrated through the entire shield body are absent. The crystallinicum is a mozaic-inhomogeneous medium with discrete boundaries between domains. Each of them has an own pattern of a low and high velocity blocks distribution in a crust-mantle space, moreover an incosistency of structural plans at the different deep levels of single crust megablock could be often recognized. The seismography is operating as usual with inhomoneteics of some hundreds meters whereas DSS can detect items of several kilometers. Integrated approach brought clear evidences on a fractal structure of the shield crystallinicum. As assumed a fractal assumption and appropriative mozaic-inhomoneneous models of crystalline bodies in lithospheric plates provide more suitable base for a correlation and co-ordination of seismologic/seismic, petrologic and geodynamic data in contrary to conventional gradual-layered conception.

## 2/3 PROJECT CRATON: EXPLORATION OF THE STRUCTURE AND EVOLUTION OF THE PRECAMBRIAN OF THE U.S. CONTINENTAL INTERIOR

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The majority of deep seismic profiles in the U.S. have focused on the crustal structure of the Phanerozoic orogens (i.e., Appalachian-Ouachita, Cordilleria and Rocky Mts.), and despite increased efforts in recent years to study the crust of the U.S. continental interior, large parts of this region remain unexplored. To a large extent this is due to the masking veneer of Phanerozoic platform strata across this region that belies the dynamic evolution of the underlying crust during middle Proterozoic time. Originating through the accretion of several (and as yet poorly delineated) terranes (~1.7-1.5 Ga) and significantly modified during subsequent widespread lower crustal anatexis and silicic magmatism (~1.45-1.35 Ga), the crust of the U.S. continental interior has been explored by deep reflection profiles across only a few of its salient features (i.e., parts of the ~1.1 Ga Midcontinent Rift, the Grenville Front, and the Trans-Hudson Orogen). However, other deep and industrial seismic profiles reveal that significant, but still poorly understood, structures are present beneath this covered region. For example, a Proterozoic stratified sequence appears to underlie large parts of the eastern U.S. continental interior; however, the age, origin, and distribution of these strata are still poorly constrained. Also, despite considerable seismic reflection profiling over many years (COCORP and GLIMPCE) to delineate the major features of the ~1.1 Ga Keweenawan or Midcontinent Rift, the structure of the eastern arm of this rift and its relationship or interaction with the Grenville Orogen, and a potential correlation with newly discovered Precambrian basins beneath southwest Ohio and northcentral Kentucky, remains obscure. Major convergent structures in the Precambrian basement have been imaged by deep seismic profiles across the Grenville Front in Canada (GLIMPCE and Lithoprobe) and beneath Ohio (COCORP), as well as across the Trans-Hudson Orogen in the U.S. (COCORP) and Canada (Lithoprobe), but similar features that likely delineate the Proterozoic accretionary evolution of the U.S. continental interior remain concealed. Through a series of multidisciplinary transects, Project CRATON endeavors to identify and explore the structure and evolution of the Precambrian of the U.S. continental interior.

## 2/4 COCORP PROFILING OF THE TRANS-HUDSON OROGEN, MONTANA AND N. DAKOTA

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Deep seismic reflection data collected across the Williston basin using Vibroseis and dynamite sources reveal the architecture of the underlying Early Proterozoic Trans-Hudson orogen (THO). Some 700 km of reflection profiles characterize the southern THO as a major crustal-scale antiform. West-dipping reflections at the western margin of the orogen define the suture zone with the Archean Wyoming craton, and truncate a zone of pronounced sub-horizontal lower crustal reflectivity that defines the Moho within the Wyoming Province. In contrast, the seismic Moho east of this suture appears non-reflective, as the western internides of the orogen are marked by west-dipping reflections extending from the lower crust to upper mantle depths of 55 km. Projection of COCRUST refraction results along strike from the north implies that the Moho cuts sub-horizontally across these dipping reflections at ~42 km depth. We interpret superposition of the seismic Moho on a preserved west-dipping reflection fabric as evidence for a static post-orogenic phase change from gabbro to eclogite in the lower crust beneath the Williston basin. The lack of Moho reflectivity beneath the southern THO contrasts markedly with the presence of a well-defined reflection Moho imaged on the LITHOPROBE transect across the northern THO in Canada. We speculate that this fundamental difference in the nature of Moho reflectivity along strike within the THO results from a combination of (1) a greater degree of collisional shortening in the south and/or (2) more thorough post-orogenic extensional modification in the north.

## 2/5 SEISMIC IMAGE OF AN EARLY PROTEROZOIC RIFT BASIN

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North of the Great Lakes, the Southern Province of the Canadian Shield consists of the Pa- leoproterozoic Huronian Supergroup (2.5 to 2.2 Ga) which was formed as a passive margin sequence. The Supergroup consists of volcanic and sedimentary rocks which lie unconformably over Archean rocks of the Superior Province and forms the Penokean Fold Belt. In 1991, Falcon- bridge Ltd. acquired three proprietary high frequency (30-140 Hz) vibroseis reflection profiles across the Huronian Supergroup in the vicinity of the Temagami Lake magnetic anomaly, one of the largest positive magnetic anomalies of the Canadian Shield. High quality seismic data were obtained through a combination of spectral balancing, refraction static corrections, and cross dip corrections. Interpretation of the seismic data is constrained by lithological data from deep boreholes. The upper metasedimentary formations are seismically transparent, the lower sedimentary and volcanic formations show prominent layered reflections. Reflections within the basement exhibit an unconformable relationship with overlying formations and structures. Steeply dipping reflections within the basement complex are interpreted as faults or shear zones. The new seismic data reveal a high quality image of one of the oldest preserved rift basins on earth. The data support a revised tectonic model for the Southern Province. The proposed sequence of events includes (1) rifting along pre-existing zones of of weakness in the Archean crust, (2) subsequent development of a passive margin stage with deposition of three sedimentary formation, and (3) deformation during the Penokean Orogeny.

## 2/6 THE STRUCTURE AND NATURE OF THE GRENVILLE FRONT UNDER THE CANADIAN SHIELD: RESULTS FROM THE 1992 LITHOPROBE ABITIBI-GRENVILLE SEISMIC REFRACTION EXPERIMENT

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The Lithoprobe Abitibi-Grenville seismic refraction experiment was conducted across the Grenville and Superior Geological provinces of the Canadian Shield in July, 1992. Major tectonic targets of interest were the Grenville Front, the Sudbury basin, the Western Metasedimentary belt, the Ottawa graben, the Central Gneiss belt, and the Abitibi-Greenstone terranes. During the survey over 17,000 seismograms were collected from 44 shot points at an average shot spacing of 30 km and station spacing of 1-1.5 km. Several hundred km of lines were also coincident with the near vertical reflection experiment which was done in 1991. Preliminary results from a tomographic analysis of the data show large variations in crustal velocities from one terrane to another. Velocities under the Central Metasedimentary belt south of the Grenville Front are significantly larger than those from the Abitibi-Greenstone terranes to the north of the Front. The Grenville Front Tectonic Zone is well imaged by the analysis as a relatively narrow south east dipping region of anomalous velocity gradients. These may be related to dipping shear zone images which have been produced in earlier studies of near vertical reflection data. Wide angle PmP signals indicate that the Moho varies from a sharp discontinuity south of of the Front to a rather diffuse boundary under the rocks of the much older Shield north of the Front.

## MOHO SIGNATURE FROM WIDE ANGLE REFLECTIONS 2/7

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A combined crustal seismic refraction and wide-angle reflection experiment was conducted over the Trans-Hudson orogen belt, northern Saskatchewan and Manitoba, in 1993 by LITHOPROBE. The program included three seismic lines extending over 1900 km in length.
This exceptionally high quality dataset contains unique seismic reflection and refraction events from the Moho and upper mantle range.
The relatively high seismic fold and unprecedented signal-to-noise ratio of the field observations made it possible to process the wide angle portion of the data set with standard signal enchantment techniques. This detailed mapping of the Moho revealed a complex interface and significant structural relieves.
The pseudo 3D map of the picked two-way travel times indicates that the depth changes of the Mohorovicic discontinuity is correlatable to known surface geological trends. The North American Central Plane conductivity anomaly (NACP) and a portion of the Glennie Domain of the Reindeer Zone appear to have anomalous Moho signatures.

## SEISMIC CROSS-SECTION OF THE ENIGMATIC SUDBURY STRUCTURE 2/8

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The Sudbury Structure on the southern margin of the Superior craton was created by a catastrophic explosion 1.85 Ga and hosts one of the world's largest Ni-Cu reserves. As a unique terrestrial geological feature, its genesis has been vigorously debated for more than a century. Pseudo-3D processing of Lithoprobe high-resolution seismic reflection data produced high-quality seismic image across the Sudbury Structure, warranting a more detailed and reliable structural interpretation. The new image has revealed a major, previously unrecognized, zone of imbricated thrusts. Interpretation of these thrusts provides critical timing constraints relating the Sudbury tectonic deformation to deposition of the Sudbury Basin sediments. The Onwatin argillites are penetrated by blind thrust-faults, whereas the overlying Chelmsford turbidites are undeformed and most likely postdate the thrusting. Thus, the uniform paleocurrent trends observed in the Chelmsford reflect subsequent deformation history and may be dismissed as evidence against an impact origin. Based on our interpretation of the seismic image, the original volume of the Sudbury Igneous Complex, likely an impact melt sheet, is –1 x $10^4$ $km^3$, supporting the claim that the Sudbury Structure represents the eroded and tectonized remanent of one of the largest impact structure (–200 km) on earth.

3/1

## LITHOSPHERIC-ASTHENOSPHERIC STRUCTURE BENEATH THE BÉKÉS BASIN

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Deep reflection measurements along the Pannonian Geotraverse in SE-Hungary allowed conclusions to be drawn concerning the elevation of the lower crust, the crust-mantle boundary and that of the lithosphere-asthenosphere boundary. Integrated interpretation with the use of geothermal, gravity, magnetic and magnetotelluric methods confirmed the seismic results. 2D model calculations and interpretation were prepared for each method. The thickness of Neogene sediments reaches 6-7 km; the basement of the Neogene basin sinks by 3-4 km. The crust-mantle boundary uplifts by 5-6 km up to a depth of 22 km, whereas the lithosphere-astenosphere boundary uplifts by 15-20 km, thus occurring at a depth of 40-45 km below the Békés basin.

3/2

## FROM DEEP SEISMIC REFLECTION PROFILING TO TOMOGRAPHIC IMAGES IN THE WESTERN ALPS

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Tomographic studies of the lithosphere and the upper-asthenosphere are the most powerful tools for imaging the present tectonic plate configuration. The tomographic images of the Western Alps reveal a significant SE-subduction of the European continental lithosphere reaching a depth of around 175 km below the Po plain. Not only are these images a proof of an asymmetric lithospheric structure beneath the Alps, but furthermore they imply that a significant amount of European continental crust got subducted at considerable depth. This fact is further corroborated by actualistic models of continental passive margins: the most internal units of the European crust presently outcropping in the Western Alps correspond to the shoulder of the N-Tethyan margin and therefore implying that the whole European margin s.str. (corresponding to a length of about a 150 km) has been subducted at depth. Hence, the size of the European plate can be calibrated for geodynamic reconstructions, thus contributing important information required to draw up paleogeographical maps with greater precision. Furthermore, correlating the tomographic images with deep seismic profiles and surface geology helps to draw lithospheric-scale geological cross-sections which clearly illustrate the relations between plate-tectonics and structural geology.

## CRUSTAL ANISOTROPY AND MANTLE REFLECTOR POLARITY FROM DEEP SEISMIC NORMAL INCIDENCE AND WIDE ANGLE REFLECTIONS. 3/3

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We present two studies of a wide-angle dataset recently acquired off the northwest coast of Scotland coincident with BIRPS deep seismic normal incidence data. The wide-angle data was gathered to measure the physical properties of the bright continuous Moho and mantle reflections observed on the original normal incidence data and includes two ship ESP, OBS and land based seismometer arrays. The wide-angle data has been processed by applying trace binning and mixing at the optimum moveout velocity to enhance deep reflection signal coherency and improve S/N ratio and resolution. Predictive deconvolution has proven successful in attenuating multiple energy.
Both wide-angle and normal incidence data have been modelled using a 2D ray inversion program, giving a well constrained model of crustal and upper mantle velocity structure. Differences in the depth of Moho derived from the two types of data are caused by the assumption that the crust is purely isotropic. This has been used to estimate the gross anisotropic nature of the region sampled. We have used Thomsen's equations of weak elastic anisotropy to test the hypothesis that the crust is transversely isotropic with vertical symmetry.
A scheme for determining the polarity and internal organisation of the impedance contrasts responsible for the mantle reflections at near normal incidence has been devised. Selected near normal incidence reflection data have been processed to give, as far as possible, noise free reflection seismograms. We are devising a scheme to determine the effective far-field source wavelet and invert the reflection seismogram, using a genetic algorithm, to determine the polarity of the reflector.

## THREE-DIMENSIONAL STRUCTURE OF LATERAL HETEROGENEITIES IN P-VELOCITIES IN THE UPPER MANTLE OF THE SOUTHERN MARGIN OF SIBERIAN PLATE 3/4

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A three dimensional model of lateral variations of P-wave velocities in the upper mantle of Southern margin of Siberia has been obtained using more than 6000 teleseismic arrival times registered at the stations of Siberia and Kazakhstan. The method was based on the triangulate block parameterization and permits to accord the output information with the density of input information. The inversion stability has been improved significantly compared to traditional approaches. Special attention was paid to the problem of testing the obtained results. The study of stability of the method (sensitivity of results toward noise) shows that the reconstruction was stable even if the noise level exceeded the relevant signal. Another test consisted in a reconstruction using two independent sets of events. For these two sets determined velocity structures were found in satisfactory coincidence.
The preliminary interpretation of the results permits to suggest some mechanisms of development of the lithosphere in the study region. According to the obtained tomographic image the upper mantle has a clear convective structure. Two positive velocity anomalies, which are interpreted as descending flows are well correlated with regions of recent mounting building of Altai and Sayan. Some possible rheology models illustrating qualitatively the obtained tomographic images are considered.

3/5

## THE ROLE OF FAULTS IN THE TECTONOSPHERE'S SEISMOGEOLOGICAL MODEL

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The horizontal-layer models of tectonosphere (earth's crust) are wi-
dely used in interpretation of profound seismical sounding. In most
cases the subvertical faults are not taken into consideration. In
particular, by relative block's displacements the parameters of sei-
smical boundaries are considered unchangeable. These displacements
have as results: a) the breach of the Earth's equilibrium state into
these blocks, caused by certain geological processes; b) the change
of PT conditions on the existed seismical boundaries. As a result
must be the change of boundary seismic velocities. In particular, in
the sea and ocean acuatoriums which are the lowered tectonosphere's
blocks the former Moho discontinuity ($M_1$) acquires a boundary velo-
city more than 8 ∓ 0.5 km/s and to the velocity 8 ∓ 0.5 km/s corres-
ponds a new boundary $M_2$ situated considerably hiqher than $M_1$. It is
one of essential problems in using the results of seismic investiga-
tions for the solution of regional tectonical problems.
There are some reasons to expect that what is fixed on the sections
as astenospere is the result of the influence of subvertical faults.

5/1

## COMBINED SEISMIC REFLECTION AND REFRACTION DATA IN THE FAEROE BASIN, OFFSHORE NW SCOTLAND.

S. Hughes, P.J. Barton and C.A. Zelt (Bullard Laboratories, Cambridge University, Cambridge, CB3 0EZ, England).

Seismic refraction data acquired from 50 ocean bottom seismometers deployed across the center of the Faeroe Basin were used to constrain the structural configuration of the basin where it is opaque to normal-incidence data owing to pervasive basaltic intrusives. Analysis of the seismic refraction data using both forward and inverse ray-based techniques produced a well constrained velocity-depth model of the sedimentary structures within the basin. The model is characterized by a structural pinch-out in the center of the basin interpreted as a thinned Paleocene sequence above a Precambrian basement ridge. In the northwesterly portion of the basin a 1 km thick sedimentary layer is imaged sandwiched between high velocity (5.0 km/s) basalts and the top of the Precambrian basement. Deep seismic reflections constrain the crustal thickness to 18±3 km suggesting that the basin is underlain by highly attenuated continental crust. Our interpretations of the Faeroe Basin are strengthened by corresponding trends observed between the seismic refraction velocities and the interval velocities obtained from co-incident normal-incidence data. The seismic refraction data can thus be used to corroborate structural information interpreted from seismic reflection sections and moreover provides valuable independent depth estimation of key structural targets

5/2

## SEISMIC INVESTIGATIONS OF THE PRE-CAMBRIAN BASEMENT IN TATARSTAN (EASTERN PART OF RUSSIAN PLATFORM)

V.Trofimov (Assn."Tatneftegeophysica",Voroshilov str.. Bugulma,Russia)

The main tasks of deep seismic investigations by CDF method in Tatar-
stan are: (1) exposing the differences in the crustal structure in the
eastern part of the republic, where the largest Romashkino oil field
is, and in the western part, where the oil fields are not found;(2)ex-
posing of the geological structure connection of Paleozoic sedimentary
mantle with the basement structure;(3)prediction of unconsolidated zo-
nes in the Pre-Cambrian basement as possible hydrocarbon traps. At the
first stage, seismic survey was conducted on seismic lines going
through the super deep wells.The gathered data allow to determine that
with the permeability unconsolidated zones in the basement connected
the generation of more intensive reflected waves, and many of the ref-
lectors have tectonic nature.The survey was conducted on seismic lines
crossing the largest tectonic elements. The depth of investigations
were 8-15 km. In 1994 it was started the third stage of seismic survey
providing 40-50 km depth of investigations. Observations are made on
two seismic lines crossing Romashkino oil field. It is supposed that
the profiles will be continued outside Tatarstan up to the Ural and
tied up with the seismic lines of the "Europroba of Russia" programme.

5/3 WESTLINE - A DEEP SEISMIC PROFILE ACROSS THE ROCKALL TROUGH

R. W. ENGLAND & BIRPS CORE GROUP (BIRPS, Bullard Laboratories, Madingley Road, Cambridge, CB3 0EZ, UK)

BIRPS shot a 450 km long near normal incidence deep profile from Rockall Bank, across the Rockall Trough to the Irish shelf in August 1993. The aims of this experiment were to examine the structure and distribution of igneous intrusives within an aulacogen with a large beta factor; to increase knowledge of the regional deep structure west of Ireland, an area of current exploration interest; and to develop methods of multiple removal essential as exploration increasingly moves into deeper water and continental margins. The most recent stacks of these data will be displayed. Brute stacks of the data are of very high quality, clearly imaging the Moho beneath Rockall Bank and the Irish Shelf and the structure of the Rockall Trough. It is expected that considerable improvements will be made during processing which will include determinative deconvolution and multiple suppression using source signature data collected during profiling. After processing is complete we hope to be able to resolve lower crustal reflections beneath the trough which are currently obscured by multiples. Brute stacks compare favourably with existing data from the trough. Both margins of the trough are characterised by rotated fault blocks developed during the syn-rift phase of mid- to late-Cretaceous stretching. Post rift sediments form a thick sequence within the basin but do not show well developed marginal overstepping unconformities. The sediments are intruded by numerous sills.

SETTING UP DEEP REGIONAL PETROVELOCITY MODELS OF THE LITHOSPHERE BASED ON A SYSTEM ANALYSIS OF EXPERIMENTAL PT-DATA AND GEOLOGIC-GEOPHYSICAL INFORMATION 6/1

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The basis of petrovelocity PT-modeling is elastic parameter differentiation of mineral medium in respective thermobaric conditions of specific deep lithospheric stages. A system analysis of data of programmed laboratory PT-studies of elastic properties of rock collection samples taken along geophysical observation profiles and generalized combined geologic-geophysical information is made. Large-scale petrovelocity modeling of layered and block media uses statistically processed experimental data for corresponding genetic groups of surface rocks that are analogues of deep mineral associations. Methods of setting up petrovelocity section of some lithospheric blocks as the basis of deep regional petrophysical models are discussed.

OFFSET VSP DATA FROM THE KOLA SUPERDEEP BOREHOLE, WITH EMPHASIS ON ANISOTROPY 6/2

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Kola Working Group (University of Wyoming-University of Glasgow-University of Bergen)

The 12 km deep drillhole on the Kola Peninsula penetrate 7 km of Proterozoic rocks of the Pechenga structure and 5 km of the Archean basement in the Baltic shield. In 1992 scientists from the universities of Wyoming, Glasgow and Bergen together with representatives from the Ministry of Geology of the Russian Republic and the Institute of Physics of the Earth of the Academy of Sciences, Moscow, carried out a seismic data acquisition in and around the superdeep well. Two VSP's with different source offsets (200m and 2.08km) were recorded, covering the depth interval from 2150 - 6000 m. Clear shear-wave arrivals are observed, and the dataset is processed/analysed with special attention to the shear-waves. Forward modelling is performed in order to identify the different arrivals. $V_p/V_s$ ratios are inferred, and interpreted in terms of lithology. Shear-wave splitting is observed in the offset VSP-data, and the main polarization directions are determined. The orientation of the rock foliation is consistent with the observed polarization directions, and is therefore suggested to be the primary cause of the observed anisotropy.

## 6/3 DEEP STRUCTURE OF THE CRUST AND THE MINERAL PROGNOSTICATION AS THE RESULTS OF THE COMPOSITE GEOPHYSICAL RESEARCH OF THE URALS

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The deep structure of the Urals was studied by the reflection and refraction seismic, gravimetry and magnetics on the system of latitudinal profiles. Petrological research with using of the shothole cores have been conducted. The combined interpretations of the data of the seismic and magnetic surveys result to the cross-sections, which was assumed as a basis for the geological sections. DSS deep sections on the profiles have been kept within the bounds of the geodynamics conseptions.

It has been defined that the Urals is jointed with the East-European plate by the deep thrust of the eastward dipping. The basement of the plate is traced below the western part of the volcanic zone. The surface and deep structures do not inherit one another. There are many thrusts, which have been flattened in the bigger depths. Gabbro massifs were bedded into allochthon because they were moved up from the depth to surface by means of the deep thrust. The large blocks of the granite-gneiss have the asymmetry of the structure and substance. The rate of metamorphism of the granite-gneiss enlarges toward the thrusts. The massifs of the ultramafic represent the rootless bodies.

The nappes (klippes) of the Urals overlap to the sedimentary rocks of the Preural zone of the folding. The fold-thrust structure of the Urals were formed on conditions and at the time of the thrusting of the east blocks over the west ones. At that time the redipositionsof the earlier formed ore deposits of copper and iron took place.

A number of the coal-bearing depressions of the Mesozoic age were overlapped by the nappes (thrusts) of the Paleozoic rocks.

In the joint zones of the Urals with the East-European plate and the West-Siberian plate in the sedimentary rockshave been formed the thrust zones which have perspective for oil.

Main part of the earthquakes on the Urals are located on the Middle Urals in the region of the ledge of the East-European plate.

## 6/4 INTERPRETATION OF REFLECTIONS FROM THE CENTRAL PART OF THE SILJAN RING IMPACT STRUCTURE BASED ON RESULTS FROM THE STENBERG-1 BOREHOLE

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In 1984, 1985 and 1990 several multichannel seismic reflection profiles were shot over the Siljan Ring, believed to have been formed by a meteorite impact approximately 360 Ma ago. The bedrock of the area consists mainly of gneisses and granites and the ring itself of Palaeozoic sedimentary rocks lying on top of granites. Dolerite dikes of different age and orientation have been mapped in the area. The existence of dolerite intrusions at depth has been verified through the drilling of two deep boreholes, Gravberg-1 and Stenberg-1. Interpretation of seismic data and borehole data from the Gravberg-1 borehole showed a strong correlation between high-amplitude subhorizontal reflections and dolerite sills.

The drilling of the Stenberg-1 borehole was finished in 1993. Geophysical and geological well logging showed the occurrence of dolerites in the borehole. Profile 4, running E-W over the borehole, has been reprocessed in order to improve the seismic image. Several thick dolerites below 4 km in the borehole correlate with higher amplitude reflectors on the seismic section. Both the logging data and the seismic interpretation support the idea that these intrusions are subhorizontal and laterally continuous. Above 4 km in the borehole, the dolerites are thinner and are in some cases associated with fracture zones. On the seismic section at these depths there is a complex system of dipping reflectors. Some of these dipping reflectors correlate to either fracture zones, thin dolerites or a combination of both. Detailed investigations on the waveform of the reflections are needed in order to determine their true source.

## Reflectivity Characterestics of the Crust from Modeling Refraction/Wide-angle Reflection and Normal-incidence Reflection Data on BABEL Line 1 6/5

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Marine normal-incidence reflection and refraction/wide-angle reflection data from the BABEL project, Line 1, in the Bothnian Sea have been used for investigating the nature of the reflectivity in the area. The data are available along the same line, and therefore the same piece of crust is probed by two seismic methods. We utilize this favorable circumstance for detailed model calculations concerning both data sets, focusing on the upper and lower crust and the Moho.
Strong subhorizontal reflections are observed on the normal-incidence reflection section at about 4 sec. The seismograms have been stacked and show a positive polarity for these reflections. These reflections have been modelled with a 1-D reflectivity method using a Ricker wavelet source.
Thickness and P-wave velocity consistent with these reflections appear to be about 200 m and 7. km/s, repectively, with a host rock velocity of 6. km/s. From the polarity, velocity and thickness. these reflections have attributed to dolerite sills in the upper crust.
Strong lower-crustal reflections are observed on the wide-angle and normal-incidence reflection sections. These reflectious appear to have a positive polarity on the normal incidence-reflection data while the wide-angle reflection data indicate a sharp velocity increase. The implied high impedance contrast of the lower-crustal reflections indicate the lower to be highly mafic. However. the waveforms obtained after stacking of seismograms show a complex pattern, implying the boundary is not just a simple interface.
Wide-angle P and S-wave reflection sections show a high impedance contrast for the Moho while the normal-incidence reflection section show a poor impedance contrast. A laminar structure may explain these observations.

## VISUALIZING SEISMIC WAVE PROPAGATION IN THE LITHOSPHERE 6/6

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B.O. Ruud (Institute of Solid Earth Physics, Allégaten 41, Bergen, Norway)
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E.S. Husebye (Institute of Solid Earth Physics, Allégaten 41, Bergen, Norway)

Video showing seismic wave propagation in a sequence of lithospheric models;

1) Homogeneous one layered crust over a halfspace.

2) Homogeneous, multilayered lithosphere model.

3) Multilayered model subjected to RMS velocity pertubations of 1.5 per cent.

Each sequence comprise nearly 3000 snapshot frames showing forward P andS propagating wavefronts, Moho and free surface reflections and P-to-S coversions etc. For the perturbed models, scattering effects dominated by P-to-S conversions are clearly visualized. In our opinion the video display provides an exceptional clear insight in seismic wave propagation in a non-homogeneous lithospere. Computational details on the 2D finite difference method used in computing the synthetics are given in the Husebye, Hestholm and Ruud presentation (ibid).

## 6/7 DEEP SEISMIC REFLECTION PROFILING OF THE PINJARRA OROGEN AND ADJACENT YILGARN CRATON, WESTERN AUSTRALIA

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Seismic reflection profiles across the Proterozoic Pinjarra Orogen and the Archaean Yilgarn Craton indicate that the proto-Darling Fault which separates the two regions extends to the Moho. Suspect terrane boundaries within the Yilgarn Craton, postulated on geological evidence, coincide with strong east-dipping reflections that extend to 2.5 s TWT, where there appears to be a detachment surface.

Data from the Pinjarra Orogen resemble those from other areas where major strike-slip structures occur e.g. the Caledonides-Appalachians of Scotland and eastern Canada. Suspect terranes have also been recognised in the Pinjarra Orogen and our data suggest accretion by strike-slip movements. Terranes of both ages contributed to the development of the Phanerozoic Perth Basin which overlies the rocks of the Pinjarra Orogen.

# AUTHOR INDEX

# THREE-DIMENSIONAL STRUCTURE OF LATERAL VELOCITY VARIATIONS IN THE UPPER MANTLE OF THE SOUTHERN MARGIN OF SIBERIA ACCORDING TO TELESEISMICAL DATA.

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A three dimensional model of lateral variations of P-wave velocities in the upper mantle of Southern margin of Siberia has been obtained using more than 10000 teleseismical arrival times registered at the stations of Siberia and Kazakhstan. The method was based on the triangulate block parameterization and permits to accord the output information with the density of input information. The inversion stability has been improved significantly compared to traditional approaches. Special attention was paid to the problem of testing the obtained results. The study of stability of the method (sensitivity of results toward noise) shows that the reconstruction was stable even if the noise level exceeded the relevant signal. Another test consisted in a reconstruction using two independent sets of events. For these two sets determined velocity structures were found in satisfactory coincidence. The preliminary interpretation of the results permits to suggest some mechanisms of development of the lithosphere in the study region. According to the obtained tomographic image the upper mantle has a clear convective structure. Two positive velocity anomalies, which are interpreted as descending flows are well correlated with regions of recent mounting building of Altai and Sayan.

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2. 4
3. No required
4. O

(Poster)

**Seismic Anisotropy of the Uppermost Mantle in Southern Germany**

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S Sobolev and K Fuchs (Both at: Geophysikalisches Institut, Universität Karlsruhe, Germany)

This paper presents an updated anisotropy interpretation for the uppermost mantle in southern Germany. The dense network of reversed and crossing refraction profiles in this area made it possible to observe almost 900 travel times of the $P_n$ phase which could be effectively used in a time-term analysis to determine horizontal velocity distribution immediately below the Moho. For 12 crossing profiles, amplitude ratios of the $P_n$ phase compared to the dominant crustal phase were utilized to resolve anisotropy (velocity) gradients with depth.

A P-wave anisotropy of 3-4% in a horizontal plane immediately below the Moho at a depth of 30 km increasing up to 10% at a depth of 40 km was determined. For the axis of the highest velocity of about 8.03 km/s at a depth of 30 km a direction of N31°E was obtained. The azimuthal dependence of the observed $P_n$ amplitude is explained by an azimuthal dependent sub-Moho gradient decreasing from 0.06 $s^{-1}$ in the fast direction to 0 $s^{-1}$ in the slow direction of P-wave velocity.

From the seismic results in this study (including the absence of the $S_n$ phase) a petrological model suggesting a change of modal composition and percentage of oriented olivine with depth was derived.

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## DEEP REFLECTION SEISMOGRAPHY IN STUDYING THE LITHOSPHERE UKRAINE

A.V. Chekunov, A.A. Tripolsky, O.M. Kharitonow (All- Institute of Geophysics, National Academy of Sciences of Ukraine, 32, Palladin av., 252680, Kiev-142, Ukraine).

Seismic studies of consolidated crust made for several decades in the Ukraine widely used the reflection method in different modifications. In the Ukrainian shield the reflection-CDP studies were made at its north, southwest and south slopes, in the Bug area, within the early proterozoic Krivoy Rog-Kremenchug and Oura synclinoria, Korsun'-Novomirgorod pluton and Novoukrainka massif. The wave fields observed have a discrete "hatched" structure and are represented by short dynamically not steadfast synphasis axes. High effectivity of reflection-CDP seismics in studying Ukrainian shield lithospheric structure is proved. Comparisons of the results of studies of the lithosphere of Ukrainian shield obtained by reflection and CDP methods with those of similar studies in the areas of postriphean consolidation show no principal difference between them. This creates favourable conditions for setting up principled similar seismic models of the consolidated crust irrespective of the age of the last folding.

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2. Seismic reflection studies of the Precambrian crust.
3. No required equipment in addition to standard
4. Preference for oral (O) presentation.

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