

ILP Proposal:

Lithosphere-Asthenosphere interactions

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ILP program themes: 3. Continental lithosphere and 4. Oceanic lithosphere

1. Scientific rationale

This ILP project will focus on the interaction between the lithosphere, the outer shell on which we live, and the asthenosphere and/or deep mantle. The dynamic processes of the Earth's interior affect our day-to-day life in a profound way. Convection in the mantle shapes the Earth's surface through plate tectonics, giving rise to mountain ranges, oil-rich sedimentary basins and mineral-rich crust. It also controls catastrophic events such as earthquakes, landslides, tsunamis and volcanic eruptions. Yet, until recently, mantle convection and its surface expression – plate tectonics – have been studied as independent systems. In convection studies, plates were generally considered as rigid rafts dragged along by the convecting mantle. On the other hand, "lithospheric" studies focused on the motion and deformation of the plates, solely represented by slab pull, ridge push, or basal drag forces.

New developments, particularly in the fluid mechanics community, have strongly changed this scenario. Indeed, the last decade has seen a clear evolution of our understanding of how plate tectonics is produced by mantle convection. A new generation of convection models has been developed in which the cold upper boundary layer of mantle convection behaves as rigid, plate-like segment bounded by narrow weak domains. However, many problems remain to be solved. Plate generation in convection models requires "exotic" lithospheric rheologies, which are not observed in deformation experiments on mantle and crustal rocks. Although the subduction - the sinking of old, cold oceanic plates into the mantle - is the most evident record of mantle convection, many aspects of this process, in particular its asymmetry and initiation, are still not understood. Moreover, seismic anisotropy measurements suggest a decoupling between the subducting slab and the underlying trench-parallel mantle flow. Finally, the temporal evolution of the convecting system is poorly known. How do continental plates and, in particular, the ancient cratonic roots form? How do they interact with the convection? Which processes control their stabilization or erosion?

Answers to many of these questions depend on a better understanding of the physico-chemical interactions between the lithosphere and the deep mantle. In addition to the new developments in fluid dynamics and convection models, significant advances on this subject have been made in recent years by both the geophysical and the geochemical communities that have challenged previously held ideas, provoked new controversies and even re-kindled some old ideas.

In geophysics, dense seismic networks are now giving unprecedented coverage and resolution in studies of the small-scale (order of 100 km) structure of the upper mantle. Seismic and large-period magnetotelluric surveys reveal large-scale seismic and electrical anisotropy patterns, which allow us to infer the flow patterns in the lithosphere and asthenosphere. New torsion devices for high-temperature, high-pressure experimental deformation of mantle rocks allow the study of the effect of strain on the upper mantle rheology and the investigation of strain-softening mechanisms.

Likewise, recent geochemical and petrological studies of mantle xenoliths and ultramafic massifs highlight the role of magma-rock reactions in lithosphere-asthenosphere interaction processes. These studies show that reactive flow of melts into lithospheric peridotites may lead to profound changes in the composition and microstructure of these peridotites, and hence modify the physical properties of the mantle. Geochemical data provides evidence for the longevity and stability of cratons since the Archaean (Kaalvaal and Siberia). In contrast some cratons, like the north China craton, have been completely eroded during the Phanerozoic due to thermo-tectonic processes.

2. Project goals

Each of the above-cited studies sheds light onto a small part of the complex physico-chemical interaction between the lithosphere and the deep mantle. It is now time to bring together scientists from a large range of backgrounds (geodynamics, mineral physics, seismology, petrophysics, magnetotellurics, petrology, and geochemistry) in order to build a more complete picture of the physico-chemical processes that shape the lithosphere.

The time is ideal for a collaborative ILP project on "**Lithosphere-asthenosphere interactions**" as there have been multiple recent step-like improvements in our understanding of the role of the plate (or lithosphere) in mantle convection and of how physico-chemical interactions with deeper layers modify the lithosphere structure and composition. This project should allow us to build a multi-national and pluridisciplinary workgroup. We hope to exploit the synergy in such a mixed group and foster collaborations, which will lead to new advances in the field, joint grant applications and joint publications.

3. Duration: 5 years

4. Scientific Committee

Andréa Tommasi	Univ. Montpellier, France	geodynamics, tectonics
Michael Kendall	Univ. Leeds, UK	seismology
Carlos Garrido	Univ. Granada, Spain	petrology/geochemistry

Jean-Louis Bodinier	Univ. Montpellier, France	geochemistry
Marie-Pierre Doin	ENS Paris, France	numerical modeling, mantle convection
Cynthia Ebinger	Royal Holloway, UK	geodynamics, rifting processes
Ben Holtzmann	Lamont Earth Observ., US	geodynamics, mantle rheology
Lucia Margheriti	IGN, Italy	seismology
Martin Menzies	Royal Holloway, UK	geochemistry
Martha Savage	Univ. Wellington, NZ	seismology
Paul Silver	Carnegie Institution, US	seismology
Fiona Simpson	Univ. Goettingen, DE	magnetotellurics
Doug Toomey	Univ. Oregon, US	seismology
Alain Vauchez	Univ. Montpellier, France	structural geology, geodynamics

5. Proposed Activities

We plan to organize the activities of this project around three types of meetings:

- biannual workshops, which main objectives are to foster the development of interdisciplinary and international collaborations and to favor the integration of young researchers in high-level scientific collaborations, by facilitating cross-disciplinary discussion at all levels. In order to promote scientific interaction, these workshops will be limited to 50-80 participants.
- working groups on hot topics (10 participants) to collaborate on specific subjects. These workgroups will be a natural outcome from the workshops.
- thematic symposiums in large meetings, like AGU or EGU, which aim is to present the project and its results to a larger audience in the Earth Sciences community.

Provisional workplan 2005-2009

2005

June 2005 - 1st Lithosphere – Asthenosphere Interaction Workshop at Fréjus, France
(see enclosed draft program)

- aim: define the state-of-the-art on the subject, identify hot topics, and organize multidisciplinary working groups for each topic, decision on the proposal of a thematic symposium at EGU 2006

July 2005: build up web site, discussion list, and project ftp site for data exchange between working groups

December 2005: internet-based discussion on the first results of working groups

2006

January or February 2006 (date still not fixed) – Société Géologique de France meeting
"La lithosphere continentale"

April 2006 – EGU – Lithosphere-Asthenosphere thematic symposium

Working group meetings: evaluation of the results / new directions
definition of the program of the 2nd Workshop

November 2006 – internet-based discussion on the results of working groups

2007

June 2007 - 2st Lithosphere – Asthenosphere Interaction Workshop

December 2007: internet-based discussion on the results of working groups, evaluation of the project

2008

June 2008 – internet-based discussion on the results of working groups

December 2008 – AGU – Lithosphere-asthenosphere interaction session

Working group meetings: evaluation of the results / new directions;
definition of the program of the 3nd Workshop

2009

June 2009 - 3st Lithosphere – Asthenosphere Interaction Workshop

Call for the 1st Lithosphere – Asthenosphere Interaction Workshop planned in Fréjus, France - 29 Mai - 2 June 2005

This first workshop will focus on the physico-chemical interactions between the lithosphere and the deep mantle. Through a series of assisted keynote presentations from senior and junior researchers on the theory, geophysics, geochemistry, and/or the experimental background to lithosphere-asthenosphere interactions, we aim to: (1) present state-of-the art developments in our understanding of the deep Earth (2) promote multi-disciplinary collaborations (3) expose young scientists and non-specialists to the wider relevance of their own research. We aim to achieve this goal by associating a series of keynote presentations, a few selected oral presentations by outstanding young researchers, poster sections, and discussion forums.

The program, whose main points are listed below, aims to bring together scientists from the following fields of study: seismology, mineral physics, geochemistry, petrology, and fluid dynamics. Many invited speakers will have expertise in more than one of these areas.

(1) Plates in mantle convection:

- Plate tectonics and mantle convection as seen by global seismic tomography
- Recycling and processing of lithosphere into the mantle on local and global scales and the geochemical evolution of the Earth's mantle
- Self-consistent plate generation in convection models
- Rheology of solid and partially molten mantle lithosphere and plate-like behavior: strain-softening mechanisms within the lithosphere; constraints from experimental data and analysis of naturally deformed upper mantle rocks

(2) Thermo-mechanical interactions at the lithosphere-asthenosphere boundary

- Mechanical coupling (or decoupling) at the lithosphere-asthenosphere boundary; *in-situ* mantle tectonics seen through regional measurements of seismic and electrical (MT) anisotropy
- Small-scale convection: thermo-mechanical erosion of the lithosphere
- Stability of cratonic roots; constraints from numerical models and geochemical observations

(3) Partial melting and the uppermost mantle composition: mantle-melt reactions during melt generation, segregation and transport

- melting/reaction fronts in mantle rocks
- modeling mantle-melt reactions during melt migration with implications for the mechanisms of melt transport in the upper mantle
- composition, stability fields, reactivity, and physical and transport properties of lithospheric fluids.
- effect of mantle compositional heterogeneities on physical properties of mantle rocks

Lithosphere-Asthenosphere Interaction Workshop 2005
Draft Scientific Programme (speaker names are only indicative)

Chairperson: Andrea Tommasi (Univ. Montpellier, France)

Scientific Committee:

Jean-Louis Bodinier (France)

Carlos Garrido (Spain)

Fiona Simpson (Germany)

David Mainprice (France)

J. Michael Kendall (UK)

Lucia Margheritti (Italy)

Cynthia Ebinger (UK)

Marie-Pierre Doin (France)

Benjamin Holtzmann (US)

Martin Menzies (UK)

Day 1: Plates in mantle convection

Morning session: Large-scale processes

9h-9h15: Welcome and general presentation

9h15-10h00: Invited presentation: *The generation of plate tectonics in mantle convection models*
to be defined

10h30-11h30: Assisted keynote presentation: *Experimental constraints on the lithosphere rheology: Strain-softening mechanisms at the sample and the lithosphere-scale?*
Luigi Burlini (Italian, ETH Zürich, CH) + Ph.D Student
or Martin Drury (British, Utrecht, NL) + Ph.D Student

11h30-12h30: Assisted keynote presentation: *Large-scale mantle convection and plate motions*
Julian Lowman (Canadian, Univ. Leeds, UK) + Ph.D Student

Afternoon session: Thermo-mechanical interactions at the lithosphere-asthenosphere boundary

15h30-16h30: Assisted keynote presentation: *Mechanical coupling/ decoupling at the lithosphere – asthenosphere boundary: evidence from seismic anisotropy*
Alain Vauchez (French, Univ. Montpellier, F) + Ph.D Student

16h30-17h30: Assisted keynote presentation: *Electrical anisotropy recorded by large-period-magnetotelluric data: an additional tool for unraveling the upper mantle flow pattern?*
Fiona Simpson (British, Univ. Goettingen, D) + Ph.D Student

17h30-18h30: Assisted keynote presentation: *Thermo-mechanical interactions at the lithosphere-asthenosphere boundary: small-scale convection and lithosphere erosion*
Marie-Pierre Doin (French, ENS Paris, F) + Ph.D Student

18h30-19h30: Short presentations of posters

19h30-21h: Poster session

Day 2: Partial melting, melt-rock reactions, and the nature of the lithospheric mantle

9h-10h: Assisted keynote presentation: *Melting/reaction fronts in mantle rocks: a moving lithosphere-asthenosphere boundary?*

Jean-Louis Bodinier (French, Univ. Montpellier, F) + PhD student

10h-11h: Assisted keynote presentation: *Melt production, accumulation and transport in the upper mantle : insights from the U-Th series*

Tim Elliot (British, Univ. Bristol, UK) + Ph.D student

11h-12h30: Poster session

16h30-17h30: Invited presentation: *Melt transport mechanisms in the upper mantle: Constraints from experimental petrology*

U. Faul (German, ANU, AU)

17h30-18h30: Invited presentation: *Physical models of melt transport in the mantle*

B. Holtzmann (American, Lamont Obs., US)

18h30-19h: Young scientist presentation: *Numerical models of reactive melt transport*

Laurent Montési (French, presently on postdoc at WHOI, US)

19h-19h30: Discussion

Day 3: Lithosphere-asthenosphere interaction: Case-studies

9h-10h: Assisted keynote presentation: *The supra-subduction mantle wedge from a petrological and geochemical view point*

Ian Parkinson (British, Milton Keynes, UK) + Ph.D Student

10h-11h: Assisted keynote presentation: *The lithospheric root of a volcanic arc*

Carlos Garrido (Spanish, Univ. Granada, Spain) + Ph.D student

11h-12h30: Short oral communications

16h30-17h30: Assisted keynote presentation: *Plume-lithosphere interactions and continental rifting*

Cindy Ebinger (American, Royal Holloway, UK) + Ph.D Student

17h30-18h30: Assisted keynote presentation: *Melt/rock interactions and seismic properties of the lithospheric mantle above mantle plumes*
Andréa Tommasi (Italian, Univ. Montpellier , F) + Ph.D Student

18h30-19h30: Wrap-up of the session: *Partial melting, mantle-melt reactions, and the nature of the lithospheric mantle*

19h30-21h30: Special forum: *Evaluation of the strengths and weaknesses of the meeting and discussion of the program of the next meeting*

Day 4: Cratonic roots

9h-10h: Assisted keynote presentation: *Lithosphere-asthenosphere interaction: from metasomatism and melting to craton destruction.*
Martin Menzies (British, Royal Holloway, UK) + PhD student

10h-10h30: Young scientist presentation: *Erosion of cratonic roots in a convecting mantle: Insights from numerical modeling*
Caroline Dumoulin (French, Univ. Nantes, F)

10h45-12h30: Discussion forum: *The nature of cratonic roots as seen by geophysics, petrology-geochemistry, and petrophysics*
Moderators: M. Kendall, M. Menzies, and A. Tommasi

Andréa TOMMASI

CNRS research fellow, Lab. Tectonophysique, Université Montpellier II, France

Born October 22nd 1965 in Ponta Grossa, Brazil
Italian and Brazilian nationalities

Current research activities: Mantle dynamics

- Analysis of the relationships between mantle flow and the anisotropy of its physical properties:
 - multi-scale numerical models of the development of olivine crystallographic orientations and seismic anisotropy in the upper mantle
 - numerical models and experimental measurements of the anisotropy of thermal diffusivity in the upper mantle
 - strain-induced mechanical anisotropy in the upper mantle: the effect of the preexisting structure of the lithosphere on continental rifting
 - deformation and seismic anisotropy in the deep mantle
- Plume - lithosphere interactions: Polynesian Lithosphere and Upper Mantle experiment (PLUME)
 - effect of reactive melt percolation on the seismic properties of the lithospheric mantle

Employment record

1998-present: CNRS Research Fellow at Lab. Tectonophysique, Univ. Montpellier II

1996-1998: Research Fellow at Univ. Leeds, UK – EEC Marie Curie postdoctoral scholarship

1996: Teaching assistant at Univ. Lyon I

Education:

Ph.D. in Earth Sciences, Université Montpellier, France, 1995

M.Sc in Earth Sciences, Universidade Federal do Rio Grande do Sul, Brazil, 1992

B.Sc in Earth Sciences, Universidade Federal do Rio Grande do Sul, Brazil, 1988

Selected publications

- 1994 - **Tommasi, A.**; Vauchez, A.; Fernandes, L.A.D. & Porcher, C.C. Orogen-parallel strike-slip faulting and synkinematic magmatism in the Dom Feliciano Belt, Southern Brazil. *Tectonics*, **13**: 421-437.
- 1995 - **Tommasi, A.**; Vauchez, A. & Daudré, B. Initiation and propagation of shear zones in a heterogeneous continental lithosphere. *Journal of Geophysical Research*, **100**: 22,083-22,101.
- 1996 - **Tommasi, A.**; Vauchez, A. & Russo, R. Seismic anisotropy in ocean basins: Resistive drag of sublithospheric mantle? *Geophysical Research Letters*, **23**: 2991-2994
- 1997 - **Tommasi, A.** & Vauchez, A. Complex tectono-metamorphic patterns in continental collision zones: The role of intraplate rheological heterogeneities. *Tectonophysics*, **279**: 327-350.
- 1998 - **Tommasi, A.** Forward modeling of the development of seismic anisotropy in the upper mantle. *Earth and Planetary Science Letters*, **160**:1-13.
- 1999 - **Tommasi, A.**, Tikoff, B. & Vauchez, A. Upper mantle tectonics: Three-dimensional deformation, olivine crystallographic fabrics and seismic properties. *Earth and Planetary Science Letters*, **168**: 173-186.
- 2000 - **Tommasi, A.**; Mainprice, D., Canova, G. & Chastel, Y. Viscoplastic self-consistent and equilibrium-based modeling of olivine lattice preferred orientations. Implications for the upper mantle seismic anisotropy. *Journal of Geophysical Research*, **105**: 7893-7908
- 2001 - **Tommasi, A.** & Vauchez, A. Continental rifting parallel to ancient collisional belts: An effect of the mechanical anisotropy of the lithospheric mantle *Earth and Planetary Science Letters*, **185**: 199-210.
- 2001 - **Tommasi, A.**, Gibert, B., Seipold, U. & Mainprice, D. Anisotropy of thermal diffusivity in the upper mantle. *Nature*, **411**: 783-786.
- 2003 - Vauchez, A. & **Tommasi, A.** Wrench faults down to the asthenosphere: Geological and geophysical evidence and thermo-mechanical effects. In: Storti, F. Holdsworth, R.E. & Salvini, F. (eds) *Intraplate Strike-Slip Deformation Belts*, Geol. Soc. London Spec. Publ., **210**, 15-34.
- 2004 - **Tommasi A.**, Godard M., Coromina G, Dautria J.M. & Barczus H. Seismic anisotropy and compositionally-induced velocity anomalies in the lithosphere above mantle plumes: A petrological and microstructural study of mantle xenoliths from French Polynesia. *Earth Planet Sci.Lett.* **227**(3-4): 539-556
- In press - **Tommasi A.**, Cordier, P.; Mainprice, D.; Thoraval, C. & Couvy, H. Strain-induced seismic anisotropy of wadsleyite polycrystals: constraints on flow patterns in the mantle transition zone. *J. Geophys.Res.*,
- Accepted - Mainprice, D.; **Tommasi A.**, Couvy, H. & Cordier, P. Pressure sensitivity of olivine slip systems: implications for the interpretation of seismic anisotropy of the Earth's upper mantle. *Nature*
- + 23 articles and 60 communications in international meetings

John-Michael Kendall

Professor of Seismology, University of Leeds, UK

Research Interests

Global, exploration and theoretical seismology with an emphasis on seismic anisotropy.

Current research in global geophysics concentrates on the structure of the lowermost-mantle, mid-ocean ridges and subduction zones. This research involves concurrent data analysis and waveform modelling. In exploration seismology, my interests lie in microseismicity, rock-fracture characterization and salt anisotropy.

Employment History

2002-present Professor of Seismology, School of Earth Sciences, University of Leeds, UK.

1999-2002 Reader in Geophysics, School of Earth Sciences, University of Leeds, UK.

1995-1999 University Research Fellow, School of Earth Sciences, University of Leeds, UK.

1993-1995 Assistant Professor, Department of Physics, University of Toronto, ON, Canada.

1992-1993 Postdoctoral Research Fellow, IGPP, Scripps Institution Oceanography, CA, USA.

1984-1986 Geophysicist, Chevron Canada Resources Limited, Calgary, AB, Canada.

Education

1984, BSc, Geophysics, Queen's University, Kingston, ON, Canada.

1991, PhD, Geophysics, Queen's University, Kingston, ON, Canada.

Dissertation: Contributions to the theory and modelling of seismic waves in anisotropic inhomogeneous media. Supervisor: Colin Thomson

Notables

1992-1993 Green's Scholar, IGPP, Scripps Institution of Oceanography, La Jolla, CA

1992 Postdoctoral Fellowship, Natural Sciences and Engineering Research Council of Canada

1993 Young Scientist's Publication Award - European Geophysical Society

1996-2000 Associate editor of the Journal of Geophysical Research

1998-present Committee member of the British Geophysical Association

2001 Bernstein Scholar in Residence, Carleton College, Minnesota

2002-present Secretary of the UK IUGG panel

2002-present UK representative to the International Association for Seismology and Physics of the Earth's Interior

2003 Bullerwell lecturer

Publications of Michael Kendall

Parts of Books (Refereed)

- (1) Spencer, C., W. S. Guest, J-M. Kendall and B. Milkereit, A three-component seismic investigation of the eastern Greenland margin: modelling heterogeneity and anisotropy, *Proceedings of the Commission of Controlled Source Seismology: Workshop meeting on seismic studies of laterally heterogeneous structures - interpretation and modelling of seismic data*, ed. E. Flüh, University of Kiel Press, Kiel, FRG, 1991.
- (2) Kendall, J-M. and P. G. Silver, Investigating causes of D'' anisotropy, invited paper for *Core-mantle boundary region*, eds. M. Gurnis, M. Wyssession, E. Knittle and B. Buffet, Geodynamic Series, 28, 97-118, Washington D. C., U.S.A., American Geophysical Union, 1998.
- (3) Blackman, D. K. and J-M. Kendall, Sensitivity of teleseismic body waves to mineral texture and melt in the mantle beneath a mid-ocean ridge, *Mid-ocean ridges; dynamics of processes associated with creation of new ocean crust*, eds. J.R. Cann, H. Elderfield, and A. Laughton, Cambridge University Press, Cambridge, UK, 1-15, 1999.
- (4) Kendall, J-M., Seismic anisotropy in the boundary layers of the Earth's mantle, invited chapter for *Earth's Deep Interior: Mineral Physics and Tomography from the Atomic to the Global Scale*, eds. S. Karato, L. Stixrude, R. C. Liebermann, T. G. Masters and A. M. Forte, Geophysical Monograph Series 117, American Geophysical Union, 149-175, 2000.
- (5) Hall, S. A. and J-M. Kendall, Constraining the interpretation of AVOA for fracture characterisation, in *Anisotropy 2000: Fractures, Converted Waves, and Case Studies*, eds. L. Ikelle and A. Gangi, Society of Exploration Geophysics, Tulsa, USA, 107-144, 2000.
- (6) Hall, S. A., R. R. Kendall, J-M. Kendall and C. Sondergeld, Analysis of anisotropic velocities in a core sample and AVOA from a fractured vuggy carbonate reservoir, in *Anisotropy 2000: Fractures, Converted Waves, and Case Studies*, eds. L. Ikelle and A. Gangi, Society of Exploration Geophysics, Tulsa, USA, 257-269, 2000.
- (7) Sleep, N., C. J. Ebinger and J-M. Kendall, Deflection of mantle plume material by cratonic keels, *The early Earth: physical, chemical and biological development*, eds C.M.R. Fowler, C.J. Ebinger and C.J. Hawkesworth, Geol. Soc. London. – Spec. Pub., 199, 135-150, 2002.
- (8) Kendall, J-M., S. Sol, C. J. Thomson, D. E. White, I. Asudeh, C. S. Snell and F. H. Sutherland, Seismic heterogeneity and anisotropy in the Superior Province, Canada: Insights into the evolution of an Archaean craton, *The early Earth: physical, chemical and biological development*, eds C.M.R. Fowler, C.J. Ebinger and C.J. Hawkesworth, Geol. Soc. London – Spec. Pub., 199, 27-44, 2002.
- (9) G. E. Lloyd and J-M. Kendall, Petrofabric derived seismic properties of a mylonitic quartz simple shear zone: Implications for seismic reflection profiling, in press, *Petrophysical Properties of Crystalline Rocks*, eds. Peter Harvey, Tim Brewer, Phillippe Pezard and Vladislav Petrov Geol. Soc. London – Spec. Pub., 2003.

(10) Kendall, J-M., D'' anisotropy, submitted to *Encyclopedia of Geomagnetism and Paleomagnetism*, eds. D. Gubbins and E. Herrero-Bervera, Kluwer Press, Utrecht, Netherlands, 2003.

Papers in Refereed Journals

(11) Kendall, J-M. and C. J. Thomson, A comment on the form of the geometrical spreading equations, with some numerical examples of seismic ray tracing in inhomogeneous, anisotropic media, *Geophys. J. Int.*, *99*, 401-413, 1989.

(12) Guest, W. S., C. J. Thomson and J-M. Kendall, Degenerate perturbation theory for S-wave polarisation on splitting rays, *Geophys. J. Int.*, *108*, 372-378, 1992.

(13) Thomson, C. J., J-M. Kendall and W. S. Guest, Geometrical theory of shear-wave splitting: Corrections to ray theory for interference in isotropic/anisotropic transitions, *Geophys. J. Int.*, *108*, 339-363, 1992.

(14) Kendall, J-M., W. S. Guest, and C. J. Thomson, Ray theory Green's function reciprocity and ray-centered coordinates in anisotropic media, *Geophys. J. Int.*, *108*, 364-371, 1992.

(15) Kendall, J-M. and C. J. Thomson, Seismic modelling of subduction zones with inhomogeneity and anisotropy, I: Teleseismic P-wavefront geometry, *Geophys. J. Int.*, *112*, 39-66, 1993.

(16) Kendall, J-M. and C. J. Thomson, Maslov ray-summation, pseudocaustics, Lagrangian equivalence and transient seismic waveforms, *Geophys. J. Int.*, *113*, 186-214, 1993.

(17) Guest, W. S. and J-M. Kendall, Modelling waveforms in anisotropic inhomogeneous media using ray and Maslov asymptotic theory: applications to exploration seismology, *Can. J. Expl. Geophys.*, *29*, 78-92, 1993.

(18) Blackman, D. K., J. A. Orcutt, D. W. Forsyth and J-M. Kendall, Seismic anisotropy in the mantle beneath an oceanic spreading center, *Nature*, *366*, 675-677, 1993.

(19) Kendall, J-M., Teleseismic arrivals at a mid-ocean ridge: Effects of mantle melt and anisotropy, *Geophys. Res. Lett.*, *21*, 301-4, 1994.

(20) Kendall, J-M. and P. M. Shearer, Lateral variations in D'' thickness from long-period shear wave data, *J. Geophys. Res.*, *99*, 11575-11590, 1994.

(21) Blackman, D. K., J. A. Orcutt, D. W. Forsyth and J-M. Kendall, Comment on "Seismic anisotropy in the mantle beneath an oceanic spreading center", *Nature*, *376*, 418, 1995.

(22) Kendall, J-M. and P. M. Shearer, Structure of the lowermost mantle beneath the southwest Pacific, southeastern Asia and Australasia, *Phys. Earth Planet. Int.*, *92*, 85-98, 1995.

(23) Kendall, J-M. and C. Nangini, D'' beneath the Caribbean and Central America, *Geophys. Res. Lett.*, *23*, 399-402, 1996.

(24) Kendall, J-M. and P. G. Silver, Constraints from seismic anisotropy on the nature of the lowermost mantle, *Nature*, *381*, 409-412, 1996.

(25) Blackman, D. K., J-M. Kendall, P. Dawson, R. Wenk, D. Boyce and J. Phipps Morgan, Teleseismic imaging of subaxial flow at mid-ocean ridges: Travel-time effects of anisotropic mineral texture in the mantle, *Geophys. J. Int.*, *127*, 415-426, 1996.

- (26) Kendall, R. R. and J-M. Kendall, Shear-wave amplitude anomalies in south-central Wyoming, *Leading Edge*, 15, 913-920, 1996.
- (27) Blackman, D. K. and J-M. Kendall, Sensitivity of teleseismic body waves to mineral texture and melt in the mantle beneath a mid-ocean ridge, *Phil. Trans. Roy. Soc. London, A*, 355, 217-231, 1997.
- (28) Kendall, J-M. and P. G. Silver, Mechanisms for seismic anisotropy in the lowermost mantle, *Mineral. Mag.*, 62A, 761-762, 1998.
- (29) Raymer, D. G. and J-M. Kendall, Seismic anisotropy in salt structures due to preferred crystal orientation, *La Revue de l'IFP*, 53, 35-43, 1998.
- (30) Caddick, J., J-M. Kendall and D. G. Raymer, Maslov shear-waveforms in highly anisotropic shales and implications for shear-wave splitting analyses, *La Revue de l'IFP*, 53, 64-71, 1998.
- (31) Harwood, S., P. S. Rowbothom, I. Bush, P. R. Williamson, H. Houllevigue and J-M. Kendall, Analysis of AVOA for determination of fracture orientation, *La Revue de l'IFP*, 53, 60-64, 1998.
- (32) Huang, X., G. F. West and J-M. Kendall, A Maslov-Kirchhoff seismogram method, *Geophys. J. Int.*, 132, 595-602, 1998.
- (33) Huang, X., J-M. Kendall, C. J. Thomson and G. F. West, A comparison of the Maslov integral seismogram and the finite difference method, *Geophys. J. Int.*, 132, 584-594, 1998.
- (34) Raymer, D. G., J-M. Kendall, G. J. Beaudoin, M. C. Mueller and R. R. Kendall, Measuring the anisotropy of salt in the Mahogany oil field, Gulf of Mexico, *AAPG Bulletin*, 65, 1335-1337, 1999.
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- (64) Kendall, J-M. and W. S. Guest, Modelling seismic waveforms in anisotropic media using Maslov asymptotic theory, *Proceedings of the 63rd Annual Int. Meeting of the Soc. Expl. Geophys.*, S4.3, Washington, D. C., 860-863, 1993.
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(88) Kendall, J-M., Raymer, D. G., and A. Tommasi, Investigating the seismic implications of salt anisotropy, research report for Shell International Exploration and Production, 64pp, 1998.

(89) Van der Baan and J-M. Kendall, Imaging of sub-basalt structures using converted waves, research paper for Fugro - GeoTeam, UK. 13pp, 2000.

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(92) Van der Baan and J-M. Kendall, Traveltimes, conversion points and parameter estimation in layered, anisotropic media, II, research paper for Shell UK Exploration and Production, 100pp, 2002.

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Citizenship: Born in Jaén (Spain) on January 16, 1968; Spanish citizenship; Married. Two children.

EDUCATION

- 1995 Ph.D. in Geological Sciences; Dep. Petrology, University of Granada, Spain. Thesis advisors: Prof. Dr. F. Gervilla & Prof. Dr. José Torres-Ruiz; Subject: Petrology of Mafic Rocks from the Ronda Ultramafic Massif; Grade: Cum Laude by Unanimity.
- 1990 B.S. Geological Sciences ('Licenciatura'), University of Granada, Spain; Grade: Honors.

POSTDOCTORAL PROJECTS

- 1998-2000: Laboratoire de Tectonophysique. ISTEEM, Montpellier, France. Advisor: J.L. Bodinier: a) constraints on the chemical and mechanical erosion of the continental lithosphere: a geochemical and quantitative microstructural study of mantle peridotites.
- 1995-1998: Woods Hole Oceanographic Institution. Advisors: Peter Kelemen & Greg Hirth: Combined geochemical and microstructural constraints on the accretion of the oceanic crust.

ACADEMIC EMPLOYMENTS

- July 2002-to date Research Scientist "Ramón y Cajal", Dep. Mineralogía y Petrología, Univ. Granada, Spain.
- July 2000-2001 Marie-Curie Postdoctoral Fellow (EC-TMR-30), IACT-CSIC, Univ. Granada, Granada, Spain.
- May 98-July 2000 Marie-Curie Postdoctoral Fellow (EC-TMR-30), ISTEEM-Lab. Tectonophysique, Univ. Montpellier II, Montpellier, France.
- May 97-May 1998 Postdoctoral Investigator, Dep. Geology and Geophysics, Woods Hole Oceanographic Institution, Woods Hole, MA, USA.
- April 95-April 97 Guest Postdoctoral Investigator, Dep. Geology and Geophysics, Woods Hole Oceanographic Institution, Woods Hole, MA, USA.
- 1990-1995 Visiting Graduate Student, Univ. Montpellier II, Montpellier, France. (Three-month stages per year).
- 1991-1992 Graduate Teaching Assistant, Dept. Mineralogy and Petrology, Univ. Granada, Granada, Spain.
- 1988-1990 Undergraduate Research Assistant, Dept. Mineralogy and Petrology, Univ. Granada, Granada, Spain.

PROFESSIONAL ACTIVITIES

Editorial Board:

2004-to date: Member of the Editorial Board of LITHOS (Elsevier).

Organization of International Scientific Meetings and Workshops:

- **2004:** 1st meeting of the European Geosciences Union, Nice, France. Convener of the Special Symposia on “Mantle peridotites and Mantle Processes”, together with Prof. Jean-Louis Bodinier, M. Godard & O. Alard (ISTEEM, University of Montpellier, France).
- **2001:** XI European Union of Geosciences, Strasbourg, France. Convener of the Special Symposia on “Structure, Composition and Accretion of the Oceanic Crust: Geophysical, Petrological and Geochemical Constraints”, together with Prof. Jason Phipps Morgan (GEOMAR, Kiel, Germany) and Dr. Benoit Ildefonse (ISTEEM, University of Montpellier, France).
- **1995:** II Workshop on Lherzolite Massifs and Mantle Processes, Granada, Spain **Co-organizer** and **co-leader** of the workshop Field Trip to the Ronda peridotite massif. Together with Dr. Dirk van der Wal (University of Utrecht, Netherlands).
- **1993:** II Biennial meeting of the Society of Geology Applied to Ore Deposits, Granada, Spain. **Co-organizer** and **co-leader** of the meeting field trip to the Ronda peridotite massif. Together with Dr. Fernando Gervilla (University of Granada, Spain).

Others :

- Official reviewer of papers for Chemical Geology, G-cubed, Journal of Petrology, Lithos.
- Member of the following scientific societies: AGU, EUG, EGS, & MCFA.

AWARDS

- 1995-Outstanding Ph.D. dissertation award of the University of Granada (Spain).

FELLOWSHIPS

- 2000- TMR-R Individual Marie-Curie Fellowship of the European Commission to work at IACT (Instituto Andaluz de Ciencias de la Tierra), University of Granada,, Spain.
- 2000- Return Research Fellowship of the Ministerio de Educación y Ciencia to work at IACT (Instituto Andaluz de Ciencias de la Tierra), University of Granada,, Spain.
- 1997- TMR30 Individual Marie-Curie Fellowship of the European Commission to work at ISTEEM Tectonophysique, University of Montpellier II, France.
- 1995-Postdoctoral fellowship of the Ministerio de Educación y Ciencia to work at the Woods Hole Oceanographic Institution, MA, USA. (Granted by MEC, the Ministry of Education and Science of Spain).
- 1995-Outstanding Ph. D. dissertation award of the University of Granada.
- 1991-1994: Four Picasso visiting fellowships. (Granted by CNRS, France & MEC, Spain).
- 1991-1994: Fellowship for graduate studies at the University of Granada (Spain). (Granted by MEC).

RESEARCH INTERESTS

- **MANTLE GEOCHEMISTRY AND PETROLOGY:** Distribution of trace elements in lithospheric mantle rocks (ultramafics and mafics). Natural partitioning of trace elements in mantle phases and geochemical nature of metasomatic fluids/melts in the subcontinental lithosphere. Melt migration in the upper mantle and mantle rheology: Geochemical, thermal and textural modifications of lithospheric peridotites induced by plume-continental lithosphere interaction as recorded in mantle xenoliths and orogenic peridotite massifs.
- **MID-OCEAN RIDGE PROCESSES:** Study of the crystallization history and post-crystallization processes of igneous rocks using microstructural observations (Crystal Size Distribution, crystal shapes, etc.) in natural samples, combining image processing procedures with geochemical data. Geochemical studies of gabbros and peridotites from ophiolites and active mid-ocean ridge setting and their relationships to the accretion of the oceanic crust and lithosphere in different mid-ocean ridge systems.
- **SUBDUCTION PROCESSES AND CRUSTAL EVOLUTION:** Study of the fractionation of trace elements associated to key subduction devolatilization and dehydration reactions as recorded in subduction-related metamorphic terranes, and their relationships with the geochemical signature of subduction-related magmatism and the genesis of Continental Crust.

SELECTED PAPERS

- Garrido C. J.**, Sanchez López-Vízcaíno V., Gómez-Pugnaire M. T., Trommsdorff V., Alard O., Bodinier J.-L. & Godard M. (2004). Enrichment of HFSE in Chlorite-Harzburgite produced by High-pressure Dehydration of Antigorite-Serpentinite: Implications for Subduction Magmatism. *Geochemistry Geophysics Geosystems* **5**, in press.
- Bach W., **Garrido C. J.**, Paulick H., Harvey J. & Rosner M. (2004). Seawater-peridotite interactions: First insights from ODP Leg 209, MAR 15° N. *Geochemistry Geophysics Geosystems* **5**, Q09F26, doi:10.1029/2004GC000744.
- Vauchez A. and **Garrido C. J.** (2001) Seismic properties of an asthenospherized lithospheric mantle: constraints from lattice preferred orientations in peridotite from the Ronda massif. *Earth & Planetary Science Letters*, **192**, 235-249.
- Garrido C. J.**, Kelemen P. B. & Hirth G. (2001). Variation of cooling rate with depth in lower crust formed at an oceanic spreading ridge: Plagioclase crystal size distributions in gabbros from the Oman ophiolite. *Geochemistry Geophysics Geosystems* **2**, doi: 10.1029/2000GC000136.
- Lenoir, X., **Garrido, C.J.**, Bodinier, J.-L., J.-M. Dautria & F. Gervilla (2001). The recrystallization front of the Ronda peridotite: thermal erosion and melting of the subcontinental lithospheric mantle beneath the Alboran basin. *Journal of Petrology*, **42**(1), 141-158.
- Garrido, C.J.**, J.-L. Bodinier & O. Alard (2000) Incompatible trace element partitioning and residence in anhydrous spinel peridotites and websterites from the Ronda orogenic peridotite. *Earth & Planetary Science Letters*, **181**(3), 341-358.
- Lenoir, X., **Garrido, C.J.**, Bodinier, J.-L. & J.-M. Dautria (2000) Contrasting lithospheric mantle domains beneath the Massif Central (France) revealed by geochemistry of peridotite xenoliths. *Earth & Planetary Science Letters*, **181**(3), 359-375.
- Garrido, C.J.** & J.-L. Bodinier (1999). Diversity of mafic rocks in the Ronda peridotite: evidence for pervasive melt/rock reaction during heating of subcontinental lithosphere by upwelling asthenosphere. *Journal of Petrology*, **40** (5), 729-754.
- Bodinier, J.-L. C. Merlet, R. M. Bedini, F. Simien, M. Remaidi & **C.J. Garrido** (1996) Distribution of niobium, tantalum, and other highly incompatible trace elements in the lithospheric mantle: The spinel paradox. *Geochimica et Cosmochimica Acta*, **60**, 545-550.

ABSTRACTS: 75 Presentations in International Meetings.