



Exploratory Workshop Scheme

Standing Committee for Life, Earth and Environmental Sciences (LESC)



## SCIENTIFIC REPORT

ESF Exploratory Workshop on

### Defining the Lithosphere-Asthenosphere Boundary beneath Continents

Dublin, Ireland, June 3—5, 2009

**Convened by:**

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# ESF EXPLORATORY WORKSHOP ON “DEFINING THE LITHOSPHERE-ASTHENOSPHERE BOUNDARY BENEATH CONTINENTS”

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## *Executive summary*

Dynamic processes within the *lithosphere* (the cool, rigid outer layer of the Earth some tens to hundreds of kilometres in thickness) and *asthenosphere* (the hot, convecting layer below) have shaped and continue to shape the continents that we live on. Volcanic activity, land rise and subsidence and sea-level variations are among well-known surface manifestations of these active processes. The lithosphere-asthenosphere boundary (LAB), that separates the lithosphere from the asthenosphere beneath it, cannot be observed directly, and its very nature has been uncertain and continues to be debated strongly. The central role of the LAB in the dynamics of the lithosphere-asthenosphere system has motivated vigorous research focussed on its properties in various fields of Earth science. The multi-disciplinary nature of the research that is required to understand the LAB has been a challenge but, at the same time, presents opportunities for productive, cross-field collaborative studies.

The European Science Foundation Exploratory Workshop on “Defining the Lithosphere-Asthenosphere Boundary Beneath Continents” (DefLAB) brought together geophysicists, geochemists, petrologists and mineral physicists; a total of 31 scientists from 10 European countries (Czech Republic, Denmark, Finland, France, Germany, Ireland, Netherlands, Poland, Spain, United Kingdom), as well as from the United States and Canada, who joined forces to focus on the LAB and its definition over three very full days.

The objectives of the workshop were:

- to discuss and evaluate critically a number of widely used proxies for the LAB;
- to compare these proxies with each other and with realistic rheological models of the “true” (i.e., mechanical) lithosphere;
- to assess the extent to which different techniques sense the same feature, and if so, to document its intrinsic characteristics; and,
- to plan for the future, by deciding what multi-disciplinary experiments need to be performed at which locations.

The Workshop program included:

- overviews of the current status of the study of the dynamics of the lithosphere-asthenosphere system and the role of the LAB;
- overviews of methods used in pertinent studies in different fields, with discussions on strengths and limitations of different approaches;

- presentations on major results and inferences regarding the properties of the LAB from recent disciplinary and inter-disciplinary studies;
- break-out sessions focussed on identifying the main problems in the study of the LAB and the lithosphere-asthenosphere system;
- break-out sessions aimed at identifying ways to solve the problems, including recommendations for future multi-disciplinary research.

Presentations and discussions during the workshop highlighted recent progress in the study of the lithosphere and asthenosphere made in seismology, electromagnetism, computational geodynamics, geochemistry, mineral physics, petrology and sedimentology. They exposed the complexity of the lithosphere-asthenosphere system, with the viscosity of the rock at depth dependent not only on its temperature and composition and on the lithostatic pressure, but also on the grain size and volatile content. Inter-connections between observations and models produced in different fields have also become more apparent.

The objectives of the workshop were achieved in the course of exciting, stimulating discussions over the 3 days of its duration. Crucially, the workshop helped to prepare ground for focussed, multi-disciplinary collaborative research to be undertaken in the near future.

### ***Scientific content of the event***

The scientific program of the workshop has delivered, to begin with, a summary of the current state of the art in the multi-disciplinary study of the lithosphere-asthenosphere system and the LAB. Following that, the discussions were focussed on what the main problems and challenges were in the study of the LAB, and on ways to address these problems and challenges.

The first four half-day sessions included:

1. multi-disciplinary state-of-the-art overviews;
2. seismological methods and observations;
3. other geophysical methods and observations, including geodynamics;
4. petrological, mineralogical, and geochemical methods and observations.

The last two half-day sessions were in break-out groups, with discussions focussed on (1) the primary problems and challenges as well as (2) on new ways to solve the problems. The results of the discussions were examined and integrated in the plenary sessions that followed.

After the opening, introductory presentations, D. Eaton overviewed the geophysical data and models pertinent to the continental LAB. Because different geophysical observables are sensitive to different properties of the rock at depth, understanding the inter-relationships of these properties was shown to be particularly important. R. Evans broadened this perspective in his overview of the study of the LAB beneath oceans and of the evolution of the oceanic lithosphere.

Reviews of body-wave and surface-wave seismological methods and results by C. Rychert and S. Fishwick were followed by case-study seismology presentations. New results of seismic receiver-function analyses show consistent signals that can be attributed both to the LAB and to intra-lithospheric discontinuities. Surface waves sample the mantle differently, and the combination of

the different data types in a joint analysis promises improvement in the resolution of the imaging and, possibly, ways to discriminate different types of interfaces at depth. E. Roux discussed and presented formal joint inversions of both seismic and magnetotelluric data.

I. Artemieva then reviewed geophysical and geological constraints on the depth to the base of the lithosphere and discussed questions regarding compatibility of various estimates, particularly the similarities and differences between a Mechanical Boundary Layer (MBL), a Thermal Boundary Layer (TBL), and a Chemical Boundary Layer (CBL). M. Pérez-Gussinyé, M. Scheck-Wenderoth and A. Jones discussed constraints on the LAB properties from the studies of the elastic thickness of the lithosphere, the sedimentary record near the surface, and from electromagnetic observations. Geodynamics presentations highlighted the complexity of lithospheric dynamics and lithosphere-asthenosphere interactions. D. Mainprice then discussed the LAB as a mechanical boundary layer based on mineral and rock physics. This perspective was further broadened in presentations of case studies using mineralogical, petrological, and geochemical observations.

Discussions of big questions regarding the LAB and its role, of particular technical problems in the field, and of ways to address and solve both were then conducted in break-out groups. Summarized in plenary sessions that followed, these discussions produced recommendations for future collaborative work.

### ***Assessment of the results, contribution to the future direction of the field, outcome***

An important result of the workshop is a deeper understanding of the data, models, and problems related to the study of the LAB by different Earth science disciplines. Particularly, all attendees became educated about the strengths and weaknesses of the approaches of the others. This was achieved by a group of experts from the various relevant fields who influence the directions of future research and who are planning to continue the work in collaborative, international, multi-disciplinary projects.

Among the issues that were identified as needing particular attention were:

- magma/fluid-lithosphere interactions (metasomatism);
- properties of the asthenosphere affecting the observations that distinguish it from the lithosphere:
  - shearing (reduced grain size? fabric?),
  - temperature,
  - melt (is it present?),
  - water (why would it be concentrated below or mineralogically fixed in the lithosphere?);
- xenoliths (rock samples from deep lithosphere): what is the sampling bias?
- breaking down the terminology of a single LAB: recognizing different physical boundaries and their inter-relationships, with viscosity as a unifying physical property.

Various technical approaches and methods that should facilitate progress in defining and understanding the LAB were discussed in detailed. General recommendations for multi-

disciplinary projects and experiments that can be set up to address the questions have also been discussed and included:

- networking: taking advantage of and building on existing data sets and active projects; making effective use of existing data;
- comparing and contrasting different types of lithosphere, from old to young, from continental to oceanic;
- using an array of methods, including measurements and analysis of the heat flow, potential fields, seismicity, attenuation;
- development of lithosphere reference models, consistent with the range of available geophysical and geological data.

The main outcome of the workshop is in its contributions to the future directions of research in the field. Part of that was achieved through the cross-disciplinary dialog and the integration of observations, models, and inferences from different disciplines. Perhaps more importantly, foundations were laid for future progress in the field, to be achieved through collaborative international network projects.

### ***Acknowledgements***

This workshop could not have occurred without the funding provided by the European Science Foundation, by the Dublin Institute for Advanced Studies, and by the International Lithosphere Programme. All three bodies are profusely thanked for their support.

This workshop would not have been successful without the energy, insight, thoughtfulness, openness, and collegiality of all who attended. Everyone is profusely thanked!

Finally, a special mention of the Geophysics Section secretary, Mairead O'Connor, who ensured that the workshop went off without any problems at all.

## ***Final Programme***

### **Wednesday 3rd June a.m.: Introduction and Setting the Scene**

<b>9:00</b>	<b>Welcome to DIAS</b>	
<b>9:15</b>	A.G. Jones	Introduction/logistics/outline
<b>09:30</b>	C. Doukas (ESF/LESC)	ESF & LESC
<b>09:45</b>	A.G. Jones	Why we are here - objectives of the DefLAB workshop
<b>10:00</b>	D. Eaton	The continental LAB: An overview
<b>10:40</b>	<b>Coffee break</b>	
<b>11:10</b>	R. Evans	Structure of the oceanic mantle: Geophysical constraints on lithosphere evolution
<b>11:40</b>	C. Rychert	Review of seismological methods - 1
<b>12:10</b>	S. Fishwick	Review of seismological methods – 2
<b>12:40</b>	Discussion	
<b>13:00</b>	<b>Lunch</b>	

### **Wednesday 3rd June p.m.: Seismology**

<b>14:00</b>	R. Kind	Studies of lithospheric plates with S receiver functions
<b>14:15</b>	T. Meier	Constraints on the LAB depth and sharpness from measurements of Rayleigh wave dispersion curves
<b>14:30</b>	J. Ritter	The lithosphere-asthenosphere boundary underneath Ireland: Data - interpretation - unknowns
<b>14:45</b>	J. Plomerova	LAB as boundary between fossil and present-day mantle seismic anisotropy
<b>15:00</b>	M. Grad	European plate crust and new digital Moho depth map
<b>15:15</b>	E. Roux	Joint inversion of magnetotelluric and surface wave data in an anisotropic earth
<b>15:30</b>	<b>Coffee break and poster viewing</b>	
<b>16:00</b>	5-minute presentations and discussion	
<b>17:00</b>	<b>Poster viewing with wine &amp; cheese</b>	

### **Thursday 4th of June a.m.: Other geophysics and geodynamics**

<b>9:00</b>	I. Artemieva	Defining the lithospheric base: semantics versus physics
<b>09:30</b>	M. Pérez-Gussinyé	Effective elastic thickness of continents and its relationship to other proxies for lithospheric structure and surface tectonics
<b>09:45</b>	M. Scheck-Wenderoth	Looking at the LAB from above - what can we learn from 3D lithosphere-scale models of sedimentary basins?
<b>10:00</b>	A.G. Jones	The eLAB
<b>10:15</b>	5-minute presentations and discussion	
<b>10:30</b>	<b>Coffee break and poster viewing</b>	

- 11:00** E. Burov Mantle-lithosphere interaction models: recent achievements and new links to geophysical data
- 11:30** I. Jiménez-Munt Lithospheric-mantle thinning beneath the Alpine-Himalayan Belt. Influence of mantle dynamics on tectonic evolution from geodynamic modelling
- 11:45** G. Houseman Lithospheric dynamics
- 12:00** 5-minute presentations and discussion
- 13:00** **Lunch**

**Thursday 4th of June p.m.: Petrology/Mineralogy/Geochemistry**

- 14:00** D. Mainprice Lithosphere-asthenosphere boundary (LAB) as mechanical boundary layer based on mineral and rock physics
- 14:30** M. Grégoire The nature and evolution of the lithospheric mantle seen by a petrologist
- 14:45** L. Viereck-Götte Petrological constraints on the LAB topography from Central European Cenozoic Volcanic Fields
- 15:00** M. Abratis Petrology, age and textural anisotropy of lithospheric mantle xenoliths of the Central European Cenozoic Igneous Province (CECIP)
- 15:15** N. Wittig The influence of LAB topography on the evolution of sub-continental lithospheric mantle in the French Massif Central
- 15:30** **Coffee Break and poster viewing**
- 16:00** 5-minute presentations and discussion
- 16:30** **Poster viewing with wine & cheese**
- 17:15** **Special Event**

**Friday 5th of June a.m.: Defining the problem(s)**

- 9:00** Break into 4 groups
- 11:00** **Coffee Break**
- 11:30** Reporter reports and discussion
- 13:00** **Lunch**

**Friday 5th of June p.m.: Identifying solutions to the problem(s)**

- 14:00** Break into 4 groups
- 15:30** **Coffee Break**
- 16:00** Reporter reports and discussion
- 17:00** Final Plenary and discussion on follow-up activities/networking/collaboration
- 18:00** **End**
- 20:00** **Workshop Dinner.** Unicorn Restaurant, 12B Merrion Court off Merrion Row, Dublin 2

## **Five-minute presentations and posters**

M. Abratis, L. Viereck-Götte, Th. Meier.

Rifting of buckled European lithosphere in combination with lithosphere-penetrating lineaments determines the composition of mafic igneous rocks in the northern CECIP

Nick Arndt.

Formation of cratonic lithospheric mantle

S. Bartzsch, S. Lebedev, T. Meier.

Resolving the LAB with surface-wave inversion

J. Fullea, J.C. Afonso, J.A.D. Connolly, M. Fernández, D. García-Castellanos.

Characterizing the lithospheric-sublithospheric upper mantle system: its thermal, compositional, seismological, and rheological structure in 3D

Alan Jones, Jarka Plomerova, Toivo Korja.

Comparison of the eLAB and sLAB for Europe

Hanneke Paulssen.

Joint inversion of lithosphere and asthenosphere using body and surface waves

Hanneke Paulssen, Xiaomei Zhang, Sergei Lebedev, Thomas Meier.

Structure of the lithosphere and asthenosphere beneath the Gulf of California

Jan Vozar.

Electromagnetic investigations of the lithosphere–asthenosphere boundary in Central Europe

## ***Final List of Participants: (Gender/Category)***

Gender: M = Male; F = Female

Category: St = Student; J = Junior scientist (<10 years post-PhD); Sr = Senior scientist

- 1: Michael Abratis, University of Jena, Germany (M/J)
- 2: Ulrich Achauer, University of Strasbourg, France (M/Sr)
- 3: Nick Arndt, University of Grenoble, France (M/Sr)
- 4: Irina Artemieva, University of Copenhagen, Denmark (F/Sr)
- 5: Evgueni Burov, Université P. & M. Curie, Paris VI, France (M/Sr)
- 6: David Eaton, University of Calgary, Canada (M/Sr)
- 7: Rob Evans, WHOI, USA (M/Sr)
- 8: Stewart Fishwick, University of Leicester, UK (M/J)
- 9: Javier Fullea, DIAS, Ireland (M/J)
- 10: Marek Grad, University of Warsaw, Poland (M/Sr)
- 11: Michel Grégoire, Observatoire Midi-Pyrénées, Toulouse, France (M/Sr)
- 12: Greg Housemann, University of Leeds, UK (M/Sr)
- 13: Ivone Jimenez-Munt, Institute of Earth Science, Barcelona, Spain (F/Sr)
- 14: Alan G. Jones, DIAS, Ireland (M/Sr)
- 15: Hana Karousova, Czech Acad. Sci, Czech Republic (F/St)
- 16: Rainer Kind, GFZ, Germany (M/Sr)
- 17: Toivo Korja, University of Oulu, Finland (M/Sr)



- 18: Sergei Lebedev, DIAS, Ireland (M/Sr)
- 19: David Mainprice, CNRS Montpellier, France (M/Sr)
- 20: Thomas Meier, Ruhr University Bochum, Germany (M/Sr)
- 21: Mark Muller, DIAS, Ireland (M/Sr)
- 22: Hanneke Paulssen, University of Utrecht, Netherlands (F/J)
- 23: Marta Perez-Gussinye, Royal Holloway, UK (F/J)
- 24: Jaroslava Plomerová, Czech Acad. Sci, Czech Republic (F/Sr)
- 25: Joachim Ritter, University of Karlsruhe, Germany (M/Sr)
- 26: Estelle Roux, DIAS, Ireland (F/J)
- 27: Catherine Rychert, UCSD, USA. (F/J)
- 28: Magdalena Scheck-Wenderoth, GFZ, Germany (F/Sr)
- 29: Celine Tirel, DIAS, Ireland (F/J)
- 30: Lothar Viereck-Götte, University of Jena, Germany (M/Sr)
- 31: Jan Vozar, DIAS, Ireland (M/J)
- 32: Nadine Wittig, GZN Erlangen, Germany (F/Sr)
  
- 33: Constantin Doukas, University of Athens, Greece. (ESF/LESC rapporteur)



***Statistical information: 32 attendees***

(not including ESF rapporteur)

**Countries of Origin:**

Canada	1
Czech Republic	2
Denmark	1
Finland	1
France	5
Germany	7
Ireland	7
The Netherlands	1
Poland	1
Spain	1
UK	3
US	2

**Gender:**

Female	11
Male	21

**Age distribution:**

20s	2
30s	9
40s	10
50s	8
60s	3

**Note:**

In addition to these official numbers, post-graduate students from DIAS Geophysics Section attended in an unofficial capacity for their future training and mentorship.