Title: **PICASSO**: Program to Investigate Convective Alboran Sea System Overturn

Proposal Code: GEO001

Contact details: School of Cosmic Physics
Dublin Institute for Advanced Studies
5 Merrion Square
Dublin 2, Ireland
Tel: 662-1333; Fax: 662-1477
Email: alan@cp.dias.ie

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Scientific abstract (changed from pre-proposal):
Continental collision is a poorly understood fundamental plate-tectonic process, especially in complex three-dimensional areas. Advances in understanding will only come through multi-disciplinary projects on carefully chosen areas. In particular, competing models of lithospheric recycling are poorly distinguished based on extant geoscientific data. Models of delamination will be examined in one of the world's most appropriate natural laboratories, the western Mediterranean, by a consortium comprising a multi-disciplinary team of scientists from Europe, the U.S.A. and Morocco. This proposal is for involvement of Irish-based scientists and students in this major geoscientific endeavour, accepted as a pilot project for both EuroArray and Topo-Europe.

Laymans's abstract (changed from pre-proposal):
How does the Earth work? This question is at the heart of the PICASSO project, which is to determine how continents collide in a project area on Europe's own doorstep, namely the western Mediterranean. The plate tectonic model, a wonderful general descriptor of our planet, poorly explains the observations made in the project area of complex geometries and structures. One particularly inadequately known process is how material is recycled from the surface back into the mantle. A large international team of scientists, from Europe, USA and Morocco, will tackle this problem through a multi-disciplinary geoscientific study.

Main collaborators:
Ramon Carbonnell (PICASSO lead co-PI), CSIC Earth Sci. Barcelona, Spain
Alan Levander (PICASSO lead co-PI), Rice University, Houston, Texas, U.S.A.
Juanjo Ledo (PICASSO MT component lead co-PI), U. Barcelona, Spain
Hans Thybo (EuroArray lead co-PI), U. Copenhagen, Denmark
S. Cloetingh (Topo-Europe lead PI), Vrije U. Amsterdam, The Netherlands

Institutional Signatory Authority
Mr. Cecil Keaveney, Registrar,
Dublin Institute for Advanced Studies
10 Burlington Road
Dublin 4, Ireland
Tel: 614-0100; Fax: 668-0561
Email: registrar@admin.dias.ie

What is the question that this proposal addresses?

To improve our understanding of the details of continental collision, a consortium of Earth scientists from Europe, the U.S.A., and Morocco is proposing a collaborative, international, multi-disciplinary geoscientific project to various funding agencies for studying the active tectonics of the Africa-Eurasia diffuse plate boundary zone in the western Mediterranean. Within the project area, shown in the box in Fig. 1, lies the Betic-Rif mountain system of southern Spain and northern Morocco (Gibraltar Arc), the purported active lithospheric delamination occurring in the Alboran Sea, the active subduction in the Gulf of Cadiz, and the far-field effects observed in central Spain and the Atlas mountains. Despite many years of geological study, the nature of the orogen is controversial (e.g., Michard et al., 2002), with a wide variety of models being permitted principally due to the paucity of high precision geometrical and physical property information for the lithospheric mantle beneath the region.

This project, primarily being organized by Spanish (leader: Dr. Ramon Carbonnell, Institut de Cienciès de la Terra "Jaume Almera", Barcelona, Spain) and U.S. (leader: Prof. Alan Levander, Rice University, Houston, Texas) investigators, is named PICASSO for *Program to Investigate Convective Alboran Sea System Overturn*, and has been selected as a pilot program for the nascent EuroArray and Topo-Europe programs. A project web page gives more details of the PICASSO proposal, including information from the workshop held in June, 2005 (wija.ija.csic.es/gt/rc/HTML/indexPICASSO.html).

The principle, overarching objective of PICASSO is to determine the three-dimensional internal structure of the crust and lithosphere, with special emphasis in the geometry of the upper mantle, in order to deduce the lithospheric processes that are taking place. The putative delamination beneath the Alboran Sea is one of the key targets of PICASSO, but understanding the whole orogen holistically is its primary objective.

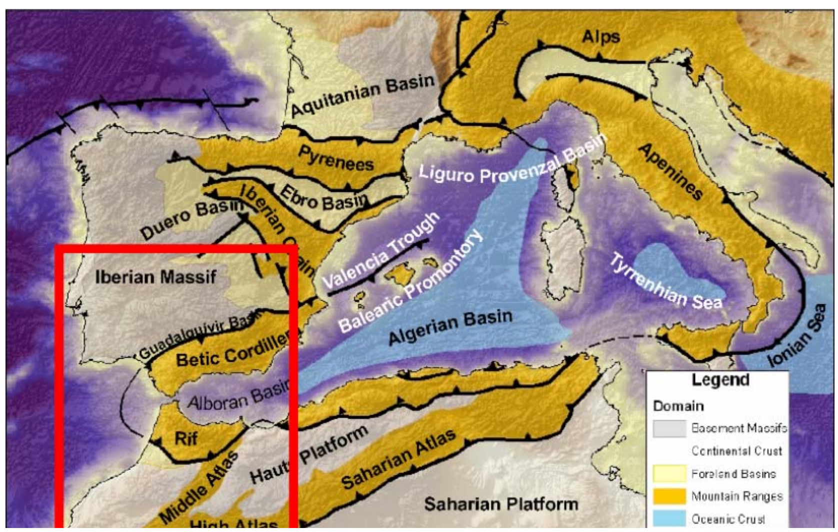

Figure 1: Tectonic map of western Mediterranean with survey area

The orogenic belt of study (Fig. 1) comprises the compressional belts of southern Spain and northern Morocco, the Gulf of Cadiz, beneath which is active subduction (Gutscher et al., 2002), the extensional Alboran Sea, which is thought to be the site of a modern, ongoing delamination event (Seber et al., 1996; Calvert et al., 2000a, 2000b), although this is disputed (Buforn et al., 2004), the Atlas mountains, inferred to be a component of the orogen (Gomez et al., 2000), a view which is also contentious (Laville, 2002; Gomez et al., 2002), and the far field regions of central Spain (uplift) and the Saharan craton of Morocco.

Evidence supporting the delamination event comes from seismicity patterns that show seismic activity extending from the base of the crust to the mantle transition zone, limited teleseismic tomography which has outlined a high velocity lithospheric slab in part decoupled from the overlying mountain belt-extensional basin system, observation of low seismic velocities at the base of the crust beneath much of the region indicative of rising asthenosphere replacing the delaminating lithosphere (Seber et al., 1996), and basaltic and exotic volcanism in and around the Alboran Sea associated with decompression melting of the rising asthenospheric mantle (Duggan et al., 2004). Prior delamination events are also concluded to have occurred within this orogen (Tubia et al., 2004).

This system provides us with a geographically compact region within which to study a wide variety of the geophysical, geodynamic, and geochemical processes associated with convergent collision, extension, subduction and delamination. Other major geoscientific questions will be addressed at the same time, such as the reason for the elevation of central Spain and for the lack of a mantle root beneath the High Atlas mountains. Moreover, unlike the Tibetan or Altiplano-Puna systems, the region offers a well developed infrastructure for fielding a sophisticated collaborative Earth science experiment.

The orogen, particularly the Alboran Sea, will never be understood without an intimate understanding of the roles of the Atlas and Rif-Betic mountain systems. The Rif-Betic mountains have a well-developed lithospheric mantle root. In contrast, the High Atlas mountains are extraordinary in that although they exhibit a crustal root, they exhibit an asthenospheric upwelling beneath them (Seber et al., 1996; Teixell et al., 2005). Thus, central to understanding the PICASSO region is precise definition of the lithosphere-asthenosphere boundary (LAB), in particular to test the recent models of Teixell et al. (2005) and Zeyen et al. (2005) constructed from heat flow, gravity, geoid and topography observations . The deduced lithospheric geometry on a NW-SE transect from the Gulf of Cadiz (GoC) across the High Atlas to the Saharan craton is shown in Fig. 2.

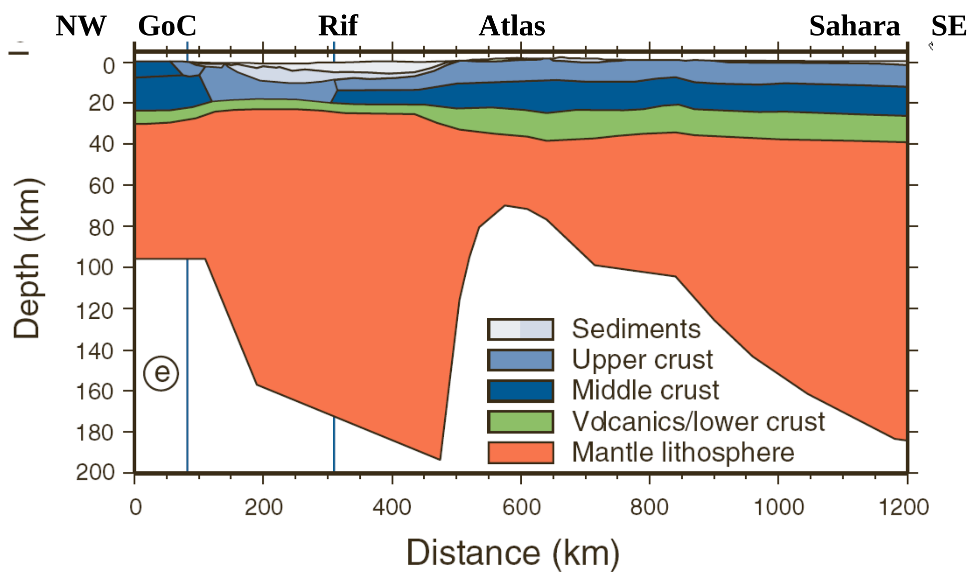

Figure 2: Lithospheric model from the Gulf of Cadiz to the Saharan craton (from Teixell et al., 2005)

As well as providing structural information within the crust (e.g., Jones, 1998), magnetotellurics (MT) is the perfect geophysical technique for imaging the LAB, as electrical conductivity is highly sensitive to the onset of even small fractions (sub 1%) of partial melt (see, e.g., Schmeling, 1986; Partzsch et al., 1995; Jones, 1999). High quality MT response estimates can resolve the LAB with a precision better than 10%. However, the only MT work to date conducted in Iberia and Morocco used broadband MT (BBMT) systems with insufficient penetration to image to the LAB (Iberia: Pous et al., 1999, 2004; Almeida et al., 2005; Marti et al., 2004; Atlas: Schwartz et al., 1992). DIAS will shortly own eight long period MT (LMT) systems, with very high sensitivity to magnetic fields (<10 pT/sqrt(Hz)), that will give responses out to 30,000 seconds and beyond that will enable imaging the lithosphere-asthenosphere boundary for the PICASSO project area.

From an MT perspective, PICASSO demands both land and marine technologies. The land-based MT work is the focus of this proposal. A companion marine proposal requires large numbers of appropriate ocean-bottom MT (OBMT) instruments, and these are simply not yet available in Europe, although there is an initiative in Germany to initiate construction of a fleet of instruments (M. Jegen, pers. comm., 2005). The PICASSO MT group is in discussions with colleagues elsewhere (U.S.A., Japan, Australia) who own such equipment, and is encouraging them to become part of PICASSO and apply to their own funding agencies for support.

Why is this problem significant?

Although we know generally how continents collide, we rarely know the specific geometries and details of the processes; in particular how continental material is recycled back into the mantle during orogenesis. This paucity of knowledge is even more acute in complex three-dimensional regions, which is precisely the case on Europe's own doorstep - its southern border with the African plate. The PICASSO consortium has chosen southern Iberia, northwestern Africa, and the westernmost Mediterranean for its study area, as it comprises, in a compact and highly accessible geographic area, many enigmatic components of continent-continent collision (convergent collision, extension, subduction and delamination).

A particular focus of PICASSO investigations is the Alboran Sea anomaly. Four competing models are proposed to explain it; retreating subduction, slab break-off, delamination (sensu stricto), and convective removal (see Calvert et al., 2000a). The first two describe plate tectonic processes, whereas the latter two are non-plate processes. Despite prior studies, the extant data are insufficient to discriminate between these models, thus even in this controlled natural laboratory we are unable to ascertain the nature of geodynamic processes that are shaping our Earth's surface. The land-based MT work will not image this region directly, as marine technology is required, but will provide the framework for addressing this particular question and will address regional questions, such as structural geometries within the orogen itself and particularly the variation in lithospheric thickness and structures within it.

The way to address the objectives of PICASSO with the highest probability of success is a large-scale, multi-disciplinary research program that includes structural geology, geodynamic modelling, magnetotellurics, gravity and multi-scale, multi-seismic experiments. These acquisition experiments would be addressed to constrain the crustal and upper mantle structure. The broad interest in the main target of this research program makes it an excellent candidate for the EuroArray pilot experiment, and for a Topo-Europe pilot project.

The new and original science outputs that will result from PICASSO *in toto* are improved understanding of the processes involved in continent-continent collision in a highly complex three-dimensional boundary. Specific outputs of the MT work proposed herein will be improved resolution of the geometry of the lithosphere-asthenosphere boundary, correlation of lithospheric seismic and electrical anisotropy, and definition of structural geometries of features in the crust, especially in the Betics and Atlas mountains.

How will the question be addressed?

Through the effort of all consortium partners, the project will include an extensive array of portable broadband land and marine seismograph and magnetotelluric stations extending from central Spain to the Sahara desert, and from the Atlantic Ocean through the Alboran Sea into the Mediterranean Sea, complementing the permanent seismograph networks in the western Mediterranean countries. Other components of the project will include land and marine active seismic investigations, petrology/geochemistry, structural geology, GPS, and geodynamic modelling.

Magnetotellurics has come of age. From its theoretical conception in the early-1950s the method has been plagued with doubt. However, with the advent of high-precision, high-quality field instrumentation, highly-advanced processing and analysis methods, and advances in multi-dimensional modelling and inversion over the last decade, MT is now able to address geological questions and give answers with confidence. The PI has been part of many of these advances. The challenge now is to take the high quality electrical images of the subsurface and infer geology and tectonic processes.

The PICASSO consortium is seeking funding from a variety of sources, including the U.S. National Science Foundation, the European Science Foundation under the aegis of EuroArray/Topo-Europe, and the individual science foundations of Europe, including this proposal to Science Foundation Ireland for Irish participation. Seismological instrumentation will be provided by the IRIS/PASSCAL instrumentation facility, the European instrumentation facility at the German GeoForschungsZentrum Potsdam (GFZ), from a proposal submission to Spanish funding sources, and from individual institutions and national governments, including DIAS's own sixteen (16) broadband portable seismic systems.

Magnetotelluric leadership and instrumentation will be provided principally by DIAS and UB, with other European (see list of collaborators), and possibly U.S., institutions taking part.

An approximate experimental plan for the seismic profiling component to be proposed to the Continental Dynamics programme of the National Science Foundation is shown in Fig. 3. This plan is subject to change depending on the successes of the proposal to the NSF.

The MT component being proposed by DIAS and UB involves three inter-related components; (1) acquisition along the main N-S profile (profile A-ESP and A-MOR in Fig. 3), (2) acquisition along three new profiles across the Atlas mountains (shown in Fig. 6) and (3) acquisition at specific locations across the Betics to complement existing data (see Fig. 5). Additional ocean-bottom seismic and magnetotelluric measurements are expected to be proposed by

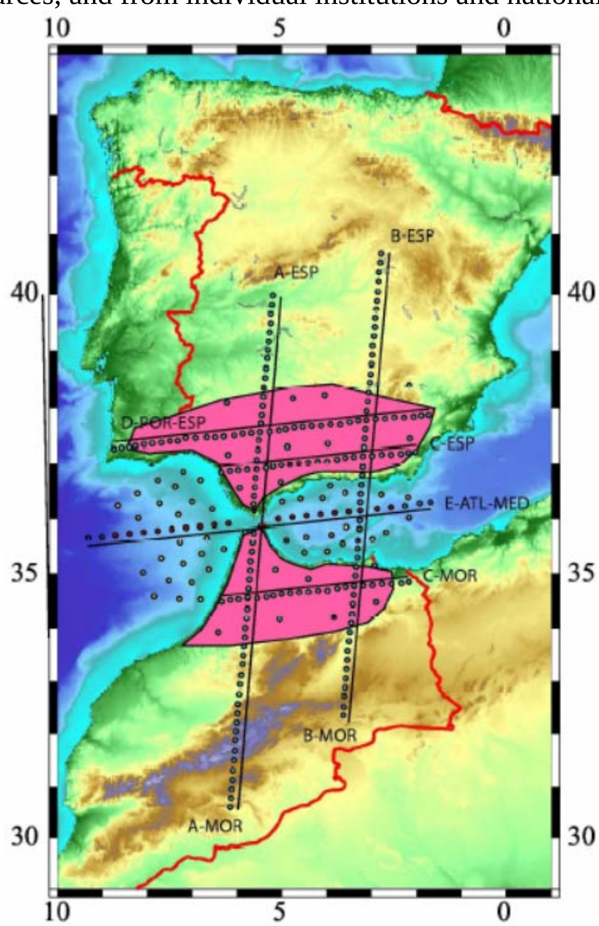

Figure 3: PICASSO proposed NSF profiles

appropriate groups in Europe and the U.S.A.

In addition to these profiles, under the auspices of EuroArray there is planned seismic and magnetotelluric acquisition on land, with a 50x50 km grid, within the whole area of study outlined in Fig. 1. The proposed EuroArray station locations are shown in Fig. 4. This ambitious acquisition plan will likely not occur in the time frame of the NSF project, but when EuroArray is finally launched.

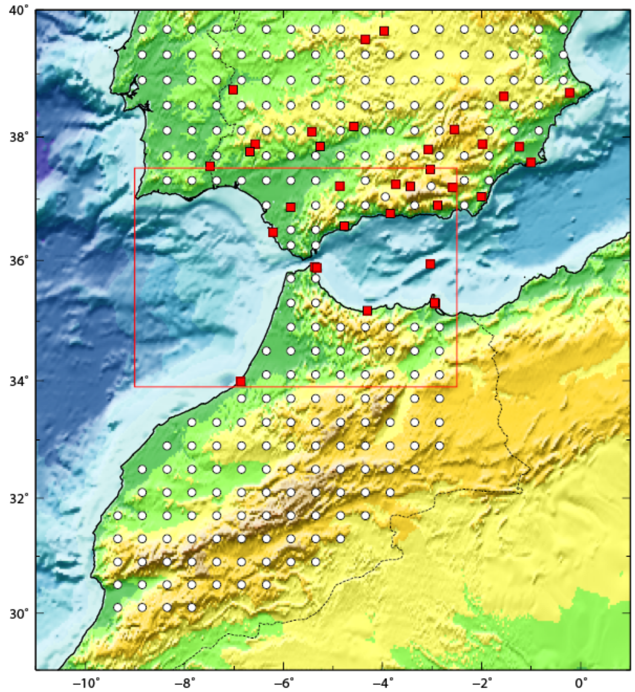

Figure 4: Proposed EuroArray sites in project area

To a large extend the magnetotelluric and seismic acquisition do not need to run concurrently, and indeed there are compelling logistical and scientific arguments for having the MT acquisition in advance of the seismic work. The fieldwork for the MT component funded by SFI would optimally take place in Autumn 2007 (end of Year 1) and Autumn 2008 (end of Year 2). The three DIAS-based students who would be supported by the project and by DIAS funding will start their studies in September 2006 or as soon thereafter as possible.

Although the acquisition, processing and interpretation methodologies for all of the geoscientific subdisciplines are well-established, this project will provide an opportunity for innovation through the integration of all of the data into a coherent, cogent, process description of the whole region. In particular, we envision bringing all models and data into a 3D GIS package, such as GoCAD or GeoExpress. (DIAS has GeoExpress funded as part of the SFI SAMTEX project.)

Land-based MT component of PICASSO

The lead institutions for the land-based MT work on PICASSO are DIAS (lead PI Jones) and the University of Barcelona (UB, lead PI Ledo). In addition, MT specialists and their students from the University of Lisbon (UL, Professors F. Santos and E. Almeida) and from the University of Granada (UG, Professor J. Galindo-Zaldivar) will be involved, with UL working principally on the Atlas profiles, and UG working principally on the Betics profiles. However, all groups will be involved in all components of the project.

For the DIAS component of the MT fieldwork, DIAS has the responsibility of leading the broadband MT (BBMT) and long period MT (LMT) acquisition along the main profile (profile A in Fig. 3), which is 850 km long, and for the long period MT (LMT) acquisition on three short profiles across the Atlas mountains (Fig. 6) and in the Betics (Fig. 5). The BBMT work on the Atlas mountain profiles will be undertaken by J. Pous (UB) and collaborators from UL, and the BBMT work in the Betics by J. Ledo, P. Queralt, and A. Marcuello (UB) and collaborators from UG. Current estimates are of approximately a total of 1800 km of profiles for the Atlas and Betics combined, with approx. 900 km in each survey area.

Main profile

DIAS has the responsibility of leading acquisition along the main profile. The principle overarching objective for this profile is definition of the LAB to yield a model similar to Fig. 2 but with higher precision and veracity. Other objectives are:

1. Correlation between seismic SKS and electrical anisotropy of the mantle (following Ji et al., 1996; Eaton et al., 2004; Hamilton et al., 2006). Correlation with regional observations of Pn anisotropy (Serrano et al., 2005).
2. Correlation of electrical resistivity with seismic velocity (obtained through tomography models).

These three are also objectives for the Betics and Atlas profiles.

Betics sites

A location map of the proposed Betics MT sites is shown in Figure 5. The existing BBMT sites, acquired by UB over the last decade, are shown as solid triangles, the planned BBMT sites as open circles, and the planned LMT sites as large open squares. The main topics to be addressed by the MT work in the Betics are:

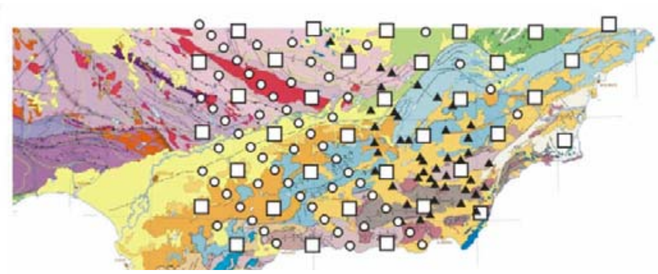

Figure 5: Planned locations of BBMT (open circles) and LMT (open squares) on the Betics. Existing BBMT sites also shown (solid triangles)

1. Subduction direction,
2. Geometry of upper crustal faults and their extension to depth,
3. Determination of uppermost mantle structure (c.f. Seber et al.,1996), and,
4. Western extension of the low resistivity anomaly found by Martí (2006, unpubl. PhD thesis) below the crust in the eastern Betics.

Atlas mountains sites

There are essentially only three access routes across the High Atlas mountains (Fig. 6, from Teixell et al., 2003), and we plan to make BBMT and LMT measurements along all three. Our planning is for the BBMT measurements to occur first, and then at appropriate locations we will follow up with LMT measurements. The principle objective of these transects is to compare and contrast lithospheric structure and geometries with the models of Teixell et al. (2005).

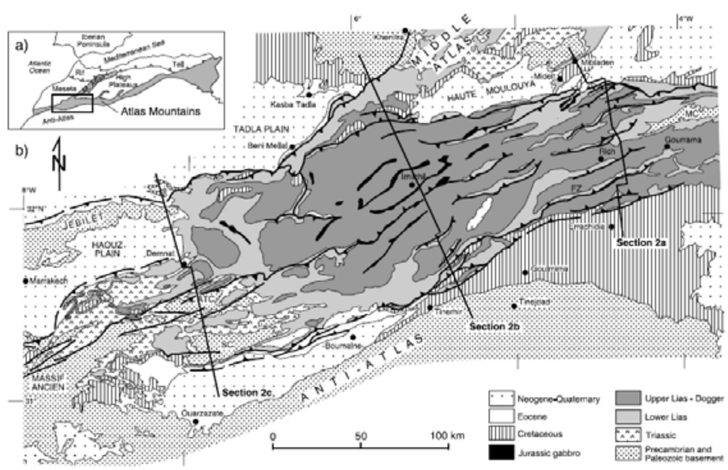

Figure 6: Access routes across the High Atlas mountains

Field plan

We plan to acquire data at the Spanish locations in one year, and at the Moroccan locations in the following year. We are proposing to make the Spanish-based measurements first, in the Autumn of 2007 (end of Year 1), given that logistically it should be far easier and it will also be easier to train all personnel. The more challenging Moroccan measurements are planned for Autumn, 2008 (end of Year 2).

We are planning for BBMT every 10 km, and LMT at every 3rd BBMT site, i.e. every 30 km. This means we need to acquire data at 85 BBMT sites and 30 LMT sites along the main profile, and a total of 60 LMT sites in the Atlas and Betic mountains. Thus, in Year 1 we plan to acquire BBMT data at approx. 45 sites, and LMT data at approx. 45 sites (15 on main profile and 30 in Betics), with similar numbers for Year 2. We estimate 60 field days are required each year to accomplish this programme.

Personnel

For the field programme, DIAS will provide the two students funded under this SFI proposal, plus the third student to be funded from DIAS internal resources, plus the full-time MT technician. Jones and Garcia will rotate leadership duties in the field. UB, UL and UG will provide personnel for all aspects of the DIAS fieldwork, and vice-versa.

Equipment

At DIAS we currently own six (6) leading-edge BBMT systems manufactured by Phoenix Geophysics (Canada), with 19 broadband coil magnetometer sensors, purchased over the last two years. We are in the process of acquiring eight (8) brand-new, state-of-the-art LMT systems from Prof. Korapanov of the Lviv Space Science Centre (Ukraine). These will be delivered by Summer, 2006, i.e., prior to the initiation of the fieldwork. We are requesting funding for electrodes, from our Hungarian supplier, as these deteriorate with use and our current stock was purchased at the initiation of the SAMTEX fieldwork in Autumn, 2003. We are also requesting funding for two hand-held GPS units, and for a laptop for each season. (We experience laptop failures at a rate of one per year, due to harsh field conditions. In 2001 we went to Tibet with four laptops, and at the end of 8 weeks only one was operational.)

UB, UG and UL between them have a total of five modern Metronix BBMT systems that will be used for the Atlas and Betics profiles.

Methodologies

Equipment: We will be using the most advanced MT acquisition systems currently available.

Processing: We will be using the latest robust multi-site remote reference data processing schemes (Egbert, 1997; Chave and Thomson, 2004), taking source field problems into account (Jones and Spratt, 2002). (Both Chave and Egbert have been invited visitors to DIAS in 2005 and we have their latest codes available to us and running at DIAS. Chave and Jones have a productive and effective working relationship that is almost two decades old.)

Analysis: Dimensionality and directionality analyses will be done using McNeice-Jones (McNeice and Jones, 2001), as well as using other methods (e.g., Marti et al., 2005). If necessary, we will extend the approach of Garcia and Jones (2001) for dealing with 3D distortion of data from over 3D regional structures. (Jones is one of the world leaders at analysis of MT data, and the McNeice-Jones code is used by almost one hundred scientists and students world-wide.)

Modelling and Inversion: Through Jones' connections to EM scientists around the world, the DIAS MT group has access to many 1D, 2D and 3D forward codes, and to many 1D and 2D inversion codes, especially the latest 2D codes of Randy Mackie (Rodi and Mackie, 2001; Evans et al., 2005). In addition, initiatives are underway to bring state-of-the-art 3D inversion capability to DIAS, either through using Mackie's code by licence from Geosystem srl., through having Dr. Weerachai Siripunvaraporn spend time at DIAS (Siripunvaraporn et al., 2005), or through advances by Dr. Dmitry Avdeev, who is a CosmoGrid Fellow at DIAS.

Limitations

The greatest limitation of the MT method, as with all geophysical methods, is that one obtains information about the lateral and vertical subsurface variation of a physical property, namely electrical resistivity. Electrical resistivity can be used to infer other physical properties, such as temperature and physical state (Mechie et al., 2004; Ledo and Jones, 2005). The challenge is to interpret the electrical resistivity model in terms of geology, then to interpret the geology in terms of formation, deformation and destruction processes. Jones has demonstrated on a number of projects that MT results can add crucial information that aids understanding of tectonic processes (e.g., White et al., 1999, 2005; Jones et al., 2002; Davis et al., 2003; Solon et al., 2005; Spratt et al., 2005).

The greatest intrinsic limitation of the MT method is resolution. Essentially, although there exist uniqueness theorems when perfect MT data exist at all frequencies and for all locations, in reality it is difficult to image conductive structures with a total conductance less than the total conductance from the surface down to the top of the structure. Such was the case in Tibet, where the highly conducting, doubly-thickened crust prevented penetration of even very long-period EM waves into the mantle, except in some locations (e.g., Solon et al., 2005; Spratt et al., 2005). The previous studies in southern Iberia and in the Atlas mountains show evidence for localised conductors in the crust, but no evidence for pervasive, highly conducting layers, as observed in Tibet. Thus, we anticipate that our LMT measurements will be able to penetrate to the LAB at many of the sites we will occupy.

Collaborators

A partial list of the institutions, with key individuals, that have thus far indicated their desire to take part in PICASSO. MT experts are underlined. For a more complete list, please see wija.ija.csic.es/gt/rc/HTML/ParticipantsPICASSO.html).

CSIC Earth Sci. Barcelona:	**R. Carbonnell (PICASSO lead co-PI)**, J. Gallart
DIAS:	A.G. Jones (EuroArray lead co-PI), X. Garcia
GFZ Potsdam:	R. Kind
IFM-Geomar	M. Jegen
U. Barcelona:	J. Ledo, A. Marcuello, J. Pous, P. Queralt
U. Bristol:	M. Kendall
U. Cadi Ayyad, Marrakesh:	M. Amrhar, A. Kchikach
UCSD:	D. Seber
U. Copenhagen:	H. Thybo (EuroArray lead co-PI)
U. Granada:	J. Galindo-Zaldivar, J. Galindo, J. Morales
U. Leeds:	G. Houseman, G. Stuart
U. Lisbon:	F. Santos, E. Almeida
U. Oregon:	G. Humphreys, D. Toomey
U. Paris-Sud:	H. Zeyen
I.S. Rabat:	T. Abdelfatah, M. Harnafi
Rice University:	**A. Levander (PICASSO lead co-PI)**, C-T.A. Lee, A. Lenardic, F. Niu
U. Utrecht.:	W. Spakman
Vrije U. Amsterdam:	S. Cloetingh (Topo-Europe lead PI)

Linkages

This MT programme described herein is an important, arguably essential, component of the PICASSO initiative. It is intimately linked to all of the other PICASSO activities. PICASSO itself is linked to the nascent EuroArray initiative (www.euroarray.org), which is an attempt by some European scientists to embark on a pan-European geoscience programme for imaging the whole continent. PICASSO is indeed the designated pilot project of EuroArray.

EuroArray is linked to the Topo-Europe initiative (www.geo.vu.nl/users/topo/), led by Prof. S. Cloetingh, the current President of the International Lithosphere Program. Topo-Europe was the top-rated Life and Earth Sciences proposal to the European Science Foundation for EUROCORES funding in 2005. Unfortunately, budget limitations prevented it being supported at that time, but it is expected to be funded in the 2006 competition.

Autonomy

PICASSO is planned as a multi-disciplinary project involving science teams from many institutions using many geoscientific tools. Proposals for funding are going into the U.S. National Science Foundation, Spanish funding agencies (for instrumentation and for geological, GPS, seismic and MT fieldwork), and the UK's NERC for instruments from the SEIS-UK pool; Danish, German and French proposals are planned. The greatest benefit will occur if all aspects of PICASSO are funded, and full integration takes place. However, given the existing geoscientific knowledge, parts can progress and make significant contributions in their own right. In particular, the MT programme defined herein, with its three components (main profile, Betics and Atlas mountains), can stand-alone if necessary. As stated, there is no knowledge at all of the lithospheric electrical resistivity structure, in particular of the variation of the LAB, because the appropriate long-period MT (LMT) instruments have not ever been deployed in Iberia or northern Africa. Recent LMT studies have made significant contributions to understanding of lithospheric processes (e.g., Jones, 1999 review paper; Jones and Craven, 2004; Jones et al., 1983, 1996, 2001, 2002, 2003, 2005; Jones and Garcia, 2006; Davis et al., 2003; Korja et al., 2003; Eaton et al., 2004; Ogawa et al., 1996).

What is the recent record of accomplishment in research that argues for project success?

Jones has a well-established track record for leading large national and international multi-institutional magnetotelluric experiments, principally through his Lithoprobe activities, INDEPTH, and most recently as project leader for SAMTEX (Southern African Magnetotelluric Experiment), and bringing them to fruition. He has over 100 publications in the international literature, of which many relate to imaging crustal-scale orogenic processes and integrating magnetotelluric data with data from the other geosciences. He has led and co-authored papers with seismologists, potential field experts, structural geologists, geochemists, petrologists and geochronologists, as well as in virtually all aspects of magnetotellurics (from theory to instrumentation to processing to analysis to modelling to inversion).

Project INDEPTH (InterNational DEep Profiling of Tibet and the Himalaya), entering its 4th Phase, is an interdisciplinary program of geophysical and geological studies designed to develop a better understanding of the deep structure and mechanics of the Himalaya-Tibet region in response to the collision of India with Asia. As such, INDEPTH parallels PICASSO in its aims and objectives. As the MT leader on the INDEPTH project, Jones graduated two students and co-authored nine papers, including three in Science and one in Nature.

Jones was a key figure in the internationally-renowned Lithoprobe programme under which multi-disciplinary geoscientific studies of Canada were conducted over the last 20 years. He was leader of the non-seismic geophysics, and was Chairman of the Scientific Committee for three years. His experience at leading such projects will prove valuable for PICASSO.

Since moving to DIAS in 2004 Jones instigated, and together with Professors H. Thybo (U. Copenhagen) and P. Maguire (U. Leicester) initiated, thinking within Europe about the necessity for a pan-European geoscience programme of study for understanding Europe's formation and evolution. This proposed programme is named EuroArray (www.euroarray.org), and presentations have been given at European (EGU) and international (AGU, IGC) conferences. EuroArray is now a component of Topo-Europe (www.geo.vu.nl/users/topo/), led by Professor S. Cloetingh (Amsterdam), for the integrated study of Europe from outer space to the inner core with particular reference to topography and societal implications of short and long term climactic and geodynamic change. PICASSO has been accepted as a pilot project under EuroArray and Topo-Europe auspices, and Jones is on the International Steering Committee of PICASSO.

Also, since 2004 Jones has built an MT group that is the envy of many, with six scientists and four Ph.D. students studying MT from theory through processing/analysis to modelling to interpretation. Through Jones, DIAS has a formal memorandum of understanding with the University of Barcelona, home to another significant and active MT group. Together, these two groups will form the nexus of the MT work on PICASSO.

What is the value of this research to the people of Ireland?

Understanding how the Earth works is fundamental to our very existence on our planet. One of the major formative processes on Earth is continental collision, yet it is not fully understood even in simple geometries (India-Tibet), never mind more complex ones, such as the PICASSO study area. Continental collision formed Ireland, when the Iapetus Ocean closed some 400 million years ago, but unravelling the history of the collision will only be possible when we understand modern collisional orogens.

Within collisional orogens, arguably the least understood of all of the active processes is the recycling of material from the surface back into the mantle. Unless and until this process is fully understood where it can be actively observed in action, or recently in action (such as the Betics, Tubia et al., 2004) we have little hope of ever explaining the past tectonic history of the Earth. In particular, the tectonic history of Ireland, with its major orogenic episodes, especially the closure of the Iapetus Ocean, will only be correctly known when we are able to understand and explain current tectonism.

Secondly, PICASSO is, in and of itself, a highly worthwhile international project, with many European (Denmark, France, Germany, Netherlands, Spain, UK) and U.S. partners, that Ireland should be a part of. The members of the multi-disciplinary geoscience team will bring almost all aspects of the respective disciplines into it, and, mimicking Lithoprobe, fundamental correlations will become evident that are simply not possible with single-discipline studies. However, PICASSO is also the pilot project for EuroArray and Topo-Europe, both of which are major proposals for pan-European geoscience for the next decade. Ireland should not miss out on the opportunity to be part of, indeed to play a leading role, in both of these.

Finally, under SFI funding for PICASSO three Ph.D.-level graduate students will be supported and trained within a large project that offers broad scale opportunities for undertaking holistic geoscience to tackle a major geoscientific problem. Two of these students will be supported directly by the SFI grant, and the other will be supported by DIAS internal funds. The students will be trained at one of the top laboratories in the world for magnetotellurics, and for integrating the results of MT with other studies. In addition, they will be exposed to other geophysics, through an exchange with the University of Barcelona (funds for this exchange will come from DIAS internal resources) and through attendance at the annual SAGE (Summer of Applied Geophysical Experience, www.ees1.lanl.gov/SAGE) educational program.

References

Almeida, E., F.M. Santos, A. Mateus, W. Heise, and J.Pous, 2005. Magnetotelluric measurements in SW Iberia: New data for the Variscan crustal structures. *Geophysical Research Letters,* 32, doi: 10.1029/2005GL022596.

Buforn, E., M. Bezzeghoud, A. Udias, And C. Pro, 2004. Seismic sources on the Iberia-African plate boundary and their tectonic implications. Pure *and Applied Geophysics*, **161**, 623–646

Calvert, A., E. Sandvol, D. Seber, M. Barazangi, S. Roecker, T. Mourabit, F. Vidal, G. Alguacil and N. Jabour, 2000a. Geodynamic evolution of the lithosphere and upper mantle beneath the Alboran region of the western Mediterranean: Constraints from travel time tomography. *Journal of Geophysical Research-Solid Earth*, 105, 10,871-10,898.

Calvert, A. E. Sandvol, D. Seber, M. Barazangi, F. Vidal, G. Alguacil, and N. Jabour, 2000b. Propagation of regional seismic phases (Lg and Sn) and Pn velocity structure along the Africa–Iberia plate boundary zone: tectonic implications. *Geophysical Journal International*, **142**, 384-408.

Chave, A.D., and Thomson, D.J., 2004. Robust, controlled-leverage processing of magnetotelluric data, *Geophys. J. Internat.*, **157**, 988-1006.

Davis, W.J., A.G. Jones, W. Bleeker and H. Grütter, 2003. Lithospheric development in the Slave Craton: a linked crustal and mantle perspective. *Lithos*, **71**, 575-589.

Duggen S., K. Hoernle, P. van den Bogaard, and C. Harris, 2004. Magmatic evolution of the Alboran region: The role of subduction in forming the western Mediterranean and causing the Messinian Salinity Crisis. *Earth and Planetary Science Letters,* 218, 91-108.

Eaton, D.W., A.G. Jones, and I.J. Ferguson, 2004. Lithospheric anisotropy structure inferred from collocated teleseismic and magnetotelluric observations: Great Slave Lake shear zone, northern Canada. *Geophysical Research Letters*, **31**, L19614, doi:10.1029/2004GL020939.

Egbert, G.D., 1997. Robust multiple-station magnetotelluric data processing. *Geophys. J. Internat.*, **130**, 475-496.

Evans R.L., G. Hirth, K. Baba, D. Forsyth, A. Chave, and R. Mackie, 2005. Geophysical evidence from the MELT area for compositional controls on oceanic plates. *Nature*, **437**, 249-252.

Garcia, X. and Jones, A.G., 2001. Decomposition of three-dimensional magnetotelluric data. *In:* Three-Dimensional Electromagnetics, edited by M.S. Zhdanov and P.E. Wannamaker, Elsevier, Methods in Geochemistry and Geophysics, vol. 35, ISBN 0 444 50429 X, 235-250.

Gomez, F., W. Beauchamp, and M. Barazangi, 2000. Role of the Atlas Mountains (northwest Africa) within the African-Eurasian plate-boundary zone. *Geology*, 28, 775-778.

Gomez, F., W. Beauchamp, and M. Barazangi, 2002. Role of the Atlas Mountains (northwest Africa) within the African-Eurasian plate-boundary zone: Reply. *Geology*, 30, 96.

Gutscher M.A., J. Malod, J.P. Rehault, I. Contrucci, F. Klingelhoefer, L. Mendes-Victor, and W. Spakman, 2002. Evidence for active subduction beneath Gibraltar. *Geology*, 30, 1071-1074.

Hamilton, M., A.G. Jones, R.L. Evans, S. Evans, C.J.S. Fourie, X. Garcia, A. Mountford, J.E. Spratt, and the SAMTEX Team, 2006. Anisotropy structure of the lithosphere derived from magnetotelluric and seismic shear-wave splitting analyses in southern Africa. *Physics of the Earth and Planetary Interiors,* in press.

Laville, E., 2002. Role of the Atlas Mountains (northwest Africa) within the African-Eurasian plate-boundary zone: Comment. *Geology*, 30, 95.

Ji, S., S. Rondenay, M. Mareschal and G. Senechal, 1996. Obliquity between seismic and electrical anisotropies as a potential indicator of movement sense for ductile mantle shear zones. *Geology*, **24**, 1033-1036.

Jones, A.G., 1998. Waves of the future: Superior inferences from collocated seismic and electromagnetic experiments. *Tectonophys*., 286, 273-298.

Jones, A.G., 1999. Imaging the continental upper mantle using electromagnetic methods. *Lithos*, 48, 57-80.

Jones, A.G., and Craven, J.A., 2004. Area selection for diamond exploration using deep-probing electromagnetic surveying. *Lithos*, 77, 765-782.

Jones, A.G., Eaton, D.W., White, D., Bostock, M., Mareschal, M. and Cassidy, J., 1996. Geophysical measurements for Lithospheric parameters. In: Searching for Diamonds in Canada, A.N. LeCheminant, R.N.W. DiLabio, and K.A. Richardson (ed.), Geological Survey of Canada, Open File 3228, 243-250.

Jones, A.G., Ferguson, I.J., Chave, A.D., I.J., Evans, and McNeice, G.W., 2001, The electric lithosphere of the Slave craton. *Geology*, 29, 423-426.

Jones, A.G. and X. Garcia, 2006. Electrical resistivity structure of the Yellowknife Fault Zone and surrounding region. In: *Gold in the Yellowknife Greenstone Belt, Northwest Territories: Results of the EXTECH III Multidisciplinary Research Project*, published by Geological Association of Canada, Mineral Deposits Division, Special Publication, Chapter 13, in press.

Jones, A.G., Lezaeta, P., Ferguson, I.J., Chave, A.D., Evans, R.L., Garcia, X., and Spratt, J., 2003. The electrical structure of the Slave craton, *Lithos*, 71, 505-527.

Jones, A.G., J. Ledo, I.J. Ferguson, C. Farquharson, X. Garcia, N. Grant, G.W. McNeice, B. Roberts, J. Spratt, G. Wennberg, L. Wolynec, and X. Wu, 2005. The electrical resistivity structure of Archean to Tertiary lithosphere along 3,200 km of SNORCLE profiles, northwestern Canada. *Canadian Journal of Earth Sciences*, 42, 1257-1275.

Jones, A.G., Olafsdottir, B. and Tiikkainen, J., 1983. Geomagnetic induction studies in Scandinavia - III. Magnetotelluric observations. *J. Geophys.* 54: 35-50.

Jones, A.G., D. Snyder, S. Hanmer, I. Asudeh, D. White, D. Eaton and G. Clarke, 2002. Magnetotelluric and teleseismic study across the Snowbird Tectonic Zone, Canadian Shield: A Neoarchean mantle suture? *Geophys. Res. Lett.*, 29 (17), doi: 10.1029/2002GL015359, 10-1 – 10-4.

Jones, A.G. and J. Spratt, 2002. A simple method for deriving the uniform field MT responses in auroral zones. *Earth, Planets and Space*, **54**, 443-450.

Ledo, J. and A.G. Jones, 2005. Temperature of the upper mantel beneath the Intermontane Belt, northern Canadian Cordillera, determined from combining mineral composition, electrical conductivity laboratory studies and magnetotelluric field observations. *Earth and Planetary Science Letters*, **236**, 258-268.

Korja, T., and the BEAR Working Group, 2003. Upper mantle conductivity in Fennoscandia as imaged by the BEAR array. Contrib. paper, EGU, Nice.

Martí, A., P. Queralt, A.G. Jones and J. Ledo, 2005. Improving Bahr's invariant parameters using the WAL approach. *Geophysical Journal International*, **163**, 38-41.

Marti, A., P. Queralt, and E. Roca, 2004. Geoelectrical dimensionality in complex geologic areas: Application to the Spanish Betic chain. *Geophysical Journal International*, **157**, 964 – 974.

McNeice, G. and A.G. Jones, 2001. Multisite, multifrequency tensor decomposition of magnetotelluric data. *Geophysics*, **66**, 158-173.

Mechie, J., S.V. Sobolev, L. Ratschbacher, A. Yu. Babeyko, G. Bock, A.G. Jones, K.D. Nelson, K.D. Solon, L.D. Brown, and W. Zhao, 2004. Precise temperature estimation in the Tibetan crust from seismic detection of the alpha-beta quartz transition. *Geology*, **32**, 601-604.

Michard A., A. Chalouan, H. Feinberg, B. Goffe, and R. Montigny, 2002. How does the Alpine belt end between Spain and Morocco? *Bulletin de la Societe Geologique de France*, **173**, 3-15.

Ogawa, Y., Jones, A.G., Unsworth, M.J., Booker, J.R., Lu, X., Craven, J., Roberts, B., Parmelee, J. and Farquharson, C., 1996. Deep electrical conductivity structures of the Appalachian Orogen in the southeastern U.S. *Geophys. Res. Lett*., **23**: 1597-1600.

Partzsch, G.M., F.R. Schilling and J. Arndt, 2000. The influence of partial melting on the electrical behavior of crustal rocks: laboratory examinations, model calculations and geological interpretations. *Tectonophysics*, **317**, 189-203.

Pous, J., G. Munoz, W. Heise, J.C. Melgarejo, and C. Quesada, 2004. Electromagnetic imaging of Variscan crustal structures in SW Iberia: the role of interconnected graphite. *Earth and Planetary Science Letters*, **217**, 435-450.

Pous, J., P. Queralt, J. Ledo, and E. Roca, 1999. A high electrical conductive zone at lower crustal depth beneath the Betic Chain (Spain). *Earth and Planetary Science Letters*, **167**, 35-45.

Rodi, W., and R.L. Mackie, 2001. Nonlinear conjugate gradients algorithm for 2-D magnetotelluric inversion. *Geophysics*, **66**, 174-187.

Schmeling, H., 1986. Numerical models on the influence of partial melt on elastic, anelastic and electrical properties of rocks. Part II: Electrical conductivity. *Physics of the Earth and Planetary Interiors*, **43**, 123-136.

Schwarz, G., Mehl, H.G., Ramdani, F. and Rath, V., 1992. Electrical resistivity structure of the eastern Moroccan Atlas System and its tectonic implications. *Geologische Rundschau*, **81**, 221-235.

Seber, D., Barazangi, M., Tadili, B., Ramdani, M., Ibenbrahim, A. and Ben Sari, D., 1996. Three dimensional upper mantle structure beneath the intraplate Atlas and interplate Rif mountains of Morocco. *Journal of Geophysical Research*, **101**, 3125–3138.

Serrano I., T.M. Hearn, J. Morales, and F. Torcal, 2005. Seismic anisotropy and velocity structure beneath the southern half of the Iberian Peninsula. *Physics of the Earth and Planetary Interiors*, **150**, 317-330.

Siripunvaraporn W, Egbert G, Lenbury Y, and Uyeshima M., 2005, Three-dimensional magnetotelluric inversion: data-space method, Physics of the Earth and Planetary Interiors, **150**, 3-14.

Solon, K., A.G. Jones, K.D. Nelson, M.J. Unsworth, and the INDEPTH MT team, 2005. Structure of the crust in the vicinity of the Banggong-Nujiang suture central Tibet from INDEPTH magnetotelluric data. *Journal of Geophysical Research*, **110**, B10102, doi: 10.1029/2003JB002405.

Spratt, J., A.G. Jones, K.D. Nelson, M.J. Unsworth, and the INDEPTH MT team, 2005. Crustal structure of the India-Asia collision zone, southern Tibet, from INDEPTH MT investigations. *Phys. Earth, Planet. Inter.*, **150**, 227-237.

Teixell, A., M.-L. Arboleya, M. Julivert, and M. Charroud, 2003. Tectonic shortening and topography in the central High Atlas (Morocco). *Tectonics*, **22**, doi:10.1029/2002TC001460.

Teixell, A., P. Ayarza, H. Zeyen, M. Fernandez, and M.-L. Arboleya, 2005. Effects of mantle upwelling in a compressional setting: the Atlas Mountains of Morocco. *Terra Nova*, **17**, 456-461.

Tubia J.M., J. Cuevas, J.J. Esteban, 2004. Tectonic evidence in the Ronda peridotites, Spain, for mantle diapirism related to delamination. *Geology*, **32**, 941-944.

White, D.J., A.G. Jones, S.B. Lucas and Z. Hajnal, 1999. Tectonic evolution of the Superior Boundary Zone from coincident seismic reflection and magnetotelluric profiles. *Tectonics*, **18**, 430-451.

White, D.J., M.D. Thomas, A.G. Jones, J. Hope, B. Nemeth, and Z. Hajnal, 2005. Geophysical Transect across a Paleoproterozoic continent-continent collision zone: The Trans-Hudson Orogen. *Canadian Journal of Earth Sciences*, **42**, 385-402.

Zeyen, H., P. Ayarza, M. Fernandez, and A. Rimi, 2005. Lithospheric structure under the western African-European plate boundary: A transect across the Atlas Mountains and the Gulf of Cadiz. *Tectonics*, **24**, doi: 10.1029/2004TC001639.