ECOS-*Sud*

Comité : Evaluation - Orientation de la Coopération Scientifique
(Argentine - Chili - Uruguay)

Programme de coopération ECOS-CONICYT (Chili)
Fiche-projet

(doit être adressée à ECOS-Sud, avec les documents annexes au plus tard le **31 mars 2011**, sous forme électronique exclusivement).

1. Titre du projet :

Maule 27-Feb-2010 Mw 8.8 Mega Earthquake .....

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.....

Mots-clés (4 maximum) : **sismologie, géodésie, séisme, aléa sismique** .....

Champ disciplinaire (cocher) : ☐ Sciences Humaines et Sociales ☐ Sciences de la Vie
☐ Sciences de la Santé ☑ Sciences de l'Univers ☐ Sciences Exactes

2. Établissement principal[1] :

en France : . . . . . .

Laboratoire[2] (ou équipe) : laboratoire de Géologie de l'ENS – UMR 8538 du CNRS. . . . . .

Nom du Directeur : Christian Chopin . . . . . .

au Chili : .....

Laboratoire (ou équipe) : Departamento de geofisica (DGF) – U-chile

Nom du Directeur : Emilio Vera .....

3. Responsables du projet[3]

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[1] Auquel appartient le responsable scientifique du projet.
[2] Indiquer le statut de l'Unité : UPRES, EA, UMR, UPR, U. INSERM, U. INRA, etc.
[3] Le responsable du projet doit être habilité à diriger les recherches.

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4. Liste des chercheurs confirmés (grade, structure de rattachement) **et chercheurs en formation** (structure de rattachement) **participant au projet (distinguer si nécessaire entre chercheurs principaux, bénéficiaires des missions, et chercheurs associés ou occasionnels ; le nombre de 3 chercheurs principaux hormis les étudiants paraît raisonnable)**

en France :

Chercheurs confirmés :

- Vigny Christophe, DR2 CNRS, laboratoire de géologie de l'ENS
- Raul Madariaga, professeur ENS, laboratoire de géologie de l'ENS

Chercheurs en formation :

- Marianne Métois, doctorante ENS (Géodésie – C. vigny), laboratoire de géologie de l'ENS
- Amaya Fuenzalida, doctorante ENS (Sismologie – R. Madariaga), laboratoire de géologie de l'ENS

au Chili :

Chercheurs confirmés :

- Jaime Campos, professeur U-Chile, DGF
- Sophie Peyrat, professeur U-Chile, DGF

Chercheurs en formation :

- Sergio Ruiz, doctorant U-Chile, DGF U-Chile Santiago
- Patricio Toledo, doctorant U-Chile, DGF U-Chile Santiago

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5. Description du projet scientifique (problématique, contexte bibliographique, méthodologie, plan du travail, implication de chaque équipe…) utiliser autant de pages additionnelles que vous le jugerez nécessaire :

Abstract

We propose to study the Mw 8.8 Maule mega earthquake of February 2010 in every possible detail and to put it into the perspective of the geodynamics of the Andean margin. The Chilean subduction is one of the most active in the world, with 4 mega earthquakes in the last 120 years (1906, 1922, 1960 & 2010). The occurrence of these earthquakes poses a number of problems that will be addressed by a group of researchers that has been working in Chile for more than 20 years, doing research that helped to set the frame for a successful study the 2010 event. The study of this event will be used as a starting point to improve our approach of active subduction: as we conduct our study of the Maule earthquake in south-central Chile, we will be increasingly focusing our attention to the regions to the North of Santiago that are now approaching the end of their respective seismic "cycles".

For the specific study of the Maule earthquake we have acquired a substantial co- seismic data set that includes campaign GPS, high dynamic range accelerograms and classical strong motion instruments. In addition to these we dispose of a set of 1 Hz continuously recording GPS antennas. This unique data set will be used to study the rupture process of the earthquake and we hope to explain why such a large event produced moderate strong motion. Is this a unique feature of this event, or is it typical of most large subduction zone mega-earthquakes? In order to answer this question we need to study the slip distribution of the main event and understand why the aftershocks stretched over an area that seems to be substantially longer than the rupture of the main event. The aftershock series did not contain any events larger than Mw 7.1, a puzzling feature indeed. We dispose of several months of aftershock recordings obtained by the CNRS-INSU researchers and our foreign and Chilean colleagues. Are these aftershock uniformly distributed or highly concentrated in a few "asperities" as preliminary results seem to suggest?

Maule 2010 is the first mega earthquake that occurs in a closely surveyed area. Studies published in the last 10 years pointed out that the interplate zone was completely locked not just inside in the so-called "Darwin gap" but well outside it, suggesting that historical earthquakes can serve to identify gaps, but not to determine their actual size. Of equal interest is the problem of after slip that will be studied with the instruments deployed before the event and by a much richer set of cGPS instruments deployed after it. We anticipate new observations that may help resolve the big questions of after slip: where does it occur and what are the properties of faults and bulk rheology that produce long episodes of silent deformation around earthquakes. This problem is closely related to that of segmentation; there is indeed substantial evidence that the Chilean margin has long standing segments associated both with features of the oceanic plate (sea mounts, transform faults and others) and of the over riding plate (faults, uplifted terraces, etc). Do they actually play a role in stopping earthquakes or at least in fragmenting them?

The Maule earthquake is a rare event; the lessons to be learned from the study of this rare earthquake will most certainly have a lasting influence in the way geoscientists and earthquake engineers approach the problem of the occurrence of these events.

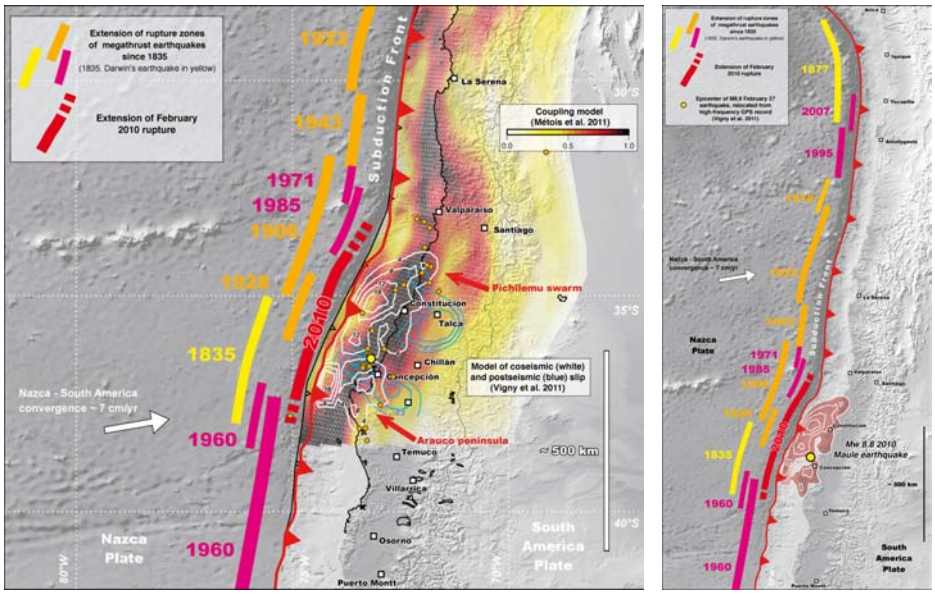

Figure: The Maule earthquake of 27 February 2010. Coupling inverted from pre-seismic GPS data (Yellow-to-red colour scale) [Métois et al. 2011], slip distribution inverted from co-seismic geodetic (GPS+INSAR) data (co-seismic/post-seismic: white/blue contour levels) [Vigny et al. 2011]. Historical earthquake segmentation (stripes along the trench).

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Important questions raised by the Earthquake / objectives of the cooperation

The 2010 Mw8.8 Maule earthquake raises challenging questions related to the understanding of the nucleation and the propagation of a megathrust earthquake rupture, the frequency contents associated to such large subduction earthquake, the segments of the subduction zone in Chile and the way large seismic gap eventually rupture. This project aims at providing new answers and perspectives to these questions, all in the light of the Maule Earthquake.

The first Challenge is to understand the Maule earthquake (a rare Mw 8.8 event) itself: Why did it generate only moderate accelerations? Why aftershocks apparently extend significantly longer than the rupture? Is that true? Why no large aftershock occurred until now? Will there be any? Is it the repeat of the 1835 Earthquake described by Darwin and Fitzroy? Did the rupture brake the entire width of the subduction plane from trench to transition zone?

A second objective is to improve our understanding of the complex patterns of earthquakes on the Chilean trench. Small/moderate earthquakes represent failure of individual asperity while great earthquake represent the collective failure of several asperities. Asperity sizes may be smaller than the inter-plate width implying along-dip and along-strike asperity interactions. Maule 2010 is an example of a great earthquake which probably ruptured the entire width of the subduction plane, implying interaction of several asperities and a complex bi-lateral source. Geodetic evidences of after-slip and post-seismic deformations also strongly suggest the importance of seismic/aseismic interactions between asperities. We want to understand the asperity origin in relation with deep structures and variations of plates coupling; to understand seismic/aseismic asperity interactions over various time and space scales; to understand the implications for earthquake dynamics and radiation. All these studies require dense high-quality observations data sets integrating cGPS, seismographs and strong motion. Such observations will be available for our project, thanks to the rapid deployment of hundreds of instruments in the Maule area and around. We dispose of unique high-rate GPS data acquired above the rupture plane as well as of strong-motion data acquired in near and intermediate field, not only during but also before and after the event. Using jointly these types of data will allow a detailed study of the dynamic of the earthquake and yield a new perspective for studying the earthquake source with GPS data. Aftershocks that followed the earthquake will be studied with one of the densest seismic network in the world, allowing for a high resolution in earthquake relocation, fault plane solutions and implications for a better knowledge of active structures and their interactions in the area. Crustal co-, post-, and inter-seismic deformations will be systematically monitored using GPS. Methodologic developments performed in the frame of this project are necessary for being able to detect small, long-wavelength deformations, and will be very useful for other environmental applications. Investigating the mechanical relations between the plates will shed a new light on our understanding of crustal deformation and megathrust generation in subduction context. The modeling of the deformation during the various phases of the seismic cycle will help understanding the mechanical properties of the subduction interface. And the integrated view of the cycle as a whole will improve our understanding of long-term deformation and segmentation. It will bring new perspectives on how one can interpret the strain field measured at the surface. Therefore we believe that this project will significantly push forward the knowledge of the mechanical behavior of mega-thrusts at the different stages of the seismic cycle. These aspects will be discussed in terms of segmentation of the subduction and potential implications for the seismic hazard in Chile.

For this project, we want to increase ties and collaborative work between two scientific communities: Seismology and Geodesy. We want to promote new methodologies like the usage of high rate cGPS data by seismologists for the study of the earthquake source mechanism. We want to develop and transmit knowledge on these topics within our own groups and between France and Chile.

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Work packages and organisation

1. Low and high frequency characteristics of the Maule earthquake of 27 February 2010 and some of its major aftershocks

Researchers : R. Madariaga (ENS), J. Campos (U-Chile), S. Peyrat (U-Chile)
Students : S. Ruiz (U-Chile) P. Toledo (U-Chile)

The 27 February 2010 Maule mega-earthquake was the fifth largest earthquake recorded since the beginning of the 20th century, yet it produced limited damage. One of the foremost questions in applied seismology (see Grand Challenges in Seismology") is whether damage in large subduction zone earthquake scale with the Moment (or equivalently Mw) or is due to some other characteristic of earthquakes that moment release does not account for. The Maule earthquake was a major event with a large rupture zone of about 450-500 km length by roughly 140 km width; it produced a significant tsunami and large geodetic deformations in the near and intermediate field. Yet, from the point of view of damage in Central Chile it was an earthquake barely more destructive than the big Mw 7.8 event that hit Valparaiso on 3 March 1985. The zone of damage in 2010 is much longer than that of 1985 extending well below the Arauco peninsula, some 600 km south of Valparaiso. A possible explanation, advanced by some engineers is that the Maule event was smoother than what was expected, producing a low level of acceleration (less than 60 % of g); another is that Chilean construction practices have significantly improved in the last 20 years. Either ways, and there may be other explanations not envisioned yet, we need to understand damage during large earthquakes better. This is important not just for Chile, but for all other areas of the world where mega earthquakes are expected, like the NW United States, Alaska, Kamchatka in Russia, Central Japan, Taiwan, Peru, Colombia, etc.

We propose to study the Maule event comparing high and low frequencies in a systematic manner. For that purpose we have three types of data: static deformation as observed by interferometry, GPS, and tsunami excitation (Delouis et al., 2010; Lorito et al., 2010; Tong et al., 2010; Vigny et al., 2011; etc). We also dispose of data on low to intermediate frequency radiation in the near and far field from continuous GPS motograms and high frequency signals from some 15 high dynamic range accelerometers and some 30 more conventional engineering accelerograms.

In order to use these data we have to demonstrate that the different recordings are compatible and determine the exact range over which they overlap. The spectral analysis of these records show that motograms contain information from static to about 0.15 Hz, while high dynamic range accelerograms are useful in the range from 0.005 to 10 Hz. A similar comparison of high dynamic range accelerograms and conventional engineering instruments show that the latter can be used in the range from 0.03 to 10 Hz. Thus we can use the bumper crop of accelerograms in order to study the origin of high frequency waves from this earthquake as suggested by (Ruiz et al., 2010 and Lancieri et al., 2010).
Acelerograms of the Maule earthquake written in the Santiago metropolitan area all have durations of about 60 s and two strong pulses of acceleration with peaks of about 20-30 % g. This is strong motion, but much less than what was expected for such a large event (see the film by National geographic, 2010). A straightforward comparison of the accelerograms recorded in the Maipo valley (Melipilla, Santiago, Llolleo) shows that records of the Mw 8.8 event of 27 February 2010 look almost identical to those of the 1985 Valparaiso event (Ruiz et al, 2010a, 2010b). A careful study of the intensity distribution by Astroza et al. reveals that the maximum recorded intensity of ground motion reach only 8 in the Mercalli scale, meaning that the 2010 event was in fact a mild earthquake.

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Work program

We propose to study the source of the 27 February Maule earthquake at the broadest possible frequency band using all available data. *We distinguish three steps in this work:*

1.1 Full kinematic inversion. We intend to carry out a full inversion that includes all the kinematic data of the Chilean earthquake already available. The main question is how far did the earthquake rupture extend in the trench direction. Studies presented at the fall AGU meeting in San Francisco using ALOS interferometry, tsunami and a few intermediate and far field GPS data seem to favour a rather narrow rupture zone. The inversion of the campaign GPS data acquired along the coast from Arauco to Llico by Vigny et al, (2011) indicates that the rupture extended significantly close to the trench. Inversion of static data is very accurate near the source but its accuracy decreases with distance from the observers. For this reason we would like to invert the static data together with the intermediate field as recoded by continuous GPS instruments in the near and intermediate field. Inversion of this data can not be done without processing because the static field is overwhelmingly dominant at the stations in Concepcion, Constitucion, San Javier and Maule. A possibility is either selectively filtering this data, but this introduces very serious time delays. Another possibility is using the ground velocity obtained by numerical derivation of the motograms. Comparison of the motograms with high rate accelerograms will be used a guide for data processing.

1.2 High and intermediate frequency inversion. We dispose of close to 30 recordings of either acceleration from 16 bits accelerograms, high dynamic range 24 bit accelerograms and the motograms already mentioned earlier. From spectral analysis we know that this data has a common frequency band 0.02 to 0.16 Hz. Once inversion is done in this band we can extend the source to higher frequencies using the low dynamic range accelerometers. The goal will be not to determine a precise distribution of intermediate frequency sources, but to identify their approximate location. Identifying these sources from the high frequency data will be done only statistically using methods proposed by Ide and Aochi in recent publications.

1.3 High and low frequency characteristics of the Maule earthquake. The ultimate goal of our project is to explain how a magnitude 8.8 earthquake produced accelerations that are similar to those produced by a Mw 8 event. This is a crucial question for future studies of seismic risk in those regions of the world where mega earthquakes are expected. Foremost, the Northern Chile gap from the Mejillones Peninsula to Southern Peru.

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2. Geodesy: pre-seismic, co-seismic and post-seismic surface deformation

Researchers : C. Vigny (ENS), J. Campos (U-Chile)
Students : M. Métois (ENS)

The Maule Earthquake showed that there was a strong correlation between inter-seismic coupling that prevailed prior to the earthquake and co-seismic slip (Ruegg et al., 2009; Moreno et al., 2010; Vigny et al. 2011; Métois et al., 2011). Roughly speaking and on average, the slip is maximum where the coupling was maximum and the rupture is stopped by areas where coupling is low. Additionally, the coupling pattern seems to correlate well with past ruptures and therefore the segmentation. Thus, although the physical mechanism for such correlation is not completely understood, quantifying inter-seismic coupling along the subduction, on segments which did not break yet, is of primary importance to quantify seismic hazard along the trench. For this task, we will continue to determine the coupling on the trench using simple elastic models based on Okada's equations and the back-slip assumption (Okada, 1985; Savage 1985). Although physically limited, these models proved efficient in determining a simple quantity (the "coupling" or "slip deficit") which revealed a good proxy for the determination of the presence of velocity weakening asperities capable of producing a seismic rupture. Models need data. Large portions of the Chilean trench remain where the amount of upper plate deformation is still poorly known. Therefore, we need new measurements where there are none or few. Additionally, we cannot push aside the fact that coupling may change with time, over long time scales. Therefore we need continuing measurements where we already have some.

Post-seismic deformation is also often observed but its causes are still not well understood. Either viscoelastic relaxation in the mantle, aseismic afterslip on the subduction fault or poroelastic rebound are invoked to explain geodetic and seismologic observations. The physics of such phenomena which involve several time scales that typically range from minutes to months and years are still debated. Viscoelastic relaxation is most likely the dominant mechanism over large time (years to tens of years) and space scales. It gives insights about the rheologies of the asthenosphere, of the mantle wedge and perhaps of the lower crust. Poroelastic phenomena constrain fluid circulation in the area of the fault zone. Afterslip is thought to relax the accumulated stresses in zones of the fault characterized by small or moderate co-seismic slip. It is important to document and understand it because it often accounts for as much slip as occurs in the main shock. Such large amount of afterslip may contribute to explain why the total seismic moment released at plate boundaries is less than expected if it were entirely released by earthquakes accommodating the plate convergence rate. Afterslip appears to relax zones of low co-seismic slip on the rupture itself, updip or downdip the rupture as predicted by state- and rate-dependent frictional models [e.g. Heki et al., 1997; Chlieh et al., 2004; Pritchard and Simons, 2006; Bejar-Pizarro et al., 2010; Perfettini et al. 2010]. Therefore studies of afterslip are important to test rate- and state-dependent friction laws. Accurate estimation of the decay time of afterslip as well as rigorous numerical tests of whether the observed decay is, in fact, logarithmic and remains so over the entire observing period should allow rate- and state-friction laws to be rigorously tested with geodetic and seismic field observations. In this task we propose to tackle the problem of early after-slip on occurring on the fault plane using a very simple elastic approach, valid for the first year of post-seismic deformation. Large scale viscous deformation that needs complete 3D visco-elastic models involving mantle convection will not be addressed here. They require a longer time span, of at leats several years, before it make sense to try to fit data by adjusting the model parameters.

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Work program

We propose to acquire/process/analyze the GPS data indispensable for this study. We distinguish two different activities in this work:

2.1 Processing/analysis of the cGPS data provided by the post-seismic network. At the time of the earthquake, our team was running continuous GPS stations which brought critical observations for the understanding of the rupture. As soon as one week after the main shock, we started to installed 11 additional cGPS stations in the rupture area. These early observations are unique (other groups deployed additional instruments, but later) and critical to detect post-seismic afterslip and constrain rate- and state-friction laws. First results show that afterslip occurring during the first days after the earthquake is complementary to co-seismic slip rather than adding on it: areas with less co-seismic slip have more post-seismic deformation and vice-versa. We need to refine and extend this type of analysis, in order to obtain an integrated view of the time and space evolution of afterslip on the subduction interface. For this purpose, an important work of GPS data analysis is necessary. Time series need to be carefully filtered from non-tectonic periodical signals, such as seasonal weather trends, water table loading, monuments stability. The reference frame in which daily coordinates are mapped needs special attention, in particular since reference stations as far as in Argentina were displaced by the earthquake.

2.2 Collection of survey GPS data in other areas of Chile, before they rupture. We will use the existent network (~150 markers) made of the original networks installed in Chile in the early 1990's (~40 markers) complemented by new markers we installed/measured in June 2010 (~30 markers), the network installed in the 4th region of Chile (Coquimbo) in the years 2004-2009 (~60 markers), and the newest markers we installed/measured in June 2010 between 23°S and 28°S where almost no measurements had ever been done (20 markers). These numerous markers design a small scale network over most of the northern part of the Chilean trench that has not ruptured yet: from Santiago to Arica. All new markers since 2000 are special bolts, sealed in the bedrock, on which the GPS antenna is directly screwed. This ensures precise measurements, both for the centering of the antenna and vertical measurements, guarantying quality results after a few years of repeated campaigns only. We will resurvey the entire network every year, including large scale markers from other networks (CAP, SAGA). The GPS surveys will be performed at the same period of the year, each year in order to reduce seasonal artifacts. Each point is measured at least during two or three 24-hour sessions, with a 30 seconds sampling, using dual-frequency receivers and geodetic antennas ensuring high quality measurements. The survey will be conducted with a maximum number of receivers provided (at free cost) by the French INSU instrumental pool and by the LIA-MdB pool in Chile (~30 to 40 instruments in total).

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Résultats escomptés au terme de l'action :

An important scientific outcome of this project will be a better understanding of the seismic hazard along the Chilean subduction zone, and its consequences.

The results of the project will be published in peer-reviewed international journals and will be regularly presented at international meetings of Geophysics. These articles will foester the international visibility of the French and Chilean teams as well as their collaborative efforts.

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6. Antécédents de coopération avec la partie chilienne (donner, le cas échéant, les références des publications co-signées, thèses, équipements réalisés, brevets, etc.). Cette rubrique devra obligatoirement faire mention des actions antérieures ECOS auxquelles a participé *chacun* des membres du projet

Publications co-signées des participants sous la coopération ECOS :

Campos, J., D. Hatzfeld, R. Madariaga, G. Lopez, E. Kausel, A. Zollo, G. Iannacone, R. Fromm, S. Barrientos, et H. Lyon-Caen. A Seismological study of the 1835 Seismic gap in South Central Chile. Phys. Earth Planet. Int., 132, 177-195, 2002.

Armijo, R., R. Rauld, R. Thiele, G. Vargas, J. Campos, R. Lacassin, and E. Kausel, The West Andean Thrust, the San Ramón Fault, and the seismic hazard for Santiago, Chile, Tectonics, 29, TC2007, doi:10.1029/2008TC002427, 2010.

Ruegg, J.C., Rudloff, A., Vigny, Ch., Madariaga, R., Dechabalier, J.B., Campos, J., Kausel, E., Barrientos, S., and Dimitrov, D., Interseismic strain accumulation measurement by GPS in south central Chile seismic gap., Physics of the Earth and Planetary Interiors, Vol. 175, p. 78–85; doi:10.1016/j.pepi.2008.02.015, 2009.

Gardi, A. Lemoine, R. Madariaga, and J. Campos ; Modeling of stress transfer in the Coquimbo region of central Chile, JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 111, B04307, doi:10.1029/2004JB003440, 2006

Ruegg, J.C. J. Campos, R. Madariaga , E. Kausel , J.B. DeChabalier , R. Armijo , D. Dimitrov , I. Georgiev , S. Barrientos, Interseismic strain accumulation in Southern Central Chile From GPS measurements 1996-1999, Geophys. Res. Letts., vol 29, N11, 10.1029/2001GL013438, 2002.

Actions antérieures ECOS

Raul Madariaga a participé à plusieurs projets ECOS dans les années 1990, puis été responsable du projet ECOS C06U02 avec le co-responsable chilien Prof Rodrigo Arias

Jaime Campos a participé à plusieurs projets ECOS/CONYCIT depuis 2000

- Study of the Constitucion-Concepcion seismic gap	1997-2000
- Estudio de la deformation actual en la laguna sismica del centro sur de Chile	2002-2004
- Morphologie, tectonique, sismicité et couplage mécanique au Chili central	2003-2005

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Adresse Internet : http://www.ecos.univ-paris5.fr

7. Moyens :

Moyens propres provenant d'autres sources de financement (à indiquer obligatoirement) :.....

En France :

- Projet ANR déposé pour la période 2012-2015 – pas encore financé.....
- Financement partiel par le LIA « Montessus de Ballore » (~3 kE/an pour le groupe) .....

Au Chili :

- Soutient du international seismological research center « Montessus de Ballore »
(Millenium project) – MIDEPLAN – 2008-2011
- projet FONDECYT #1100429 « The Tocopilla Earthquake (Mw 7.7) of november 14 : A multidisciplinary study

Moyens sollicités dans le cadre ECOS-CONICYT pour la première année :

Nombre de missions France-Chili pour chercheurs confirmés, avec justification scientifique, en mentionnant obligatoirement leur durée (14 jours minimum) et les bénéficiaires (une priorité sera accordée aux jeunes chercheurs) :.

1 mission pour C . Vigny – formation au traitement des données GPS du personnel technique du DGF ..... 30 jours

1 mission pour R. Madariaga – préparation de la Thèse de S. Ruiz, étudiant en co-tutelle, soutenance prévue à Santiago ..... 14 jours

Nombre de missions Chili-France pour chercheurs confirmés, avec justification scientifique, en mentionnant obligatoirement leur durée (14 jours minimum) et les bénéficiaires (une priorité sera accordée aux jeunes chercheurs) :

1 mission pour J. Campos – mission 30 jours : Cinematic inversion of the source that includes all the data of the Chilean earthquake already available.

1 mission pour S. Peyrat - mission 30 jours : Dynamic inversion of the source (seismology and geodesy).

Stages pour chercheurs en formation (doctorants ou post-doctorants) chiliens en France ou français au Chili (annexer le CV et le programme de travail) :

1 mission pour M. Métois (France->Chili) – acquisition des données GPS en collaboration avec le DGF ..... 21 jours

1 mission pour S. Ruiz (Chili –> France) – Phisics of the source (dynamic and cinematic studies) ; Ph.D. Thesis ..... 30 jours

1 mission pour P. Toledo (Chili->France) – Aftershocks study related to main moment release for Maule Eqk. ; Ph.D. Thesis ..... 30 jours

.....

Information sur les thèses en cours ou à venir, en particulier les thèses en co-tutelle ou en co-direction, reliées au projet : donner le nom, le titre de la thèse et la date de commencement

(1) M. Métois (bourse MRES – Octobre 2009) : Quantification du couplage au long de la subduction Chilienne .....

(2) A. Fuezalida (bourse AXA – Octobre 2009): Etude du risque sismique et Tsunami au nord du Chili .....

(3) S. Ruiz (cotutelle – Octobre 2009) : Etude du mécanisme de rupture des séismes de Tocopilla et Michilla au Nord du Chili .....

(4) P. Toledo (cotutelle – courant 2011) : Etude des répliques du séisme de Maule de 2010.....

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Adresse Internet : http://www.ecos.univ-paris5.fr

8. Informations complémentaires (cocher) :

☐ Ce projet a été présenté en totalité ou en partie à un autre organisme (indiquer les moyens éventuellement obtenus) :

.....

☑ Ce projet n'a été soumis à aucun organisme, même partiellement.

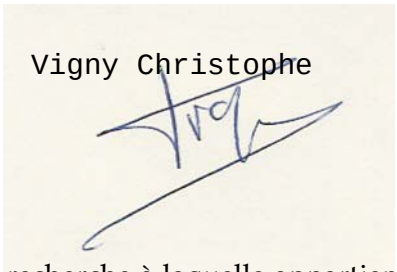
.....

☐ Ce projet est tripartite avec l'Argentine ☐, l'Uruguay ☐. En cas de réponse positive, le projet doit être déposé également dans le cadre de l'appel à projets correspondant (date limite 15 avril 2011, pour l'Argentine et 31 mars 2011, pour l'Uruguay).

Existence d'un accord Inter-universitaire : oui ☐ ; non ☐ ; je ne sais pas ☐

Date :30-mars-2011

Nom et signature du responsable français du projet : Vigny Christophe



Avis, nom et signature du responsable de l'unité de recherche à laquelle appartient le responsable de projet :

Christian Chopin, directeur de l'UMR 8538

Avis, nom et signature du Chef d'Établissement (les projets provenant d'UMR Université-CNRS pourront transiter indifféremment soit par l'université ou par le Délégué Régional du CNRS compétente ; pour les autres EPST, il s'agira du Directeur des Relations Internationales ou de l'Administrateur Délégué Régional, qui se chargera de recueillir les avis scientifiques éventuellement requis.)

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ATTENTION

Les projets ne seront recevables **que sous forme électronique** (**Un seul** fichier (Word, RTF ou PDF) regroupant : 1) la fiche projet en français avec ses annexes ; 2) un Curriculum Vitae rédigé en français et la liste des publications sur les cinq dernières années des responsables français et chilien.
Par ailleurs un exemplaire **papier** de la fiche projet (sans nécessairement le descriptif intégral du projet scientifique) doit être adressé, dûment signé, **sous couvert du chef d'établissement**.
L'ensemble doit parvenir avant le 31 mars 2011.

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Annexe 1 : CV des responsables du projet C. Vigny/J. Campos

VIGNY Christophe
Born 02 Mars 1964; Married, 3 children; now "Directeur de recherches" at CNRS

EDUCATION/DIPLOMAS

1987: Master of physics – option astronomy and fluid mechanics
1989: PhD in Earth Sciences entitled "Geoïd and internal dynamics of the Earth"
1990: PostDoc at ONERA "modeling of space gravimetric measurements: ARISTOTELES/GRADIO satellite project"
1991: PostDoc at MIT "Spatial Geodesy (GPS) and plate tectonics"
2006: H.D.R. entitled "GPS: from plate tectonics to seismology"

PROFESSIONAL EXPERIENCE

1992- full time position "Chargé de recherches" CNRS at "laboratoire de Géologie" of ENS
1999-2004 Head of geophysics team of the "laboratoire de Géologie" (8 full-time researchers – 1 administrative staff).
1999-2003 "Chargé de mission" at INSU (l'Institut National des Sciences de l'Univers) - for satellite observation of the Earth.
2000-2004 Member of the scientific comitee of « Institut Geographique National » (IGN)
2002-2006 Director of GDR « Géodesie-Géophysique » a multi-institute cooperation implying CNRS, CNES, IGN, CEA, IRD, SHOM).
2007-2011 Co-Director of International Laboratory (LIA) "Montessus de Ballore" a joint-venture between French CNRS and Chilean U-Chile
2007- promotion "Directeur de recherches" CNRS at "laboratoire de Géologie" of ENS
2008 invited professor at DGF, U-Chile, Santiago, Chile (4 months)
2009- Member of the Scientific Advisory Board of the Earth Observatory of Singapore

Since 1991, I am at "Laboratoire de Géologie" at ENS, Paris, France, working on the geodetic measurement of the Earth crustal deformation associated to active faults with high seismic hazard. I use modern style space geodesy (GPS): I install arrays of permanent cGPS and networks of geodetic benchmarks which I survey regularly. These measurements allow quantify the crustal deformation before, during and after an earthquake. My goal is to understand how major earthquake nucleate and I apply these methods on different faults around the world where seismic hazard is high: South-East Asia (Indonesia – Sumatra and Sulawesi, Malaysia, Thailand, Myanmar), Chile (from Patagonia to Atacama), Iran (Zagros, Alborz), Nepal (Himalayas), Djibouti (East African Rift), etc...My last works were 1/ a comprehensive study of the sequence of earthquakes since 2004 on the Sumatran trench & 2/ a post-seismic intervention after the Mw8.8 Maule, Chile earthquake.
Advisor of 9 PhD thesis, I teach courses of Geophysics & Geodesy both in France and abroad (course at the graduate scholl of the Chinese academy of science; courses in the framework of the Asia-Link program in Bangkok, Thailan; Kuala Lumpur, Malaysia, Bandung Indonesia; course at the international summer school of Do-Son, Vietnam, course at U-Chile, Santiago.

PUBLICATIONS

Author of 41 publications in peer-reviewed international journals [Citation Index 1207 – H-Index 19]
47 communications in congress, and 13 articles in broad audience journals and book chapters. (complete list on http://www.geologie.ens.fr/~vigny/biblio.html)

5 most recent and/or most significant publications:

1. Insight into the 2004 Sumatra-Andaman earthquake from GPS measurements in southeast Asia
   Vigny, C., W. Simons, S. Abu, R. Bamphenyu, et al.
   Nature, vol 436,14/07/05, pp201-206,doi:10.1038/nature03937, 2005
2. A decade of GPS in SE Asia: Resolving Sundaland motion and boundaries
   Simons, W., A. Socquet, **C. Vigny**, B. Ambrosius, et al.
   J. Geophys. Res., 112, B06420, doi:10.1029/2005JB003868*,* 2007.
3. Upper plate deformation measured by GPS in the Coquimbo gap, Chile
   Vigny, C., A. Rudloff, J.C. Ruegg, R. Madariaga, J. Campos, M. Alvarez
   PEPI, doi, 2009.
4. Interseismic strain accumulation measured by GPS in the seismic gap between Constitucion and Concepcion in Chile
   Ruegg, J.C., A. Rudloff, **C. Vigny**, et al., *PEPI,* Vol 175, issue 1-2, June, 10.1016/j.pepi.2008.02.015 , 2009.
5. Central Chile finally breaks
   Madariaga, R., M. Métois, **C. Vigny** and J. Campos
   Science; 2010.

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JAIME A. CAMPOS

PROFESSIONAL ADDRESS :

Departamento de Geofísica
Universidad de Chile
Blanco Encalada 2002, Casilla 2777, Santiago, Chile
Fone (56 2) 696 6563 Fax (56 2) 696 8686
e-mail: jaime@dgf.uchile.cl

PERSONAL DATA :

Date and place of birth : January 28, 1961, Santiago (Chile)
Citizanship : Chilean
Family status : Married, 3 childrens

EDUCATION:

M.Sc. (Geophysics), University of Chile 1989
Graduate Studes (D.E.A. Geophysics) IPGP-University Paris 7, France,1991
Ph.D. (Geophysics-Seismology) IPGP-University Paris 7, France, 1995

ACADEMIC CAREER:

1985 - 1989 Research Assistant (Seismology), University of Chile
1989 - 1996 Assistant Instructor, University of Chile
1996 - 2003 Assistant Professor, University of Chile
2003 - Associate Professor, University of Chile

OTHER ACTIVITIES:

1998 - 2006 Director National Seismological Service, University of Chile.
1999 - 2002 Member of Executive Committee of the International FSDN
2004 - 2006 Director Millennium Science Nucleus of Seismotectonics and Seismic Hazard, U. of Chile.
1998 - National scientist responsible for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO), with its headquarters in Vienna, Austria, and for the Provisional Technical Secretariat (PTS).
2008 - Coordinator Earth Solid Group, Dept. Geophysics, University of Chile.
2006 - Director Laboratoire International Associé of Seismology between CNRS-France and University of Chile.
2008 - Director Montessus de Ballore International Earthquake Research Center, U. of Chile.

AFFILIATIONS :

- American Geophysical Union (AGU)
- European Geophysical Society (EGS)
- Member, Executive Committee, Federation of Digital SeismologicalNetwork (FDSN) 1998-2004.

MS.SC. THESIS ADVISOR

- **MARCELA VILLARROEL, MS.SC. GEOPHYSICS, UNIVERSITY OF CHILE, 1999.**
- **ROBERT FROM, MS.SC. GEOPHYSICS THESIS, UNIVERSITY OF CHILE, 2001**
- **FELIPE LEYTON, MS.SC. GEOPHYSICS THESIS, UNIVERSITY OF CHILE, 2001**
- **JAVIER RUIZ, MS.SC. GEOPHYSICS THESIS, UNIVERSITY OF CHILE, 2002**
- **PATRICIO TOLEDO, MS. SC. GEOPHYSICS THESIS, UNIVERSITY OF CHILE, 2007**
- **NATALIA SILVA, MS.SC. GEOPHYSICS THESIS, UNIVERSITY OF CHILE, AT PRESENT IN PREPARATION.**
- **SEBASTIAN RIQUELME, MS. SC. GEOPHYSICS THESIS, UNIVERSITY OF CHILE, AT PRESENT IN PREPARATION.**

PH.D. THESIS ADVISOR

- **ADRIANA PÉREZ, PH.D. THESIS IN SEISMOLOGY, UNIVERSITY OF CHILE / GFZ-POTSDAM - GERMANY, AT PRESENT IN PREPARATION.**
- **SERGIO RUIZ, PH.D. THESIS IN SEISMOLOGY, UNIVERSITY OF CHILE / ENS - FRANCE, AT PRESENT IN PREPARATION.**
- **PATRICIO TOLEDO, PH.D. THESIS IN SEISMOLOGY, UNIVERSITY OF CHILE / ENS - FRANCE, AT PRESENT IN PREPARATION.**

5 most recent publications:

1. Ruiz, S., Madariaga, R., Astroza, M., Saragoni, R., Lancieri, M., Vigny, Ch., and Campos, J., Short Period Rupture Process of the 2010 Mw 8.8 Maule Earthquake in Chile, accepted to Earthquake Espectra, March, 2011.

2. Pollitz, F., Brooks, B., Tong, X., Bevis, M., Foster, J., Burgmann, R., Smalley, R., Vigny, Ch., Socquet, A., Ruegg, J.C., **Campos, J.,** Barrientos, S., Parra, H., Baez, J., Cimbarro, S., Blanco, M.; Coseismic slip distribution of the February 27, 2010 Mw 8.9 Maule, Chile earthquake; *accepted GRL, February 2011*.

3. Armijo R., Rauld R., Thiele R., Vargas G., **Campos J**., Lacassin R., Kausel E., The West Andean Thrust (WAT), the San Ramón Fault and the seismic hazard for Santiago (Chile), Tectonics, vol.29, TC2007, doi:10.1029/2008TC002428, (2010).

4. Ruiz, S., Kausel, E., **Campos, J.,** Saragoni, R., and Madariaga, R., Identification of Displacement Pulses from Earthquake Asperities Along the Chilean Subduction Zone Using Strong Motion, *Pure Appl. Geophys., DOI 10.1007/s00024-010-0117-x, January 2010*.

5. Kuge, K., Y. Kase, Y. Urata, **J. Campos**, and A. Perez (2010), Rupture characteristics of the 2005 Tarapaca, northern Chile intermediate-depth earthquake: Evidence for heterogeneous fluid distribution across the subducting oceanic plate?; JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 115, B09305,, *doi:10.1029/2009JB007106, May 2010.*

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Annexe 2 : CV des chercheurs en formation pour lesquels des stages sont demandés

CV M. Métois
CV S. Ruiz
CV P. Toledo

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Marianne Métois

6th December 1986

125, rue de la Glaciere
75013 PARIS
06 78 47 42 53
marianne.metois@ens-lyon.org or
metois@geologie.ens.fr

Education

2009–2011 **Ecole Normale Supérieure and IPGP**, *PhD candidate at the ENS Laboratory of Geology and at the IPGP Laboratory of Lithospheric tectonics*, *Quantification of the coupling distribution along the Chilean subduction zone*.

2008–2009 **Institut de Physique du Globe - IPGP, ENS Paris and University Paris-Diderot**, *Master (master's degree)*, Sciences for Earth and Planets (STEP), Equivalent to a specialisation in Geophysics, pass with 80% upwards.

2007–2008 **Ecole Normale Supérieure de Lyon ENSL**, *Preparation for the competitive exam to get the High School teacher authorization in Biology and Geology*, option Geology, pass with rank 03.

2006–2007 **ENS Lyon**, *Master first year*, Physics and Chemistry of Earth and Planets - PCTP, equivalent to a specialisation in physics and chemistry of Earth.

2005–2006 **Entered ENS Lyon, a selective university-level school training for research and teaching**, *"Junior" year "L3 Sciences de la Terre et des planètes"*, equivalent to a specialisation in Geology.

2003–2005 **Lycée Clemenceau, Nantes**, *"Classe préparatoire aux grandes Ecoles en Biologie, Chimie, Physique, Sciences de la Terre" equivalent to a university-level preparation for competitive entrance exam to engineering schools*, specialisation in Biology and Geology.

Research experiences

2009-2011 **PhD under the supervision of Christophe Vigny and Anne Socquet**, *Laboratoire de Géologie, ENS Paris - Laboratoire de tectonique et mécanique de la lithosphère, IPGP*, *Quantification of the coupling distribution along the Chilean subduction zone*.

2009 **6-month internship under the supervision of Christophe Vigny and Anne Socquet**, *Laboratoire de Géologie, ENS Paris*, *Determination of the coupling distribution on the Chilean subduction interface using GPS data*.

2007 **3-month internship under the supervision of Marta Pérez-Gussinyé**, *Institut de Ciences de la Terra Jaume Almera (ISTJA, Barcelone)*, *Determination of the effective elastic thickness of Africa using spectral methods and satellite derived gravity model*.

2006 **2-month internship under the supervision of Olivier Grasset**, *Planetology and Geodynamic Laboratory of Nantes University*, *Numerical simulation of a silicate sphere falling down in a high-pressure icy mantle : application to Callisto*.

Languages

English good reading, writing and verbal skills

Spanish good reading, writing and verbal skills

Arabic basic reading, writing and verbal skills

Computing

Programming AWK, GMT, Fortran

Other Linux, LaTeX, UniX, Windows, Matlab

Fieldwork

2005–2008 5 geological fieldworks in Southern and Central France

2008–2009 Fieldwork in Greece : tectonic of the Corinth Gulf and Peloponese

nov-dec. 2009 Fieldwork in Northern and Central Chile for c-GPS stations maintenance and campain GPS measurements

may 2010 Postseismic fieldwork with LIA team in the area affected by the Maule earthquake (Mw 8.8, feb. 27th 2010), c-GPS semi-permanent installing and campain GPS measurements

june 2010 Fieldwork in North-Chico area : installing of new campain GPS network

dec. 2010 Fieldwork in Central Chile, measurement of campain GPS network

Publications

R. Madariaga, M. Métois, C. Vigny, and J. Campos. Central Chile finally breaks. *Science*, 328(5975) :181, 2010.

M. Pérez-Gussinyé, M. Métois, M. Fernández, J. Vergés, J. Fullea, and AR Lowry. Effective elastic thickness of Africa and its relationship to other proxies for lithospheric structure and surface tectonics. *Earth and Planetary Science Letters*, 287(1-2) :152–167, 2009.

Papers in preparation

M. Métois, A. Socquet, and C. Vigny. Interseismic coupling, segmentation and mechanical behaviour of the central chile subduction zone. *in prep. for submittal in Journal of Geophysical Research*, 2011.

C. Vigny, A. Socquet, J.-C. Ruegg, M. Métois, R. Madariaga, S. Morvan, R. Lacassin, J. Campos, D. Carrizo, M. Bejar-Pizarro, S. Barrientos, and R. Armijo. The 27 february 2010 earthquake of maule, chile monitored by gps. *submitted to Science*, 2011.

Procedings

M. Metois, A. Socquet, and C. Vigny. Variable coupling controls the seismic segmentation and transient creep on the central Chile subduction. In *AGU Fall Meeting Abstracts*, volume 1, page 04, 2010.

M. Métois, A. Socquet, and C. Vigny. Upper plate deformation is dominated by varying coupling on the chilean subduction. French-Japanese International Workshop on Earthquake Source, oct. 2009.

Conferences

M. Métois, A. Socquet, and C. Vigny. Upper plate deformation is dominated by varying coupling on the chilean subduction. French-Japanese International Workshop on Earthquake Source, oct. 2009.

M. Métois, A. Socquet, and C. Vigny. Upper plate deformation is dominated by varying coupling on the chilean subduction zone. AGU Chapman conference, Valparaiso-Vina del mar, May 2010.

Socquet A., Bejar-Pizzaro M., Vigny C, Doin MP, Ducret G, Carrizo D, Métois M, and Peltzer G. Modelling the source of the the maule mw 8.8 earthquake and early afterslip using gps and insar data. AGU Chapman conference, Valparaiso-Vina del mar, May 2010.

M. Metois, A. Socquet, and C. Vigny. Variable coupling controls the seismic segmentation and transient creep on the central Chile subduction. In *AGU Fall Meeting Abstracts*, volume 1, page 04, 2010.

M. Métois, A. Socquet, and C. Vigny. Interseismic coupling, segmentation and mechanical behaviour of the central chile subduction zone. Congrès des doctorants, IPGP, Paris, France, Feb. 2011.

CURRICULUM VITAE (Marzo 2011)

Apellidos:	**Ruiz Tapia**
Nombres:	Sergio Arturo
Fecha de Nacimiento:	1 Diciembre 1977
Lugar de Nacimiento:	Rancagua, Chile
Nacionalidad:	Chilena
Dirección:	Huérfanos 1880, Dpto. 31D, Santiago, Chile.
Teléfono:	56-9-187-47-25
E-mail:	sruiz@ing.uchile.cl
Titulo:	**Ingeniero Civil,** Universidad de Chile, 2002.
Grados:	**Msc Geofísica,** Universidad de Chile. **Msc Ingeniería Sísmica,** Universidad de Chile **Candidato Ph.D Geología – Ciencias de la Tierra**. Universidad de Chile – Paris 7 – Ecole Normale Superieur.

ANTECEDENTES ACADÉMICOS

2008/2- : **Candidato a Doctor**, Doctorado en Geología en co-tutela entre la Universidad de Chile, Chile y el IPGP (Paris 7 - Ecole Normale Superieur), Francia.

2006 - 2008/1 : **Magíster en Geofísica**, Universidad de Chile, Chile. Facultad de Ciencias Físicas y Matemáticas. Departamento de Geofísica.

2005 – 2007/2: **Magíster en Ingeniería Sísmica**. Universidad de Chile, Facultad de Ciencias Físicas y Matemáticas. Departamento de ingeniería Civil.

1996 – 2002/1 : **Ingeniero Civil mención Estructuras - Construcción**. Universidad de Chile, Facultad de Ciencias Físicas y Matemáticas. Departamento de ingeniería Civil

BECAS

2006 – 2007. **Beca de Conicyt** – Gobierno de Chile. Beca de Magíster para Magíster en Geofísica, Universidad de Chile.

2008/2 – **Beca de Conicyt** – Gobierno de Chile. Beca de Doctorado para Doctorado en Geología, Universidad de Chile.

2009/2 – **Beca de Conicyt** – Gobierno de Chile. Beca de Pasantía en Ecole Normale Superieur de Paris, Francia.

PUBLICACIONES EN REVISTAS ISI

1. **Ruiz, S**. and Saragoni, G. R. (2009). “Free Vibration of Soils during Large Earthquakes”. ***Soil Dynamic and Earthquake Engineering.*** 29, 1-16.

2. Leyton, F., **Ruiz,** S. and Sepulveda, S. (2010). “Reevaluación del Peligro Sísmico Probabilístico en Chile Central”. ***Andean Geology*****,** 37 (2) , 455-472.

3. **Ruiz, S.**, Kausel, E., Campos, J., Saragoni, G. R. y Madariaga, R. (2010). “Identification of Earthquake Asperities Along Chilean Subduction Zone Using Strong Motion”. **Pure and *Applied Geophysics***.168 (1-2), 125-139

4. Lancieri, M., Fuenzalida, A., **Ruiz, S.** and Madariaga, R., (2011). “Investigation of early warning parameters used for the Tocopilla (Chile) earthquake, and its aftershocks”. ***Bulletin of the Seismological Society of America (BSSA)****;* 101 (2); 447-463; DOI: 10.1785/0120100045.

PUBLICACIONES SOMETIDAS EN REVISTAS ISI

1. **Ruiz, S**. and Leyton, F. (2011). “Comparison of Fundamental Period of Soil using Strong Motion data of 1985 Central Chile Earthquake (M=7.8) and H/V Microvibration Measures”. (**ENVIADO a *Soil Dynamic and Earthquake Engineering* el 11/01/2010**).

2. **Ruiz, S** and Astroza, M. (2011) Relationship between Destructiveness, Asperities and Surface Geological conditions in the Maule 2010 Chilean Earthquake, Mw = 8.8. (**ENVIADO *a Andean Geology el 25/11/2010)***

3. **Ruiz, S** and Madariaga, R. (2011). Determination of the friction law parameters of the Mw6.7 Michilla earthquake in northern Chile by dynamic inversion. (**ENVIADO *a Geophysical Research Letters (GRL) el 16/02/2011).***

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5. Saragoni, G.R., Astroza, M. and **Ruiz, S.,** (2008). "*Study of the Accelerogram destructiveness of Nazca plate subduction earthquakes*". 14th World Conference on Earthquake Engineering. China.

6. Leyton, F., **Ruiz, S.,** Silva, N., Campos, J., Kausel, E., (2008). "*Reevaluation of the Seismic Hazard in Central Chile*". XXXIII Jornadas Sudamericanas de Ingeniería Estructural, Santiago, Chile.

7. Ramírez, R., Saragoni, G.R., **Ruiz, S**., (2008). "*Interpretación de los acelerogramas de los terremotos intraplaca de profundidad intermedia de El Salvador 2001 Ms = 7.8 y Tarapaca, 2005, Chile, Ms = 7.8 considerando ondas sísmicas de alta frecuencia*". XXXIII Jornadas Sudamericanas de Ingeniería Estructural, Santiago, Chile.

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5. Leyton, F, Sepúlveda, S.A., González, L., Astroza, M., Rebolledo, S., **Ruiz, S**., Foncea, C., Herrera, M. 2010. “Microzonificacion sismica de la cuenca de Santiago, Chile”. X Jornadas Chilenas de Sismología e Ingeniería Antisísmica, Santiago, Chile.

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TESIS

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"*Estudio del Proceso de Ruptura del Terremoto de Tocopilla 2007 (M=7.7), Chile*", bajo la supervisión de los profesores Jaime Campos de la Universidad de Chile, Chile y Raúl Madariaga de la Ecole Normale Superieur, Francia.

EXPERIENCIA ACADÉMICA

2006 – 2009. Auxiliar curso Ingeniería Sísmica (CI72B). Curso obligatorio del magíster de Ingeniería Sísmica, Universidad de Chile.

2008. -2009 Auxiliar curso Diseño Sísmico de Estructuras (CI52S). Curso de Ingeniería Civil, Universidad de Chile.

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EXPERIENCIA LABORAL

Investigador: Julio/2007 – Julio/2008. Acondicionamiento de macizos rocosos en minería. ***Instituto de Innovación en Metalurgia y Minería (IM2-CODELCO).***

Investigación: 2002 – 2005. Desarrollo de investigación en el área de ingeniería sísmica, junto al profesor Rodolfo Saragoni del departamento de ingeniería civil de la ***Universidad de Chile.***

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Teaching

- Crust deformation (with Muriel Gerbault), University of Chile, 2005.
- Earth Thermodynamics (with Diego Morata), University of Chile, 2001.
- Geochemistry (with Diego Morata), University of Chile, 2000.
- Numerics (with Raúl Gormaz), University of Chile, 1998.

Academic Awards

- Visiting fellowship, Ambassade de France au Chili (Laboratoire de Géologie, École Normale Supérieure) 2010.
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Publications

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Book chapters

P. Toledo. Determinación del coeficinente de carter para una fractura radial. In G. González Loguercio, editor, *Manual de preacondicionamiento CODELCO CHILE*. en publicación, 2010

Working Experience

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: SRK Consulting S.A. Santiago, Chile. Hydrogeological and Geophysical study of leakages in tailings dams (numeric and conceptual models).

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: GP Consultores S.A. Santiago, Chile. Hydrogeologic and engineering studies (well testing, evaporation under dry conditions, mitigation of leakages).

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Geophysical auditing, 2007
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