Programme Catastrophes Telluriques et Tsunami (2005)

APPEL A PROJETS DE RECHERCHE

I - FICHE D'IDENTITE DU PROJET

N°dossier :
(ne pas renseigner)

Titre du projet *(maximum 120 caractères)*

GRANDS TREMBLEMENTS DE TERRE DU CHILI ALEA SISMIQUE

LARGE SUBDUCTION EARTHQUAKES IN CHILE AND ASSOCIATED SEISMIC RISK

Acronyme ou titre court *(12 caractères)* **SubChile**

Mots-clés (la liste des mots-clés sera donnée sur le logiciel de soumission)

Coordinateur du projet (Partenaire 1)

Civilité	Nom	Prénom	Laboratoire (nom complet)	Type (établissement public, fondation, association, entreprise)
M	Vigny	Christophe	ENS – Laboratoire de Géologie – CNRS UMR 8538	EP : ENS Paris

Autres partenaires[1]

Civilité	Nom	Prénom	Laboratoire (nom complet)	Type (établissement public, fondation, association, entreprise)
M	**Vilotte**	**Jean-Pierre**	IPGP – Laboratoire de Sismologie –UMR 7580	**EP : IPG Paris**
Mme	**Berge-Thierry**	**Catherine**	**IRSN** - Bureau d'évaluation des risques sismiques pour la sûreté des installations	EP : Institut de Radioprotection et de Sûreté Nucléaire

Nombre de personnes impliquées dans ce projet (en équivalent temps plein : ETP) :
Chercheurs et enseignants-chercheurs permanents __________
Post-doctorants déjà recrutés ________ Etudiants __________ Ingénieurs et techniciens ___________

Durée du projet : □ 24 mois **X 36 mois**

Montant total de l'aide demandée : 477 160 Euros
(reporter ici le total du tableau D-a)

Estimation (pour information) du coût complet de la demande : 802 778 Euros
(reporter ici le total du tableau D-b)

[1] Insérer autant de lignes que nécessaire

Résumé du projet *(maximum 3000 caractères)*

(objectifs, résultats attendus, méthodologie) La zone de subduction du Chili a une forte activité sismique avec, en moyenne, un séisme de magnitude 8 tous les dix ans et un tremblement de terre de M>8.7 au moins une fois par siècle. Il est possible de capturer et étudier en détail un de ces séismes si nous collaborons étroitement avec nos collègues chiliens. Nous proposons d'étudier en temps semi-réel la déformation qui précède l'un de grands futures séismes du Chili, en suivant la déformation avec des stations GPS permanentes, avec des inclinomètres. Nous proposons aussi d'étudier les évolution temporelle de la sismicité avec des stations sismologiques permanentes et temporelles et, finalement, d'intégrer ces données dans un modèle des séismes de subduction . A partir des projets précédents nous avons identifié trois lacunes sismiques au Nord et au Centre du Chili qui nous semblent être proche de la rupture. Dans deux de ces lacunes il n'y a aps eu de tremblement de terre majeur depuis 130 ans. Nous proposons d'instrumenter ces lacunes avec des GPS permanent, d'utiliser l'interférométrie pour étudier la déformation, détecter des changements dans la sismicité et l'inclinaison et déterminer la signature tectonique de séismes historiques de la région.

Du point de vue de l'étude de la subduction, le Chili possède certaines avantages uniques, la plus important étant naturellement la facilité d'accès à la zone sismogène qui est situé en grand partie sous terre ou très proche du bord de la mer. Le climat semi-désertique du Chili Nord-central est aussi très approprié pour des études d'interférométrie radar sur des vastes zones à l'intérieur des terres. Nous pensons que ce projet a des applications à plusieurs des objectifs français aux Caraïbes, où la zone de subduction est de difficile accès. On peut utiliser la subduction du Chili comme un terrain d'apprentissage pour les zones d'arc insulaire de difficile accès.

Ce projet est construit sur la base d'une longue collaboration avec des sismologues universitaires chiliens coordonnés par le département de géophysique de l'Université du Chili. Entre autres réalisations coopératives nous avons déjà installé deux stations très large bande Géoscope, une douzaine de stations GPS permanentes et des nombreuses études de la sismicité, la déformation et la tectonique de failles actives du Chili. Ces activités ont été financées par plusieurs projets de l'INSU-CNRS, le programme ECOS-Sud et, récemment, par un PICS entre la DRI du CNRS et le CONICYT du Chili. Parmi nos activités dans la dernière décennie, nous avons fait une étude complète du séisme d'Antofagasta, Mw=8, de 1995, du tremblement de terre de compression intra-plaque m=7.3 à Punitaqui en 1997 et du récent séisme intraplaque m=7.8 du 13 juin 2005 de 100 km de profondeur dans la région de Tarapacá au Nord du Chili, à coté de l'un des plus dangereuses lacunes sismique du Chili.

Abstract *(Not exceed 3000 car.)*
(objectives, expected results, methodology)

The Chilean subduction zone is extremely active with an average of a M=8 event every ten years and at least one M>8.7 per century. Capturing one of these large earthquakes with appropriate equipement is possible if we collaborate closely with Chilean seismologists. We propose to study in almost real time the deformation leading to large future earthquakes in the Chilean subduction zone, detect changes in seismicity using permanent and temporary seismic stations and to intergrate these data in a model of subduction earthquakes that intergrates tectonics, geodesy and seismology . From earlier collaborations with chilean colleagues we have identified 3 gaps in North and Central Chile where the earhquake preparation process seems to be very advanced, in two of them there has been no major thrust event in at least 130 years. We propose to instrument these gaps with permanent GPS stations, do inSAR studies of the deformaton, detect changes in seismicity and tilt and determine the tectonic signature of large historical earthquakes.
Chile presents many unique advantages for the study of the subduction processes and earthquake generation, the most important is easy access to the vicinity of the seismogenic zone that is mostly under land, or very close to the coast. The semi-desertic climate of North-Central Chile is also very appropriate for using interferometric techniques on very broad zones around the subduction border. We also believe that the results of this project will have applications to several research objectives in the Caribean where the subduction zone is not as readily accessible as that of Chile. The Chilean subduction zone can be used as learning grounds for many subduction zones covered by the ocean.

This project builds upon a long standing collaboration with Chilean seismologists from several Chilean Universities led by the Department of Geophysics of the University of Chile. Among other realisations, our coperation has led to the installation of two Geoscope stations in Chile, a dozen permanent GPS stations and numerous studies of seismicity, deformation and the tectonics of active faults. These activities have been supported by a number of projects from INSU-CNRS, by the ECOS-Sud program, by the European Commission and, recently, by a PICS between CNRS and CONICYT in Chile. Our previous cooperative research with Chile include the study of the M=8 Antofagasta earthquake in 1995, the Punitaqui slab-push event of October 1997 and the recent M=7.8 intermediate depth event in Tarapaca at 100 km depth.

Je déclare exactes toutes les informations contenues dans ce document

Lu et approuvé, date et signature du coordinateur du projet

Lu et approuvé,
13/07/2005,

Christophe Vigny

Visa du Directeur du laboratoire

Nom, prénom, date et signature

13/07/2005,

Raul Madariaga

En cas de recouvrement thématique avec d'autres appels à projets lancés par le GIP ANR, les porteurs de projet devront veiller à choisir l'appel d'offres le mieux adapté à leur projet. Les équipes impliquées dans plusieurs AAP soumis au GIP ANR devront le mentionner explicitement.

Programme Catastrophes Telluriques 2005

APPEL A PROJETS DE RECHERCHE

<u>II - PRESENTATION DETAILLEE DU PROJET</u>

A - Identification du coordinateur et des autres partenaires du projet

Acronyme ou titre court du projet :

A-1 – Partenaire 1 = Coordinateur du Projet

Un coordinateur, responsable scientifique du projet, doit être désigné par les partenaires.

Civilité [2]	**Nom [2]**	**Prénom [2]**
………M……	………VIGNY……………..	…CHRISTOPHE………………………………
Grade [2]	…CR1 CNRS…………………………………………	
Mail [2]	**vigny@geologie.ens.fr**	
Tél [2]	**01 44 32 22 14**	**Fax [2] 01 44 32 22 00**

Laboratoire [2] *(nom complet)*	
Laboratoire de Géologie de l'Ecole Normale Supérieure (ENS)	
N° Unité *(s'il existe)*	UMR 8538………………….
Adresse complète du laboratoire [2]	
Laboratoire de Géologie Ecole Normale Supérieure 24 rue Lhomond	

Ville [2]	**PARIS**	**Code postal [2]**	**75231**	**Région [2]**	**IDF**

Organismes de tutelle *(indiquer le ou les établissements et organismes de rattachement, souligner l'établissement susceptible d'assurer la gestion du projet)* **:**

CNRS
ENS

Principales publications :

Liste des principales publications ou brevets (max. 5) de l'équipe 1 (définie tableau ci-dessous) au cours des cinq dernières années, relevant du domaine de recherche couvert par la présente demande dans l'ordre suivant : Auteurs (faisant apparaître en <u>souligné</u> les auteurs faisant effectivement partie de la demande), Année, Titre, Revue, N°Vol, Pages. N'indiquez pas les publications soumises.

[2] Champ obligatoire

Vigny, C., W. Simons, S. Abu, R. Bamphenyu, C. Satirapod, N. Choosakul, C. Subarya, A. Socquet, K. Omar, H. Abidin, and B. Ambrosius, 2005, Insight into the 2004 Sumatra-Andaman earthquake from GPS measurements in Southeast Asia, *Nature*, V436 ,pp201-206
Vigny, C., H. Perfettini, A. Walpersdorf, A. Lemoine, W. Simons, D. Van Looon, B. Ambrosius, C. Stevens, R. McCaffrey, P. Morgan, Y. Bock, C. Subarya, P. Manurung, J. Kahar, H. Abidin, S. Abu., 2002, Migration of seismicity and earthquake interactions monitored by GPS in S.E. Asia triple Junction : Sulawesi, Indonesia., *J. Geophys. Res*, 107(B10), pp 2231.
Campos, J., D. Hatzfeld, R. Madariaga, G. Lopez, E. Kausel, A. Zollo, G. Innacone, R. Fromm, S. Barrientos, and H. Lyon-Caen, 2002, A seismological study of the 1835 seismic gap in the South Central Chile, *Phys. Earth Planet. Int*., 132, 177-195.
Lemoine, A., R. Madariaga, and J. Campos, 2002, Slab-pul and slb-push earthquakes in the Mexican, Chilean and Peruvian subduction zones, *Phys. Earth Planet. Int*., 132, 157-175.
Lemoine, A., J. Campos, and R. Madariaga, 2001, Evidence for earthquake interaction in the Illapel gap of Central Chile, *Geophys. Res. Lett.*, 28, 2743-2746.

Coordinateur (Partenaire 1)

	Nom	Prénom	Emploi actuel	% de temps consacré au projet	Rôle/Responsabilité dans le projet 4 lignes max
Coordinateur	VIGNY	Christophe	CR1	75%	Coordinateur du projet Coordinateur du volet GPS GPS dans les lacunes centre-sud : installation des stations, traitement des données, modélisation.
Membres de l'équipe					
	RUDLOFF	Alain	Doctorant	100%	GPS dans les lacunes centre-sud : installation des stations, traitement des données, modélisation.
	LASSERRE	Cécile	CR1	40%	Co-responsable du volet InSAR Traitement/Modélisation des données InSAR, Intégration InSAR/GPS Etude Sismotectonique (déformations Quaternaire)
	MADARIAGA	Raul	Professeur	10%	Etude Sismologique, Intégration Géodésie/Sismologie
	FINDLING	Nathaniel	Technicien	10%	Maintenance/Préparation des récepteurs GPS

Pour chacun des membres de l'équipe dont l'implication dans le projet est supérieure à 25%, fournir une biographie **d'une page maximum** qui comportera :

A/ Nom, prénom, âge, doctorat, stage post-doctoral, situation actuelle
B/ Autres expériences professionnelles
C/ Liste des 5 publications (ou brevets) les plus significatives des cinq dernières années
D/ Prix, distinctions

Christophe VIGNY

Né le 02 Mars 1964 à Lyon, France

Doctorat	en Sciences de la Terre Paris XI -- ORSAY / ENS Ulm Titre: Le Géoide et la dynamique interne de la Terre. Jury: Froidevaux, Woodhouse, Ricard, Montagner, Rabinowicz, Sotin.
Post-Doc 1	à l'ONERA, équipe de P. Touboul, Modélisation des mesures gravimétriques par satellite (accéléromètres spatiaux) pour le projet ARISTOTELES/GRADIO
Post-Doc 2	au MIT, équipe de B. Hager Géodesie spatiale et tectonique des plaques
Situation actuelle :	**Chargé de recherches au CNRS** Sur la thème de la mesure de la déformation de l'écorce terrestre par géodésie spatiale (GPS). J'ai été impliqué dans de nombreux projets sur différents thèmes comme le rebond post-glaciaire (en Antarctique), l'érosion des plages (Merlimont), et la tectonique par la collision continentale (les Alpes, l'Himalaya), l'extension (les Afars), la subduction (en Indonésie et au Chili), et les grandes failles décrochantes (Sumatra et Palu en Indonésie, Sagaing en Birmanie). Je travaille actuellement sur les phénomènes transitoires et la préparation des grandes ruptures détectés et quantifiés au moyen du GPS continu.

B/ Autres expériences professionnelles

- Responsable de l'équipe de géophysique du laboratoire de 1999 à 2004
- Chargé de mission à l'INSU pour l'observation de la Terre par satellite de 1999 à 2003
- Directeur du GDR « Géodesie-Géophysique » de 2002 à 2005

C/ Publications importantes sur les 5 dernières années

1. New constraints on Antarctic plate motion and deformation from GPS data.
   M-N Bouin and **C. Vigny C**
   J. Geophys. Res. , **105**, pp 28279-28294, 2000.
2. Migration of seismicity and earthquake interactions monitored by GPS in S.E. Asia triple Junction : Sulawesi, Indonesia.
   C. Vigny, H. Perfettini, A. Walpersdorf, A. Lemoine, W. Simons, D. Van Looon, B. Ambrosius, C. Stevens, R. McCaffrey, P. Morgan, Y. Bock, C. Subarya, P. Manurung, J. Kahar, H. Abidin, S. Abu.
   J. Geophys. Res, 107(B10), 2231, doi:10.1029/2001JB000377, 2002
3. Present day crustal deformation around Sagaing fault, Myanmar
   Vigny, C., A. Socquet, C. Rangin, N. Chamot-Rooke, M. Pubellier, M.N. Bouin, G. Bertrand, M. Becker.
   J. Geophys. Res, **108**(B11), 2533, doi:101029/2002JB001999, 2003.
4. Present day crustal deformation and plate kinematics in Middle East constrained by GPS measurements in Iran and northern Oman
   Vernant, P., F. Nilforoushan, D. Hatzfeld, M. Abbasi, **C. Vigny**, F. Masson, H. Nankali, J. Martinod, A. Ashtiani, R. Bayer, F. Tavakoli, J. Chéry.
   Geophysical Journal International, **157**, 381-398, 2004.
5. Insight into the 2004 Sumatra-Andaman earthquake from GPS measurements in Southeast Asia
   Vigny, C., W. Simons, S. Abu, R. Bamphenyu, C. Satirapod, N. Choosakul, C. Subarya, A. Socquet, K. Omar, H. Abidin, and B. Ambrosius.
   Nature, **436** , pp201-206, 2005.

D/ prix et distinctions

- lauréat du concours général en Portugais, 1981
- médaille de bronze au championnat de France windsurfer 1984 (Brest)

Cécile LASSERRE

Née le 27 Novembre 1971 à Paris XVème, Nationalité: Française

Chargée de Recherche CNRS (CR1) :

ENS - Laboratoire de Géologie (UMR 8538)
24 rue Lhomond
75231 Paris Cedex 05

tél : 01 44 32 22 08
fax : 01 44 32 20 00
e-mail : lasserre@geologie.ens.fr

CURSUS UNIVERSITAIRE

1994 Diplôme d'ingénieur en Géophysique-Géotechniques. Institut de Sciences et Technologies (IST), Université Paris VI.

1995 DEA de Géophysique Interne à l'Institut de Physique du Globe de Paris (IPGP). Université Paris VII.

2000 Doctorat de Géophysique Interne de l'Université Paris VII, Laboratoire de Tectonique et Mécanique de la Lithosphère de l'IPGP (direction Y. Gaudemer). *Fonctionnement sismique, cinématique et histoire géologique de la faille de Haiyuan (Gansu, Chine).*

EXPÉRIENCE PROFESSIONNELLE

1998-1999 **ATER** (demi-poste) à l'IPGP (Cartographie et Instrumentation géophysique).

2000-2002 **Post-Doctorat** à UCLA, Department of Earth and Space Sciences (Collaboration avec G. Peltzer). *Etudes InSAR de la : Déformation intersismique au travers de la faille de l'Altyn Tagh ; Déformation cosismique associée au séisme de Kokoxili (Mw=7.8, 14/11/01) le long de la faille du Kunlun, au nord-est du Tibet.*

Depuis 2002 **Chargée de recherche** (CR1) CNRS au Laboratoire de Géologie de l'ENS Paris Enseignement dans le Master des Sciences de la planète Terre de l'ENS et de P6.

5 PUBLICATIONS SIGNIFICATIVES

- C. Lasserre, Peltzer, G., Crampé, F., Klinger, Y., Van der Woerd, J. and P. Tapponnier, Coseismic deformation from the 2001 Mw=7.8 Kokoxili earthquake in Tibet, measured by SAR interferometry, accepté à *J. Geophys. Res.,* **2005.**
- Y. Klinger, Xu Xiwei, P. Tapponnier, J. Van der Woerd, C. Lasserre, G. King, High-resolution satellite imagery mapping of the surface rupture and slip distribution of the Mw~7.8, November 14, 2001 Kokoxili earthquake (Kunlun fault, northern Tibet, China), sous presse à BSSA, **2005**.
- C. Lasserre, Y. Gaudemer, P. Tapponnier, A.-S. Mériaux, J. Van der Woerd, Yuan Daoyang, F.J. Ryerson, R.C. Finkel, M.W. Caffee, Fast Late Pleistocene slip-rate on the Leng Long Ling segment of the Haiyuan fault, Qinghai, China, *J. Geophys. Res*., 107(B11), 2276, doi:10.1029/2000JB000060, **2002**
- C. Lasserre, B. Bukchin, P. Bernard, P. Tapponnier, Y. Gaudemer, A. Mostinsky, Rong Dailu, Source parameters and tectonic origin of the 1996 June 1tianzhu (Mw=5.2) and the 1995 July 21 Yongden (Mw=5.6) earthquakes near the Haiyuan fault (Gansu, China), *Geophys. J. Int*., 144, pp 206-220, **2001**
- C. Lasserre, PH. Morel, Y. Gaudemer, P. Tapponnier, FJ Ryerson, GCP. King, F. Métivier, M. Kashgarian, Liu Baichi, Lu Taiyi and Yuan Daoyang, Postglacial left slip-rate and past occurrence of M> 8 earthquakes on the western Haiyuan fault, Gansu, China, *J. Geophys. R.*, 104, pp 17633-17651, **1999**

Alain RUDLOFF

Date de naissance : 07/03/1979

CURSUS UNIVERSITAIRE

Depuis sept. 2002 **Thèse de doctorat au laboratoire de géologie de l'ENS Paris**.
2001/2002 DEA 'géodynamique et physique de la Terre' à l'ENS Paris.
Sept 1999 Entrée à l'ENS d'Ulm

COMMUNICATIONS LORS DE CONGRES INTERNATIONAUX, ET ARTICLES :

Rudloff A., Vigny C., Madariaga R., Campos J.,Ruegg J.C., Seismo-tectonic of the Concepcion's gap by GPS, (En préparation).

Rudloff A., Vigny C., Madariaga R., Campos J., Crustal deformation in the Concepcion Region. *EGU - 1st General Assembly, Nice, France,* 2003 (Oral).

Acronyme ou titre court du projet

A-2 : Autres partenaires du projet [3]

Un responsable scientifique de l'équipe partenaire doit être désigné

Partenaire 2

Civilité [4]	**Nom [4]**		**Prénom [4]**
…… M…	VILOTTE		Jean-Pierre
Grade[4]	…Physicien……………………………………………		
Mail [4]	vilotte@ipgp.jussieu.fr		
Tél [4]	0144273888	**Fax [4] :** 0144274894	

Laboratoire [4] *(nom complet)*	
.Laboratoire de Sismologie, Institut de Physique du Globe de Paris	
N° Unité *(s'il existe)*	………………UMR 7580….
Adresse complète du laboratoire [4]	
IPGP – Laboratoire de Sismologie 4 place Jussieu	

Ville [4]	Paris Cedex 05	**Code postal [4]**	75252	**Région [4]**	**IDF**

Organismes de tutelle *(indiquer le ou les établissements et organismes de rattachement, souligner l'établissement susceptible d'assurer la gestion du projet)* **:**

CNRS
IPGP

Principales publications :

Liste des principales publications ou brevets (max. 5) de l'équipe du partenaire 2 (définie tableau ci-dessous) au cours des cinq dernières années, relevant du domaine de recherche couvert par la présente demande dans l'ordre suivant : Auteurs (faisant apparaître en souligné les auteurs faisant effectivement partie de la demande), Année, Titre, Revue, N°Vol, Pages. N'indiquez pas les publications soumises.

Bernard, P., F. Boudin, S. Sacks, A. Linde, P.-A. Blum, C. Courteille, M.-F. Esnoult, H. Castarède, S. Felekis, and H. Billiris, Continuous strain and tilt monitoring on the Trizonia island, Rift of Corinth, Greece, C.R. Acad. Sci., 2004

Chlieh, M., J.-B. de Chabalier, J.-C. Ruegg, R. Armijo, R. Dmowska, J. Campos and K. Feigl (2004), Crustal deformation and fault slip during the seismic cycle in the North Chile subduction zone, from GPS and InSAR observations, *Geophys. J. Int., 158*, 695-711.

Ruegg, J.C., J. Campos, R. Madariaga, E. Kausel, J.B. de Chabalier, R. Armijo, D. Dimitrov, I. Georgiev, and S. Barrientos, Interseismic strain accumulation in south central Chile from GPS measurements, 1996-1999, Geophys. Res. Lett., 29, 11, 10.1029/2001GL013438, 2002.

J. C. Ruegg , M. Olcay, R. Armijo, J.B. de Chabalier and D. Lazo Pre-seismic transient and long term post-seismic relaxation associated with the 2001 South Peru earthquake, Geophys. J. Intern, *in press,* 2005.

Shapiro, N.M., S.K. Singh and J. Pacheco, A fast and simple diagnostic method for identifying tsunamigenic earthquakes, Geophys. Res. Lett., 25, 3911-3914, 1998

Shapiro, N.M., M. Campillo, L. Sethly, and M.H. Ritzwoller, High resolution surface wave tomography from ambient noise, Science, in press 2005.

[3] Remplir une fiche par équipe partenaire
[4] Champ obligatoire

Partenaire 2

	Nom	Prénom	Emploi actuel	% de temps consacré au projet	Rôle/Responsabilité dans le projet 4 lignes max
Responsable	VILOTTE	Jean-Pierre	Physicien	20%	Modélisation réponse de bassin, modélisation conjointe sismologie/GPS, paramètres de la source
Membres de l'équipe					
	ARMIJO	Rolando	Physicien	40%	Responsable Volet Sismotectonique. Etude des déformations Quaternaire (soulèvement côtier, tectonique active au front ouest des Andes et paléosismologie) et des enregistrements stratigraphiques et sédimentaires de tsunamis passés.
	BERNARD	Pascal	Physicien	10%	Analyse de la sismicité, inclinométrie, sismologie large bande
	BRIOLE	Pierre	DR2	5%	Expertise Géodésie
	CHARADE	Olivier	IR	10%	Calculs GPS. Coordination technique. Expertise en informatique et systèmes de communication.
	DE CHABALIER	Jean-Bernard	Physicien adjoint	40%	Responsable Volet InSAR Traitement/Modélisation des données InSAR. GPS dans la lacune Nord-Chili Intégration InSAR/GPS
	FESTA	Gaetano	Post-Doc	15%	Inversion cinématique, analyse sismologique
	GARDI	Anna Lisa	ATER	20%	Modélisation GPS/Sismologie
	LACASSIN	Robin	DR2	20%	Etude des déformations Quaternaire
	LEMOINE	Anne	Post-Doc	100%	Analyse sismologique de la sismicité, inversion non linéaire de la source
	NERCESSIAN	Alex	Phys. Adj.	5%	Réseaux sismologiques large bande, GPS, analyse sismologique/GPS
	PESQUEIRA	Frederick	Technicien	10%	Développement de systèmes d'acquisition et de communication.
	SHAPIRO	Nikolai	DR2	20%	Large bande, dispersion ondes de surface, bruit sismique, tsunami earthquake

Pour chacun des membres de l'équipe dont l'implication dans le projet est supérieure à 25%, fournir une biographie **d'une page maximum** qui comportera :
A/ Nom, prénom, âge, doctorat, stage post-doctoral, situation actuelle
B/ Autres expériences professionnelles
C/ Liste des 5 publications (ou brevets) les plus significatives des cinq dernières années
D/ Prix, distinctions

Nom *Vilotte Jean-Pierre*

Date de Naissance 22/02/55

Nationalité Française

Adresse Laboratoire de Sismologie (IPGP/CNRS UMR7580)

Institut de Physique du Globe de Paris

4 Place Jussieu , 75251 – Paris cedex 05

Éducation

1983 Thèse de Troisième cycle, Géophysique, Université de Montpellier

1989 Doctorat d'état, Géophysique, Université de Montpellier

Emploi

Position Physicien des Observatoires, première Classe

Affectation Institut de Physique du Globe de Paris

Laboratoire de Sismologie (CNRS-UMR7580)

Sujets de Recherche

Modélisation de la dynamique des tremblements de Terre
Modélisation de la propagation d'ondes en milieux complexes
Modélisation numérique et calcul parallèle

Encadrement et Enseignement

Enseignements aux niveaux L2, M1 et M2
Directeurs de 11 Thèses (dont 7 défendues)

Responsabilités

Directeur du Laboratoire de Sismologie (IPGP/CNRS-UMR 7580)
Responsable du Département de Modélisation Physique et Numérique de l'IPGP
Responsable du groupe Modélisation et Tomographie Géophysique du laboratoire de Sismologie

Publications

Auteur et co-auteur de 53 publications internationales

Komatitsch, D., J.-P. Vilotte, The Spectral Element Method: an efficient tool to simulate the seismic response of 2-D and 3-D geological structures, BSSA, 88, 368-392, 1998
Komatitsch, D., J.-P. Vilotte, R. Vai, J.M. Castillo-Cobarrubias, and F.J. Sanchez-Sesma, Spectral Element approximation of elastic waves equations: application to 2D and 3D seismic problems, Int. J. Num. Meth. Engng., 45, 1139-1164, 1999.
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Vilotte, J.-P., G. Festa, Spectral Element simulation of dynamic rupture along kinked faults, Geophys. Research Abstracts, Vol. 7, A-05122, 2005.

Rolando ARMIJO

BORN: December 14, 1950, at Santiago, Chile; Male.

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EDUCATION:

B.Sc. in Earth Sciences, University of Paris (1975).
Doctorat de 3ème cycle, Structural Geology, University of Paris (1977).
Doctorat d'Etat ès Sciences (Ph.D.), University of Paris (1986).

POSITIONS HELD:

Assistant, University of Paris (1977-78).
Research Fellow, CICESE, Mexico (1978-80).
Associate Professor, Institut de Physique du Globe de Paris, (1980-88).
Professor of Geophysics, Institut de Physique du Globe de Paris, (1988-present).

HONORS:

"1994 Best Paper Award", Structural Geology and Tectonics Division, Geological Society of America.
Prize "Eugénie de Rosemont" (Sciences), Chancellerie des Universités de Paris, 1997.
Prize "Constantinos Ktena" (Geology), Academy of Athens, 1997.

SCIENTIFIC CONTRIBUTIONS:

(1) Pioneered interpretation methods in geomorphology and active continental tectonics, produced comprehensive studies in different regions as Tibet, the Chilean subduction zone and the Mediterranean.
(2) Mapped many major active faults using fieldwork and various remote-sensing techniques; studied the deformation associated to recent and past earthquakes; contributes to current studies of deformation transients related to the seismic cycle using space geodesy (GPS and SAR interferometry) and mechanical modeling.
(3) Leads an international multi-disciplinary project on the seismic hazard in Turkey and the North Anatolian Fault, including studies on land and several oceanographic cruises to study the Sea of Marmara pull-apart.

SELECTED PUBLICATIONS:

Armijo, R., Meyer B., G. C. P. King, Rigo A., and Papanastassiou D. (1996), Quaternary evolution of the Corinth Rift and its implications for the late Cenozoic evolution of the Aegean, *Geophys. J. Int.*, *126*, 11-53.

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Çakir, Z., J.-B. de Chabalier, R. Armijo, B. Meyer, A. Barka, and G. Peltzer (2003), Coseismic and early postseismic slip associated with the 1999 Izmit earthquake (Turkey), from SAR interferometry and tectonic field observations, *Geophys. J. Int., 155*, 93-110.

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Jean-Bernard de CHABALIER

Né le 22 Février 1965 à Craponne (69), France

1993	doctorat	Doctorat en Géophysique interne de l'Université Paris 7 Titre: Topographie et déformation tridimensionnelle du rift d'Asal Djibouti, Prix de la CNFGG.
94-96	post-doc	au CEA, LDG, équipe de J.P. Avouac Modélisation mécanique de la déformation. Installation d'un réseau géodésique au Népal.

Situation actuelle : Physicien adjoint a l'Institut de Physique du Globe de Paris, Equipe de Géodésie et Gravimétrie.
Thèmes : mesure et modélisation des déformations de surface (GPS et interférométrie radar) pour l'étude du cycle sismique et plus particulièrement les phénomènes de glissements transitoires associés à la préparation du grand tremblement de terre de subduction (Chili et Antilles). J'assure mes taches d'observatoire par la surveillance par GPS de l'activité sismique et volcanique du département français aux Antilles (Guadeloupe et Martinique) et en République de Djibouti.

Publications importantes sur les 5 dernières années

Chlieh, M., J.-B. de Chabalier, J.-C. Ruegg, R. Armijo, R. Dmowska, J. Campos and K. Feigl, Crustal deformation and fault slip during the seismic cycle in the North Chile subduction zone, from GPS and InSAR observations, submitted to Geophys. J. Int., 158, 695-711, 2004.

Çakir, Z., J.-B. de Chabalier, R. Armijo, B. Meyer, A. Barka, and G. Peltzer, Coseismic and early postseismic slip associated with the 1999 Izmit earthquake (Turkey), from SAR interferometry and tectonic field observations, submitted to Geophys. J. Int., 155, 93-110, 2003.

A. Barka, H.S . Akyûz, G. Sunal, Z. Cakir, A. Dikba, B. Yerli, R. Armijo, B. Meyer, J.B. de Chabalier, T. Rockwell, J.R. Dolan, R. Hartleb, T. Dawson, S. Christofferson, A. Tuc ker, T. Fumal, R. langridge, H. Stenner, W. Lettis, J. Bachhuber, W. Page, The August 17, 1999 Izmit earthquake, M=7.4, Eastern Marmara region, Turkey : study of surface rupture and slip distribution, Bull. Seism. Soc. Am., special volume, 92, 43-60, 2002.

Ruegg, J.C., J. Campos, R. Madariaga, E. Kausel, J.B. de Chabalier, R. Armijo, D. Dimitrov, I. Georgiev, and S. Barrientos, Interseismic strain accumulation in south central Chile from GPS measurements, 1996-1999, Geophys. Res. Lett., 29, 11, 10.1029/2001GL013438, 2002.

Meyer, B., R. Armijo, D. Massonnet, J.B. de Chabalier, C. Delacourt, J.C. Ruegg, J. Achache, P. Briole, and P. Papanastassiou, The 1995 Grevena (Northern Greece) earthquake : Fault model constrained with tectonic observations and SAR interferometry, Geophys. Res. Lett., 23, 19, 2677-2680, 1996.

Anne LEMOINE

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30 ans, vie maritale, un enfant

<u>Expérience professionnelle</u>

2002-2004 Chercheur en sismologie, *UNIVERSIDAD DE CHILE, SANTIAGO, CHILI.*
Programme ECOS-Conicyt, **collaboration franco-chilienne**

2001-2002 Attaché Temporaire d'Enseignement et de Recherche,
ECOLE ET OBSERVATOIRE DE SCIENCES DE LA TERRE, STRASBOURG.

1998-2001 Chercheur doctorant, *ECOLE NORMALE SUPERIEURE DE PARIS.*

Formation 2001 Doctorat en Sismologie, *ECOLE NORMALE SUPERIEURE, UNIVERSITE PARIS XI.*

Grands séismes intraplaques en Amériques du Sud et en Amérique Centrrale

<u>Compétences Communication</u> :

4 articles parus, 2 articles acceptés. Thèse de Doctorat, rapports de stages.
Nombreuses présentations en anglais (oraux et posters) lors de congrès scientifiques internationaux.
Séminaires en français et espagnol.
Elaboration de projets, instances nationales et internationales (Europe, Chili)**.,** rédaction de **rapports d'activité**.
Collaborations Nationales et internationales (Etats-Unis, Chili, Mexique, Salvador, Indonésie, Italie, Royaume-Uni, Espagne).

Expérience internationale (chili, un an et demi, Etats-Unis, Italie, Pays-Bas).

<u>Sismologie</u> :

Données large-bande, accéléromètre, courte-période, GPS

1. **Méthodologie** : inversion et modélisation d'un signal, localisations, relocalisations de séismes, transfert de contrainte, déformation.
2. **Terrain** : installation de capteurs (France, Chili), mesure de bruit de fond (Alsace),
3. sismique réflexion (Chili), observations de glissements de terrain (chili).

Langues étrangères : anglais et espagnol courants, allemand scolaire
Divers : Photographie, lecture, voyages (Europe, Amériques), escalade, trekking, voile, secouriste, permis B.

Acronyme ou titre court du projet

A-2 : Autres partenaires du projet [5]

Un responsable scientifique de l'équipe partenaire doit être désigné

Partenaire 3

Civilité [6]	**Nom** [4]	**Prénom** [4]
Mme	BERGE-THIERRY	Catherine
Grade[4]	………………………………………………	
Mail [4]	catherine.berge@irsn.fr	
Tél [4]	01 58 35 74 11	**Fax** [4] 01 58 35 74 11

Laboratoire [4] *(nom complet)*	
Bureau d'évaluation des Risques Sismiques pour la Sûreté des Installations – Institut de Radioprotection et de Sûreté Nucléaire……………..	
N° Unité *(s'il existe)*	…………………..
Adresse complète du laboratoire [4]	
IRSN/DEI/SARG/BERSSIN BP 17	

Ville [4]	Fontenay aux Roses cedex	**Code postal** [4]	92262	**Région** [4]	IDF

Organismes de tutelle *(indiquer le ou les établissements et organismes de rattachement, souligner l'établissement susceptible d'assurer la gestion du projet)* **:**

Principales publications :

Liste des principales publications ou brevets (max. 5) de l'équipe du partenaire 2 (définie tableau ci-dessous) au cours des cinq dernières années, relevant du domaine de recherche couvert par la présente demande dans l'ordre suivant : Auteurs (faisant apparaître en souligné les auteurs faisant effectivement partie de la demande), Année, Titre, Revue, N°Vol, Pages. N'indiquez pas les publications soumises.

Fukushima, Y., C. Berge-Thierry, P. Volant, D.A. Griot-Pommera, F. Cotton, 2003, Attenuation relation for west Eurasia determined with recent near-fault records from California, Japan and Turkey, Journal of earthquake engineering, Vol.7, N°4, 573-59

Berge-Thierry, C., F. Cotton, O. Scotti, D-A. Griot-Pommera, Y. Fukushima, 2003, New empirical response spectral attenuation laws for moderate European earthquakes, .Journal of Earthquake Engineering, Vol. 7, No. 2; 193-222

Berge-Thierry, C., Bernard, P; Herrero, A. , 2001, Simulating strong ground motion with the 'k' kinematic source model: An application to the seismic hazard in the Erzincan basin, Turkey. JOURNAL OF SEISMOLOGY, 5, 85-101(17)

[5] Remplir une fiche par équipe partenaire
[6] Champ obligatoire

Coordinateur (Partenaire 3)

	Nom	Prénom	Emploi actuel	% de temps consacré au projet	Rôle/Responsabilité dans le projet 4 lignes max
Coordinateur	BERGE-THIERRY	Catherine	Ingénieur	20%	Coordinateur du volet Aléa sismique, Région métropolitaine de Santiago
Membres de l'équipe					
	BEAUMONT VOLANT	David Patrick	Ingénieur Ingénieur	20% 20%	Mouvements forts, modèles K2 Effets de site et structure de bassin
	BONILLA	François	Ingénieur	20%	Mouvements forts, effets non linéaires
	BAIZE	Sebastien	Ingénieur	20%	Géologie, géothecnique

Pour chacun des membres de l'équipe dont l'implication dans le projet est supérieure à 25%, fournir une biographie **d'une page maximum** qui comportera :

A/ Nom, prénom, âge, doctorat, stage post-doctoral, situation actuelle
B/ Autres expériences professionnelles
C/ Liste des 5 publications (ou brevets) les plus significatives des cinq dernières années
D/ Prix, distinctions

Programme Catastrophes Telluriques 2005

B - Description du projet

La partie (B) pourra être rédigée en français ou en anglais

Acronyme ou titre court du projet :

B-1 – Objectifs et contexte : *(2 pages maximum en arial 11, simple interligne)*
On situera le projet dans le contexte international en y précisant les objectifs et les enjeux.

Subduction zones are regions of high seismic and tsunami hazards. The largest earthquake of the past 100 years, the May 22 1960 Chilean earthquake of magnitude 9.5, occurred along the Chili subduction zone and generated a giant trans-Pacific tsunami that caused catastrophic damage along the coasts of Hawaï and Japan. The devastating December 26 2004 Sumatra-Adaman (Mw=9.2) island's earthquake occurred in the subduction zone along the Indonesian coast and the tsunami radiated outward in the Indian ocean and caused catastrophic damage. Reliable estimation of earthquake hazard of the most active subduction zones in the world, e.g. Japan, Western South America, North Western America and Indonesia, is today's a challenging issue for the earth sciences that requires improved observations and physical understanding of the subduction-zone processes generating earthquakes integrating seismology, geodesy, geology and earthquake engineering.

Chile is a unique natural laboratory for instrumentation and study of subduction-zone earthquakes and their tsunami potential. The Chilean subduction has one of the highest levels of seismic activity in the world, with a large earthquake of M>8 every five to ten years. This events are the consequence of subduction of the Nazca plate beneath South America at a convergence rate as high as 8 cm/yr in the N 78°E direction. Western South America is the only major subduction zone where an entire oceanic slab descends under a continent, closely associated with active shortening across a major parallel mountain belt. In Chile, several studies have shown an along strike variation in the dip angle of the slab, and possible segmentation of the subduction zone, well expressed at the surface geology and morphology. The fast convergence is accommodated by large inter- and intra-plate earthquakes, and by shallow earthquakes associated with intra-continental fault systems in the Andes cordillera and the Altiplano-Puna. The study of Chilean earthquakes has a long history and major seismic gaps, e.g. Central Chile (Constitución-Concepción) and North Chile (Antofagasta-Arica), are reaching the end of the seismic cycle with a high megathrust earthquake risk in the 21st century. The seismogenic zones, together with the downdip transition zone, are located directly under land or very close to the coast. Moreover, the lack of vegetation cover in Central and Northern Chile make these regions quite exceptional for remote sensing, for example InSar. Compared to other subduction zones of interest for French researchers Chile allows therefore direct access to the earthquake preparation zone greatly facilitating the installation of GPS, seismic stations, interferometry and geological dating of paleoseismic earthquakes.

Studies of the seismicity Chile led to the identification of several seismic gaps of special interest: in the North, between Antofagasta and Arica (18°S-27°S); in South Central Chile, between Constitución and Concepción (35°S-37°S), a region that has not had large earthquakes in the last 170 years. Even if these gaps do not break regularly in time, the rate of seismicity is such that an earthquake of M=8 occurs every 10 years between 18° S et 42 °S, and an earthquake of magnitude greater than 8.7 each century. Unfortunately identification of these gaps does not solve the mean term prevision problem due to the space and time variability of the seismic activity which often occurs in swarms, whose origin remains to be elucidated. Interplate earthquakes are not the only destructive earthquakes in Chile. Several observations suggest intraplate earthquakes as potentially more destructive, e.g. slab-pull earthquakes of the 2005 (Tarapacá), 1950 (Antofagasta), 1939 (Chillán) as well as slab-push earthquakes 1997 (Punitaqui). Central Chile is also shaken by earthquakes at shallow depths. In the Metropolitan area, the earthquakes of Las Melosas (1958) and recently of Curicó (2004), are the signature of the active deformation and faulting associated with the building of the Andes. The seismic risk of these shallow earthquakes, pointed out by recent studies of active faulting along the western front of the Andes, is still poorly understood. Last, but not least, the Chilean subduction coast has a recorded history of tsunamigenic earthquakes, dating back to the beginning of the 16th century. Four to five times per century these earthquales put all the Pacific in jeopardy. Special attention have been recently focussed on the analysis of shallow subduction-zone earthquakes that present a tsunamigenic potential due to anomalous slow faulting process.

French researchers from several research laboratories and institutions have heavily invested in Chile, with intensive field work in seismology, geodesy, tectonics and the installation of permanent seismic and GPS stations. This long term effort has yielded its first fruits with the observation of co- and post-seismic deformation during the Antofagasta earthquake in July 1995, field studies of its effects and complete modelling of the main event and some aftershocks. More recently, a M=7.9 earthquake occurred in Tarapacá on 13 June

2005, 105 km below a network of 8 permanent GPS stations installed by IPG and Chilean Universities, that has been recently complemented with a small broadband network.

We feel that the time is ripe to increase this effort and to approach the problem of large earthquakes in Chile in close collaboration with our Chilean partners of the Departamento de Geofísica of the Universidad de Chile. This group has succeeded in developing an extensive seismological network in central Chile where most of the population lives. The very broad band Geoscope station in Peldehue, near Santiago, was the first of more than 25 digital broad band instruments connected by the internet in Central Chile. Recently, in close collaboration with participants in the present proposal, DGF has installed about a dozen permanent GPS stations that are readily accessible.

These continuous French efforts in Chile have been previously funded by the ECOS-Sud program that provided funds for starting a close collaboration with Chilean earth scientists. INSU provided funds for the acquisition and installation of most of our instrumentation in Chile. The European Union supported our detailed study of the seismicity of the longest standing gap in Chile, that of Constitución-Concepción where the last earthquake occurred in 1835. The DRI of CNRS funded a PICS program in Chile in order to increase our participation in Chilean research projects and the ACI "risques naturels" supported several of our field projects in geodesy.

We propose to build on top of the present close collaboration and extend it so as to be able to contribute seriously to the study of interseismic processes in Chile, to study the effect of earthquakes in the large cities, to improve detection of tsunami earthquakes, and of course to advance our knowledge about subduction, one of the most important processes in geodynamics.

We ask ANR to support an ambitious project in Chile so that we can follow in almost real time the deformation leading to large earthquakes, detect changes in seismicity using the national Chilean network, improving our current instrumentation and opening new avenues of research. In order to tackle these topics, we have established a trans-disciplinary research team that includes seismology, geodesy and tectonic in two research laboratories (IPGP and ENS) and a research and operational laboratory (IRSN). Each partner is qualified by its previous works in one or more of these topics. The collaboration proposed through this ANR project will create a momentum with which France can contribute to the international scientific research effort, especially through Eurpean collaborations and programs involving the GFZ (Postdam).

The results of this project will have applications to many French research objectives in the Caribean where the subduction zone is not as readily accessible as that of Chile. The Chilean subduction zone can be used as earning grounds for the study of Caribean seismicity.

B-2 – Description du projet et résultats attendus *: (8 pages maximum en arial 11, simple interligne)*
On décrira le déroulement prévisionnel et les diverses phases intermédiaires ainsi que les méthodologies employées. L'originalité et le caractère ambitieux du projet devront être explicités. L'interdisciplinarité et l'ouverture à diverses collaborations seront à justifier en accord avec l'orientation du projet. La capacité de ou des équipes « porteuse(s) » devra être attestée par la qualification et les productions scientifiques antérieures de leurs membres. Leur rôle dans les différentes phases du projet devront être précisés et la valeur ajoutée des collaborations entre les différentes équipes sera argumentée. Les moyens demandés devront être en accord avec les objectifs scientifiques du projet. La structure et l'organisation du management du projet devront être précisées dans le cas de projets complexes dans leur mise en œuvre.

INTRODUCTION

We hope within the next decade to be able to capture a very large earthquake in at least one of the four seismic gaps that we have instrumented and studied in Chile: The Tarapacá gap that dates back to 1877, the Antofagasta gap that dates back to 1868, the Coquimbo gap from 1946 and the Constitución gap that dates back to 1835 (Lomnitz, 1971, Beck et al, 1998). Geodetic and seismological observations will be used to detect time-dependent variations that may precede great earthquakes. Geologic and geodetic studies will permit us to define a framework for the loading and unloading process of the Chilean crust in response to both slow and rapid motion of the Nazca plate under South America.

The high continuous seismic activity – which seems accelerating in certain regions – raises some very of the fundamental questions that we want to address in the SubChile project:

1) How to improve the detection and the analysis (mechanism, frequency content) of the source properties of intraplate earthquakes and how intra- and interplate source properties control the strong motions?
2) How can we improve the detection of shallow tsunami earthquakes?
3) What is the influence of the dynamical earthquake and seismic/aseismic slip interactions in the generation of the seismic swarms observed today's in Central Chile?
4) How much fault-slip is accommodated aseismically and how does aseismic slip occur, as continuous or as strain transients?
5) Can tectonic tremors be observed in Central Chile in relation with potential slip transients and dehydration processes like in Japan and Alaska?
6) Is the intermediate seismicity in Central Chile, related to the breaking of the subducting plate, possibly enhanced by dehydration processes depending on the apparent subduction angle?
7) What is the nature of shallow seismic sources and their relationship to the Andean faulting processes.
8) Is the today's increase of the seismic activity a result of statistical fluctuations in the seismicity rate or an indication of a change of regime?
9) Is this potential change linked to the approach of the strength limit of the asperities, or to aseismic slip acceleration in the transition zone and/or in between the asperities?
10) The Santiago basin raises also important issues in terms of seismic hazard
11) What is the relative importance of shallow Andean earthquakes with respect to the intermediate deep earthquakes?
12) What is the potential effect of Santiago basin structure on the seismic hazard?
13) How can we reduce uncertainties in the attenuation relationship for strong ground motions applied in Santiago Basin?

To address the issues raised above an integrated approach is needed that requires strong collaboration among seismology, geodesy, seismotectonics and engineering seismology. We propose three focus areas within the larger Chilean subduction region: the central Chile; the northern Chile and the metropolitan region. Logistic are easiest in theses areas. Below, we discuss the scientific issues relevant to the three regions, although the general approach would be similar: combining seismometers and GPS instruments across the region of interest with more instruments in the areas of greater focus. The backbone network of permanent GPS sites, which is focussed on seeing strain transients associated with the subduction zone, would be augmented by campaign GPS. And the backbone seismometer and accelerometer network operated by the University of Chile will be augmented by French/GFZ instruments. The new geophysical measurements would be integrated with growing GPS and seismological data sets at the DGF (University of Chile), as well with new geological mapping conducted during this project.

RESEARCH PROGRAM

A/ Present-day deformation along the Chilean subduction zone, from GPS and InSAR studies

This part of the study will focus on the seismic gaps of Central and North Chile, which did not experienced major subduction earthquakes since the 19th century (Fig. 1). These gaps offer a unique opportunity to

understand the mechanical processes that take place during the maturation and triggering of large earthquakes. Our goal is to understand the seismic and aseismic processes that take place during the seismic cycle. We propose to map the spatial distribution of the surface deformation and its temporal evolution along the Chilean coast, using both SAR interferometry and continuous GPS (cGPS) data. We will develop dense cGPS networks in the selected areas, to obtain crucial data to identify spatially and temporally transient processes (e.g. Japanese and North American cGPS networks, Draegert et al. 2001; Osawa et al. 2002). We will also exploit the SAR images archive from the ERS satellites (spanning the 1992-2002 period) and the newly acquired SAR data from the ENVISAT satellite (after 2002) covering the seismic gaps area.
We will derive models of slip distribution at depth along the fault system, which will be analyzed in terms of fault segmentation, aseismic or seismic deformation (continuous or transient), and variations of coupling at the subduction interface along the coast. This will help characterizing the influence of the interface geometry on the deformation, and the maturation stage of each fault segment within the seismic cycle.
Throughout our past experience with geodesy along Chile, we have demonstrated the reliability of such a joint GPS/InSAR approach as: (1) The rate of deformation (~8cm/yr of relative convergence between Nazca and South America) is significant, producing large surface deformation which can be detected by both techniques, not only during major earthquakes, but also during the inter-seismic loading or during transient aseismic or seismic phases (Chlieh et al. 2004, Gardi et al., in press). (2) InSAR data provide a remarkable spatial coverage of the deformation zone. The region is exceptionally dry, allowing to calculate perfectly coherent interferograms over long periods of time (> 5years). The relative geometries of the InSAR data acquisition system and of the fault system in Chile are also optimal to detect the deformation. (3) cGPS data provide the best temporal resolution and complement InSAR data (orbital errors can be corrected, deformation maps can be tight to an absolute reference frame) to provide deformation maps in 4 dimensions. The temporal continuity of cGPS data is essential to detect, date and follow possible transient processes.

<u>Study areas:</u>

- THE NORTH CHILE GAP : IPGP GROUP (J.B. DE CHABALIER, O. CHARADE, P. BRIOLE) COLL. WITH DGF, UAP, UCN, UTAR

It did not experience any large subduction earthquake since 1877 (M~8.8). However, the 1995 (M=8.1) Antofagasta and the 2001 (M=8.4) South Peru earthquakes indicate that this segment is loaded at his two extremities (Fig. 1). The geometry of the slab along the gap, the coupling, and the post-1995 Antofagasta earthquake relaxation is now understood (e.g. InSAR/GPS study: Chlieh et al., 2004). The recent Tarapaca event (13 june 2005, M=7.7), a slab-pull earthquake in the subducting Nazca plate, may be a precursor of a future large thrust event (Astiz and Kanamori, 1986), as was the 1950 intermediate event before the 1995 Antofagasta earthquake (Fig. 1). Preliminary processing of cGPS data of the Iquique coastal station shows the post-seismic deformation associated with the 2005 event that can be related to aseismic transient relaxation in the subduction interface (Fig. 2b).
The northern Chile gap offers a unique opportunity to identify and model the transient aseismic slips that take place in the transition zone, where the large earthquake will nucleate in the next years. However, the area to cover is very large (500km x 250km). From 1995, we have initiated an international cGPS network in the area, with a common data base. Six cGPS have been deployed by IPGP (UAPE and PICN from 1995; UTAR, PMEJ and UCNF from 2003; PCHA following the 2005 Tarapaca event). Since 2003, the IRD GPS Team in Santiago (conducted by S. Bonvallot) participates with two other cGPS and three semi permanent stations (Fig.1). In 2006, the GPS group of Caltech will install 6 new sites filling holes, mainly in the northern part of the existing network. These 3 groups are coordinated by the DGF in Chile to avoid double stations and to participate to the common data base. For the next years, we propose to install 5 new stations particularly in the southern part, in the inter-segment zone of the Mejillones Peninsula, that seems to act as a barrier as well as a possible initiation site for the future rupture (e.g. Antofagasta earthquake) (Fig. 1). These data will be combined with SAR interferometry data. We will focus on the study of the 2005 Tarapaca M=7.7 earthquake and of the ongoing associated deformation, combining the deformation data with the seismologic data. Acquisition of ENVISAT data have already been programmed for the next 4 months.

- CENTRAL CHILE : ENS GROUP (C. VIGNY, C. LASSERRE, A. RUDLOFF, N. FINDLING) AND DGF

(a) In this region, where most of the population is living, the ENS group will focus on two specific targets:
-The Central-North segment, between La Serena (30ºS) and Los Villos (32ºS). It is presently the place of a remarkable seismic activity that started in 1997: a M=7.1 Punitaqui slab pull event occured in October 1997, following a series of four shallow M>6 thrust earthquakes on the plate interface (at all more than 12 earthquakes of M>6 occured since 1996, Lemoine et al. 2001, Gardi et al., in press). Simple stress transfer modelling indicates that aseismic slip can explain this sequence. This puzzling seismicity could be either the erald of a major earthquake initiation and/or the manifestation of slow aseismic transient slip on the subduction interface. Two cGPS have been installed in 1994 and 1995 to follow the deformation. We propose to install 8 new cGPS stations along this segment, to be able to localize the area of aseismic slip in the subduction interface (Fig. 1). To assess the spatio-temporal evolution of strain associated with the 1997 sequence, we will

combine cGPS data with InSAR ERS data (to study the seismic crisis) or Envisat data (to follow the ongoing associated deformation).
-The Concepcion-Constitucion segment. It can be considered as the most mature seismic gap in Chile since it didn't experience any thrust event since 1835. This region has been extensively studied since 1996, with temporary seismologic networks and recurrent geodetic surveys (Ruegg et al., 2002). It shows an intense seismic activity contrasting with the other areas and a strong interseismic strain accumulation twice as big as those observed farther north. This clearly raises the question of the slip partitionning between the slab interface and the Cordillera, and of the variations of coupling at the interface in space and time. Three permanent GPS have been installed across an EW profile since 2003. To follow the spatio-temporal evolution of the deformation along the fault segment, we propose to install 8 cGPS, covering the central part and both north and south inter-segments (Fig. 1). These data will be combined with SAR interferometry using the same methodology as in the other gaps.
(b) Between these two segments, the Metropolitan region of Santiago hosts 50% of the population of Chile. The DGF is in charge of an ambitious project to better assess the seismic hazard and reduce the seismic risk in this very populated area. This group is developing seismic and cGPS stations networks, seismotectonics and geotechnical studies. Their GPS data are available for this project, allowing an extensive coverage of the Chilean coast by continuous cGPS network from 30S to 38S.

To adress the fundamental problem of earthquake initiation, we thus plan during the next 3 years of this project to establish 21 new stations. This is a minimum to be able to characterize the loading evolution on the studied segments, and to understand the variations of coupling along Chile (i.e. the role of the inter-segments). This topic is at present time the subject of an important competitiveness. The present project could be the French contribution to the scientific debate. Three stations will be installed in the North the first year of the project. The others will be installed in the Central part the second year.To install the stations, improve the aquisition system and data base, and implement an automatic data processing in Chile and in France we request one person on a 1 year temporary contract.

Both ERS and Envisat data will be obtained through Category 1 proposals of the European Space Agency (ESA) – ERS AO3-362, Envisat AO720 -, allowing quotas of free SAR scenes. Initially centered to the North, these projects have been extended to cover the whole Chilean coast. Beyond quotas, additionnal, recurrent Envisat data acquisitions over the study zones will be programmed; funding for this is requested in the present project.

Schedule :
1st year: Installation of 3 GPS in the North; Improvement of the acquisition and data base system, implementation of an automatic data processing in Chile, preparation of the equipment; Programation of Envisat acquisition, processing and modelling of available SAR data in the two selected areas.
2nd year: Installation of the Central network; Installation of the 2 last northern stations; Processing of both GPS and InSAR data; Publication of the first results.
3rd year : Processing of the data; Modelling of the data; Publication of the results.

Deliverable:
- cGPS data and temporal series available for the scientific community. All data acquired in Chile by the DGF, CNRS groups (IPG, ENS), IRD (Bonvallot group), and in the future, by the Caltech group, will implement the data base developped with the DGF since 2002.
- Strain field maps of coseismic to interseismic deformation in targeted study areas
- Derived fault slip distribution models at depth along the subduction zone. Relation with the fault system geometry and segmentation, the stage of faults segments within the seismic cycle, and past earthquakes history.
- Improvement of the seismic hazard knowledge.
- Publications.

B/ Seismology and Earthquakes

B1/ Central Chile

Participants: R. Madariaga, A. Lemoine
Collaborations: DGF (University of Chile)

Large earthquakes strike Chile regularly all along the Chile-Peru subduction zone. Since the late1970s these events have been studied and modelled with the goal of determining accurate fault plane solutions, depths and duration (Malgrange et al, 1981, Lemoine et al, 2002). Since early 1990s the moment tensor determinations made routinely by Harvard and USGS have simplified this work because they provide good starting points for investigating the details of the rupture process of the larger events. Harvard moment tensors are not accurate enough because of the lack of stations on the Pacific side. This leads to poor longitudinal control of the centroid and the strike of shallow faults. Improved modelling techniques and joint relocation of hypocenters have led to a better understanding of the seismicity that occurred in the Coquimbo area of Chile, where we suggested that more than 15 medium to large sized events of M>6 interacted strongly through shear stress transfer from the continuous slip at depth. Recent observations of slip vectors in the area have confirmed our earlier findings (Gardi et al, 2005). Preliminary results indicate that the Coquimbo area is coupled at only 50% so that continuous slip contributes significantly to stress transfer and may be an important element that was missing in the interpretation of the seismicity of this seismic gap.

<u>Strategy</u>
We propose to continue modelling Chilean seismicity in close collaboration with our colleagues from DGF at the University of Chile. We have now a new non-linear method to model earthquake kinematics that we have already applied to the study of the 2001 M=8.3 earthquake in southern Peru (thesis A. Sladen, 2005) and we plan to start a more systematic determination of source parameters for all large events of M>6.5 that affect the Central Chile subduction zone where accelerometric data is becoming available. The study of large earthquakes is essential to understand possible changes in slip vectors that we are determining from the regular survey of GPS networks in the different gaps that we have identified.

B2/ North Chile

Participants: N. Shapiro, J.-P. Vilotte, A. Lemoine, A. Nercessian, G. Festa
Collaborations: DGF (University of Chile), GFZ (Postdam)

The 400 km region between Antofagasta and Arica defines the North Chile gap where the last major earthquake Tarapacá earthquake of maginitude 8.4 that dates back to 1877. Several seismological studies, in particular by the DGF group (Comte et al, 1994) in collaboration with IRD/IPG Strasbourg and by the GFZ team, has shed light on the subduction geometry and structures. In 1995, the Antofagasta earthquake (Mw=8.1) ruptured the southern segment of the Tarapacá gap. In 2001, the Arequipa earthquake (Mw=8.3) ruptured the northern segment and a major part of the South Perú gap. The Tarapacá gap is generally believed to be now a zone of high seismic hazard. This has been recently reinforced by the 2005 slab-pull Tarapacá (Mw=7.8) that occurred on 13 June 2005, at 105 km below a network of 8 permanent GPS stations installed by IPG and Chilean Universities. These type of events are thought by some seimologists to occur before large subduction events when the gap gets closer to rupture. The Tarapacá gap is therefore a unique site for studying the end of the seismic cycle and in particular the transient loading mechanisms of the coupled zone.

The main objectives here are :
a) The determination of the source parameters of the Tarapacá (Mw=7.8) earthquake using the non linear kinematic inversion developed at ENS.
b) The analysis of the postseismic seismic activity and of its potential updip migration following the Tarapacá earthquake as well as of the intraplate seismic swarm observed in this area during several years by the GFZ Postdam.
c) Observing potential transients in subduction zone slip and understanding their relationship to the updip seismicity and the loading process of the interplate coupled zone.
d) Observing potential microtremors associated with strain transients and their relationship with the updip seismicity.
e) improved 1D models by combining surface waves and seismic noise (with receiver functions)
f) Analysis of the frequency content of shallow seismic sources based on broadband records

<u>Strategy</u>
Short period permanent networks, e.g. 13 stations beween Arica (18°S) and Iquique (21°S) and 9 stations around Antofagasta, installed by the DGF in collaboration with the IRD and the IPG Strasbourg, are in operation since 1994 and 1991 respectively with the help of the Universities of Arica and Antofagasta. They provide a spatio-temporal resolution of the seismic activity for earthquakes with magnitude greater than 2, and have been used for the analysis of the seismic activity prior and after the 1995 Antogasta earthquake (Mw=8) by Delouis and collaborators. Since 2001, a network of 10 accelerometric stations is operational in a triggering mode between Arica and Antofagasta, e.g. with two stations at Tarapacá and Pica, under the responsibility of the DGF and the ETH Zurich.
Following the 2005 Tarapacá earthquake (Mw=7.8) a small triangular network of 4 broadband stations (3 STS2 and 1 Guralp) have been installed by the IPGP and the DGF and centered around the Tarapacá epicentre. This is the nucleus of a broader broadband network that should be installed in the North Chili in collaboration with the GFZ Postdam next December for more than one year. This network will have about 8

stations which will augment the 4 already installed by the IPGP/DGF. This network would be focused on the goal of resolving potential slip transients, spatio-temporal evolution of the seismicity and shallow earthquake sources. Shallow earthquakes (< 50 Km and M> 4.5) are expected in the south part and the north part of the network with back azimuths of ~4°W. This last direction will also be fulfilled by teleseismic subduction-zone events. This network should be dense enough to improve existing structural studies (Comte et al, 1994) using surface waves, an important issue to improve the localization and the determination of the CMT mechanism of small earthquakes. This will be done combining earthquake surface wave measures and seismic noise using receiver functions techniques. Using seismic noise, one could get short period measures (5-20s) and long period measures using earthquake events. North Chile region is highly productive and comparing measurements of, for example, anisotropy, made using slab events and teleseisms should make it possible to separate anisotropy coming from within the mantle wedge from anisotropy coming from the rest of the mantle.

Schedules
1st year: Source inversion of the Tarapacá earthquake and analysis of the postseismic activity; Installation with GFZ Postdam of a broadband network in North Chile. First publication on the Tarapacá earthquake
2nd year: First analysis of recorded seismic activity, especially shallow earthquakes ; analysis of potential slip transients and microtremors; improved structural and anisotropy studies.
3rd year: Processing of the data; Modelling of the data; Publication of the results.

Deliverable:
- Improved earthquake catalogs and source parameters integrated in the seismogy data base of the DGF.
- Transient slip events and microtremors data set
- Improvement of structural models of North Chile.
- Improvement of the seismic hazard knowledge.
- Publications

B3/ Tsunami earthquakes

Participants: N. Shapiro, P. Bernard, A. Lemoine, J.-P. Vilotte

Seismic tsunamis can be grouped into several types according to the generating earthquakes. The first type is large shallow subduction-zone earthquake. They are today's routinely detected in less than 10 minutes by the global digital broadband seismological networks of the FDSN (IRIS, Geoscope,..). The second type is unusual tsunami shallow earthquake which generates much larger tsunamis than expected from seismic waves. Because current tsunami warning systems rely on seismic waves to forecast tsunami heights, it may not work very well for tsunami earthquakes. The last type is those earthquakes occurring on environments over than subduction zones. Two typical examples of tsunami earthquakes are the 1992 Nicaragua earthquake (Ms 7.2), the 1996 Peru-Chimbote (Mw 7.5).

Detailed studies have shown that tsunami earthquakes may be characterized by (1) long source duration (slow rupture velocity ~ 1 Km/s) which relatively low energy release at high frequencies; (2) the rupture propagates up-dip to very shallow depths; (4) a relatively high percentage of normal faulting aftershocks; (5) a subducting sedimentary layer and only a small accretionary prism in the trench; (6) the ocean floor near the trench is highly faulted.

The objectives here areas
a) Investigating the source spectra together with the centroid and body wave locations of shallow subduction-zone earthquakes
b) Development of a seismic discriminator for tsunami earthquakes calibrated for the Chile

Strategy
The high frequency energy release deficit of shallow tsunami earthquakes has been identified as a potential mean for the detection of this type of earthquake. Three principal methods have been proposed: the determination of the mantle magnitude Polet and Kanamori (2000) ; the high and low frequency energy release ratio, e.g. Shapiro et al. (1998), the comparison between source spectra up to 1 Hz determined using broadband P-waveform recordings and the moment determined by CMT inversion of very long-period surface waves, e.g. Polet and Kanamori (2000). But to be operational, they must be calibrated in the Chilean region since they depend on regional attenuation.

Reliable estimation of the low frequency seismic radiation requires long recording of surface waves. Considering a minimal velocity of 2 Km/s, broadband stations must located not further than 500 Km/s from the potential earthquake source in order to detect tsunami earthquakes for about 5 minutes. This way a station can monitor ~ 1000 Km of the coast. This means than 4 to 5 broad band stations, installed along the Chilean coast, could potential be used for a regional tsunami warning system. The broad band stations that will be installed in collaboration with the GFZ in the North Chile, augmented by the already installed STS1 stations of Geoscope (Peldehue) and Geofun (Calama), would provide infill for increased resolution of the regional seismic catalogue and for regional attenuation estimation. This information would allow the calibration such a warning system.

Schedules
1st year: Synthesis of available of available shallow subduction-zone earthquakes data set in North Chile
2nd year: Analysis of the shallow subduction-zone source spectra and calibration of the method..
3rd year: Processing of the data; Modelling of the data; Publication of the results.

Deliverable:
- Improved shallow subduction-zone source spectra analysisearthquake.
- Tsunami warning system based on seismic discriminator for tsnami earthquakes
- Publications

B4) Inclinometry

Participants: P. Bernard, F. Boudin
Collaborations: DGF (University of Chile)

Strain transients have been observed for many years in seismically active zone (Linde et al., 1996). More recently, large transients have been reported for subduction zones in the Cascades (Dragert, 2001) and in Mexico (Lowry et al, 2004). A first transient in a rifting environment has been reported in the rift of Corinth (Bernard et al., 2004). Tectonic tremors have also been discovered recently, at greater depths in the Cascade and Japanese subduction zones .

These slip transients, related to friction instabilities and/.or fluid episodic migration, reveal a new form of crustal processes whose link with the plate tectonics and the generation of earthquakes remains to be understood (Bernard, 2001). These observations thus open a new, fascinating field of investigation, possibly related to the question of earthquake precursors. Let us recall here that the “Plate Boundary Observatory” project in western US clearly states that its “ primary scientific objective is to resolve transient events”.

Since small scale transients are more numerous than the largest, their resolution requires arrays of sufficiently high resolution instruments. In addition to the now standard continuous GPS and broad-band seismometer arrays, tiltmeters and strainmeters appear to be necessary to cover typical period range between a few hours and several month., which are not or poorly resolved by GPS and broad band seismometers: at 1000 s period, the resolution of strain and tiltmeters reach 10^{-9} or better, more than 1000 better than for the GPS. For the Corinth Rift Laboratory instrumentation, we have developed at IPGP a high resolution hydrostatic long-base strain meter, with silicium floaters and LVDT sensors, to complement our long expertise in silicium penduli (Blum type), which are noisier in the medium to long term (Bernard et al., 2004). We have now expertise on such tiltmeters of 10 to 150 m long. Our proposition is thus to install a few of these instruments in the Central and/or northern Chile seismic gaps, for detecting transient slip from the transition zone, or from the deepest part of the locked zone. .

Strategy
In the ANR project, we propose two options and our final choice will depend on the funding of other arrays and on the qualities of the available sites.
In the first one, we propose to install a long base hydrostatic tiltmeter near Iquique, in deep (3 m) and long (several hundred of meters) trenches, which is favoured by the nearly perfect horizontality of the Central Valley, and by its total absence of rain (the latter is an important source of noise); silicium penduli will be installed at the same site, for comparison and control.
In the second option, we plan to install simple silicium penduli within the underground shelter prepared for the STS2 array, thus reducing the cost of installation. The first option will thus test the adequation of long-base tiltmeter to the Chilean conditions; the second option will provide an array of 8 sites with simple tiltmeter all over the northern gap.

Schedules
1st year: Recognition of the potential sites and decision of the strategy depending on the financial suport
2nd year: Preparation of the instrumentation and site installations.
3rd year: Processing of the data; Modelling of the data; Publication of the results.

Deliverable:
- New inclinometric instrumentation in Chile.
- GPS/Seismology/Inclinometry analysis tools
- Publications

C/ Seismic hazard assessment and quantification

C1/ seismotectonic study

Participants: R. Armijo, R. Lacassin, C. Lasserre
Collaborations: DGF and Geological Department of University of Chile

Many of the largest earthquakes and tsunamis observed on Earth have been produced by the South American subduction zone. There the subduction process has also generated the Andes-Altiplano, which is the second largest mountain belt in the planet. However, the physics of the relation between mountain building and earthquake generation processes remains elusive so far, despite that the problem has been raised since Darwin's observation of coseismic uplift associated with the 1835 earthquake in central Chile.
Modern observations of coseismic deformation in Chile reveal that the ends of ruptured segments, generally interpreted as asperities or barriers along the subduction interface, coincide with specific regions along the coast where significant Quaternary uplift has occurred. An example is the Mejillones peninsula that is characterized by a staircase of marine surfaces (Armijo & Thiele, 1990): Mejillones is on top of the southern end of the M 8.8 1877 earthquake rupture (barrier) and also on top of the region where the Mw 8.1 1995 earthquake rupture nucleated (asperity) before propagating southwards (Ruegg et al., 1996). During this project, we will focus on two "intersegment" regions: Mejillones and La Serena (between the M 8.4 1922 et M 8.3 1943 ruptures, Fig. 1), where the morphologic record of marine terraces is particularly accurate. We will use high-resolution digital topography and satellite imagery to characterize the large-scale geometry of long-term deformation. We will incorporate geological, geophysical and seismic information to model this deformation. Cosmogenic dating of terraces (36Cl and 10Be) will be used to constrain rates. Our aim is to propose a first-order mechanical model for persistent barriers along the subduction zone.
The paleoseismological and tsunami studies are insufficient in Chile, compared to other subduction zones as Cascadia or Japan, where the record of large past earthquakes have been studied through seismic profiling and deep sea cores (by deciphering coseismic turbidites) and that of tsunamis by stratigraphy of sediments collected in littoral mudflats. An attempt to identify past tsunamis has been performed in the Mejillones bay (hit by the 1877 tsunami). The results are promising but ambiguous. During this project, we will examine with our Chilean colleagues the available geological and geophysical data on some specific targets (shallow-water bays and littoral swamp areas) to evaluate the feasibility of future projects on these subjects.
Active deformation occurs along the western front of the Andes-Altiplano (~80 km landward from the coastline), contributing to the mountain building. That front is the locus of persistent intra-plate seismicity and represents a possible source of large (M 6-7) shallow-depth earthquakes threatening densely populated areas. It has been found recently that Chile's capital Santiago is built by an active fault of such frontal fault system (San Ramón Fault, Armijo et al., in preparation). During this project, we will pursue the study of similar faults landward of the proposed areas (La Serena and Mejillones).

Deliverables
- Mechanical models of the large-scale Quaternary deformation for two targeted inter-segment regions along the coast.
- Conclusions on feasability of paleoeismological and tsunami studies in Chile
- Seismic hazard assessment in Santiago Metropolitan area.

C2/ Seismic risk in the metropolitan area of Santiago

We shall concentrate our action in the Santiago Metropolitan area. The city of Santiago is rapidly increasing with today's more than 4.7 millions of habitants. Santiago is surrounding a large sedimentary basin with potentially active faults at the eastern side, e.g. for example, the San Ramon fault, and is located in a large valley between the Coastal Cordillera and the Andean Cordillera. The high seismik risk of the Santiago city is linked to different types of earthquake

1. Subduction-zone earthquakes, with magnitude much greater than 7, at less than ~ 100 km from the town, e.g. like the 1985 Valparaiso earthquake (Mw=7.8) ;
2. Crustal earthquakes along active faults in the eastern part of the city, e.g. the 1958 Las Melosas earthquake (Mw=6.9) ;
3. Intermediate depth earthquakes with magnitude close to 8 with potential destructive effects despite their larger distances, e.g. the 1945 Santiago earthquake (M=7.2)

The main objective of this project is to propose a tool allowing the strong motion prediction for small up to

major earthquakes combining observations and numerical simulations. This will be done in close collaboration with the Nucleo Millenium project of the University of Chile to which both IPGP and IRSN participate.
A seismic velocity and a structural model for the Santiago area is a major issue. More precisely, three different scales are required: (1) local site effects in the Santiago city ; (2) Deep structure of the Santiago basin ; (3) crustal structure at regional scale.

C2.1/ Basin response and regional structure

Participants: N. Shapiro, J.-P. Vilotte, G. Festa
Collaborations: Servicio Sismologico, Nucleo Millenium « Seismotectonics and seismic hazard » (R. Verdugo, J. Campos), University of Chile

The Servicio Sismologico has succeeded in developing an extensive broadband and accelerometer seismological network in the Metropolitan region where most of the population lives. In this project, we propose to augment this network with a small mobile network of broadband stations that could be composed of ~ 6 stations STS2 or Guralp. All these stations could record signal up to periods of 30s and half of them very long periods.

The objectives would be to

a) Measure and inversion of dispersion curves using short period surface waves and seismic noise correlation techniques (Shapiro et Campillo, 2004)
b) Estimate site effect using transfer functions between reference stations on rock and within the basin.

<u>Strategy</u>
For deep structure and seismic response of the Santiago basin, we would install the stations within and on the border of the Santiago basin. The stations could remain for a period of é 6 months with a geometry that could be changed once or twice during the experiment. This way seismograms at 15 to 20 sites can be recorded. These data would be augmented with data recorded by the Servicio Sismologico of Chile operating two broadband stations and several accelerometers and short-periods in the Metropolitan area. This data set would be used to : (1) measure the dispersion curves of short-period surface waves in order to estimate the S-wave structure of the Santiago basin ; (2) caracterize the incident seismic fields on the basin for different types of earthquakes ; (3) estimate the response of the basin for various types of earthquakes by computing the transfer functions between reference sites on the rock and in the basin. These results would provide important constrains for numerical simulations of the 2D and 3D response of the Santiago that are part of a close IPGP/DGF collaboration within the Nucleo Millenio project of the University of Chile.

For crustal structure and regional attenuation studies, we would install a ~ 500 km profile between Santiago and La Serena, using available broadband stations at DGF and IPGP. Combining this profile with the existing permanent broadband stations we could measure the surface waves dispersion curves, the receiver functions and seismic wave attenuation. This would allow to improve a crustal model at regional scale.

<u>Schedules</u>
1st year: Preparation of the broadband experiments with the DGF
2nd year: Broadband experiments in the Santiago basin and broadband profile experiment.
3rd year: Processing of the data; Modelling of the data; Publication of the results.

<u>Deliverable</u>:
- Improved large scale seismic structure of the Santiago basin.
- Regional attenuation and improved structure models
- Seismic response of the Santiago basin
- Publications

C2.2/ Strong ground motion prediction in the Santiago basi : geometrical and geological site effects.

Participants: C. Berge-Thierry, D. Baumont, P. Volant, F. Bonilla and S. Baize, J. Ruiz
Collaborations: Nucleo Millenium « Seismotectonics and seismic hazard » (R. Verdugo, J. Campos), University of Chile

The main objectives are here

a) Strong ground motion modelling
b) Wave propagation and site effects studies

Strategy

For strong ground motion modelling, we would improve the deterministic k-square source model, initially proposed by P. Bernard, A. Herrero and C. Berge-Thierry, and calibrate this approach for the Santiago basin. Improvements are linked to kinematic source modelling (rupture velocity variation, variable focal mechanism, non-planar rupture surface) and propagation modelling (complete wave field, empirical Green's function).

For site effects studies and strong motion simulations, a major issue is to better constrain the geometry, the geology and the geotechnic characteristics of the Santiago basin. In the case of the Santiago basin, a synthesis of available geological knowledge is needed. The construction of a well constrained basin model accounting for the spatial velocity distribution is required to permit computation of accurate numerical Green's functions: such numerical approach, limited due to time computation for high frequency modelling (greater than 10 Hz), should be completed or compared with empirical Green's functions methods.

One of the most difficult problems in strong motion modelling is the response of soft soils to large amplitude wave fields. This is the domain of non linear site response. The potentiality for sediment to present non-linear behaviour under a seismic solicitation can be estimated by laboratory tests on samples. In the framework of this project it is planned to perform some lab tests on selected samples. If some potentially non-linear areas can be identified, the strong motion modelling should account for such characteristics.

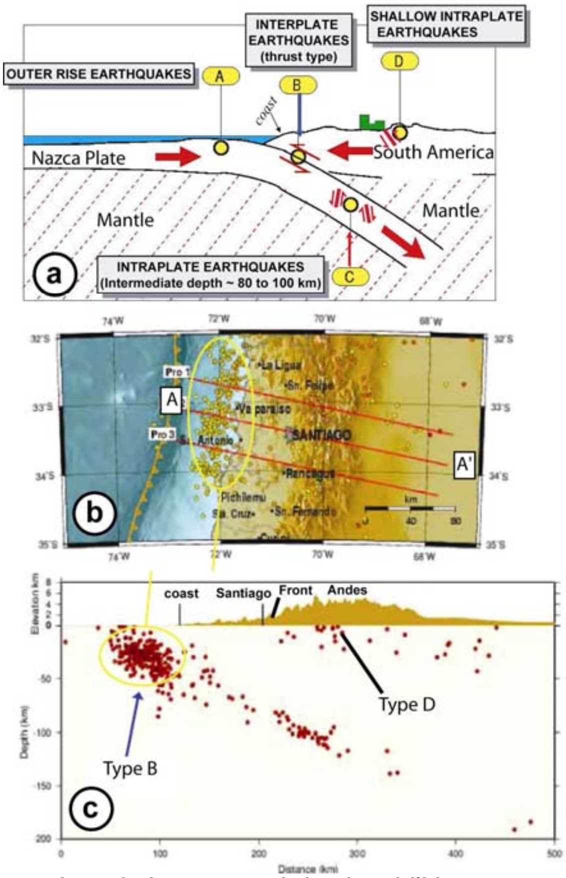
D/ Data integration and expected results

We hope within the next decade to be able to capture a very large earthquake in at least one of the four seismic gaps that we have instrumented and studied in Chile: The Tarapacá gap that dates back to 1877, the Antofagasta gap that dates back to 1868, the Coquimbo gap from 1946 and the Constitución gap that dates back to 1835. We already did it in the Northern Chile gap in June 2005 but the earthquake was a large M=8, slab pull event. Those events are thought to occur before large subduction events when the gap gets closer to rupture. Even though this is still quite controversial, it is something that we will take carefully into account.

International Collaborations :

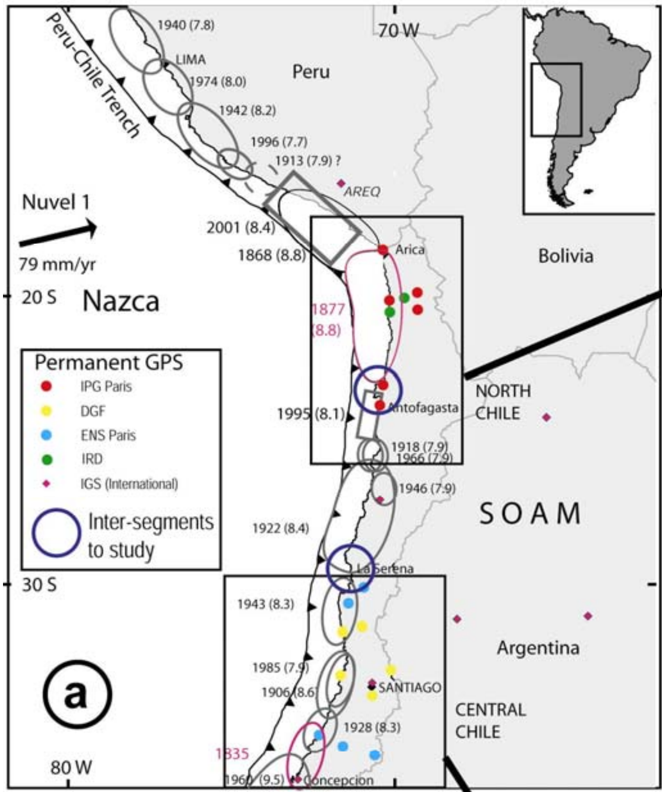
- DGF, Université du Chili (Santiago) :
    - J. Campos, Professeur
    - V. Clouard, Professeur
- Université de Conception :
- UCN, Université Catholica del Norte :
    - M. S. Bembow, Professeur
    - G. Gonzales, Professeur
    - D. Carrizo (doctorant)
- UAP, Universite Arturo Prat (Iquique)
    - M. Olcay, Professeur
    - D. Lazo (Professeur)
- UTAR, Universite de Tarapaca (Arica)
    - B. Glass, Professeur
    - N. Alvarez, Ingenieur
- Laboratoire de Géologie, Université du Chili (Santiago) :
    - G. Vargas, Professeur Assistant

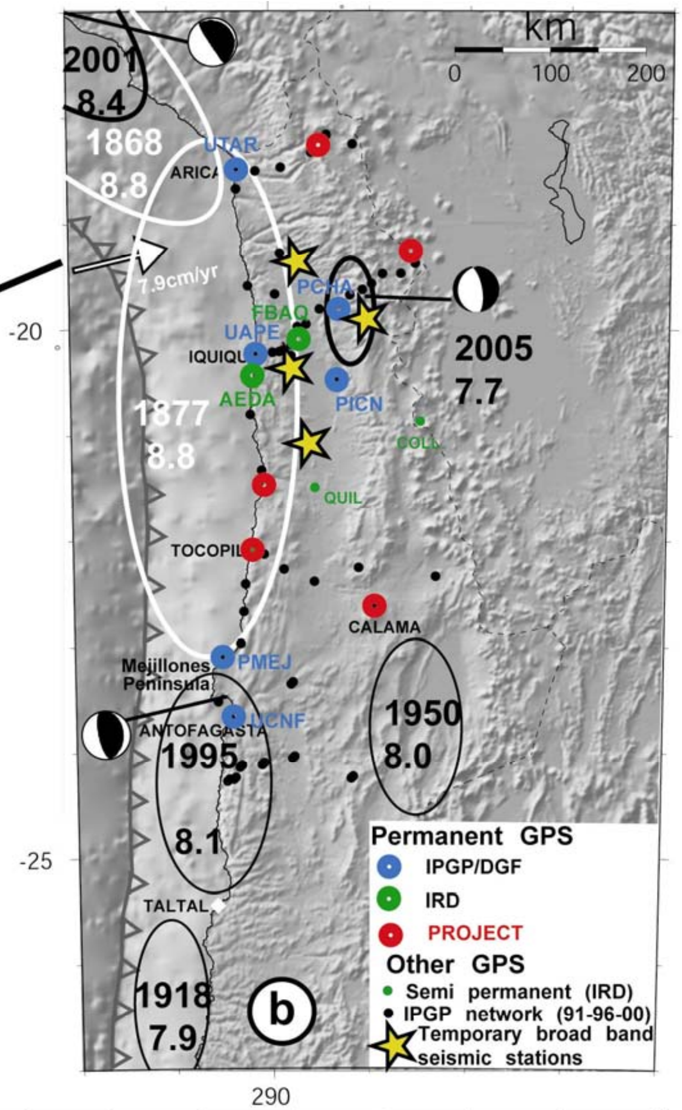
FIGURES



Caption of Figure 1 : subductionchili.jpg
a) Typical eartquakes in subduction zones
b) Seismicity in the Central Chile (1996-2003) from seismologic service (DGF, Chile). AA' locates the cross section presented in c)
c) Cross section of the seismicity perpendicular to the trench. Front locate the western subandin front. Type B and C refer to taxonomy presented in a).

Figure : projetGPSfinal.jpg





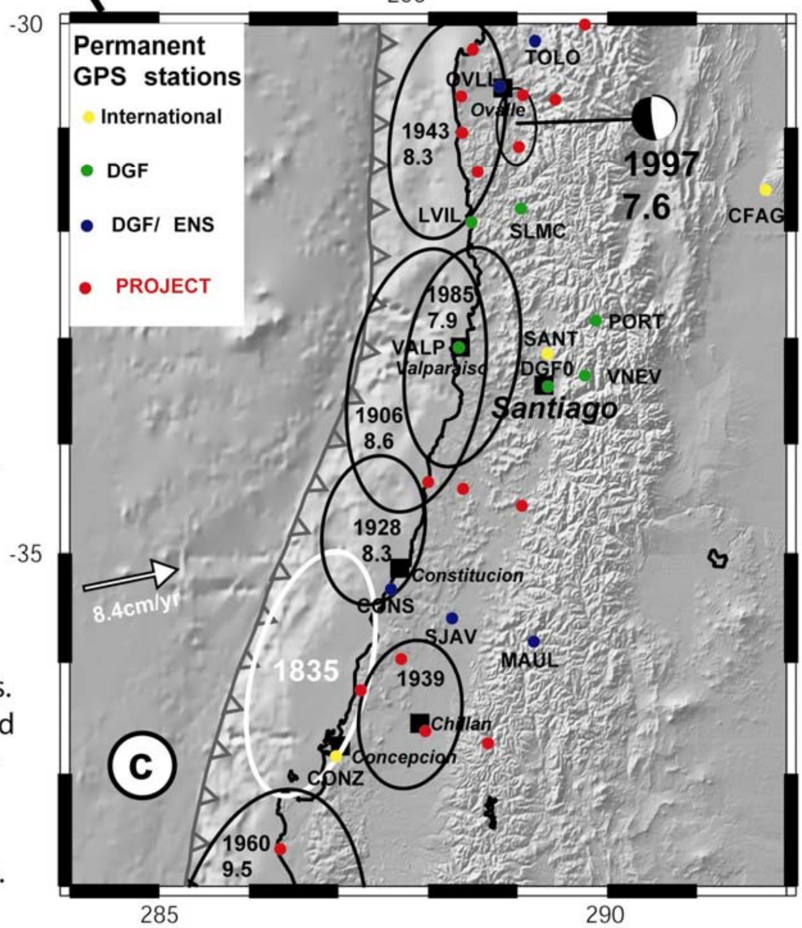


Figure :

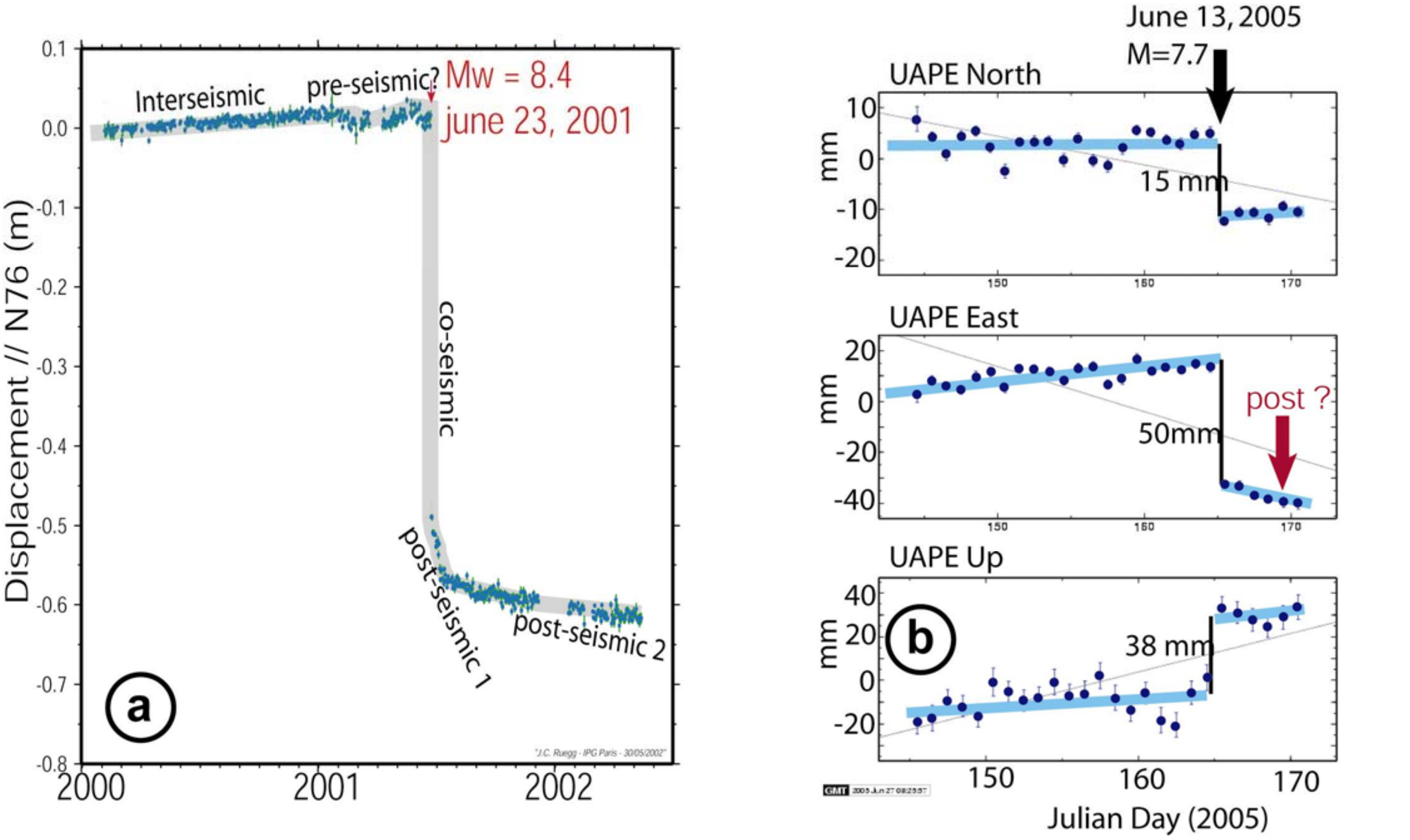
a) Large subduction earthquakes along the Peru-Chile trench and present permanent French-Chilean cGPS network. Elipses represent approximate extend of rupture zones. Pink ellipses represent the location of the last seismic gaps. The two studied areas are located with the frames.

b) Major Earthquakes in northern Chile, and location of existing and planed GPS stations. Four broad band stations have been installed by the DGF and IPGP following the 2005 Tarapaca earthquake (yellow stars).

c) Major earthquakes in central Chile and location of existing and planed GPS stations.

Caption of Figure : serietemporelle.jpg

a) Temporal serie of the AREQ cGPS station showing the seismic cycle of the June 23, 2005 South Peru earthquake (Ruegg et al. 2001). The displacement is projected in the direction of the convergence.
b) Temporal serie of UAPE (Iquique) North Chile station during the m=7.7, June 13, 2005 Tarapaca earthquake. From top to bottom, respectively north, east and vertical component displacement during 26 days.



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Propositions d'experts et confidentialité

- Chaque porteur de projet devra fournir une liste de 3 à 5 noms d'experts français ou étrangers (avec coordonnées complètes : adresse postale et adresse électronique) susceptibles d'évaluer le projet avec lesquels il n'a ni conflit d'intérêt, ni collaborations en cours.
- Les membres du Comité d'évaluation et du Comité stratégique sont astreints à la confidentialité.

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C - Moyens financiers et humains demandés par chaque équipe partenaire du projet

Chaque équipe partenaire remplira une fiche de demande d'aide selon les modèles proposés ci-dessous (laboratoire public ou fondation ; entreprise ou association) en fonction de son appartenance.

On présentera une brève justification scientifique des moyens demandés pour chacune des équipes impliquées dans le projet.

IPGP

La demande d'équipement IPGP porte sur (a) GPS ; (b) Sismologie ; (3) Inclinométrie.

(a) GPS : 5 stations GPS pour améliorer la résolution du réseau Nord en tenant compte des stations du Caltech (7) qui doivent être installées en septembre de manière coordonée

(b) Sismologie : 1 station large bande STS2 complète. Pour ce projet une demande complémentaire pour 2 stations STS2 complète sera déposée au BQR IPGP en 2006. Par ailleurs, nous demanderons 6 stations STS2 sur le parc national large bande mobile (RLBM) pour une durée d'1 an. 3 stations STS2 du RLBM sont actuellement installées dans le Nord. Elles doivent être remplacées par les 3 stations IPGP pour s'intégrer dans le réseau IPGP/GFZ dont l'installation est prévue courant décembre 2005.

(c) Inclinométrie : la demande dépendra de l'option retenue. Elle porte soit sur un inclinomètre longue base + numériseur ; soit sur les inclinomètres de type Blum dont l'installation complètera les STS2 du réseau Nord.

Au niveau des missions la demande comprend des missions d'installation GPS permanent et des campagnes de remesures des points du réseau IPGP/IRD Nord. Ces points seront complétés par les points du réseau Allemand GFZ Postdam.i

ENS Paris

Matériel :

GPS : 16 continuously recording GPS stations to be deployed in the Central and South Central Chile gaps.
We ask for sufficient funds for field work in the form of « missions ».
Interferometry: We need to acquire INSAR Images for a total of 30 kEuros
Petit matériel de Laboratoire nécessaire pour assurer l'entretien des stations GPS

Personnel:

We also request a total of 42 kEuros in order to hire a CDD that will take care of the installation and processing of the GPS data together with the reserchers that participate in the project. This item is essential in order to insure appropriate installation and repair of the GPS stations. This can not be provided by our Chilean partners.

IRSN:

La contribution de l'IRSN dans le cadre du présent projet est réalisée sous la forme de travaux doctoraux (étudiant Javier Ruiz en thèse), financés par l'IRSN. L'encadrement de la thèse est assuré par un ingénieur de recherche IRSN. La contribution demandée correspond donc à un soutien pour mener à bien ces travaux (moyens informatiques dédiés), et permettront à l'étudiant de les présenter à la communauté scientifique lors de congrès internationaux (participation aux frais de mission et inscriptions). La contribution ANR sera également utile pour la publication dans les revues internationales des produits de la recherche.

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Fiche de demande d'aide – Laboratoire public / Fondation

Acronyme ou titre court du projet SubChile

LABORATOIRE DE GEOLOGIE, ENS

Responsable scientifique (coordinateur ou partenaire) (nom, prénom) : VIGNY Christophe

Estimation du coût marginal du projet pour le laboratoire :
Les valeurs obtenues dans les cellules du tableau P à W serviront à renseigner le tableau « estimation du coût complet » ci-dessous

	Année 1			Année 2			Année 3			Total (Euros)
	Nbre h/m	*Coût h/m*	*Coût total*	*Nbre h/m*	*Coût h/m*	*Coût total*	*Nbre h/m*	*Coût h/m*	*Coût total*	
Dépenses de personnel (1) (catégorie 1) (catégorie 2) …				12	3500	42000				42000 (P)
Equipements (2),(4)	90 000 (9 stations GPS à 10000 euros par station comprenant station+PC+systeme de communication...)			70 000 (7 stations GPS à 10000 euros par station comprenant station+PC+systeme de communication...)						160000 (Q)
Achats de petits matériels, de consommables etc (2)							15000 (120 images Envisat programmees, hors quotas d'images gratuites, 125 euros/image)			15000 (R)
Prestations de service(2),(3)										(S)
Frais de missions (2)				16000 (1000 euros par station GPS de frais de mission + mise en place des sites+voiture, petit materiel...))			12000 (1 campagne pour 3 personnes, 15 jours)			28000 (T)
Frais généraux (4 % des dépenses)	3600			5520			1080			10 200
Total (Euros)	93 600			143 520			28 080			
Aide demandée (Euros)	93 600			143 520			28 080			**255200**

(1) Personnel non statutaire directement affecté au projet exprimé en hommes mois. Les dépenses éligibles se limitent aux salaires et aux charges sociales. Pour cet appel les doctorants ne doivent pas être pris en compte. Exemple : post-doc (catégorie 1), ingénieur d'études (catégorie 2)

(2) Y compris TVA non récupérable.

(3) Le montant des prestations de service est limité à 50% du montant global du fonctionnement demandé.

(4) Matériel dont la valeur unitaire est supérieure à 4000 euros HT

Evaluation (pour information) du coût complet du projet pour le laboratoire

EQUIPEMENT (1) (2)	FONCTIONNEMENT				TOTAL Equipement + fonctionnement
	Dépenses de personnel	Prestations de service (1)	Autres dépenses de fonctionnement (1)	Total fonctionnement	
(a)	(b)	(c)	(d)	(e) = (b) + (c) + (d)	(f) = (a) + (e)

160000	142000		53200	195200	**355200**

(1) Coût HT majoré le cas échéant de la TVA non récupérable
(2) Équipement : matériel dont la valeur unitaire est supérieure à 4 000 euros HT
(3) Dépense du personnel rémunéré par d'autres sources de financement (charges sociales comprises) affecté au projet, au prorata de leur implication dans le projet (y compris les doctorants)
(4) Taux d'environnement de l'établissement

Programme Catastrophes Telluriques 2005

Fiche de demande d'aide – Laboratoire public / Fondation

Acronyme ou titre court du projet SubChile

LABORATOIRE DE SISMOLOGIE, IPG Paris

Responsable scientifique (coordinateur ou partenaire) (nom, prénom) : VILOTTE Jean-Pierre

Estimation du coût marginal du projet pour le laboratoire :
Les valeurs obtenues dans les cellules du tableau P à W serviront à renseigner le tableau « estimation du coût complet » ci-dessous

	Année 1			Année 2			Année 3			Total (Euros)
	Nbre h/m	*Coût h/m*	*Coût total*	*Nbre h/m*	*Coût h/m*	*Coût total*	*Nbre h/m*	*Coût h/m*	*Coût total*	
Dépenses de personnel [1] (catégorie 1) (catégorie 2) …										(P)

Equipements (2),(4)	60 000 (4 stations GPS à 10000 euros par station comprenant station+PC+systeme de communication... ; 1 station ST2 + numériseur+ communication …)	50 000 (2 stations GPS 90 000 (9 stations à 10000 euros par station comprenant station+PC+systeme de communication... ; Inclinométrie)		110 000
Achats de petits matériels, de consommables etc (2)	3 000 (sismotectonique)	3000 (sismotectonique)	8000 (sismotectonique + datation)	14 000
Prestations de service(2),(3)				(S)
Frais de missions (2)	29 000 euros (4 x 1000 euros par station GPS de frais de mission + mise en place des sites+voiture, petit matériel... ; 12 000 pour 1 campagne sismo pour 3 personnes, 15 jours ; 13 000 pour 1 missions Sismotectonique pour 3 personnes, 15 jours)	34 000 euros (12 0000 pour 1 campagne sismo pour 3 personnes, 15 jours ; 10 000 pour 1 campagne/installation GPS pour 3 personnes 15 jours ; 12 000 pour 1 mission sismotectonique pour 3 personnes 15 jours)	12 000 (1 campagne sismotectonique pour 3 personnes, 15 jours)	75 000
Frais généraux (4 % des dépenses)	3680	3480	800	7960
Total (Euros)	95 680	90 480	20 800	206 960
Aide demandée (Euros)	95 680	90 480	20 800	**206 960**

(1) Personnel non statutaire directement affecté au projet exprimé en hommes mois. Les dépenses éligibles se limitent aux salaires et aux charges sociales. Pour cet appel les doctorants ne doivent pas être pris en compte. Exemple : post-doc (catégorie 1), ingénieur d'études (catégorie 2)
(5) Y compris TVA non récupérable.
(6) Le montant des prestations de service est limité à 50% du montant global du fonctionnement demandé.
(7) Matériel dont la valeur unitaire est supérieure à 4000 euros HT

Evaluation (pour information) du coût complet du projet pour le laboratoire

EQUIPEMENT (1) (2)	FONCTIONNEMENT				TOTAL Equipement + fonctionnement
	Dépenses de personnel	Prestations de service (1)	Autres dépenses de fonctionnement (1)	Total fonctionnement	
(a)	(b)	(c)	(d)	(e) = (b) + (c) + (d)	(f) = (a) + (e)
110 000	108,178.12		86 960	195 078.12	**305 078.12**

(1) Coût HT majoré le cas échéant de la TVA non récupérable
(2) Équipement : matériel dont la valeur unitaire est supérieure à 4 000 euros HT
(5) Dépense du personnel rémunéré par d'autres sources de financement (charges sociales comprises) affecté au projet, au prorata de leur implication dans le projet (y compris les doctorants)
(6) Taux d'environnement de l'établissement

Programme Catastrophes Telluriques 2005

Fiche de demande d'aide – Entreprise / Association

Acronyme ou titre court du projet SubChile

Responsable scientifique (coordinateur ou partenaire) (nom, prénom) : IRSN (BERGE-THIERRY, Catherine)

Estimation (en coûts complets H.T.) du projet pour l'entreprise :

	Année 1			Année 2			Année 3			Total (Euros)
	Nbre m	*Coût /m*	*Coût total*	*Nbre/ m*	*Coût /m*	*Coût total*	*Nbre m*	*Coût /m*	*Coût total*	
Amortissements d'équipements de R&D										
Dépenses de personnel [1] *Catégorie 2* *Catégorie 3*	5	8 500	42 500	5	8 500	42 500	5	8 500	42 500	127 500
Prestations de service [2] **:** - Information scientifique et technique - Propriété industrielle - Faisabilité technique - Conception, analyse de la valeur - Essais, tests, caractérisation - Prototypage - Etudes économiques - Autres prestations										
Frais de mission	4 000 (mission chili synthèse bassin)			4 000 (mission chili, mesures géotechniques)			4 000 (mission Chili, intégration données bassin)			12 000
Autres dépenses de fonctionnement				1500 (publications, congrès, matériels terrain)			1500 (publications, congrès, matériels terrain)			3 000
Dépenses liées à l'utilisation d'autres équipements de R&D que ci-dessus [3]										
Autres dépenses [3]										
Frais (assistance, encadrement, coût de structure) [4]										
Total H.T. (Euros)	46 500			48 000			48 000			**142 500**
Aide demandée (Euros)	4 000			5 500			5 500			**15 000**

(1) *Personnel directement affecté au projet, chiffré en hommes mois par catégories de personnel.*
(2) *Chiffré par types de prestations*
(3) *Justifiées selon une procédure de facturation interne*
(4) Ces frais seront remboursés jusqu'à un plafond défini par les règles propres à l'ANR. Ce plafond est calculé en fonction des éléments donnés dans le tableau (frais de personnel, équipement, …)

Note : *En cas de décision de financement de ce projet, le porteur de projet devra alors fournir un dossier complémentaire comportant un planning de déroulement du projet et des documents administratifs et financiers (entreprises, laboratoires et/ou associations) dont la liste lui sera précisée.*

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D - Récapitulatif global de la demande financière pour le projet

Acronyme ou titre court du projet :

a-Total de l'aide demandée
(reporter les valeurs (W) des fiches des différents partenaires)

	Aide demandée
Coordinateur (ENS)	**255200**
Partenaire 1 (IPGP)	**206960**
Partenaire 2 (IRSN)	**15 000**
Total à reporter sur la première page du dossier	**477160**

b-Estimation (pour information) du coût complet de cette demande
(reporter les valeurs (X) des fiches des différents partenaires)

	Coût complet
Coordinateur (ENS)	**355200**
Partenaire 2 (IPGP)	**305 078**
Partenaire 3 (IRSN)	**142 500**
…	
Total à reporter sur la première page du dossier	**802778**

Contrats sur les trois dernières années (effectués et en cours)

Nom du membre participant à cette demande	% d'implication	Intitulé de l'appel à projets Source de financement Montant attribué	Titre du projet	Nom du coordinateur	Date début - Date fin
Vigny Lasserre Madariaga	30 10 10	ACI CatNat	Etude géodésique de la lacune de Coquimbo	R. Madariaga	2002-2005
Vigny Madariaga	20 20	PICS Chili	PICS Chili	R. Madariaga	2004-2005
Vigny	20%	Ambassade de France en Indonésie 2004 :12 kE 2005 : 15 kE	Programme « géodésie-Indonésie »		
Lasserre	40%	DyETI INSU 10kE	Cinematique et fonctionnement mécanique du système de failles décrochantes Polochic-Motagua en Amérique Centrale (frontière Caraibes/Amérique du Nord)	Lasserre/Lyon-Caen	2004-2005
Armijo Lacassin	10 10	ECOS-Sud	Morphologie, structure tectonique, sismicité et couplage mécanique au Chili central	R. Armijo	
Armijo Bernard De Chabalier Lacassin Lasserre Madariaga Vigny Vilotte	40% 30% 40% 25% 40% 40% 40% 20%	DyETI INSU	Sismicité, déformation, et tectonique active de la subduction chilienne	J.-P. Vilotte	2004-2005
Vilotte Bernard Favreau Madariaga	30% 20% 30% 10%	ACI Catastrophes naturelles	Simulation numérique des séismes naturels	J.-P. Vilotte	2003-2005

Demandes de contrats en cours d'évaluation [7]

Nom du membre participant à cette demande	% d'implication	Intitulé de l'appel à projets Source de financement Montant demandé	Titre du projet	Nom du coordinateur
Lasserre	30%	ANR blanche 580kE	Traitements Interférométriques Radar Orientés Apllications (TIROA)	E. Trouvé
Lasserre	30%	ANR Catastrophes telluriques 580kE	Lacune	Y. Klinger
Lasserre Bernard Madariaga Vilotte	30 20% 30% 30%	ANR ANR	SEIsmic SIMULATion in complex sOuRce-Site context	H. Aochi
Madariaga	20%	ANR	Tsumod (Tsunami Modelling)	H. Hébert

[7] *Veuillez mentionner ici les organismes auprès desquels vous avez déposé un autre projet, en particulier au GIP ANR, que ce soit comme coordinateur ou comme partenaire. Pour chacun donnez le nom de l'appel à projet, le titre du projet et le nom du coordinateur.*