Rentrée 2021

PROPOSITION DE SUJET DE THESE

Formulaire demande de financement : ARED - ISblue - ETABLISSEMENTS - …

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Identification du projet

Acronyme du projet *(8 caractères maximum)* **: SIS-RIFT**

Intitulé du projet *en langue française* : Résistance crustale, crises sismiques et variations spatio-temporelles des propriétés rhéologiques : Application au rift Baïkal (Russie) et comparaisons aux rifts actifs mondiaux

Intitulé du projet en langue anglaise : Crustal strength, seismicity crises and space-time changes of rheological properties: Application to the Baikal rift and comparisons with active rifts worldwide

Présentation de l'établissement porteur (bénéficiaire de l'aide régionale)

Établissement porteur du projet : UBO

Ecole Doctorale : EDSML ☒ SP ou MATHSTIC pour les projets ISblue ☐

Identification du responsable du projet (futur directeur de thèse)

Nom du laboratoire d'accueil : Laboratoire Géosciences Océan
Code du laboratoire (U/UMR/USR/EA/JE/…) : UMR 6538
Directeur[1] du Laboratoire : M-A. Gutscher
Nom de l'équipe de recherche : Dorsales, Marges, Rifts (DMR)
Nombre HDR dans le laboratoire : 27 Nombre de thèses en cours : 27 Nombre de post-docs en cours : 7

Nom et prénom du directeur* de thèse (HDR), porteur du projet : DEVERCHERE Jacques

- **e-mail : jacdev@univ-brest.fr**
- **Téléphone : 02 98 49 87 20**
- **Publications récentes du directeur de thèse** *(nb total et 5 références max au cours des 5 dernières années)* **:**

20 publications depuis 2016 – Références récentes :

DOBRYNINA A., SANKOV V.A., CHECHELNITSKY V.V., & DEVERCHERE J., Spatial changes of seismic attenuation and multiscale geological heterogeneity in the Baikal rift and surroundings from analysis of coda waves. *Tectonophysics*, 675, 50-68, doi:10.1016/j.tecto.2016.03.010, **2016**.

GRAPPIN C., HUMLER E., AGRINIER P., BACHELERY P., BERNARD P., DELOUIS B., DEVERCHERE J., GRASSO J-R., JAUPART C., VERGNE J., VIGNY C., Quand la Terre tremble - Séismes, éruptions volcaniques et glissements de terrain en France. *CNRS Editions, Ouvrage collectif*, 264 pp., ISBN 978-2-271-12467-8, **2019.**

HAMAI L., PETIT C., LE POURHIET L., YELLES K., DEVERCHERE J., BESLIER M-O., & ABTOUT A., Towards subduction inception along the inverted North African margin of Algeria? Insights from thermo-mechanical models. *Earth Planet. Sci. Letters*, 501, 13-23, doi:10.1016/j.epsl.2018.08.028, **2018**.

STRZERZYNSKI P., DOMINGUEZ S., BOUDIAF A., & DEVERCHERE J., Interplay between tectonics erosion and sedimentation during inversion of a passive margin: insights from experimental modeling applied to the central Algerian margin. *Tectonics*, in press, **2021**.

TIBERI C., GAUTIER S., EBINGER C., ROECKER S., PLASMAN M., ALBARIC J., DEVERCHERE J., PEYRAT S., PERROT J., MSABI M., FERDINAND-WAMBURA R., MUZUKA A., MULIBO G., & KIANJI G., Lithospheric modification by extension and

[1] Ce formulaire est rédigé en style épicène

magmatism at the craton-orogenic boundary: North Tanzania Divergence, East Africa. Geophysical Journal International, 216, 1693-1710, doi:10.1093/gji/ggy521, **2019.**

- Expériences d'encadrement et co-encadrement de doctorants (passées et en cours)

(nom des doctorants dirigés et en cours et antérieurement, sur les 6 années passées : sujet, financement, date de soutenance, et situation professionnelle actuelle si connue)

- **HAIDAR Shaza** : Contraintes géophysiques sur la formation et l'évolution tectonique, sédimentaire et volcanique du bassin algérien – Financement : Bourse Libanaise - Soutenance prévue en juin 2021
- **LEFFONDRE Pierre** : Inversion tectonique d'une marge passive : le cas de la marge algérienne – Financement : Contrat doctoral Handicap du MESRI - Soutenance prévue en juin 2021
- **LAURENCIN Muriel** : Etude de la géométrie, de la nature et des déformations de la zone de subduction des Petites Antilles du Nord - Financement : ½ Ifremer et ½ ARED - Soutenance en novembre 2017 - Post-Doc : Earth Obs. Singapour

Co-encadrante scientifique 1 : PERROT Julie (Maître de conférences, UBO-IUEM)

Laboratoire de recherche co-encadrant (nom + code U/UMR/USR/EA/JE/…) : Laboratoire Géosciences Océan - UMR 6538 **- e-mail : jperrot@univ-brest.fr - Téléphone : 02 98 49 87 24**

- Expériences d'encadrement et co-encadrement de doctorants (passées et en cours)

(nom des doctorants dirigés et en cours et antérieurement, sur les 6 années passées : sujet, financement, date de soutenance, et situation professionnelle actuelle si connue)

- **GIUSTI Marion** : Apport des donnés hydroacoustiques pour l'étude de la sismicité de la dorsale médio-Atlantique Nord Financement ARED- financement ARED-Labex Mer - Soutenance en mars 2019.
- **KAUB Caroline** : Déformation active intraplaque : étude pluridisciplinaire terre-mer du risque sismique en Vendée, à partir du séisme du Marais Breton de 1799 (M6) - financement ½ CEA et ½ ARED – Soutenance en mars 2019.
- **BOT Anna** : Rupture continentale oblique : évolution tectonique du Golfe de Californie (Basse Californie du Sud) du Néogène à l'actuel, financement ARED-Labex Mer, Soutenance en septembre 2016.

Le cas échéant, autres collaborations (co-encadrant et laboratoire concerné) :

Co-encadrante scientifique 2 : RADZIMINOVICH Natalia (« Senior Researcher », Académie des Sciences de Russie, branche sibérienne)

Laboratoire de recherche co-encadrant (nom + code U/UMR/USR/EA/JE/…) : Department of Geophysics and Recent geodynamics, Institute of the Earth's Crust, Irkutsk, Russia **- e-mail : nradzim@crust.irk.ru**

Co-encadrante scientifique 3 : RENOUARD Alexandra (ATER, UBO-IUEM)

Laboratoire de recherche co-encadrant (nom + code U/UMR/USR/EA/JE/…) : Laboratoire Géosciences Océan - UMR 6538 **- e-mail : alexandra.renouard@gmail.com**

Co-encadrante scientifique 4 : DOBRYNINA Anna (« Senior Researcher », Académie des Sciences de Russie, branche sibérienne)

Laboratoire de recherche co-encadrant (nom + code U/UMR/USR/EA/JE/…) : Laboratory of Engineering Seismology and Seismogeology, Institute of the Earth's Crust, Irkutsk, Russia **- e-mail : dobrynina@crust.irk.ru**

Financement du projet de thèse

En cas de financement à 50 %, le cofinancement est-il déjà identifié *(oui/non)* **: non**

Si oui, préciser la nature du cofinancement (*ANR, partenaire privé, Ademe, etc.*) :

Si le cofinancement n'est pas encore confirmé, date prévue de réponse du cofinanceur : printemps 2021

En cas de non-obtention du cofinancement demandé, une autre source de cofinancement est-elle identifiée *(oui/non)* **: non**

Si oui, laquelle :

Sollicitez-vous un co-financement Is-Blue (y compris ARED Is-Blue) *(oui/non)* **? oui**

Important : Veillez à bien compléter les différents co-financements sollicités sur le serveur Thèses en Bretagne Loire lors du dépôt de votre dossier.

Projet de thèse en cotutelle internationale

S'agit-il d'un projet de thèse en cotutelle internationale dans le cadre d'une convention *(oui/non)* **: non**

Si oui, préciser l'établissement pressenti (*et le pays de rattachement*) :

Ce projet de thèse fera-t-il l'objet d'un cofinancement international *(oui/non)* **: non**

(Rémunération du doctorant par l'établissement implanté sur le territoire régional (18 mois sur 36 mois), et l'établissement étranger, qui s'engage également à rémunérer le doctorant dans le cadre de son séjour à l'étranger, soit durant 18 mois -a minima-)

En cas de cofinancement international, préciser *-si vous en avez connaissance-* **l'organisation du calendrier des périodes de séjour :**

Préciser quel est le stade du projet international (joindre une lettre d'engagement du partenaire)

In Fall 2020, it has been hypothesized to apply to the Programme « Bourses doctorales Vernadski » from the French MESRI (https://ru.ambafrance.org/Bourses-doctorales-Vernadski), but we did not manage to find at time a Russian candidate. That is why we apply to a French grant open to all foreign candidate, including russian ones. We have obtained the official support of the Russian partners to use jointly their seismic database (see letter attached).

Présentation du projet (en langue française ou anglaise, 2 à 3 pages)

Résumé du projet *(4000 caractères maxi espaces compris) :*

Understanding the factors controlling the strain localization and seismic crises within the crust remains a major challenge. Oceanic lithospheres and continental rifts share evidence for strong magmatic-tectonic interactions that need to be better described and understood. In this project, we aim at performing a systematic and precise study of the link between earthquake time-space distribution and rheological properties of the crust. To do so, we rely on the best worldwide catalog of earthquakes recorded in a continental rift (the Baikal Rift), which will serve as a proxy to highlight the parameters able to modify the seismogenic pattern in response to various triggering or pre-conditioning mechanisms favoring localized deformation and earthquake nucleation, such as local high fluid pressure or pre-existing structural fabrics within strong but dominantly viscous crust. The originality of the work will lie on a new analysis of the seismicity catalog, separating the background seismicity, swarms and aftershocks by the use of artifical intelligence techniques to detect and isolate quarry blasts and clean the database. The upper and lower seismicity cut-off depth will be determined and interpolated, and some favorable earthquake series selected using both methods of absolute and relative location. The sparse, seldom intraplate seismicity recorded in Brittany will also benefit from this approach. This research is built on a long-term cooperation between the Labs LGO-Brest and Institute of the Earth's Crust in Irkutsk, Russia. The Russian partners are interested in sharing new methodologies in the analysis of seismicity catalogs to improve their conceptual and practical knowledge. The PhD student will benefit from a high-quality, unique database, a fine international environment and a methodology combining geophysical modelling and artificial intelligence developed in the frame of ISblue partnership. By combining techniques widely used in the academic world, industry and design offices, with an innovative methodology, the PhD student will develop skills that will facilitate future recruitment. In addition, he will use data sets coming from several study areas (Baikal, East Africa in particular), which will be an additional asset.

Présentation détaillée du projet :

1 - Hypothèse et questions posées, état de l'art, identification des points de blocages scientifiques (4000 caractères maxi espaces compris)

Understanding the modalities of **strain localization** in the lithosphere is critical to describe the formation and evolution of plate boundaries, either during continental rifting, breakup or seafloor spreading stages. Active strain

localization produces seismicity clustering occurring either as non-tectonic (i.e. volcanic or hydrothermal) or tectonic (i.e. fault-related) processes. Earthquake catalogs reveal fundamental rheological properties of the upper lithosphere, i.e. either the transition from brittle faulting to plastic flow in the crust, or a change in the frictional sliding process. However, limitations come from inaccuracy in depth location, too short time duration of earthquake catalogs or uncertainties in the modelling of the long-term lithospheric thermo-mechanical properties. Additionally, recent studies have evidenced **strong magmatic-tectonic interactions** within oceanic lithospheres or continental rifts, thus making the correlation of seismicity with rheology rather tricky to perform :

- Oceanic ridges : recent works by French teams have recently evidenced that in the mid-Atlantic ridge, oceanic detachments (long-lived faults exposed at the seafloor) are systematically linked to hydrothermalism, suggesting a magmatic source within the footwall (**Escartin et al., 2017**). Space-time distribution of seismicity also reveal magma-dike intrusions triggering dense earthquake swarms (**Giusti et al., 2018**). Unfortunately, the factors controlling the seismicity clustering are unclear owing to the lack of accuracy on hypocenters (**Tsang-Hin-Sun et al., 2016**). Segment-scale crustal heterogeneities and regional-scale contrasting accretion processes are assumed to play a key role (**Tsang-Hin-Sun et al., 2016)**, whereas low-magnitude seismicity rates appear to directly depend on along-axis variations in lithosphere rheology and temperatures (**Goslin et al., 2012**).

- Continental rifts : in the East African rift (EAR) of Tanzania, an hot mantle rising triggers a deep crustal melting (2-3%) that is enough to initiate strain localization controlled by inherited fabrics and enhanced by lateral compositional and hydration variations (**Tiberi et al., 2019**). Similarly to oceanic ridges, the EAR displays foreshock-aftershocks sequences and swarms (**Albaric et al., 2009, 2014**). Even during the initial stages of continental rifting, slow slip on normal faults is able to promote subsequent dyke intrusion by stress unclamping (**Calais et al., 2008**). In the south Baikal rift, high velocity anomalies in the lower crust evidence mafic and ultramafic dyke intrusions into the ductile lower crust, resulting in an increase in crustal thickness (up to 43 km) compensating thinning of the crust due to rift extension (**Nielsen and Thybo, 2009**).

The way fault zones interact with dyking and the importance of mechanical and rheological heterogeneities in the strain localization process need thus to be better evidenced by **performing a more systematic and precise study of the link between earthquake time-space distribution and rheological properties of the crust**. Although composition, fluid content and geothermal gradients may differ between oceanic and continental rifts, the magmatic and tectonic interplays in continental rifts have the potential to provide new insights in the processes responsible for seismogenesis changes within the crust, owing to the much lower magnitude threshold and to the quality and abundance of seismicity catalogs on land.

The main scientific lock that we expect to lift within the 3 years of the thesis is first to test the ability of the Yield Strength Envelopes (YSE) built with the depth distribution of events (DDE) to actually unravel the rheological properties of the crust. To reach this goal, we rely on the best worldwide catalog of earthquakes recorded in a continental rift (the Baikal Rift), which will serve as a proxy to highlight the parameters able to modify the seismogenic pattern in response to various triggering or pre-conditioning mechanisms favoring localized deformation and earthquake nucleation, such as local high fluid pressure (**Reyners et al., 2007**) or local zones of weakness (i.e., pre-existing structural fabrics) within strong but dominantly viscous crust (**Fagereng, 2013**).

2 - Approche méthodologique et techniques envisagées : (4000 caractères maxi espaces compris)

From the analysis of the times series of events, we aim to extract the transient factors explaining the seismic crises (swarms, aftershocks, foreshocks) and thus the time/space changes of the long-term strength of the crust. Until recently, at sea and on land, the major limitation has been the inaccuracy of the determination of foci depth. We propose to take benefit of the high-quality seismicity catalog of the Baikal rift by performing a systematic and careful analysis of the distribution of events in order to decipher compositional, structural and fluid effects that are disturbing the « background » activity. **The objective of this thesis** is to analyze the links between long-term strength of the crust and DDE, determine the role of deep fluids and of active faults in the space-time changes relative to rheological properties, and launch a comparison with other active rifts (Rhine, East-African, Rio Grande, North China). Lake Baikal seismicity is monitored by dense regional networks. More than 185,000 events are

recorded in 50 years of permanent instrumental observations (**Radziminovich et al., 2013**). Epicenters display well-delineated belts and numerous clustered events. Since 2003, all stations are operated in a digital continuous regime and are equipped with 3-component, 0.5–20 Hz short-period seismometers with sampling rate of 100 Hz (**Radziminovich et al., 2013, 2019**). The main steps of the PhD thesis are :

(1) to map spatial variations of the long-term rheological properties of the Baikal rift: A bibliographic analysis will lead to construct a regional structural model of the Baikal rift crust (heat flow, gravimetric anomalies, seismic experiments, seismic attenuation from analysis of coda waves). A method similar to the one used by **Anikiev et al. (2020)** will be first used, based on a detailed 3D geological and thermal model. Later on, the candidate will build YSEs using a declustered seismic catalog, separating the background seismicity, swarms and aftershocks. We will use artifical intelligence techniques (**Linville et al., 2019**) to detect and isolate quarry blasts (frequent in the Baikal rift) and clean the database (**Radziminovich et al., 2012**). We will define the upper and lower cut-off depth and relocate some favorable earthquake samples using both methods of absolute and relative location using appropriate velocity models. The analysis by interpolated YSE will be similar to the one led in Western Europe by **Cloetingh et al. (2005)**. The 3D-mapping of the results will be made under Python (Bokeh, Matplotlib) and the interpolation using python PyGMS (GFZ procedure);

(2) **to analyze DDE space and time changes in the vicinity of large active faults on the basis of aftershocks and swarms**, in order to determine whether there are systematic local variations from previous results, including the use of relative relocation or probabilistic methods. We thus expect to be able to identify for the first time changes of the seismic-aseismic transition during the earthquake cycle in a continental rift, as reported in San Andreas Fault (**Rolandone et al., 2004**). In the Baikal rift, significant clustered earthquakes like aftershocks of strong earthquakes are located more precisely due to deployment of temporary stations and relocation procedures, so several samples located in different areas and main shocks with different kinematics (normal faulting and strike-slip) will be selected in order to identify possible variations;

(3) **to perform a comparison of Baikal rift seismic behavior regarding steps (1) and (2) with results from other active rifts** (Rhine, East-African, Rio Grande, North China) in order to identify the role of deep fluids (magmatic, dyke injection at the base of the crust for swarms, or specific rheological properties within active fault gouges for foreshocks/aftershocks). This will include the possibility to reprocess available catalogs of these rifts, at least partly, in a way similar to what has been done for the Baikal rift, in order to help the comparisons of results.

3 - Positionnement et environnement scientifique dans le contexte régional, national et international :

Previous studies in continental rifts have shown that at a regional scale, it is indeed possible to link long-term strength of the crust and DDE in a relatively confident way and thus to decipher the complex nature of rheological transitions, provided that background (i.e., « declustered ») seismicity is extracted (**Déverchère et al., 2001** ; **Albaric et al., 2009**). However, the mechanisms responsible for earthquake clustering appear to be highly variable in space and time and prevent from a straightforward interpretation of the DDE. The interest of this work is not limited to continental rifts : the sparse, seldom intraplate seismicity recorded in Brittany will also benefit from this approach, since it is expected that after the analysis of clustered and background seismicity, we can better understand the causal links between the relatively deep seismicity recorded in aftershock sequences like the Mw 4.3, 2002 Hennebont event (**Perrot et al., 2005**) and the variations in rheological properties of the crust (fluids or structural fabrics). There are indeed significant recent results supporting that brittle deformation may occur together with viscous shearing flow in the middle crust. This suggests that observed tremors and slow slip events could result from brittle-viscous deformation in mixed-material shear zones, possibly amplified by local fluctuations in fluid pressure (**Fagereng et al., 2014**). This research may also help to re-assess historical seismicity in slow-rate intraplate settings like in Brittany and Vendée (**Kaub et al., 2021, in press**).

This research is built on a long-term cooperation between the Labs LGO-Brest and Institute of the Earth's Crust in Irkutsk, Russia. The Russian partners are interested in sharing new methodologies in the analysis of seismicity catalogs to improve the conceptual and practical knowledge of their labs and to better extract reliable information from the space-time distribution of events regarding potential risk assessment and rheological constraints. Their

skills in the regional seismicity, seismotectonics of the Baikal Rift System, clustering seismicity (N. Radziminovich) and in seismic wave attenuation (A. Dobrynina) are quite complementary from the French team's ones which will provide inputs in relocation procedure and Artificial Intelligence for data processing (Renouard, 2020; Renouard et al., 2021).

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4 - Contexte scientifique et partenarial : éléments généraux (ERC, CPER, FEDER, Breizhcop …) (4000 caractères maxi espaces compris)

Vous sollicitez un financement ISblue, ou une ARED ISblue :

Précisez le lien du sujet avec les thèmes ISblue

Thème ISblue	**Thème principal**	**Thème secondaire** (si nécessaire)	**Autre** (si nécessaire)
la régulation du climat par l'océan			
les interactions entre la Terre et l'océan	Interactions fluides-magmatisme-tectonique – sismogenèse et rhéologie		
la durabilité des systèmes côtiers			
l'océan vivant et les services écosystémiques			
les systèmes d'observation à long terme		Utilisation catalogue sismicité sur 50 ans	

Expliquez/précisez <u>en quelques lignes</u> dans quelle mesure votre demande correspond à l'un ou plusieurs des critères ISblue ci-dessous :

1- Originalité, impact potentiel du projet (4 lignes maxi)

Le projet SIS-RIFT innove en associant étroitement la sismicité complexe des rifts et les conditions rhéologiques. Dans le rift Baïkal, les données disponibles permettent d'étudier 1/ les déformations qui, au stade plus avancé de l'océanisation, constituent l'héritage structural qui influe sur la tectonique des dorsales océaniques ; et 2/ de disposer d'un analogue pour utiliser la sismicité comme proxy des processus géodynamiques et de la rhéologie des rifts et dorsales.

2- Positionnement international du sujet, cotutelle ou co-encadrement international (4 lignes maxi)

Le LGO et l'Institut de la Croûte Terrestre à Irkoutsk (Russie) sont forts d'expertises complémentaires et d'une collaboration ancienne. Nous tirerons partie de la maturité du réseau sismologique russe pour élaborer conjointement une stratégie d'analyse nouvelle des données sismologiques du Lac Baïkal en associant nos compétences (connaissance sismotectonique, géologique et de l'atténuation des ondes côté russe, apport d'une

méthodologie combinant modélisation géophysique et intelligence artificielle côté français). Le sujet supposera des missions de ~2 mois par an à Irkoutsk pour le doctorant, à soutenir dans le cadre des appels à mobilité internationale de ISblue. Le doctorant bénéficiera ainsi d'un environnement scientifique stimulant et complémentaire de celui de Brest.

3- Effet intégrateur entre unités de recherche et / ou interdisciplinarités (4 lignes maxi)

SIS-RIFT est un projet alliant géophysique, géologie et mécanique, avec une part importante de programmation pour le développement des outils de traitement des données. L'étudiant recruté sera au centre d'un réseau de collaboration faisant intervenir des compétences multidisciplinaires : sismotectonique, sismologie, géologie, modélisation, apprentissage-machine. Une étape importante du travail consistera à préparer une base de données sismologiques filtrée des événements parasites (notamment les nombreux tirs de carrière de la région du Baïkal). Pour cela, un outil spécifique basé sur l'apprentissage machine sera développé en s'appuyant sur l'expertise du département informatique de l'IMT atlantique, l'intelligence artificielle étant un axe majeur d'intérêt en matière de recherche et d'innovation au sein de l'IMT. L'idée serait d'affiner l'approche employée par Renouard (2020) en utilisant un mode hybride supervisé/non-supervisé et en s'appuyant sur l'expertise de l'IMT atlantique.

4- Potentiel d'insertion à un haut niveau dans la communauté académique ou non académique du docteur (4 lignes maxi)

En combinant des techniques largement utilisées à la fois dans le monde académique, dans l'industrie et dans les bureaux d'études, avec une méthodologie innovante incorporant notamment l'intelligence artificielle, l'étudiant développera des compétences qui faciliteront son recrutement futur. Par ailleurs, il interviendra sur plusieurs zones d'études (Baïkal, Afrique de l'Est notamment), ce qui constituera un atout supplémentaire.

Le candidat

Profil souhaité du candidat (spécialité/discipline principale, compétences scientifiques et techniques requises) :

Master 2 ou équivalent dans l'un des champs suivants : géosciences, géophysique, physique. Aptitude à travailler en équipe internationale, solide formation en géophysique/géologie. Des compétences en programmation (Linux, python) seraient un plus ou devront être acquises. La maîtrise du français en début de thèse n'est pas exigée. Bon niveau en anglais (lu, écrit, parlé) nécessaire.

МИНОБРНАУКИ РОССИИ

ФЕДЕРАЛЬНОЕ ГОСУДАРСТВЕННОЕ БЮДЖЕТНОЕ УЧРЕЖДЕНИЕ НАУКИ
ИНСТИТУТ ЗЕМНОЙ КОРЫ
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На №_____от_____

SIS-RIFT Project

Institute of the Earth's crust is ready to cooperate on the topic and to facilitate the access to the data set necessary to perform the work.

The data obtained from the Institute of the Earth's Crust may be used for non-commercial purposes and may not be transferred to third parties.

Secretary of scientific affairs,
PhD

Anna A. Dobrynina