SAGER Initiative and Marine Proposals for 2007-2008

SUMMARY

Satish Singh, IPG Paris
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1. EXECUTIVE SUMMARY

SAGER is a research initiate to study the Sumatran mega-thrust earthquakes and was initially set-up by the French marine geosciences community soon after the Great Sumatra Andaman earthquake of 26th December 2004. The main scientific objective is to understand how the surface deformation due to 26th December event is linked with source at depth using an integrated, systematic approach. The first French experiment, Sumatra-Aftershocks, took place in July-August 2005, where passive OBS, swath bathymetry, sediment cores, heat flow, and 3.5 KHz data were acquired. The second cruise, a deep seismic reflection survey, is planned to take place in April-May 2006 on *Geco Topaz* of WesternGeco, and will be followed by a deep seismic refraction survey in July-August 2006. Here, we re-submit three proposals that were submitted last year to acquire high-resolution seismic reflection, heat flow and SAR and ROV data. In this summary, I will first summarise the SAGER initiative, then its links with international research initiatives, and finally answer the Commissions questions and concerns. UK and Germany have developed very ambitious marine research programmes, and France having taken the lead and having the best technical capacity (high resolution seismic, SAR, ROV and heat flow) and scientific expertise should make a long-term commitment to the SAGER Initiative. I would be happy present the overall project to the commission and answer questions and concerns. I also include letters of support, MOU and email from WesternGeco.

2. SAGER

Motivation: The tsunami from the Great Sumatra earthquake of 26th December, 2004 has killed over 280,000 people in South-East Asia and has caused unaccountable loss of properties. The main earthquake (Mw=9.3), is the largest earthquake that occurred since the establishment of the plate tectonics theory - the main discovery in Earth Sciences - and the second largest event since the advent of instrumental seismology. This mega-thrust earthquake broke the plate boundary over 1200 km x 150 km and down to about 50 km depth along the Sumatra subduction arc. It was followed by hundreds of lesser though still large magnitude aftershocks (some of which reached magnitudes > 7). This earthquake will be and is already being studied by the international scientific community using state-of-the-art techniques, and the results will provide a reference for any future event of this type. This is a unique opportunity to make a major breakthrough in the understanding of the processes responsible for mega-thrust earthquakes. More specifically, we hope to identify and measure seafloor ruptures and deformations, and to image the seismogenic zone at depth. Subduction earthquakes represent 90% of seismic energy released by the Earth and tend to produce disastrous tsunami waves. Therefore, it would be vital to study this earthquake and associated seismic ruptures in detail, in order to mitigate for any future large earthquake further north along the India-Eurasia boundary (Himalaya) and along the Australia-Eurasia (Sumatra) boundary. An integrated approach is necessary to conduct this study.

Historical development: Soon after the 26th December event, the French marine geosciences community mobilised to study this event and its causes. A deployment of OBS to record aftershocks was proposed around the epicentre in January 2005, which led to the creation of Sumatra-Aftershocks proposal. In the meantime, we requested Schlumberger-WesternGeco to

acquire a deep seismic reflection survey, which they kindly agreed to shoot (two long lines) using their best equipment. IFREMER extended the call for proposals from 15th January to 15th March 2005. Four proposals were submitted: Sumatra-OBS, Sumatra-SHR-SAR, Sumatra-ROV, Sumatra-Flux, and Sumatra-Bio. Only Sumatra-OBS was given the first priority.

INSU funded €6,000 to initiate the Sumatra project. In order to enter in the Indian waters, a meeting was organised in New Delhi in March 2005 by the Indo-French Centre for Advancement of Research. The meeting was a success, but as we have seen in the recent past, Indian government has decided not share data with any other country. We submitted a proposal to IPGP BQR and received €60,000. A couple of visits (May-June, 2005) were made to Indonesia (Singh, Diament, Sibuet) in order to develop collaboration and Memorandum of Understanding was signed between LIPI and IPGP and BPPT and IPEV. In June 2005 a proposal was submitted to the Delegation Inter-gouvernementale Post-Tsunami (*DIPT*) to fund Indonesian partners, and we received €400,000 in July for three years, of which €150,000 is to rent the Indonesian R/V *Baruna Jaya* to do bathymetry and seismic in the territorial waters. We also submitted an *ANR* proposal and have received €600,000 to fund the approved SAGER projects. We have been advised to re-submit a proposal to ANR in 2006 for the three cruises that are being submitted here.

The Sumatra-Aftershocks experiment was very successful. Four abstracts were presented at AGU Fall Meeting in San Francisco, and a paper was published in EOS on the 30th November 2005. We had visits of three Indonesian partners to analyse cores and to develop future projects.

The WesternGeco experiment is programmed to take place either in April or in May as the *Geco Topaz* traverses epicentral region (see Carl Trawell's email). An organisational meeting is planned to take place at Gatwick at the end of January. The Sumatra-OBS cruise is programmed to take place on *Marion Dufresne* in July-August 2006. The *Baruna Jaya VIII* cruise was programmed to take place in February 2006 but has been delayed due to logistic reasons, and we are in negotiation with LIPI for re-scheduling the cruise.

Scientific Objectives: The 26th December earthquake seems to have initiated near Banda Aceh at about 30-40 km depth and propagated to about 20 km depth at about 500 km from Nicobar and continued to Andaman. The total volume of the Earth involved during the earthquake is about 1200 km x 150 km x 40 km. The subsequent Nias earthquake of March 28, 2005, broke about 200 km of the plate boundary south of Banda Aceh. Therefore, one must study the whole region from seafloor down to 50 km depth, from a few meters scale on the surface to tens of kilometres scale. Here, we will focus our study offshore western Sumatra, where the maximum displacement occurred during the 26th December earthquake.

The questions we wish to address are:
- How does such a large earthquake occur and why?
- How are the surface features and processes linked to the source region down to 50 km depth?
- How does the deformation (at the surface and in the sub-surface) vary along the first 400 km of the rupture zone?
- Use this knowledge for understanding the processes further north in the Himalayan region and south in Sumatra, and Antilles, where future large earthquakes are likely to occur.

We will address these scientific objectives using a series of land and marine observations. For land study, we will cooperate with Professor Kerry Sieh at Caltech, British colleagues (Oxford, Cambridge) and Indonesian colleagues. We have proposed a set of seven marine experiments, that started in July 2005 to acquire surface bathymetry, long gravity cores,

gravity, magnetic, deep seismic reflection and refraction, high-resolution seismic reflection, heat flow, deep-towed SAR, and remotely operated submersible. We recorded aftershocks and monitored seismicity using ocean bottom seismometers in order to locate the active zone. Below is a brief description of the marine experiments**:**

(a) Funded or approved experiments

i) Sumatra-Aftershocks: The Sumatra –Aftershocks experiment took place from July 15 to August 8, 2005 under the leadership of Jean-Claude Sibuet of IFREMER. Twenty OBS were deployed to record aftershocks for about ten days. Over 2000 events were recorded during this period and the data are presently being analysed at IFREMER by a post-doc. In this short cruise, we were able to acquire bathymetry and imagery over 380 km x 80 km area (Figure 1) covering area from the subduction front in the south up to the Sumatra fault in the north, ten sediment cores and eight heat flow measurements in the box. High heat flow was observed between the front and West Andaman fault, suggestive of fluid movements and tectonic activities. Piezometer measurements made on along one of the slopes that was identified as a recent slope failure, suggest that this failure was not due to 26th December event, but material was close to the liquefaction state. It was a very successful experiment. Four papers were presented at AGU in December and a paper appeared in EOS on November 30, 2005.

ii) ***Sumtra-Deep seismic reflection survey (Schlumberger/WesternGeco):*** The earthquake initiated at about 30-40 km below the seafloor near the epicentre and propagated northward to about 20 km near Nicobar Islands (Ammon *et al.*, Science, May 20, 2005). The maximum displacement was near the epicentre (16 m) and near Nicobar Islands. In order to image the source region of Sumatra earthquake, and hence obtain information about its nature, we need to get an image down to 50 km depth. However, existing methods of seismic imaging using academic vessels utilise 4-6 km long streamers and normal airgun sources, which provide seismic images down to 10-15 km depth at most. There are two main problems encountered when using seismic reflection method for deep imaging: first, the presence of water bottom multiples hampers imaging of the structures below the multiples, second the penetration of seismic energy at such large depths is poor. The multiples could be removed using a long streamer - say 12 km, while a large low frequency focused source will allow deep penetration of energy.

We requested Schlumberger-WesternGeco to provide their vessels to shoot three lines, and they kindly agreed to allocate 10 days of *Geco-Topaz*, a vessel equipped with Q-Marine system, carrying 12 km streamer and a cluster of 36 airguns providing a large (10000 cu.in.) source. With this time, we shall be able to shoot two seismic lines (Figure 1). Wide-angle seismics will be acquired along the same lines during the OBS experiment.

iii) ***Sumatra-OBS tomography:*** The image obtained using the above deep seismic reflection survey will be in two-way travel time. In order to interpret these results in depth, we require velocity information, which will be obtained through this tomography experiment. Our results will allow us:

1. to obtain a depth image of the subduction plate and of the seismogenic contact zone from the coincident profile of reflection seismics to be acquired by the Schlumberger-WesternGeco part of the project;
2. to identify potential subducted topographical structures, of large dimension, which area likely to lie at depth on the subduction contact zone;
3. to obtain the velocity structure of the subducting oceanic lithosphere; in particular the possibility to image the possible alteration of the lithoshperic mantle under the effect of deep fluid flow (serpentinisation);

4. to obtain the velocity structure of the overlapping lithosphere in its crustal deep part, and the corner of the lithospheric mantle under the fore-arc and arc, in relation with the possible alterations resulting from the dehydration of subducting crust.

Sixty OBS will be deployed along line CD and 40 of them along line AB, at 7.5km interval. These lines will be extended by 50km on either side of the reflection lines in order to have a co-incident velocity information along the whole reflection lines. We will use a large low frequency (8000 cu. in.) source at 150 s intervals to record energy up to 300 km distance (50 km depth). A joint reflection-refraction tomography will be performed to obtain velocity structure. Waveform modelling will allow us to refine the model. A full waveform might be applied to obtain detailed P and S-wave velocity structure of the sub-surface if the data quality is good.

This experiment is programmed on R/V *Marion Dufresne* in June-July 2006.

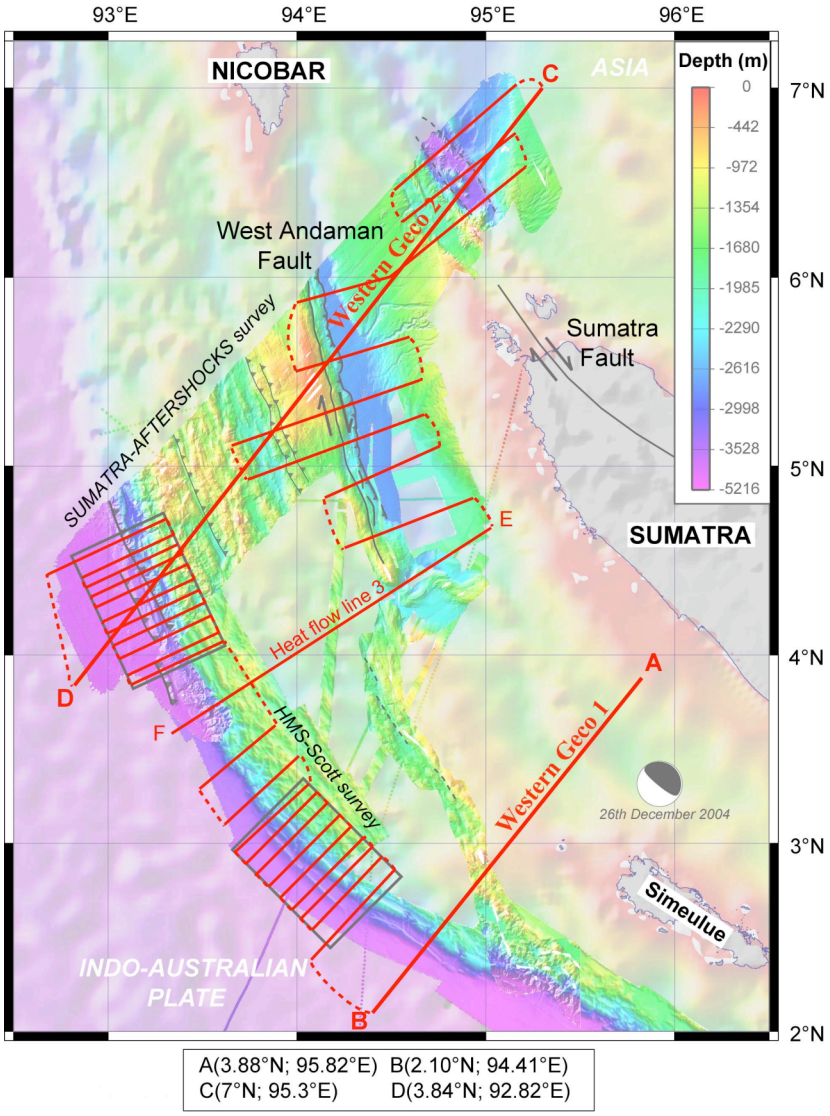

Figure 1: HMS Scott and R/V Marion Dufresne bathymetry merged with bathymetry derived from satellite altimetry. AB and CD are the regional deep seismic reflection and refractions lines. Short lines are the SHR lines. Line EF is SHR. Heat flow will be measured along all the regional lines (AB, CD, EF). Heat flow along line AB will be acquired in collaboration the British colleagues. The two box is for SAR and ROV surveys.

iv) Baruna Jaya VIII Survey: The Delegation Inter-gouvernementale Post-Tsunami approved €150,000 to fund an Indonesian vessel in order to do bathymetry in the territorial waters. The LIPI research vessel, *Baruna Jaya VIII* has EM 1002 and seismic system (700 m long streamer and four airguns). During the Padang meeting with LIPI and BPPT (August 2005), it was agreed that we should acquire bathymetry and seismic data around Simeulue in order to image the boundary between December 2004 and March 2005 events (Mw=8.7). Singh *et al* (2005) suggest that the West-Andaman fault observed on the Marion Dufresne bathymetric data may continue near Simeulue and join the subduction front and might be a re-activated lithospheric boundary separating the two events. Sieh *et al* (a paper under review in Science, Figure 2) show that there was uplift in the west and subsidence in the east on Simeulue Island during the December event whereas the reverse happened during the March event. They find that the minima of the uplift (saddle) are along a line whose strike is similar to the West Andaman fault. Hence there might be some link between the West Andaman fault and Simeulue saddle. The existing seismic reflection data around Simeulue show two disconnected strike-slip faults NW of Simeulue but they do not continue north of Simeulue. The objective of the *BJ VIII* cruise would be to image this boundary using seismic and bathymetric data. The cruise was planned to take place in January-February, 2006 but has been postponed due to logistic reasons. We are in contact with LIPI and shall do the survey at earliest opportunity.

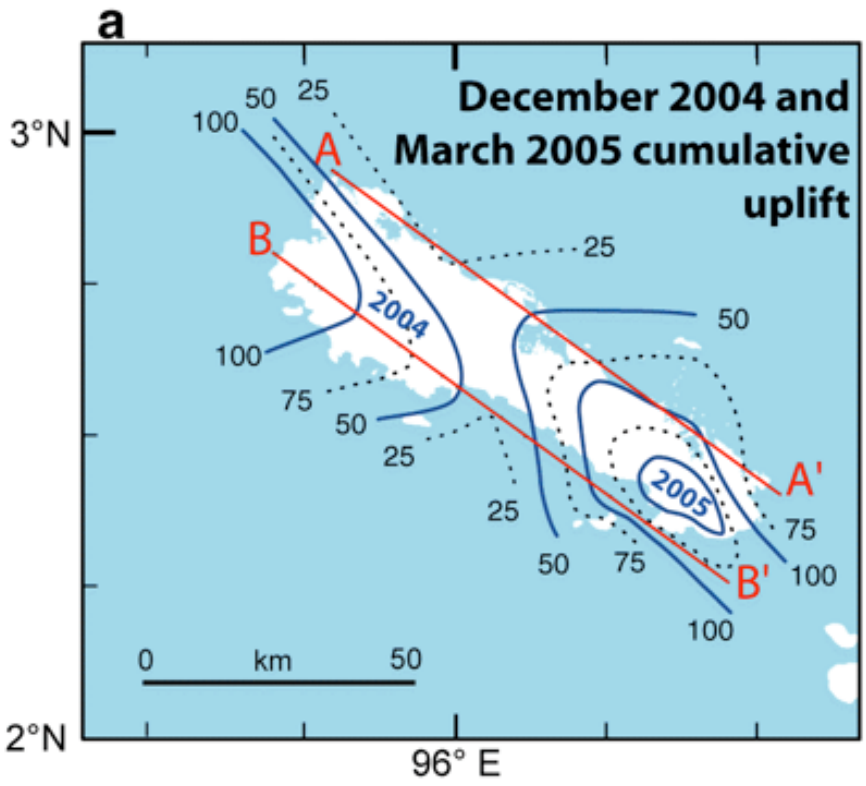

Figure 2: Cumulative uplift during the December 2004 and March 2005 earthquakes (Sieh et al, paper under review in *Science*: Not for duplication). Note that the strike of the minima is not NS, but is N40W, similar to West Andaman Fault (Figure 1).

(b) Marine Proposals for 2007-2008:

In the last one year, the French science community has shown that it is capable of launching an ambitious research program with our British colleagues and other international partners. Here we re-submit three proposals (high-resolution seismic, heat flow and SAR and ROV) for 2007-2008 asking to make use the best technology available in Europe. There has been some

changes in our strategy. Firstly, we have re-oriented our study in Indonesian waters focused around the Marion Dufresne bathymetric data. Secondly, we have separated SHR from SAR and have combined SAR with ROV. This is because a *Suroit*-type vessel could be used for SHR and heat flow but it is not capable of towing SAR in deep water (4500 m). The new research vessel, *Pourquoi pas*?, is designed to host two submersibles, such as SAR and ROV, and therefore would be ideal for a combined SAR and ROV survey.

v) Sumatra-SHR: The deep seismic reflection data that is planned to be acquired by WesternGeco could be made only along a few 2D lines because the costs of this survey is very high (e.g. $200,000/day for Q-Marine system). In order to relate near surface information with the deep structure, we require coincident high-resolution seismic lines. Furthermore, to extend 2D information at depth provided by this survey with 3D information along the major structures (front, strike-slip faults) observed on Marion Dufresne data, we need to acquire a series of short high-resolution seismic lines along these structures. Indeed, high-resolution seismic reflection data provide detailed information about active faults down to 1-2 km depth, which is extremely important to understand the geodynamics, and could be used as an interface between surface geology and deep seismic studies described above. Furthermore, high-resolution seismic reflection images are fundamental for SAR and ROV surveys, and also to correlate with the long cores that were collected last summer. We will also be acquiring 3.5 kHz data that provide resolution on the scale of tens of centimetres.

Our high-resolution seismic studies (near-seafloor studies) are focused on three major structures: (1) subduction front, where we believe the maximum deformation is likely to take place, (2) West Andaman fault, where strike-slip motion is partitioned with thrust deformation, and (3) offshore continuation of Sumatra fault and the deep pull-apart basin along it (Figure 1). All these structures are associated with the subduction process and images across them would allow us choose appropriate site for SAR and ROV surveys. A total of 3800 km of high-resolution seismic reflection profiles will be acquired (Figure 2). The main objectives of this survey are to

1. Image the sub-surface (1-2 km below the seafloor) expression of the active fault system in detail and link them with thrust fault at depth in the seismogenic zone
2. Study the morphological variations (segmentation observed on bathymetry data) along the subduction front that might be related to the change in obliquity of the convergence, and understand the partitioning of motion
3. Image the sub-surface expression of active dextral strike-slip West-Andaman and Sumatra faults, which have accumulated stress and are likely to produce large earthquakes in the near future

These lines will be complemented by the British colleagues further east.

vi) Sumatra-Flux: Seismic reflection and OBS data will provide information about the structure of the seismogenic zone, but in order to understand the earthquake failure processes, we require information about the thermal and rheological state of the sub-surface. This will be estimated using heat flow measurements. The main point is to understand why the width of the seismogenic zone varies along the Sumatra subduction arc. We will acquire 4 lines perpendicular to the trench, in areas that either broke during the December earthquake or that have not broken yet (Figure 1 and see Sumatra-Flux proposal).

200-250 measurements will be made using IPG Paris heat flow instrument. Our method is however restricted to deep water (> 1000 m), where annual variations of the seafloor temperature are small. One line will traverse the Marion Dufresne box from the trench to the Andaman Sea providing information about the thermal state of the whole system. This line will be a unique line along which deep seismic data, SHR, and heat flow data would have been acquired, that cuts across the subduction front, strike-slip faults and volcanic arc.

This study will allow us to constrain and model the thermal regime at depth, determine the rheological state associated with the seismogenic zone, and better understand why its width varies along the subduction zone. Similar studies on Cascadia and Japan active margins suggest that the lower terminations of seismogenic zones are associated with temperatures less than 350°C (i.e. above the Moho in the fore-arc), which does not seem to be case for Sumatra where the seismogenic zone seems to extend below the Moho in the fore-arc. Therefore, these studies will be fundamental for understanding the rupture mechanism at subduction zones.

vii) Sumatra-SAR-ROV: Seismic modeling of the 26th December rupture and tsunami suggest that there should several meters of displacement of the surface (Ammon et al, Science, 2005). Initial results from the Japanese survey (Akari et al, 2005,AGU) suggest that the aftershocks continue up to the surface near the front (20 to 30 km from the front). The bathymetry data shows that the seafloor topography changes from 4.5 km to 1.0 km within 30 km of the front. Based on these results, there was consensus at the last AGU meeting that the rupture came to the surface within the first 20-25 km of the front. The very limited ROV dives (Japanese and US) show features that might be related to the 26th event, but it has not been possible to identify THE rupture or THE set of ruptures that were produced during this earthquake. Here we propose to carry out a systematic SAR survey followed by ROV survey to locate the rupture zone, which would be fundamental to understand how the surface deformation takes place during mega-thrust earthquakes and also for tsunami modeling. Based on bathymetry data we have chosen two areas, where the maximum vertical displacement is expected. The British colleagues will be doing TOBI survey (similar to SAR) at the third area that we had identified, and if the TOBI results are promising, i.e. they show the possible presence of the 26th December rupture, we might do ROV survey in that box. In the coming months, we will be analyzing bathymetry, imagery and 3.5 KHz data, along with the high-resolution seismic data that we propose to acquire, we should be able to pinpoint the precise location for SAR and ROV surveys. France is the only country in Europe that has both technical capability and scientific expertise to use the SAR and ROV tools to locate, observed and quantify the 26th December rupture on the seafloor.

3. INTERNATIONAL SCENARIO

There has been significant development over the last one year. Below I will discuss these developments in the context of our proposal.

Indonesian-French Collaboration: France has had a long history of collaboration with Indonesia between 1980 and 2002 on earthquake and volcanic research in Java and Sumatra; many Indonesian earth scientists received training in France, who have taken senior positions in Indonesia. An Indonesian-French meeting was organised by LIPI (Indonesian CNRS) on May 17-18 in Bandung, with officials from LIPI, ITB, BPPT, PPPG, UNPAD, BRKP-OKP, GRDC and UI. A MOU (memorandum of understanding) was signed between IPG Paris (French Coordinator) and LIPI (Indonesian Coordinator) in order to develop a common project. A second French visit was made by IFREMER in June, where a MOU between IPEV and BPPT was signed to implement the "Aftershocks" cruise. A proposal was submitted to Délégation Inter-gouvernementale Post-Tsunami (DIPT) to fund Indonesian scientists to participate in the joint programme, and to rent Indonesian research vessel to acquire data in the territorial waters. We received €400,000 for this project. Six scientists from Indonesia participated in the Sumatra-Aftershocks survey. Two Indonesian scientists visited France in December to analyse sediment cores from the Sumatra-Aftershocks cruise. A senior scientist from LIPI visited France in December to coordinate Indonesian-French research program. From DIPT, we have funds to recruit two Indonesian Ph.D. students in France and many short and long visits for Indonesian scientists. Our Indonesian colleagues have been very efficient in getting permits and finding scientists to join the Indonesian-French research program.

Indian-French Collaboration: In order to carry out a marine survey, one requires permission to enter the exclusive economic zone waters. India does not allowed any foreign vessels to enter the Indian waters (whereas 75% of the rupture zone lies in Indian waters). A Indo-French meeting was organised by Indo-French Centre on March 24-25 in New Delhi, which was attended by senior Indian Government officials (the Secretary of the Department of Sciences and Technology and the Secretary of Department of Ocean Development in India) and IFREMER, IPGP, ENS, Ministry of Research, INSU in France. Indian colleagues agreed to provide all the support possible to make this project successful (see the minutes of the meeting). An Indian scientist participated in the Marion Dufresne cruise in July 2005 and two may participate in Sumatra-OBS cruise. However, the policy of the Indian government has become rather hard (see some recent publications in media and Nature), even though the senior government officials do not fully agree with the government policy (Nature, 2005). Under the present circumstances, we remain open to Indian participation in our cruises, but have oriented our project in Indonesian waters. India may commission an extensive marine survey in the Indian water, and it is very likely that we would be invited to participate in some of the cruises and share the results (Krishna, personal communication).

British NERC Consortium project: The British were the first one to send their vessel, *HMS Scott*, to do bathymetric survey, and were kind enough to show their results to us in March 2005 and joined the SAGER Initiative. In our collaboration, they submitted a Consortium proposal to NERC using the similar ideas (cruises) proposed within the SAGER program but focused on the earthquake barrier and fault segmentation problems. They propose to study the segment boundary of the two mega-thrust earthquakes (December 2004 and March 2005, Box SB1, Figure 3) and eastern boundary of March 2005 and future earthquakes (Box SB2).

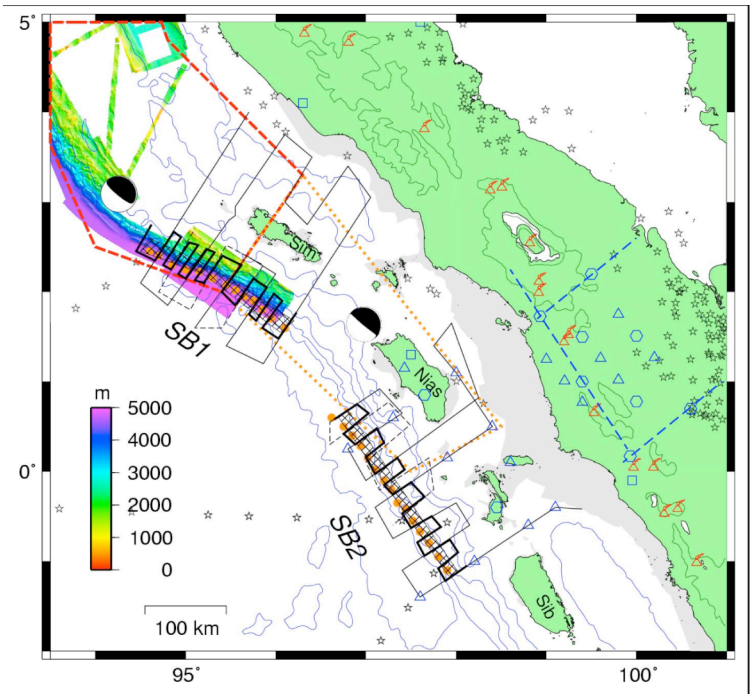

Figure 3: The British survey area. SB1 is at the boundary of December and March event and SB is between March and future earthquakes. Long lines are reflection/refraction lines and short lines (dark black) are high-resolution seismic lines. TOBI survey will be carried out around high-resolution seismic lines. Blue triangles are for passive seismic study. BBOBS will be deployed in SB2 box (do not copy without the British colleagues approval).

They plan to use conventional seismic reflection method (3 km streamer) and record the shot on an array of 3D OBS for 3D tomography. They will acquire high-resolution seismic, TOBI, heat flow, and passive seismology data. We are formally involved in the British proposal (Tapponnier, Lucazeau, Singh) with significant French contribution. Our seismic line AB would provide initial information for their 3D tomography study in SB1 box. The heat flow measurement along line AB is funded by the British partners and would be an integral part of our heat flow study. There will be another heat flow line east of Simeulue funded by the British partners. In total, we shall have six heat-flow lines (4 French and 2 British). A total of 47 OBS (27 British and 20 French) will be deployed in the SB1 for 3D tomography and similar number in SB2. Passive BBOBS (3 French and 7 British) and 20 broadband land seismometers will be deployed in SB 2 box for six months. There is a seismic gap within the SB2 box and major earthquake may occur in the coming future (Sieh, personal communication). Padang, the main city in western Sumatra with a population of over a million, has had tsunami in 1797 and 1833, and is facing tsunami and earthquake risk. High-resolution seismic data acquired in the east by the British colleagues will complement our high-resolution study in the west, and will provide coverage from the India-Indonesia border to Siberut Island. They will also acquire TOBI data in the two boxes near the subduction front, which will complement SAR survey. They have agreed to provide the data for any eventual French ROV survey.

For these surveys, they have been funded 93 days of ship time in 2007-2008 and about £2,000,000 for the experiments, three post-doctoral fellows and two Ph.D. students, and other expenses. This significant funding from NERC (two proposals funded out of 20) clearly demonstrates the scientific merit of the SAGER Initiative. This is an excellent opportunity for France to participate in an ambitious research program with our British partner and share the vessels for the French and British led marine surveys in Sumatra.

German BGR Initiative: The German government has funded €45,000,000 for tsunami warning system in Indonesia and has commissioned several marine cruises of over five months of ship time. The first cruise was in October-November 2005 on R/V Sonne, where they acquired bathymetry, gravity, magnetic data between Nias and Siberut. They have also deployed 25 OBS around Simeulue to record aftershocks. The second cruise is planned from January 20 to March 20, 2006, where they will acquire conventional seismic reflection data (Figure 4), two refraction lines along with gravity, magnetic and bathymetry. The third cruise is planned to take place in August-October 2006 further east of Siberut. We are in close contact with the German colleagues and are coordinating the location of lines and survey area with them. A workshop is planned in May 2006 in Hanover to discuss the formal coordination of all the research initiatives. Their bathymetry data is mainly east of Simeulue and complements the British and French bathymetry.

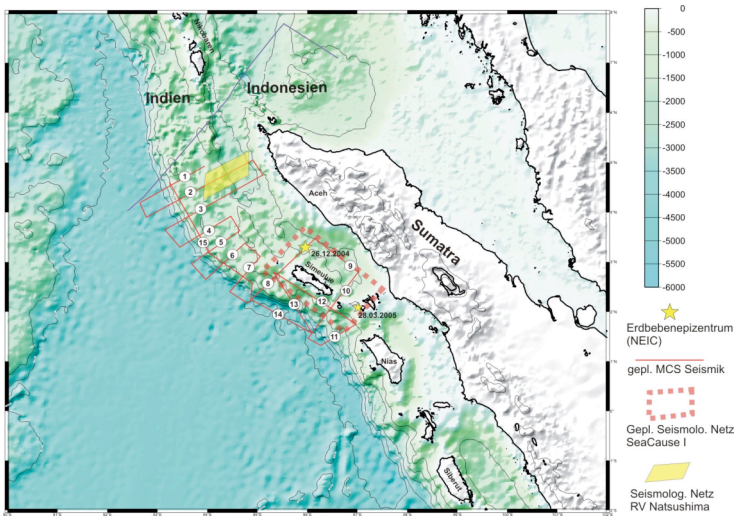

Figure 4: German seismic survey area. 25 OBS have been deployed in the box (dotted red) around Simeulue. The reflection lines are long red lines. OBS lines will be on the two sides of Simeulue (in the Box).

Japanese JAMSTEC Initiative: JAMSTEC carried out a two leg marine survey (Feb 14 to March 26) using R/V Natsushima acquiring bathymetry data (Figure 5). Bathymetry data overlaps to a large extent with HMS Scott and R/V Marion Dufresne surveys. The vessel was capable of acquiring data in water depth less than 3000 m. Eight dives of ROV Hyper-Dolphin were made in the frontal area (water depth 3000 to 2000 m) and along West Andaman fault. The results from the frontal area shows rupture 4 m wide 2 m deep and 1 km long, suggesting shaking due to the 26th December event, but it was not possible to locate large rupture as expected from the 26th December event. One should have an extensive high quality high-resolution seismic and SAR data prior to dives as proposed in the SAGER Program. The dives on the West Andaman fault suggest that the fault is active but it did not move during the 26th December event, and hence it must have accumulated stress due the 26th December event as suggested by Singh *et al* (2005). The aftershocks data suggest the earthquake activities continue up to 20-30 km from front and there might be a thrust coming to the surface (Araki *et al*, AGU, 2005) (within our SAR and ROV box). Japan is in the process of setting up their research program, and they should inform the community about it in May during the workshop in Hanover.

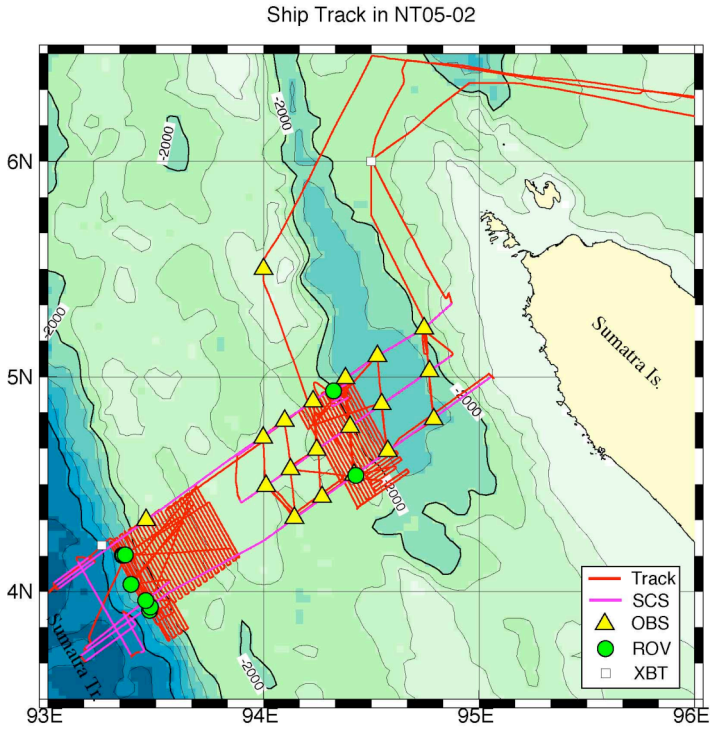

Figure 5 a: The Japanese survey area. The triangles are the OBS locations and green circles are the ROV dive locations. (From Soh et al., 2005, Cruise Report)

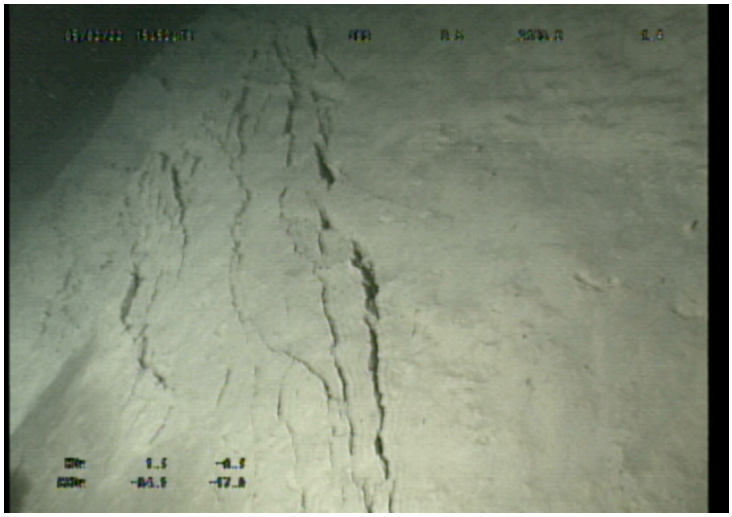

Figure 5b: The photograph of the seafloor at 2185m water depth near the front showing a fresh cracks that must have been formed shaking during the 26th December earthquake (Soh et al, 2005, Cruise Report).

US Initiatives: In May 2005, a US team conducted single channel high-resolution seismic survey and ROV dives at seven locations (Figure 6). Again given the limited time and the nature of the survey, the group was not able to do systematic study. They found some recent faulting and folding near the 'Ditch' site that they attribute to be due to the 26th December event (Figure 7). Their conclusions were very similar to the Japanese dives (Moran et al, AGU, 2005). Single-channel high-resolution data show some landward verging folds in the basin. Based on very limited seismic lines Mosher et al (AGU, 2005) (Figure 5) state that the most significant surface displacement resulting from the Great Sumatra earthquake occurred at the toe thrust/leading edge of the accretionary prism, in 4500 m water depth. We believe that the deformation comes to the surface either at the first steep slope and or at the second, and requires a thorough investigation.

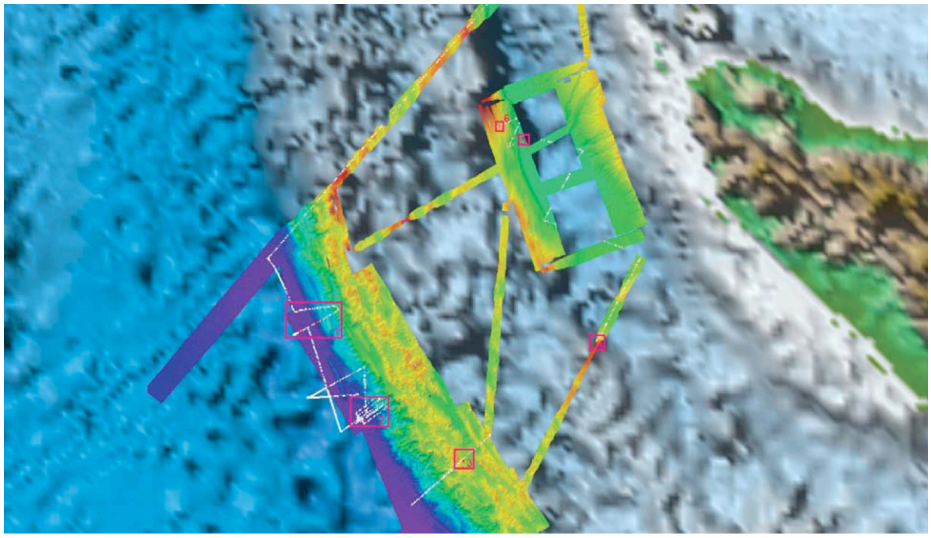

Figure 6: The US survey sites over the HMS Scott bathymetry. White lines are single channel high-resolution seismic reflection lines and the red boxes are ROV dives area (SEATOS Cruise report) (Not for reproduction).

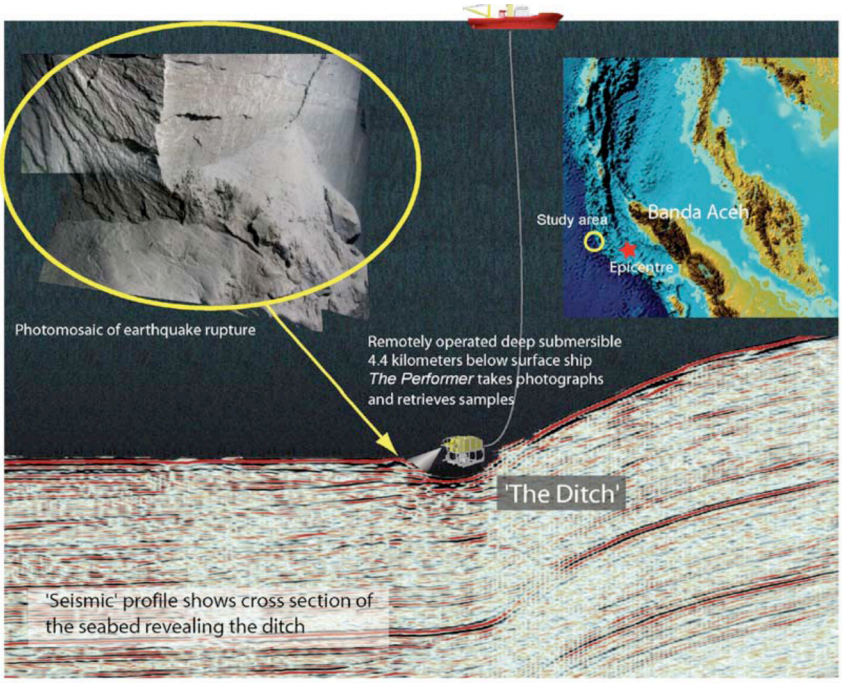

Figure 7: High-resolution seismic reflection data and ROV photograph at the 'Ditch' observed on the HMS Scott and Marion Dufresne data. The possible location the surface rupture (not for reproduction).

A cruise is funded by the NSF to acquire sediment cores in channels in order to determine the paleo-seismic events (Chris Goldfinger), and we are in close contact with Chris for interpretation of their results. There does not seem to be any other US research program in Sumatra.

3. RESPONSE TO THE COMMENTS:

1. **Coordination with other organizations working in the area:** Three countries (France, UK and Germany) have extensive research programs offshore Sumatra, which have been discussed above. There is a close coordination among all the three partners as stated above (see the letters), in particular with the British partner. It should be noted that France has technical advantage in terms having secured Schlumberger Q-Marine survey, and has excellent high-resolution seismic system, SAR, ROV and heat flow equipments, and expertise and experience to use these system for active tectonics problems.
2. **Integrated approach:** Our approach is indeed integrated and systematic; from large-scale features to fine scale features, and from deep to surface. We started with bathymetry survey (Marion Dufresne and HMS Scott) that covered the area from the subduction front in the south to the Sumatran fault in the north, covering all the major structures. We have also acquired passive seismic data that should provide insight into recent seismic activity, sediment cores and preliminary heat flow data. Deep seismic reflection and refraction data should provide the structure down to 30-40 km depth, which will be complemented by heat flow data along the whole subduction system. High-resolution survey (SHR) would be the next scale that should allow to link up the deep structure with shallow structures. It is focused on three major targets (short lines) of the subduction system and will help us to refine targets for the SAR survey, which will in turn help us to position ROV dives. The experience from the US and Japan dives suggests that one should focus on one area using all the relevant data (SHR, bathymetry) rather than disperse all over the place. We have already processed the data in 40 m x 40 m (instead of 200 m x 200m) and are in the process of analyzing 3.5 kHz data and imagery data, which along with SHR should allow to further refine our SAR and ROV survey areas.

3. **Deformation due to landslides and/or tectonics:** From the US ROV dives and analysis of Marion Dufresne and HMS Scott data it is now confirmed that the role of the landslides on tsunami was very minor, and that the tsunami was mainly produced by the tectonic movement. Therefore, this point has been resolved.
4. **Surface rupture due 26th December event:** The localization of the rupture on the seafloor is one of the most important questions that remains to be solved and the main objective of the SHR, SAR and ROV surveys. The systematic approach proposed in SAGER is the only way to address this question. Once the rupture is located, samples from the rupture zone using Pb and C dating techniques will allow the precise dating of the events in a manner used in paleo-seismology on land (see ROV Proposal for detail).
5. **Multidisciplinary French team:** I am very surprised by this remark, and have two points to make: (1) The team is in fact multi-disciplinary, from theoretical seismologists, modelers, tectonics, seismics people to sedimentologists, and such a remark is not justified. (2) It is obvious from the International Scenario that the SAGER is an international effort, we have international partners, and therefore, such a remark should not be made by a National Commission, particularly as we are a major partner in the British project.
6. **Publication of Marmara and Shalimar results:** Results from MarmaraScarps were published in GGG in 2005. A 269 pages Ph.D. thesis on SeisMarmara and Shalimar data was successfully defended on December 19, 2005, with felicitation des jury, by Hélène Carton at IPG Paris, and the second thesis on Shalimar data (Ata Elias) will be defended on February 17, 2006 at IPG Paris. When students are involved in data analyses, which are enormous tasks for seismic data, a compromise has to be made between writing the thesis and publishing papers in open journals. At least four papers are likely to be published from Hélène's thesis and two from Ata's thesis in the coming year. In the case of SisMomar survey, we are fortunate to have three CNRS scientists working on the project and have Ph.D. students working on data analysis, who started before the cruise. Four abstracts were presented at AGU and a paper is under preparation for submission to *Nature*. We are also fortunate for the SAGER project. Four abstracts were presented at the last AGU, and a paper has already been published in *EOS*. A dedicated post-doc is analyzing OBS data at IFREMER, we have a post-doc funding from ANR, and Hélène Carton is working on the project along with a Master student. As noted above, we have funding for two Indonesian students, and we plan to recruit them to start in October 2006. Human resource is vital for the analyses of marine data, which is well in place for the SAGER initiative.
7. **Why Sumatra?** This point has become irrelevant as the Commission first approved Sumatra-Aftershocks and then supported Sumatra-OBS cruise. ANR has set up the Programme Catastraphes Telluriques et Tsunami and has funded €600,000 in 2005 and has recommended us to apply again in 2006.

Other points in the proposals: Pasisar has been removed. The references to the French scientists work have been included, wherever appropriate.

Email of Carl Trowell, Vice-President, Sales and Marketing, WesternGeco

X-Ids: 166
Date: Fri, 16 Dec 2005 11:53:55 +0000
From: Carl Trowell <ctrowell@gatwick.oilfield.slb.com>
Subject: Re: Sumatra
X-Sender: ctrowell@gb0135-pop3.mail.slb.com
To: Satish SINGH <singh@ipgp.jussieu.fr>
MIME-version: 1.0
Content-transfer-encoding: 7BIT
X-Greylist: IP, sender and recipient auto-whitelisted, not delayed by milter-greylist-1.7.2 (shiva.jussieu.fr [134.157.0.166]); Fri, 16 Dec 2005 12:54:04 +0100 (CET)
X-Antivirus: scanned by sophie at shiva.jussieu.fr
X-Miltered: at shiva.jussieu.fr with ID 43A2AADB.000 by Joe's j-chkmail (http://j-chkmail.ensmp.fr)!

Satish

I tried calling, but got an answer machine and no capacity to leave a message.
At present it looks like the Topaz may be in a position to acquire the
survey in either early April or mid may as it transits respectively back
into and then out of Indonesia.

BR
Carl

University of Southampton

School of Ocean & Earth Science

Professor A P Roberts, Head of School

National Oceanography Centre, Southampton
University of Southampton Waterfront Campus
European Way Southampton SO14 3ZH United Kingdom
Tel +44 (0)23 8059 2011 Fax +44 (0)23 8059 3059
Fax +44 (0)23 8059 3052 Email soes@noc.soton.ac.uk

January 11, 20(

Dear Satish,

We would like to express our very strong support for your multiple proposals to be submitted for study of the offshore Sumatran subduction zone. The proposed work will be very valuable for understanding the structure and deformation of the subduction zone and to better understand future hazards from this subduction zone and others. The varied elements of the proposals make it a strong multidisciplinary effort with many international partners.

We are all aware that a coordinated international approach is essential for study of this large region which has lacked modern marine datasets until this time and will maximise scientific knowledge gained. We are therefore keen to collaborate closely with our international partners.

As you know, we have recently had a consortium proposal funded through the Natural Environment Research Council (NERC) here in the UK, which will fund 3 research cruises and related research, anc associated personnel (including postdoctoral researchers and PhD students). The project will collect seismic, TOBI, heat flow, bathymetric and core data. You and your team are collaborators on this gran as we are on yours, therefore we will be able to share results and datasets from the 2 major projects which will undoubtedly make for more rapid and further advances of our understanding of this region. As PI's on this consortium grant, we confirm that your group will act as a collaborator/partne and therefore will work with us on the project including sharing of results and data between the two projects.

We wish you luck with the proposals.

Regards,

Tim Henstock and Lisa McNeill

National Oceanograpl Centre, Southampton

Bundesanstalt für Geowissenschaften und Rohstoffe
Postfach 51 01 53, 30631 Hannover

Dr. Satish Singh
IGP - Inst. De Physique de Globe

4 place Jussieu
75005 Paris
France

Bundesanstalt für Geowissenschaften und Rohstoffe
Federal Institute for Geosciences and Natural Resources

Prepared by Stefan Ladage

Your ref., your correspondence of	My ref. (please use in all replies)	Direct dial +49 511 6 43 -	Hannover
	B3.22-220 LA	3737 e-mail S.Ladage@bgr.de	11.01.2006

Letter of Intent on project-level collaboration offshore Sumatra

Dear Satsih Singh,

Thank you very much for the outline of your research plans offshore Sumatra in the aftermath of the giant Sumatra Earthquake of Dec. 26th, 2004. Your research objectives nicely complement the activities of the BGR offshore Sumatra. The research program of the BGR is fully funded by the German Ministry of Eductaion and Research and involves multichannel seismic, wide-angle seismic, magnetics and gravity profiling as well as sediment sampling and multibeam bathymetric surveys.

Beginning in late 2005 with the first of a set of three cruises – called SEACAUSE I - with the German research vessel SONNE, magnetic and gravity profiling as well as bathymetric mapping started, mainly to the south-east off the Island of Nias and Siberuet. Also 25 long-term OBS have been deployed. The second cruise - SEACAUSE II - consisting of two legs from Jan. – Mar. 2006 will focus on multichannel reflection seismic profiling, accompanied by the magnetics, gravity and bathymetric surveying. Leg 2 will conduct refraction seismic experiments and recover the long-term OBS. The third cruise - called SUMATRA - is scheduled for August-October 2006. During two legs geophysical profiling as well as geological sampliing will be conducted with a regional focus on the fore-arc basins. The main scientific objectives of these cruises are to investigate the geodynamic and tectonic setting of the Andaman-Sumatra subduction zone in the context of the devastating Sumatran Earhtquake on 26th Dec., 2004.

We look forward to collaboration with the "Institue de Physique de Globe de Paris; Dr. Satish Singh". Collaboration includes coordination of experimental work to avoid duplication and ensure complementarity of data sets as well as scientific exchange and continued coordination of further work. Future collaboration has been already initiated during the AGU-Fall-Meeting, San Francisco, 2005. Furthermore in May, 2006 a workshop on "Offshore studies of the Andaman-Sumatran Earthquakes" will be conducted at the BGR. This workshop is intended to detail and coordinate the international research efforts offshore Sumatra.

Best regards

Stefan Ladage
(B3.22 Structural Geology)

p.p. Christian Reichert

Dir+Prof. Dr. H. Kudrass
(Head of Department B3)

Office
Alfred-Bertz-Haus
Stilleweg 2
30655 Hannover

How to reach BGR
tram no. 3 to Lahe (terminus),
then Bus 127 or 133,
bus stop Pappelweise/Geozentrum
E-Mail
Poststelle@bgr.de
Poststelle@geozentrum-hannover.de

Telephone
+49 511 6 43 - 0
Telefax
+49 511 6 43 - 3663
Internet
http://www.bgr.de

Bundeskasse Halle
Deutsche Bundesbank - Filiale Dresden -
(bank code 850 000 00) account no. 850 010 11
IBAN: DE 28850000000850010011
SWIFT-BIC: MARKDEF1850
Tax payer number at the local tax office, Hannover North: 25/252/00085
V.A.T.-ID: DE 811288832

Joint agreement on the planning of a Indonesian-french cooperative research programme on the Sumatra subduction zone.

As a result of a broad scientific discussion and exchanges of ideas that we had during our meeting in Bandung, both sides decided to reinforce the cooperation and to jointly develop a research programme in the area of Sumatra affected by earthquakes since December 26, 2004. This research programme will be devoted to the understanding of the structure of the seismogenic zones and to the geodynamic processes involved. It will comprise marine, land and possibly remote sensing studies. Its ultimate goal is to bring significant improvement in the mitigation of large earthquakes and eventually related tsunamis hazards.

Both sides endorse the following statements :

- This research programme will benefit from the common experience and from the results gathered in the framework of the past cooperation programme on the geodynamic of the Sunda Strait and on Sumatra between France and Indonesia that was active between 1982 and 1995.
- Our goal is to contribute to the international effort to study the areas where the recently large tsunamogeneic earthquakes occurred.
- Our main objective is to map the structure of these zones at various scales from the rupture zone to the surface using the most up to date technology and methodology.
- Scientific and educational exchanges will be central in our cooperation, which will include the training of students and post-docs workers and exchanges of scientists.
- It is our intention that data acquired in the framework of this programme will be made available to the international scientific community. However, for a reasonable period of time, the data might be restricted to the participants of the programme in order to allow early publications. Both sides should benefit from scientific outputs in terms of publications in international as well as in national journals.
- Several projects have already been proposed and should be funded by the French side. They are : 1- a monitoring of aftershocks using OBS's on R/V Marion-Dufresne in 2005, 2 – deep refraction study using OBS's (and a French research vessel and possibly an Indonesian one) and on land seismic stations in 2006, 3 – a deep seismic reflection survey using Schlumberger's means (funded by Schlumberger). Others projects are still under consideration such as heat-flow measurements, high resolution sea-floor imaging using SAR and ROV, high-resolution bathymetry,…
- These preliminary proposals will benefit from joints discussion by the scientist involved (Indonesian and French). Both sides will raise other proposals depending upon the common scientific objectives and targets that will be defined after additional exchanges between both parties. These exchanges may benefit from joined "brain-storming meetings".
- The French partners will apply for the major part of the project funding. These efforts include costs for manpower, ship time, geophysical equipment and for scientific and educational exchanges. The Indonesian side will provide scientists and technicians from Indonesian institutions staff (LIPI, ITB, PPPGL, PPPG, BPPT, BRKP-DKP, BMG, UGM, UNPAD, UI…), and possibly the access of Indonesian research vessels and other geophysical equipment. The Indonesian side will also help for the necessary administrative work. LIPI will act as coordinator on Indonesian side.

Bandung, May 18, 2005

Dr. Ir. Hery Harjono (LIPI)

Prof. Satish Singh (IPGP)

Dr. Ir Haryadi Permana (LIPI)

Prof. Michel Diament (IPGP)

Minutes of the meeting held at IFCPAR on 25th March 2005 on Indo-French joint proposal by the committee constituted by Hon. Secretaries, DST and DOD.

Executive Summary: An Indo-French meeting was organized by IFCPAR on March 24-25, 2005, which was attended by 25 Indian scientists and six French delegates. On March 24, ten talks were given by Indian scientists in morning that was followed by six French presentations in the afternoon. A joint Indo-French proposal to study the disastrous Sumatra-Andaman earthquake was presented by Professor Satish Singh of IPG Paris on March 25, 2005 in the presence of DST and DOD Secretaries. The Secretaries were supportive of the proposal and constituted a committee to assess the feasibility of the joint Indo-French proposal, with a particular emphasis on what can be achieved using only Indian resources, French equipments on Indian vessels and French equipments on French vessels. This report constitutes a detailed summary of the committee and its recommendation.

The committee feels that this Indo-French project on post tsunami studies would indeed provide in-depth information about the regional tectonics in the highly active region.

Scientific Rationale: The Great Sumatra Earthquake and the tsunami that followed have shaken the minds of most of the earth scientists in the world. This fear is further enhanced by the lack of aftershocks further north and south of the broken plate boundary, which might trigger large mega-thrust earthquakes in near future. Therefore, it is vital to understand this earthquake in a great detail. Since the earthquake occurred offshore, one requires special technology and techniques to understand the earthquake. The rupture length is believed to be about 1200 km long, from Sumatra to Andaman, in about 150 km wide zone (Figure 1), covering hundreds of aftershocks (Figure 1, left). The source modeling suggests that the maximum displacement occurred from Sumatra to just north of Nicobar (Figure 1, right), and this will be area for the first phase of our study. This region is both in Indian and Indonesian waters.

International Scenario: The world marine geosciences community is mobilizing their effort to study this earthquake. The British Navy vessel, HMS Scott, carried out a high-resolution bathymetric survey in January-February 2005. These data provide image of the seafloor of unprecedented nature. Japan (JAMSTEC) has sent R/V Natsushima and ROV Hyper Dolphin to carry out more bathymetric survey, deploy ocean bottom seismometers to record micro-earthquakes, and photograph the seafloor using ROV in very fine detail. JAMSTEC has a plan to return to the area in July 2005 and again in 2006. Germany has planned to deploy 25 OBS in October 2005 and carryout bathymetric, gravity and magnetic survey. They will return in February-March to acquire reflection and refraction data. United States of America is setting up an extensive GPS network in Indonesia. All these surveys will be carried in Indonesian EEZ. However, to understand the tsunamigenic earthquake, we need to study the complete zone from Sumatra to Andaman, which requires an international effort.

Indo-French Collaboration:

It was realized that one requires an integrated study from Sumatra to Andaman region, which was broken after the earthquake (1200 km). This requires pooling of resources and technology of highest level from both Indian and French research communities. A set of proposals will be jointly executed in the coming years.

The questions to be addressed under the proposed scientific work are:

1. How such a large earthquake occur and why?
2. How the surface features are linked to source region down to 50 km depth?
3. How the deformation varies along 1200 km of the fault?
4. Use such knowledge to understand the tectonics of the region, and use this knowledge for understanding the processes further north in the Himalayan region.

An Indo-French meeting was organized by IFCPAR on March 24-25, 2005, where 15 presentations from Indian and French scientists were made. Indian Scientists presented reports about the initial post-tsunami cruise by India. French scientists presented their work and express their willingness to work with Indian colleagues:

Dr. N. K. Thakur, NGRI, Hyderabad
Dr. V.K. Gahlaut, NGRI, Hyderabad
Dr. V.M. Tiwari, NGRI, Hyderabad
Dr. K.S.R. Murthy, NIO, Visakhapatnam
Dr. G.C. Bhattacharya, NIO, Goa
Dr. K.S. Krishna, NIO, Goa
Dr. K.A. Kamesh Raju, NIO, Goa
Dr. J. Mallick, IIT Kanpur
Dr. Sen Gupta, GSI, Kolkata
Dr. Das Gupta, GSI, Kolkata
Dr. M. Sudhakar, NCAOR, Goa
Dr. S. Rajan, NCAOR, Goa
Dr. Dhananjai Pandey, NCAOR, Goa (Convener)

The role of the committee was to identify existing Indian resources that could be used for the project, in particular Indian marine facilities and to outline the research that could be carried out using 1) Indian research vessels, 2) using French equipments on Indian research vessels, and 3) research that requires highly specialized equipments that could only be deployed using French research vessel.

Existing Data: Over the last 30 years, GSI has mapped the geology of the Andaman-Nicobar Islands on 1:50000 scale and on 1:25000 scale, which could be used for future land study. India has acquired extensive seismological and GPS data before and after the earthquake, and these data could be available for joint study. GSI has also conducted

marine survey (point bathymetry and magnetic) around Andaman-Nicobar region, and these data could be used for designing future marine surveys.

The following areas of study under the proposed Indo-French collaboration were identified which can be carried out:

A) Studies that can be undertaken with Indian Resources:
(In this section, we discuss the projects that could be undertaken using the Indian vessels and resources in collaboration French colleagues).

1) **SWATH BATHYMETRY offshore Andaman-Nicobar:**
The purpose of this study is to conduct the Swath Bathymetric investigations to track the northward continuation of the deformation front mapped by the recent surveys by HMS *Scott* (UK) offshore Sumatra. As the first phase activity, it is proposed to carry our survey from the India-Indonesia maritime boundary northward till off Nicobar. Early completion and mapping of the area will enable the planning of deep seismic profiles in order to understand the geometry of the subduction zone. The proposed bathymetric survey is estimated to take about 4-5 weeks. During the second phase, it is proposed to extend the bathymetric surveys northward to the end of the fault zone (off Andaman). The expected ship time is about 8-10 weeks. Facility for this work is available onboard R/V *Sagar-Kanya*. Concurrent underway geophysical data is also proposed to be collected. Bathymetry data are vital for all other marine projects.

2) **PASSIVE OBS EXPERIMENT:** A joint passive OBS experiment could be undertaken offshore the Andaman-Nicobar Islands for measuring the micro-seismicity of the subduction zone. The OBSs which are being acquired by NGRI, may be used for a month-long data acquisition. The offshore data could be integrated with the land-based measurements concurrently, utilizing the facilities of broadband seismic instruments on the islands, involving various other organizations. This could be carried out in August 2005 using an Indian vessel that would be complementing the R/V *Marion Dufresne* cruise planned concurrently in the Indonesian waters.

3) HEATFLOW-MEASUREMENTS: Heat-flow measurements are proposed as they provide important constraints on the strength of the faults located in the source region. NGRI informed that they are in the process of procuring heat-flow probes. The proposed studies will utilize these instruments in offshore regions of Andaman-Nicobar, vis-à-vis similar experiments being planned by our French colleagues in the Sumatra region.

B) Studies using joint Indian and French Resources:
(In this section, we will discuss the experiments that require resources from the two countries.)

1) **ACTIVE OBS EXPERIMENT:** It is proposed to carry out an active OBS experiment along two profiles across the Andaman-Nicobar subduction zone to understand the deep crustal structure of the area. One profile traverses through the

epicenter in the Indonesian waters and the second line is planned in the Inidan waters. This experiment requires OBS (ocean bottom seismometers) as well as a source. It is proposed to utilize the 10 OBS that are being procured by the NGRI as well as the 60 OBSs to be provided by France. An Indian vessel could be used for the deployment and recovery of OBSs, while the French vessel could be used for providing the source and recording, thereby reducing the experiment time thus allowing opportunity to possibly shoot another line further north in the Andaman region in the Indian waters.

) Studies that can be undertaken by French Resources:
(In this section, we will discuss the projects that require specialized instruments that are either fixed on a particular vessel (French or Industry) or significant alteration would have to be added if they were to be transferred onto Indian vessel.)

) **STATE-OF-THE-ART- Q-STREAMER SEISMIC DATA:** It is proposed to shoot two deep seismic lines (one in the epicentral region and another south of Nicobar Islands, Figure 2) using industry vessels equipped with state-of-the-art Q-Marine system (12 km long with hydrophones every 3 m and a large low frequency air gun source of 10000 cubic inch volume) to obtain the high precision sub-surface image down to 50 km deep. This project is already approved. It would be important to have such data also across the Andaman region for which further funding would be required. This would provide unprecedented image of the active faults and provides unique opportunity to get experience on exceptional technology. Such a technology is only available in the industry.

) **LONG SEDIMENT CORING**: For the purpose of palaeo-tsunami investigations, we require long sediment cores in the Andaman region. Such facilities are available only onboard R/V *Marion Dufresne*, which will be conducting the passive OBS experiment in the Indonesian water in August 2005 (see the passive OBS section above). Possibilities should be explored to utilize this exceptional facility to acquire long cores in the Andaman-Nicobar region.

) 3) **HIGH-RES-SEISMIC DATA**: The high-resolution seismic image provides high precision information about the fault movements and the small-scale deformation. High-resolution seismic reflection data are fundamental to relate near surface features with deep seismic data (source region) and are pre-requisite for SAR and ROV survey. We propose to acquire about 2500 km of high-resolution seismic reflection data in the frontal region (Figure 2) from Sumatra to Nicobar. A 20 days survey is proposed either on the French research vessel R/V *Suroit* or R/V *Atalante*. The high-resolution seismic survey could be extended further north or east of Nicobar Island where a cluster of aftershocks is observed.

Note: High-resolution seismic could be deployed using Indian vessel however, one needs to look into the logistics with French side, and the logistics of shooting two-thirds of the survey in Indonesian water (see Figure 2) in order to achieve the scientific objectives.

4) SAR-PASISAR: SAR (Systeme Acoustique Remorque) is very specialized equipment and provides the image of the seafloor on the scale of one metre. It is towed at 100 m above the seafloor at 2 knots, and could be used in a water depth of 6 km. It covers a strip of 1.5 km during the survey. France is the only country that has such a equipment. It was used to obtain the precise image of the famous *Titanic*. SAR image is necessary for ROV survey. A small streamer is towed by the SAR that can record seismic source on the sea-surface (PASISAR) simultaneously, providing a very high-resolution seismic image. IFREMER is in the process of developing a deep towed source that would increase the resolution further. A 20 days SAR-PASISAR survey (Figure 2) on R/V *Suroi*t or R/V *Atalante* or or R/V *Pourquoi Pas?* is proposed.

5) Remotely Operated Vehicle (ROV): The French ROV Victor can be used for micro-bathymetry with a resolution of 10 cm and also provides photograph of the seafloor down to a water depth of 6000 m. It is operated at a vessel speed of 0.5 knot. There are only a few countries that have such a ROV. We propose a 35 days cruise on R/V *Atalante* or R/V *Pourquoi Pas?* in the frontal zone over selected areas from Sumatra to Nicobar (Figure 2).

BENTHIC ECOLOGY: It is proposed to study the impact of the deformation caused by the M_w=9.3 earthquake on the benthic community and its ecology. This will require ROV Victor that can be deployed using either R/V *Atalante* or R/V *Pourquoi Pas*.

D) Technical Collaboration on other ongoing Programmes of India: The ongoing CSIR network programme on Ridges supported by DOD, and the Gas-hydrate Programme of DOD propose to use specialized equipments mentioned above to acquire high-resolution seismic data, micro-bathymetry and visual – acoustic observations of the seafloor at selected locations. At an appropriate time and when the French vessel(s) are in the vicinity of Indian areas of interest/investigation, these equipments may be requested from the French collaborators to work on other projects beyond the present scope in the Andaman & Nicobar region.

LAND OPERATIONS:

Paleo-Seismology and Quantitative Geomorphology:

Delineation of active tectonic features using high resolution satellite data, understanding of landscape changes and estimation of millennial and century-scale uplift/subsidence rates by dating uplifted coral reefs and wave-cut platforms; and Chronology of seismogenically induced paleo-tsunami events for understanding the recurrence patterns of mega-earthquakes. GPS measurements would be made along the Andaman Nicobar islands to understand the pre/post and aseismic deformation.

GPS measurements

It is proposed to occupy the already existing GPS sites in Andaman and Nicobar and Indonesia, Malaysia and Thailand to study the mechanism of post-seismic deformation and possible region of occurrence of future big aftershocks or earthquakes. The sites in India will be occupied by Indian counter part and sites in Indonesia and other neighboring regions will be occupied by French participants. The data collected by the two groups will be analysed jointly. We may also try to take measurements using absolute gravimeter for vertical deformation and mass changes.

Organisations: The project will be executed on equal partnership basis. The participant organizations that have shown interest in the proposal are: NGRI, NIO, NCAOR, GSI, Delhi University, IIT Kanpur, IIT Mumbai, WIHG, CMMACS, SOI, Cochin University and in France IPG, Paris, IFREMER, CNRS, Universities of Brest, Nice, and many other organizations.

Concluding Remarks and Recommnedation: The 9.3 Sumatra-Andaman earthquake provides an unique opportunity to initiate an ambitious Indo-French project to understand the causes of large mega-thrust earthquakes using the state-of-the-art technology that could be used to study the future earthquakes further north in the Himalayan region. Indian scientists are excited about the project and fully endorse the project.