UNIVERSITY OF OSLO

Centre for Earth Evolution and Dynamics

Object:
Report for the STMS period of Karyono karyono visit to ETH Zurich

1. Summary.

Karyono STSM took place from the 30 of March to the 29th of April. During this period Karyono collaborated with experts in seismology at the ETH-Zurich under the guidance of Anne Obermann.

The STSM focused on three main activities:

- Completion and submission of the manuscript "Bridging surface and subsurface observations from the geysering Lusi eruption, Java, Indonesia" to the journal *Terra Nova.*
  The submitted manuscript focusses on a multidisciplinary study completed at the Lusi eruption site combining visual observations and subsurface data acquired with 5 seismic stations positioned around the Lusi crater. Results reveal insights about the different modes of geysering activity.
- Preparation of poster and oral presentation for attending the EGU conference (16-23April). Karyono presented his results with a poster describing the results of the manuscript submitted to Terra Nova and gave an oral presentation on the focal mechanism study of the seismicity in NE Java.
- Study of the focal mechanism of the 1.5 years seismic data from the 31 seismometers network installed in Indonesia.
  This study has been one of the core activities during the STSM trip and Karyono scanned through a large database and learned the use of new softwares and techniques.

2. Purpose of the STSM

The STSM completed by Karyono had multiple purposes that included 1) the submission of a manuscript, 2) attending and presenting at the EGU conference, and 3) actively processing acquired data. More specifically the main goal was to get familiar with the software for earthquake location and focal mechanism determination. For the event localization, he aimed to complete a relative relocalisation and improve the velocity model of the region. The pourpose of Karyono's work was to:

1)Analyse nearly two years of seismic data recordings obtained from 31 seismic stations deployed around Lusi and reaching the volcanic arc, including the fault zone. Karyono needs to adapt triggers and various scripts for event localization and various other routines for seismic data processing;

2) Refine the velocity model of the area

3) Localize seismic events and invert moment tensor solutions to determine the seismic activity occurring in the area.

3. Description of the work carried out during the STSM and relevance for flows

The first accomplishment of Karyono STSM was to complete his work on the combined surface and subsurface observations of the geyser behavior of Lusi. He successfully defined four activity phases of the Lusi activity related to geysering. In addition he managed to characterize the tremor events associated to the rise of mud and gas mixtures in the conduit. For this purpose, the seismic activity associated with the geysering cycles has been studied and linked to camera recordings of the surface activity. We could characterize the geysering cycles and identify volcanic tremor events that are associated with rising gas pockets in the column during the geysering activity. This novel study has been compiled in a manuscript that was submitted ("Bridging surface and subsurface observations from the geysering Lusi eruption, Java, Indonesia" and submitted to the journal Terra Nova).

The second important goal of Karyono's visit was to attend his first international conference: EGU in Vienna. He contributed with two papers submitted at the session "Ten years of Lusi eruption - lessons learned about modern and ancient piercement systems“. He presented his new manuscript results with a poster “(Monitoring and Characterizing the Geysering and Seismic Activity at the LUSI Mud Eruption Site, East Java, Indonesia”) and gave on oral presentation on the data processed during his STSM experience (“Analysis of Focal Mechanism and Microseismicity around the Lusi Mud Eruption Site, East Java, Indonesia”). Both contributions gathered relevant interest by the audience attending the session.

The most important goal of karyono’s STSM to investigate the relationship between seismicity, volcanism, faulting and Lusi activity, a network of 31 seismometers had been deployed in January 2015 (still running) within the framework of the ERC-Lusi Lab project. This network covers a large region that monitors the Lusi activity, the Watukosek fault system and the neighboring Arjuno- Welirang volcanic complex.

3.1 Data

The local seismic network is shown in **Fig. 1**, consisting of 10 broadband (blue) and 21 short-period (red) seismic stations covering the Arjuno-Welirang volcanic complex, the Watukosek fault system and Lusi.

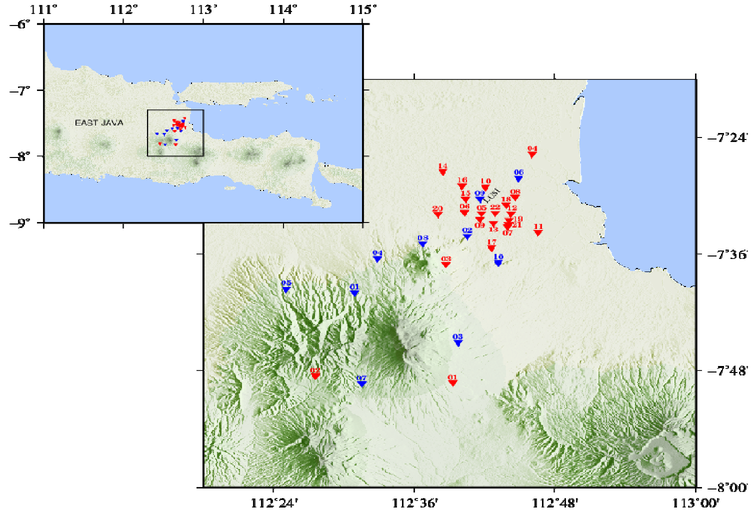


Figure 1: *The seismic network consisting of 10 broadband (blue) and 21 short-period (red) seismic stations around the Lusi site.*

As a first step, we evaluated the local site conditions by studying the seismic background noise at each station. For this purpose we study the power spectral density from each individual station and check whether it lies in between the USGS High and Low noise model (Peterson 1993). The USGS Noise Model summarize the lowest/highest observed vertical seismic noise levels throughout the seismic frequency band. It is extremely useful as a reference for assessing the quality seismic stations and for predicting the detectability of small signals. In **Figure 2**, we show an example of a „good“ and a „noisy“ site. With the red square we indicate the frequency band of interest for the study of local earthquakes. The „good“ sites are mostly broadband stations located on bedrock within the volcanic arc, whereas the noisy sites are mostly shortperiod sensors on sediments close to populated areas (around Lusi).

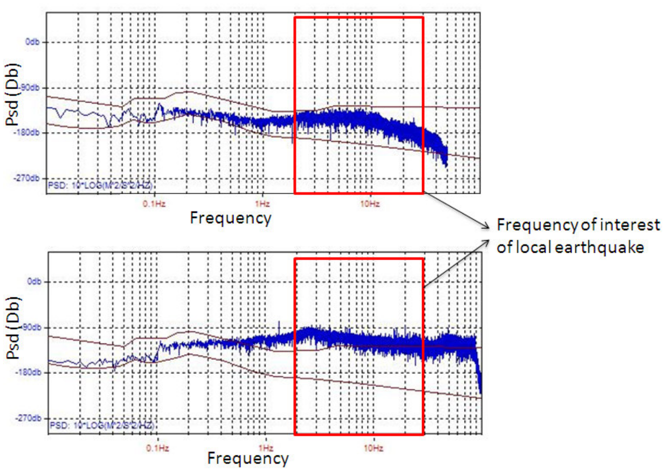


Figure 2: *Background soise levels at two sites (a) typical example of a broadband station (BB08) on bedrock. (b) typical example of a shortperiod station (SP13) on sediment close to a populated area.*

3.2 Methods

3.2.1. Earthquake detection and picking

The first and most time consuming step is the detection and picking of local earthquakes in the continuous records. This very important step is done manually. We have to differentiate between local, regional and distant earthquakes, of which only the local ones are of interest for us.

We use the seiscomp3 software for this procedure and follow a couple of criteria to obtain good quality picks:

(a) We use a bandpass filter of 1-30 Hz; (b) A clear P-phase must be detected on at least 8 stations; (c) The picks are assigned manually; (d) We assign picking uncertainties to have a quality control for the later studies. An example of this picking procedure is shown in **Figure 3**.

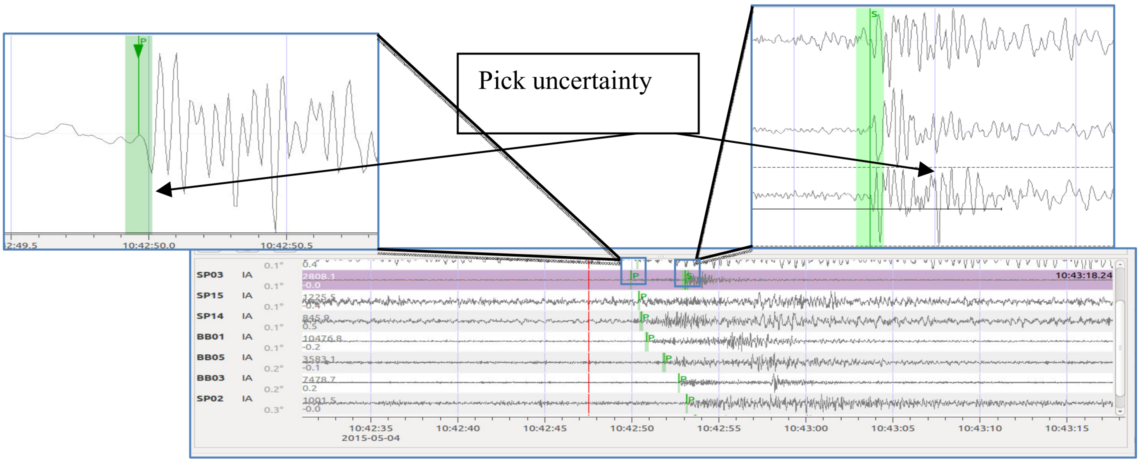


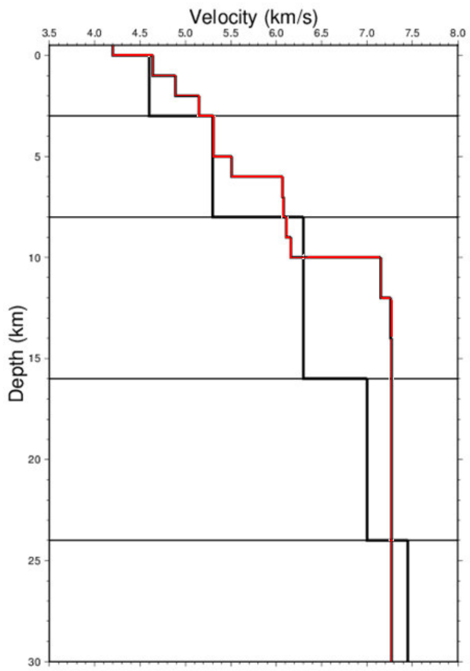
Figure 3. *Picking earthquakes with the seiscomp3 software with assigned uncertainties.*

3.2.2 Minimum 1-D velocity model

The next step is the localization of the seismic events. As the seismic velocity model in the area is unknown, we first use the data to determine a minimum 1-D velocity model that will be used to assess the quality of the stations and relocate the seismic events.

We use the software *Velest* (Kissling et al. 1994) for this purpose. We first select a subset of the clearest (strongest) local earthquakes under following criteria:

Azimuthal gap < 180°	Station number > 8	Rms < 0.5 seconds



These criteria left us with 70 events. For these events we simultaneously invert for hypocenter location, velocity structure and station quality. In **Figure 4**, we show the resultant averaged 1D velocity model for the region (red) compared with the averaged velocity model for the island of Java (black). We notice substantial differences at depths from 10-15 km.

Figure 4 : *Minimum 1-D velocity model averaged for the region (red) and compared with the 1D velocity model for the entire island of Java (black).*

From the inversion we also obtain station corrections, which are basically the delay times of the individual seismic station compared to a reference station (marked with a star in **Figure 5**). These station corrections are interesting parameters as they can be used to get an idea of the geology of the area and to assess systematic shift in the location of seismicity. Negative station corrections mean that the real velocities are faster than the 1D velocity model, positive station corrections indicate that the local velocities are slower than 1D velocity model. As we can see in **Figure 5**, the Lusi area has higher values of station corrections, indicating that this area has slower velocities than the rest of the region. This is not surprising seen the amount of uncosolidated mud ejected by Lusi.

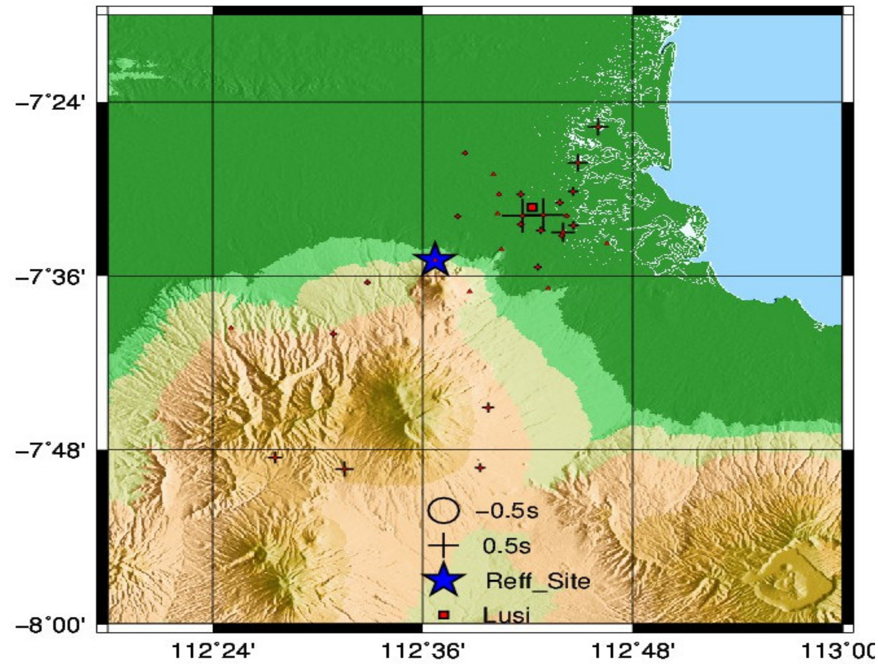


Figure 5: *Station corrections in and around Lusi indicating delay times of the individual stations compared to the obtained minimum 1D model obtained at the reference site (blue star).*

3.3. Relocation of seismicity

We use the 1D velocity model obtained in the previous section to relocate all seismic events. The preliminary locations are shown in **Figure 6**. We notice that there are hardly any events below Lusi. The seismicity clusters around the Arjuno-Welirang volcanic complex. The events depth varies between 10-15 km, the two events at 45 km might be errors and will be reinvestigated.

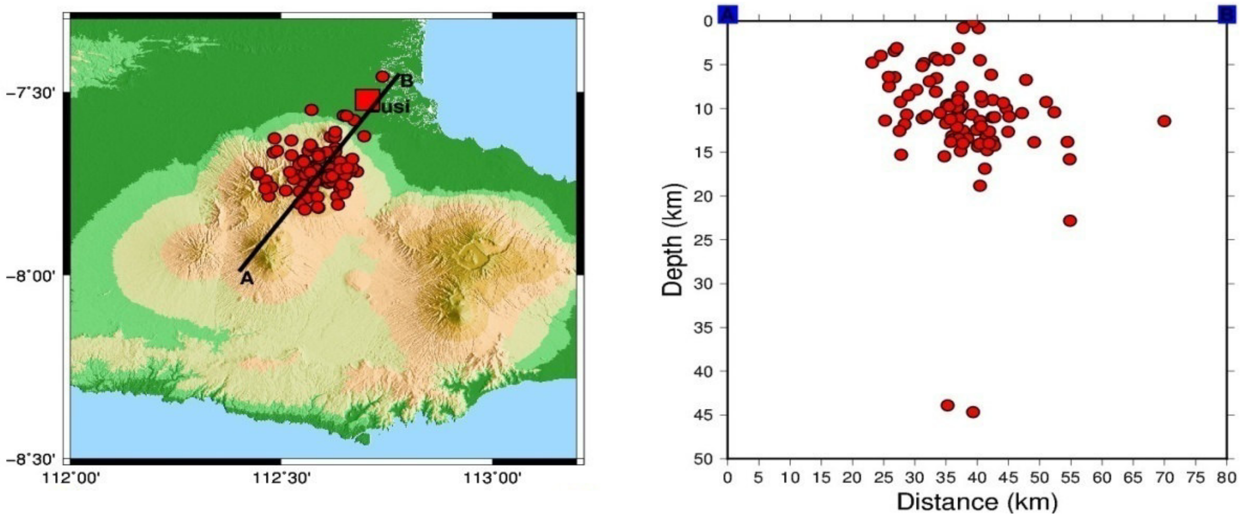
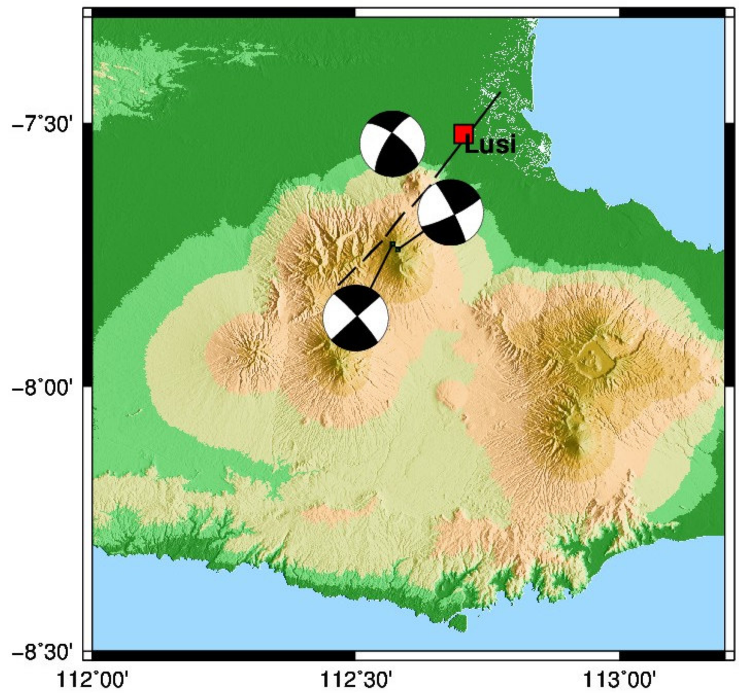


Figure 6 : *Relocated seismicity in the Lusi area. The events cluster below the Arjuno-Wlirang vocanic complex. The depth of the events is mainly between 10-15 km.*

3.4. Focal mechanism



We take the best three events to determine the focal mechanisms that are a proxy for local tectonic settings. All three events are shown in **Figure 7** and indicate a strike slip mechanism with right lateral movement of the fault. This is consistent with the general tectonic settings in this area.

Figure 7 : ***Focal mechanism of the three strongest events in the area indicate strike slip motion.***

3.5 Preliminary conclusion and future work

From an analysis of the data from 1 year, we are surprised by the overall low rate of microseismicity in the region (90 events with M0.6-M2). We notice that most of the seismicity falls into the volcanic complex and occurs within shallow depth (10-15km). The local noise conditions (high noise especially around Lusi) make it complicated to detect microseismicity and might bias the study. The preliminary analysis of the source mechanism of some selected events indicates strike-slip, which is consistent with the general tectonic settings in the area.

Description of the main results obtained in light of the objectives of the FLOWS action

Understanding the interaction between seismicity, volcanism, fluids seepage and strike-slip phenomena is indeed extremely relevant and pertinent for the FLOWS activities. Karyono's work encompassed the various aspects of these geological phenomena. In particular, he aimed to understand the consistent pattern of the source mechanism, relative to the general tectonic stress in the study area.

Future collaboration with the host institution

The collaboration between CEED and the ETH in the framework of the Lusi Lab project is already ongoing since a couple of years. Karyono's PhD and visit is one of the main positive outcomes of this successful cooperation. There is no doubt that the collaboration between these institutes will continue in the following years. As a next step, we will analyse the remaining 6 months until June 2016 and finalize our study.

Foreseen publications/articles resulting from the STSM

In addition to the submitted article, a second manuscript is being prepared to describe the results of the observed seismicity in and around the Lusi eruption site.

Yours Sincerely,

Karyono Karyono