Deep oceanic submarine fieldwork – Script elements for Lab Session

Goals for students :
- using raster and vector data in QGIS
- observing, measuring and reporting on the field
- produce seismotectonic structural scheme of the area
- understand the 2004 Les Saintes earthquake based on a set of geophysical and morphological observations.

Part 1 – Context and mapping

Seismotectonic context :

On Novembre 21st of 2004, a Mw 6.3 earthquake shake the Guadeloupe island. This is the strongest event registered in France since decades and it causes one death and significant material losses in particular in Les Saines, SW of the Grande Terre Island.
Since then, the scientists are trying to better understand this earthquake. This lab session aims at analyzing the earthquake which epicenter is located offshore using specific morphologic and seismic data.

I – The regional seismotectonic context

Two documents issued from scientific publications (Leclerc et al. 2016, Feuillet et al. 2002) are presented below.

1- What are the tectonic plates involved in the Guadeloupe context ?

2- In which tectonic context the island has formed ? Is it rather divergent of convergent ?

3- Are relative plate motions indicated in figure 1 important ?

4- On figure 2, focal mecanisms are shown for the most important earthquakes registered in the Lesser Antilles before 2004. Which seismic motion dominates ? Are these different motion types spatially organized ? Using a simplified sketch, propose a way deformation is accommodated in the area.

5- Seismic hazard in the area is principally associated with the possibility of the occurrence of a 1843-type earthquake. Its supposed rupture zone is indicated with an ellipse in figure 2. Assuming that the rupture propagated downdip on a 40km distance along the subduction plane, and that this portion of the subduction is fully locked since 1843, can you estimate the magnitude of such an earthquake if it should occur today ?

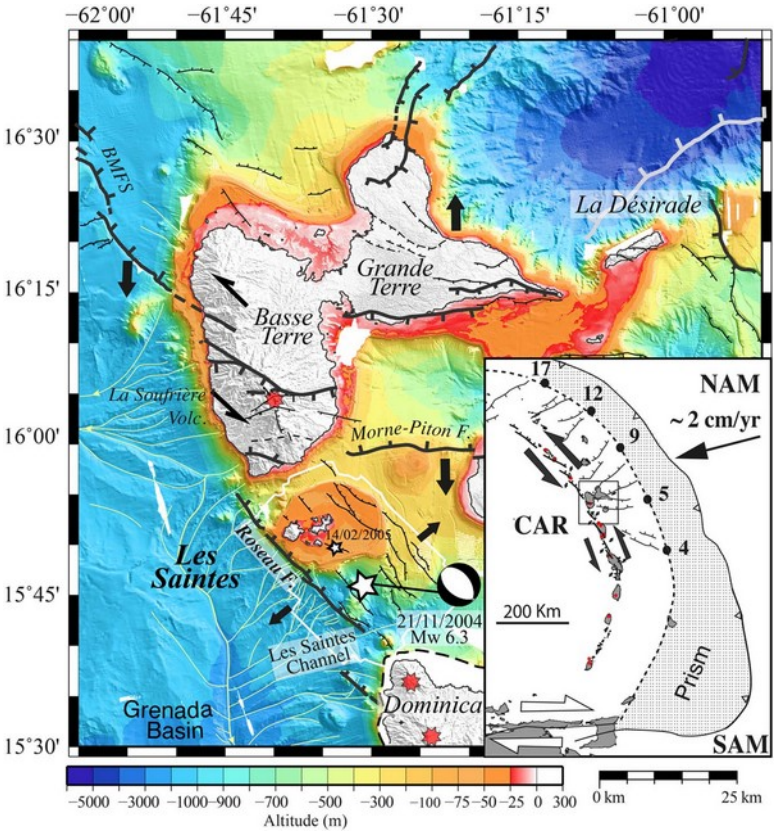


Figure S1. Tectonic context of Les Saintes archipelago (located by a black box on the inset figure). Active faults in black modified after Feuillet et al. [2010]. Topography from IGN. Red stars indicate onland active volcanic centers. Canyons flowing from the windward coasts of the islands toward the Grenada Basin in light yellow. BMFS: Bouillante-Montserrat Fault System. Bathymetry from the 50 m DEM. BATHYSAINTES area encircled by a white line. Location (white stars) of the Mw 6.3 Les Saintes earthquake, associated with focal mechanism, and main aftershock [Bazin et al., 2010; Feuillet et al., 2011]. Inset: lesser Antilles geodynamic context modified after Feuillet et al. [2010]. Vector of convergence between the North and South American plates (NAM-SAM) and the Caribbean one (CAR) from DeMets et al. [2000]. Numbers and dots along the gravity anomaly figuring the backstop (dashed line from Bowin [1976]) represent the trench parallel component of shear that increases from 4 to 17 mm/yr between Martinique and Saba, after Lopez et al. [2006] and Feuillet et al. [2010].

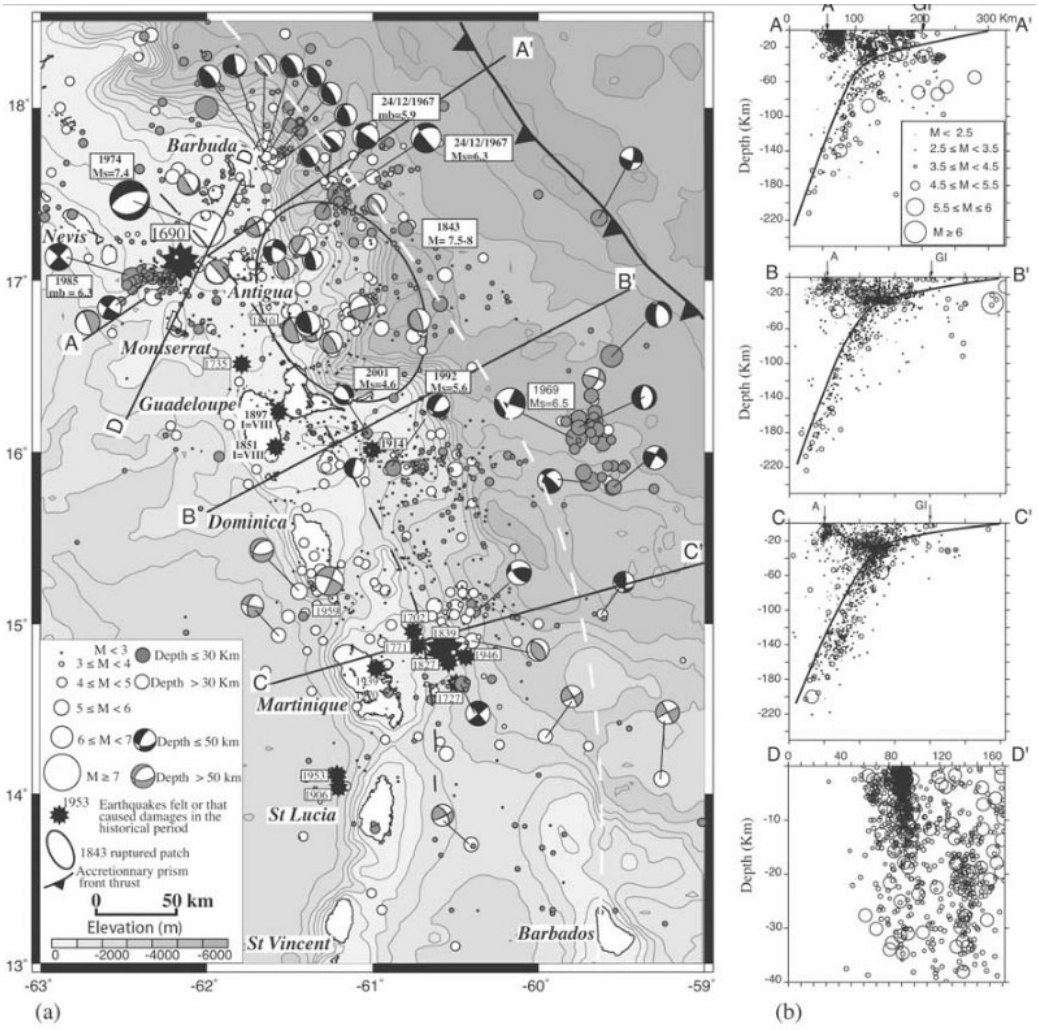


Figure S2 (a) 1950–2001 seismicity in Lesser Antilles arc. Historical seismicity and focal mechanisms

II- The Les Saintes earthquakes (2004, Mw 6.3)

1- The USGS website provides informations on earthquakes occurring worldwide together with focal mechanism (see figures 3 and 4). What is the motion associated with this earthquake ? Its depth ? What is the structure that could have ruptured based on the previous context analysis ?

2- Mapping of active faults. The strong intensity reported inland (figure 4) argues for a relatively shallow earthquake that may have ruptured up to the seafloor surface. Two scientific cruises were set up in 2009 and 2010 to precisely map the bathymetry over the epicentral area (GWADASEIS, BATHYSAINTES).

Several techniques for high resolution bathymetry and exploration tools have been deployed :

a- using a scientific ship equipped with acoustic emitter/receiver (resolution around 10m depending on the depth)

b- using autonomous submarine robots (AUV autonomous underwater vehicule, resolution from 2m to 10cm)

c- Optical images (photo/movies) from Remotely Operated Vehicule (ROV) for geological observations and sampling using articulated pliers

d- Photogrammetry based on optical images (resolution is lower than cm)

We have access to a 25m (or 10m) spatial resolution DEM around Les Saintes area that can be visualized via the QGIS software (version > 2.7).

- Using the edition tools in QGIS, caption the DEM and finalize your work as a structural drawing of the zone. You will take a specific care in mapping the main fault scarps, coral reefs and volcanoes. For clarity, the seismic catalog should be unticked.

- Can you identify the motion associated with the active faults visible on the DEM ? What is their strike and dip ?

- Based on several examples, discuss the relationship (both in time and space) between the active faults and the volcanic reliefs.

3- Seismicity analysis. Display the seismic catalog and have a general view of it via dezooming. What is the earthquakes repartition with depth ?

4- Identify the earthquakes sequence associated with the main shock (Mw 6.3, 2004). Why do we observe a higher density of small magnitude earthquakes in the area than elsewhere ?

5- Identify the main shock. Referring to your structural drawing of the area, which fault is the best candidate for hosting such a large rupture ? Where should we launch the ROV to find the fresh scarp associated with the Les Saintes earthquake ?

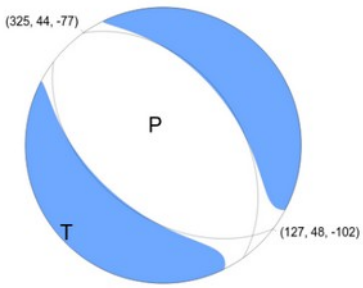
Figure S3

Contributed by US [3] HRV last updated 2014-11-07 01:24:03 (UTC)

✓ The data below are the most preferred data available
✓ The data below have been reviewed by a scientist

Centroid Moment Tensor (Mwc)

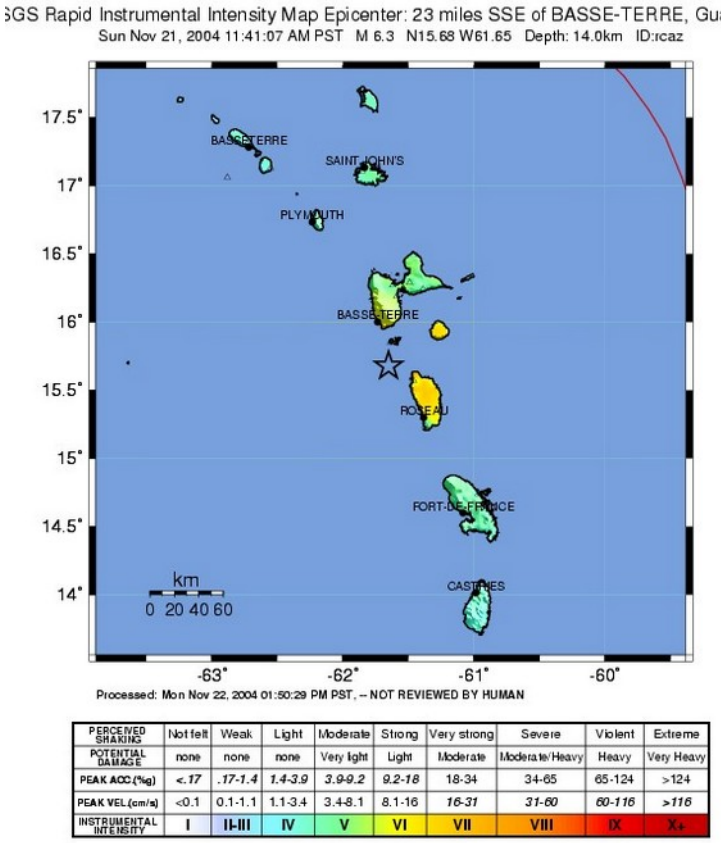
Moment	3.450e+18 N-m
Magnitude	6.29
Depth	12.0 km
Percent DC	83%
Half Duration	3.50 s
Catalog	US
Data Source	HRV
Contributor	US [3]



Nodal Planes

Plane	Strike	Dip	Rake
NP1	127°	48°	-102°
NP2	325°	44°	-77°

Figure S4



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	*<.17*	*.17-1.4*	*1.4-3.9*	*3.9-9.2*	*9.2-18*	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	*16-31*	*31-60*	*60-116*	*>116*
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Part 2 – Virtual fieldwork

III- Deep oceanic submarine fieldwork

You have previously identified, in agreement with the scientists involved in the ODEMAR and SUBSAINTES cruises the Roseau fault as the best candidate for hosting the 2004 Les Saintes earthquake. Submarine robots were sent in the area where the fault scarp is best visible.

1- Watch the video recorded by the ROV
https://www.youtube.com/watch?v=TV3TUeRfxoc&feature=youtu.be
Display on your QGIS project the layer "ROV path". Labels show the time when the ROV passed through an area. Identify the exact place where the video has been taken and note the associated coordinates. What is the local depth ?
Can you identify the parameters that display on the lower left corner of the movie ? What are they for ?

2- Based on this video, list the advantages and drawback of submarine fieldwork using ROV compared to standard fieldwork inland.

3- The videos acquired by the ROV have been used to compute a very high resolution DEM and DOM of the Roseau fault that you will explore using the virtual reality Minerve software. Entering the VR environment, take a first look at the outcrop from above. The beige DEM is 1m resolution and enables you to measure the strike of the structure and its overall heigh.
Then, zoom on the centimetric resolution Digital Outcrop Model.

Gather your observations on a representative drawing (properly scaled) on your field notebook. What is your interpretation for the structures observed ?

4- Which observations could allow you to estimate the coseismic slip amount and rake associated with the 2004 earthquake ? Are your measures consistent with the expected magnitude for such an event ?

5- Compare the total cumulative cliff height with the fresh scarp you just measured. Propose a scenario that could explain the building of such a large relief.

6- Looking closely to the DOM, identify dark ribbons on the fresh scarp. This is usually interpreted as a manganese rich level that could indicate a former base level. Using this new observation, could you propose a scenario for the formation of the cumulative scarp ?

7- Underwater, erosion rates are very low. The current scarp is therefore exceptionally preserved. Assuming that the cumulative scarp has formed during a 4kyr time span, and that the Roseau fault ruptures following the characteristic earthquake model (same earthquake returning regularly), how many 2004-like earthquakes occurred in the last 4kyr ? What is therefore the expected recurrence time for this fault ? When will the next earthquake occur ?

8- Based on the standard scaling laws used in seismology, calculate the theoretical fault length associated with the 2004 earthquake. Do you think we could map the entire rupture length using the ROV ?