Seismological Study of Earthquake Swarms in South-Eastern Puerto Rico

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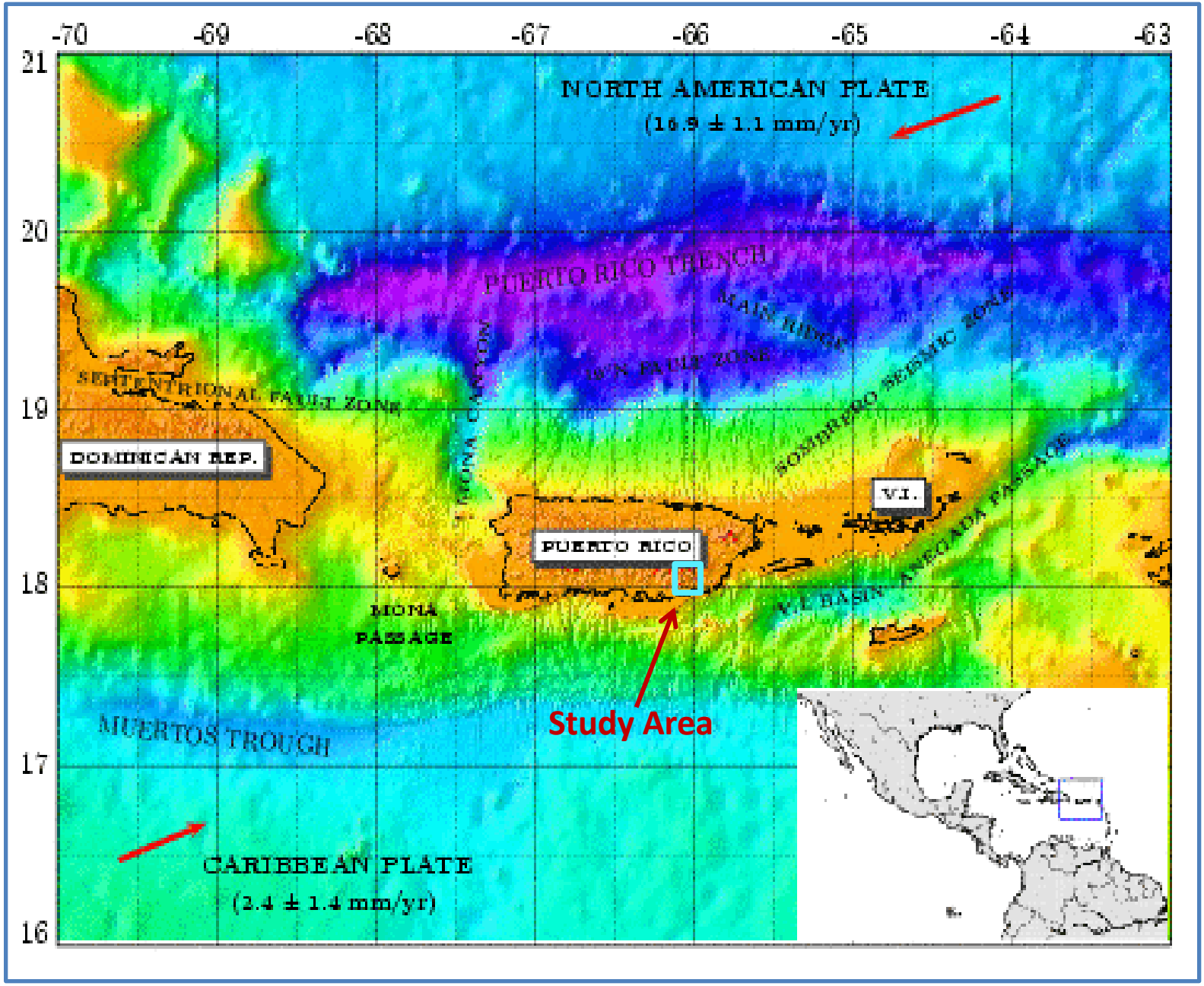
-70
-69
-68
-67
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-65
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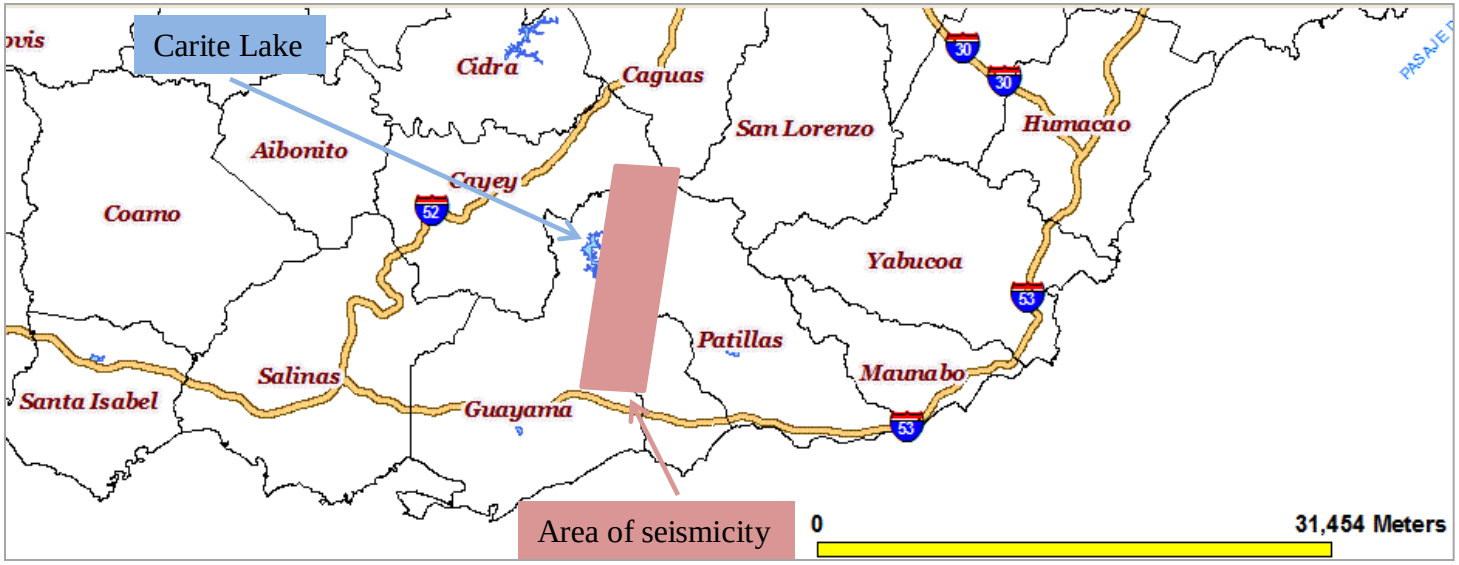
21
20
19
18
17
16
NORTH AMERICAN PLATE
(16.9 ± 1.1 mm/yr)
PUERTO RICO TRENCH
MAIN RIDGE
19°N FAULT ZONE
SEPTENTRIONAL FAULT ZONE
DOMINICAN REP.
MONA CANYON
SOMBRERO SEISMIC ZONE
ANEGADA PASSAGE
V.I.
PUERTO RICO
V.I. BASIN
MONA PASSAGE
MUERTOS TROUGH
Study Area
CARIBBEAN PLATE
(2.4 ± 1.4 mm/yr)

We are conducting a detailed seismic analysis of 181 shallow events, magnitudes 0.3-3.1(Md)

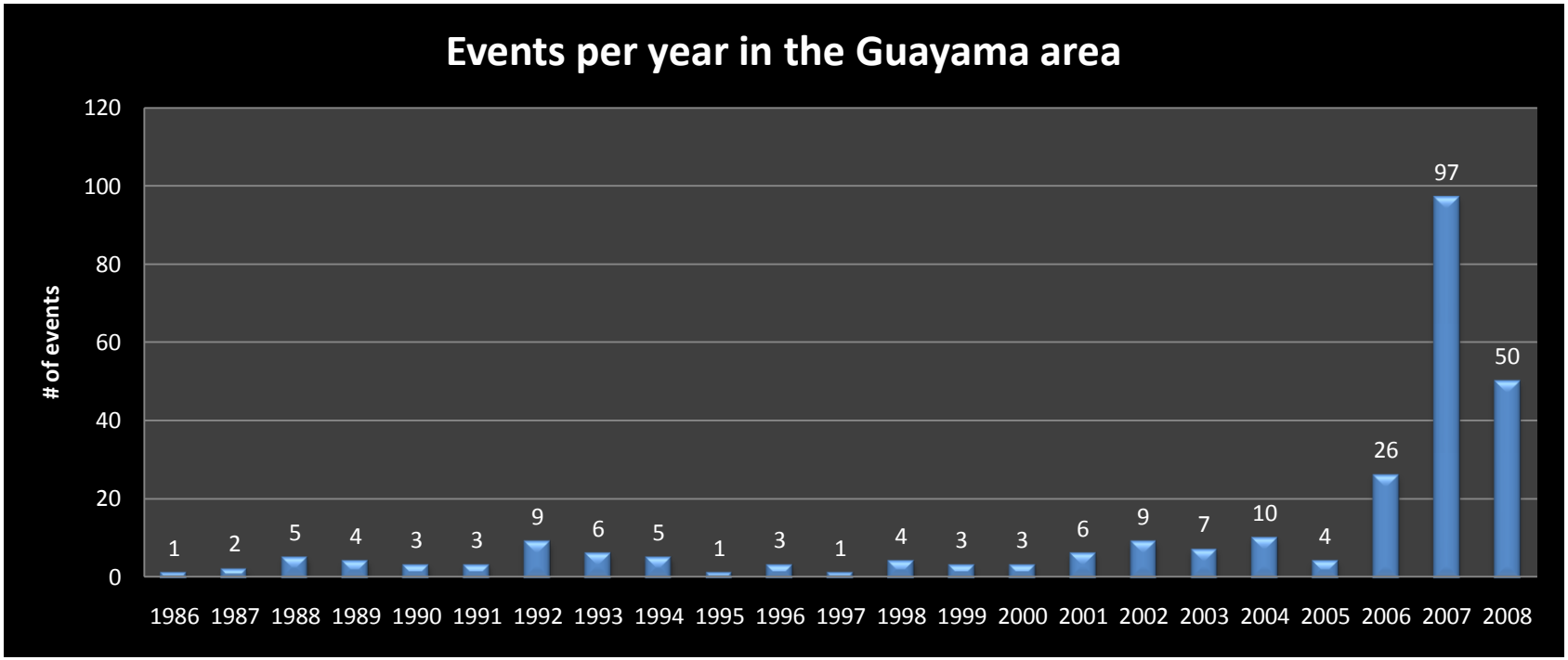
- January 2006 – December 2008
- lat 18.00^0N-18.15^0N, long 66^0W-62^0W
- It covers the towns of Arroyo, Cayey, Guayama and Patillas.
- A change in the seismic behavior has been observed



Our problem…

Characteristics of Microseismicity

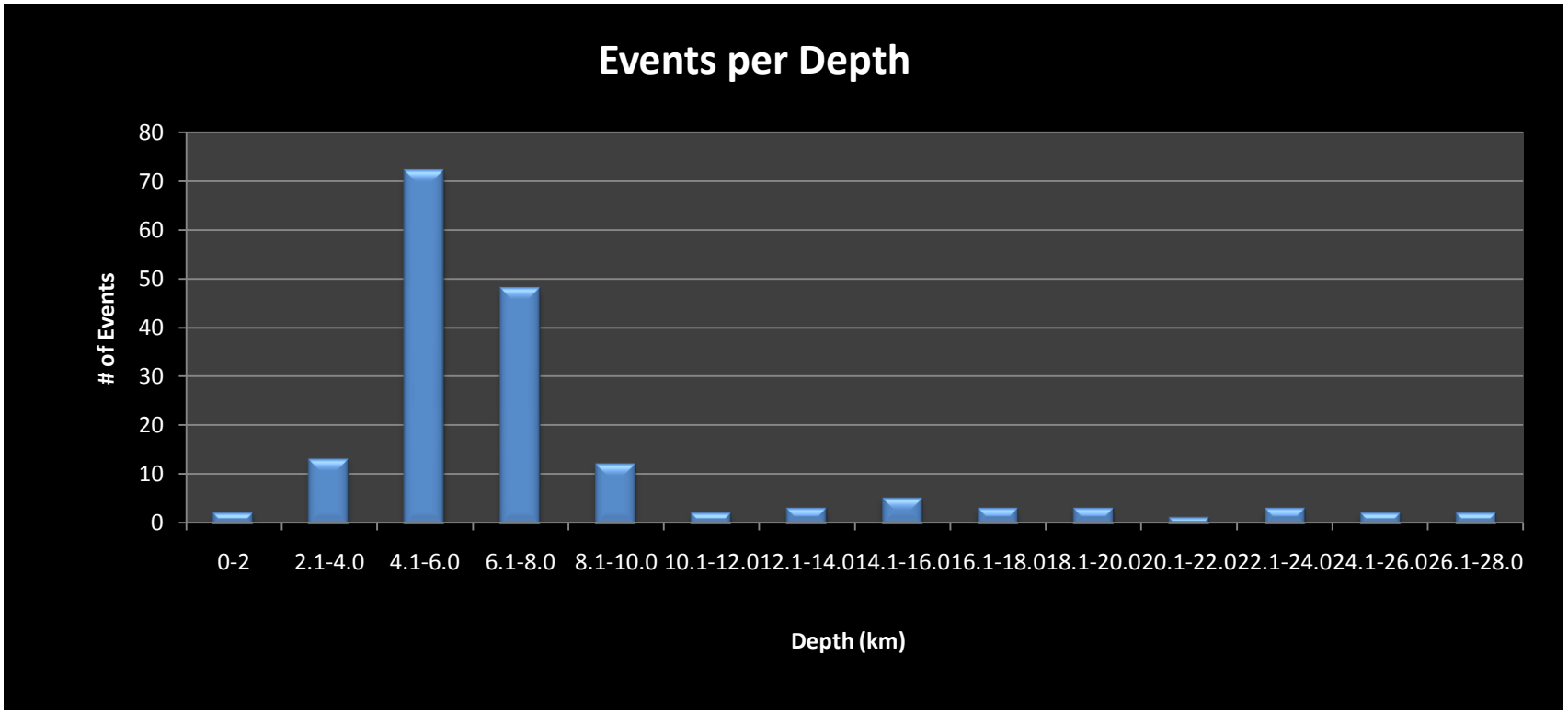
- A significant increase in the number of events (200 %)



Histogram showing an increase on seismic activity during 2006-2008.

Characteristics of Microseismicity

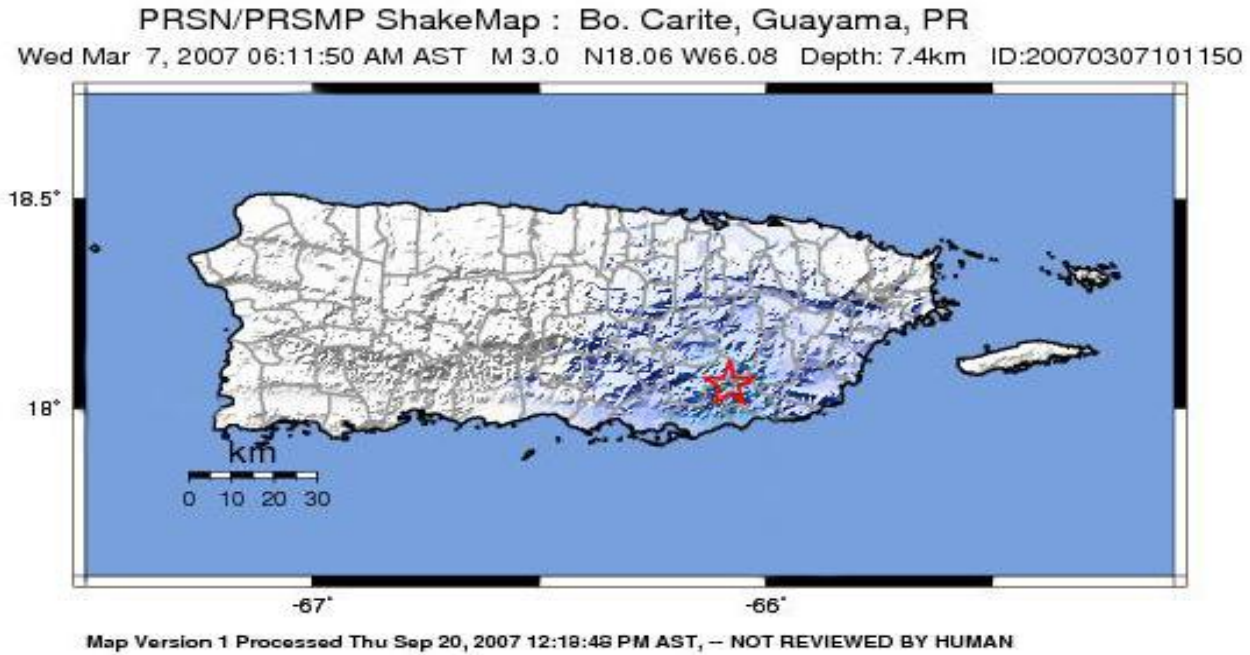
- A significant increase in the number of events
- Microseismic activity concentrated at depths of 4.0 to 8.0 km



Histogram showing microearthquakes depth distribution.

Characteristics of Microseismicity

- Felt Events
  - Nineteen (19) events during 2007 and 2008 with reported maximum intensity of V, Modified Mercalli Scale
  - The empirical shakemap for the largest event shows an intensity distribution (II-IV) for most of the southeastern part of the Island



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+

Characteristics of Microseismicity

•Swarm activity: registered on March 2007 and May 2008

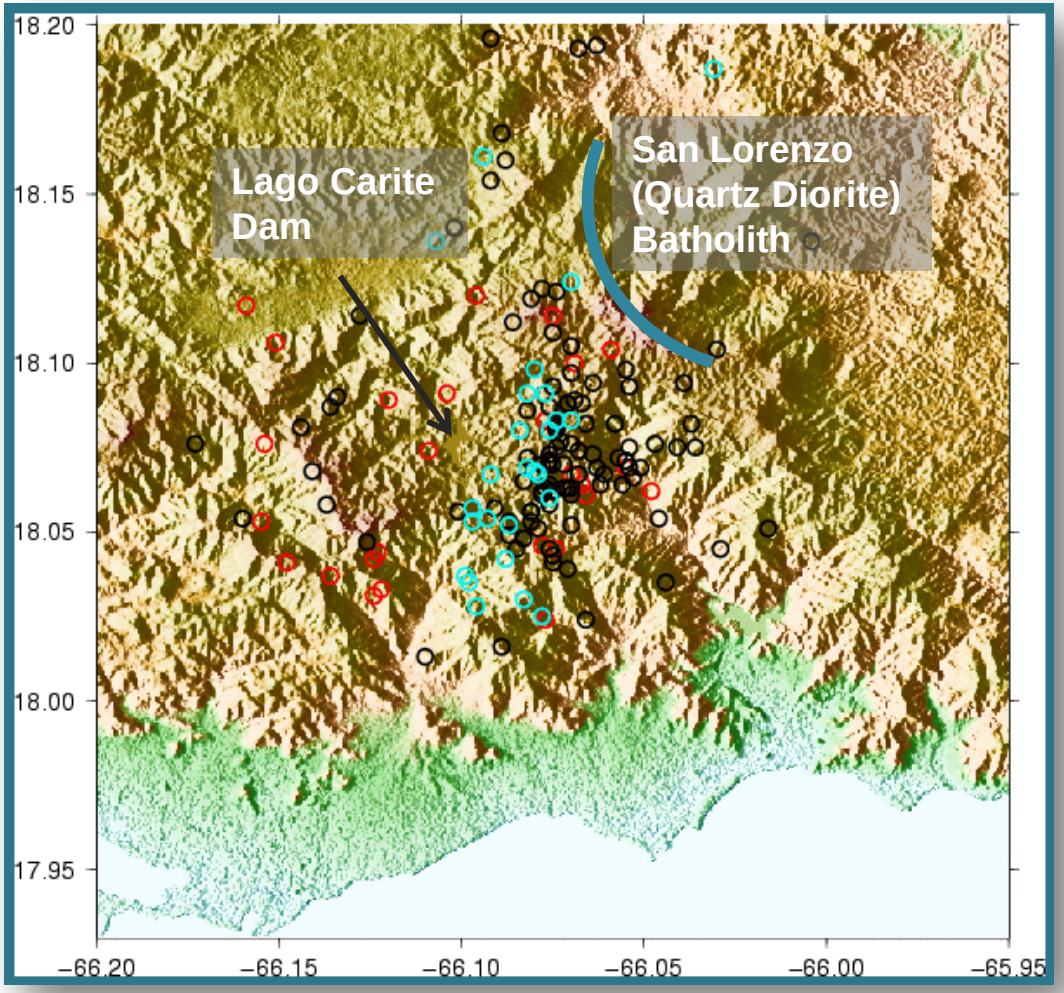
Event Locations

PRSN locations for the 181 microseisms additional events identified at SJG (13 km NW)

•(**red**) 2006 → sparse epicentral distribution

•(**black**) 2007 → align in a N-NE to S-SW direction → east of Lago Carite

•(**blue**) 2008 → locate parallel and to the east of the 2007 sequence



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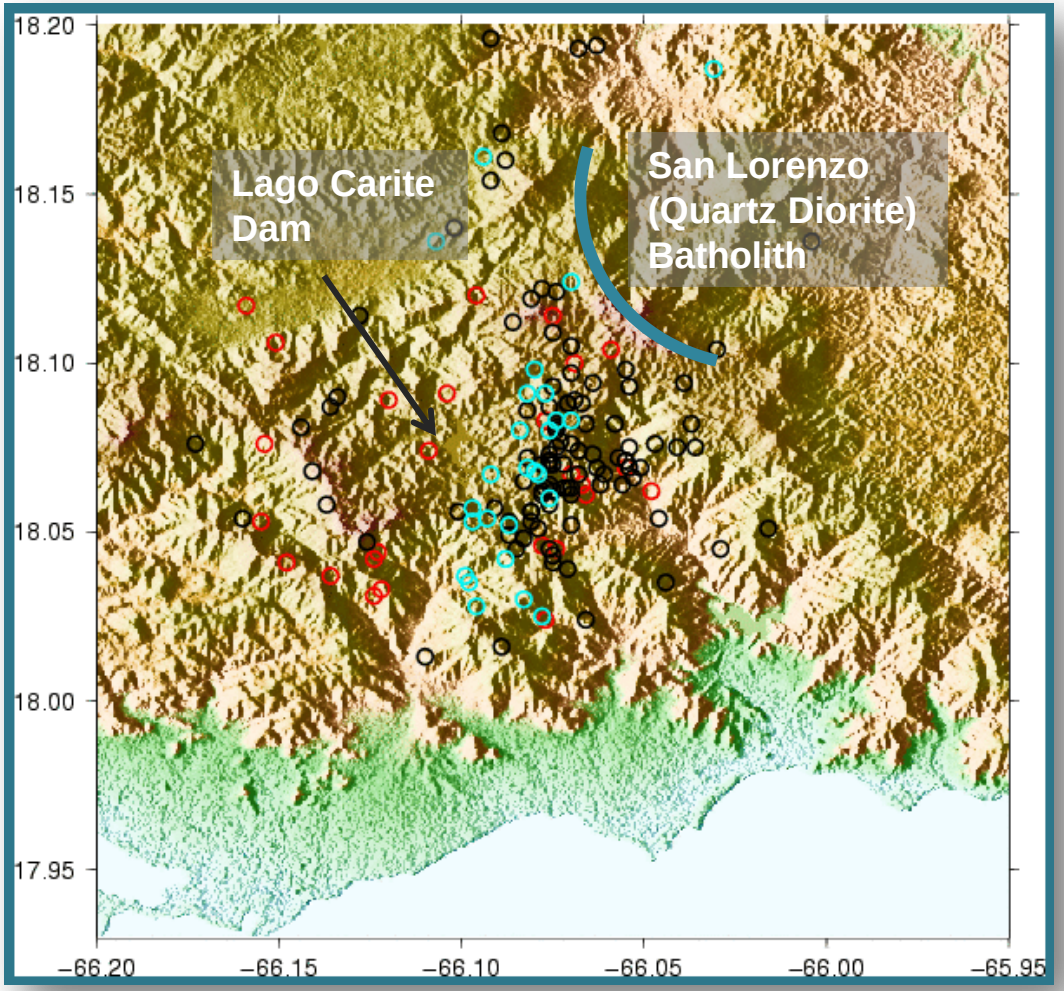
Seismicity:

➢Swarm events migration

➢It stops at contact with the San Lorenzo Batolith

➢It seems to be confined to the less competent pyroclastic material.



Additional Considerations

The study and understanding of the seismological, geological and tectonic processes affecting the study area is of the utmost importance due to their possible impact on the local and regional infrastructure and, the property and life of residents in local and nearby towns.

➢Proximity to Lago Carite Dam

Seismicity concentrates east of Lago Carite → aligns in N-NE to S-SW direction

➢Proximity to populated areas

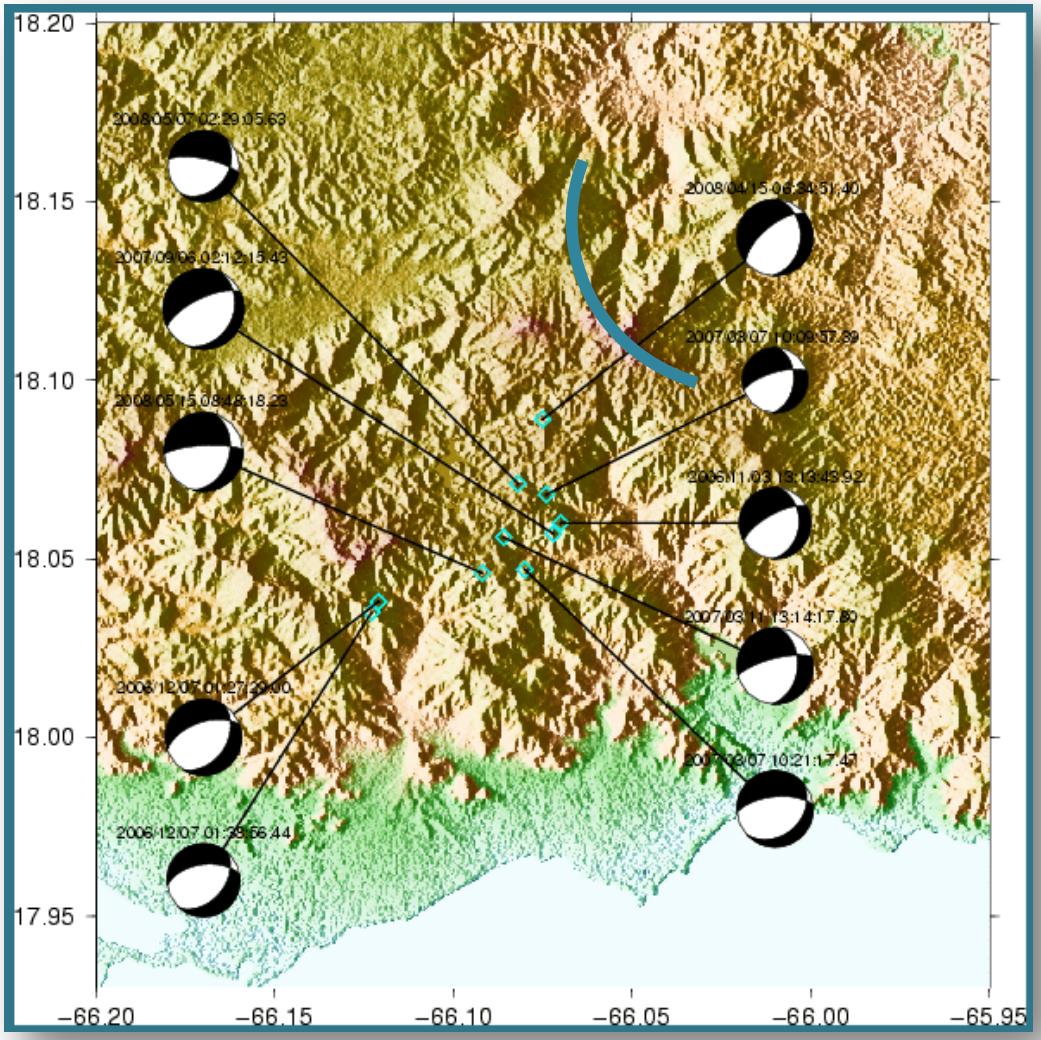
(population over 130,000)

shallow seismicity → seismic wave attenuation is minor than for deeper earthquakes →ground shaking will be stronger

➢Landslide prone area

September 21, 2008 heavy rainfalls associated to a tropical wave → Study area & nearby towns declared as major disaster zone by US President

Preliminary Assessment



First Motion Focal Mechanisms

•35 events with mag ≥ 2.5 (Md).
•Locations refined by re-picking and using only the best quality phases
•Focal mechanisms were determined for events with the largest amount of phases and best station distribution.

•Two NNE-SSW striking normal faulting earthquakes; 2006 events

•2007-2008 swarm activity: double-couple fault plane solutions for also show a normal faulting stress pattern with a strike-slip component.

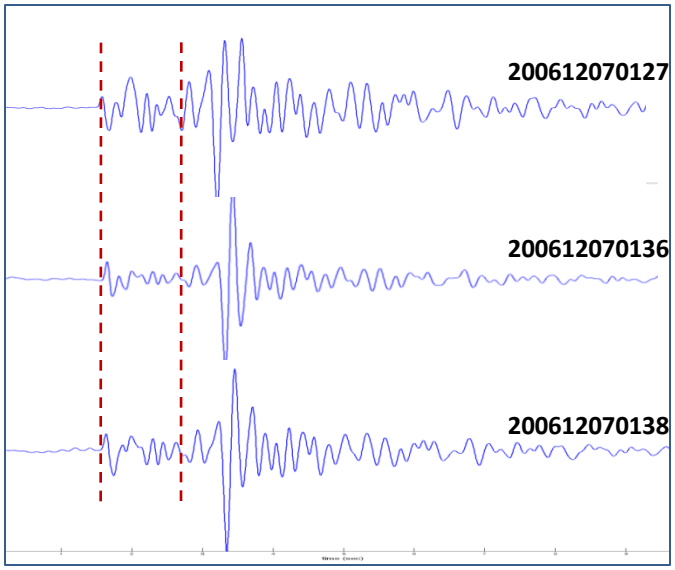
First motion focal mechanisms suggesting an extensional regime in the study area.

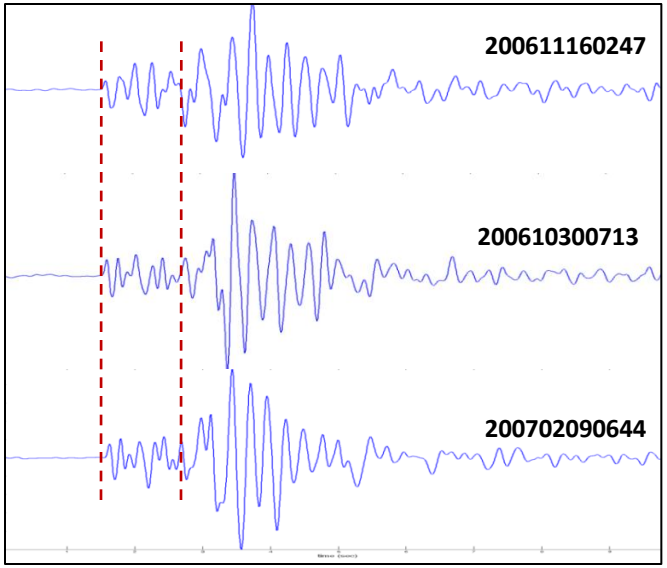
Waveform and Time-Frequency Analysis

Waveforms from the subset of 35 events (Md≥2.5) → vertical component of SJG

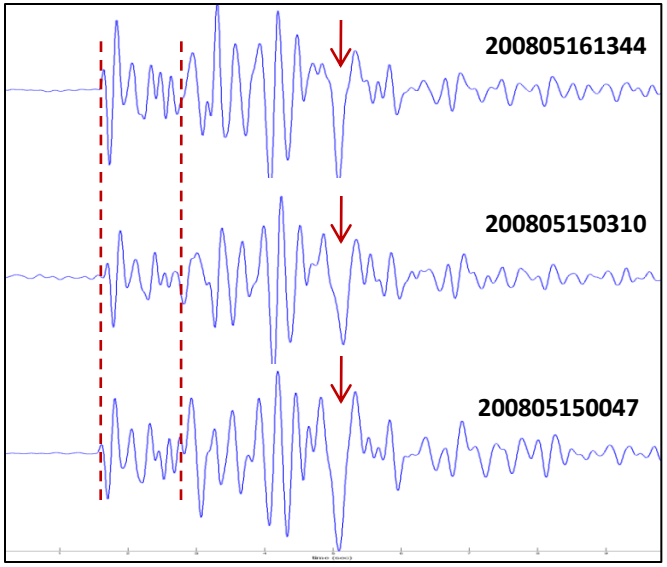
Filtered, normalized, aligned and plotted for a window of 10 seconds.
Events were classified into three groups based on their waveform similarity.

Group 1





Group 2



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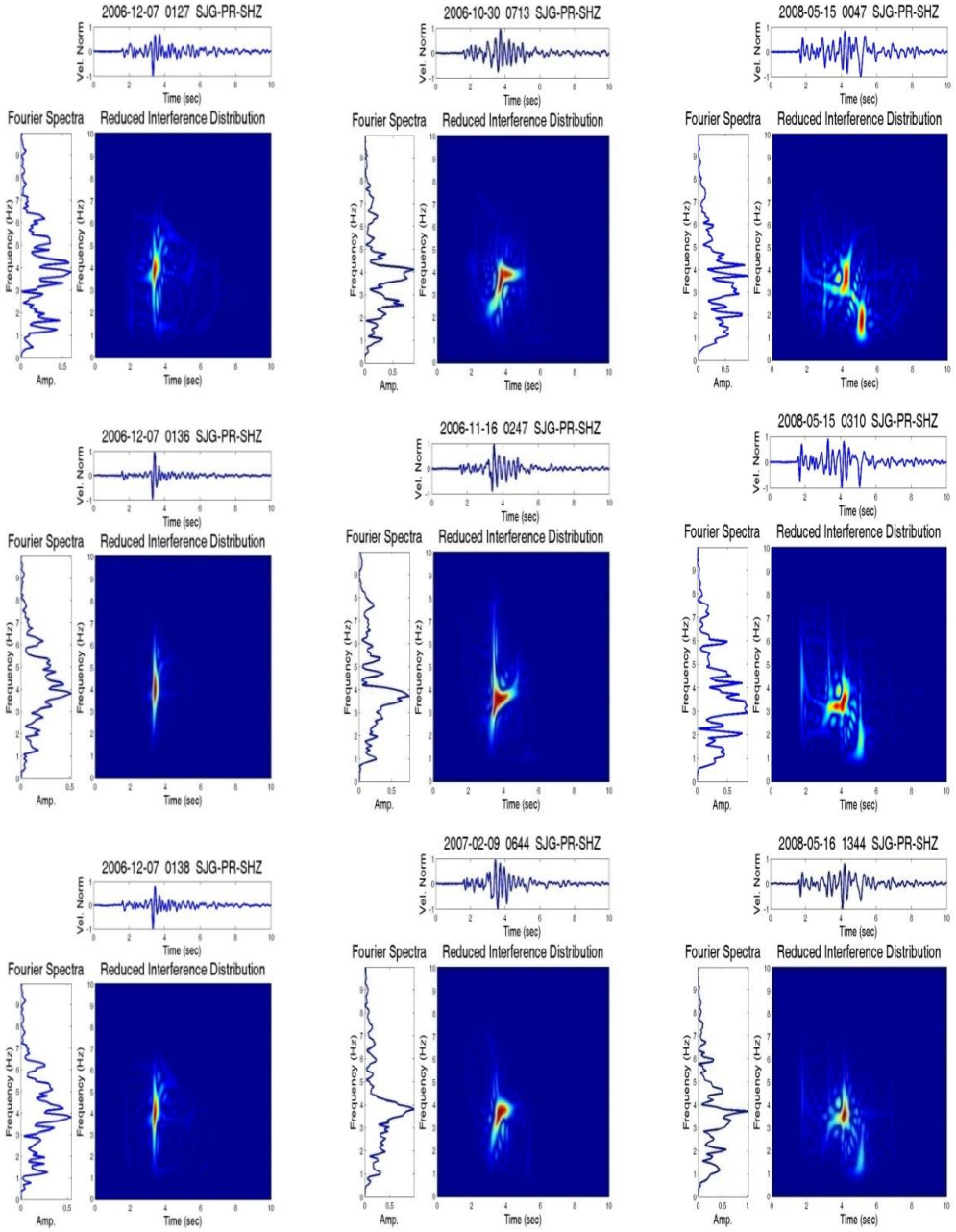
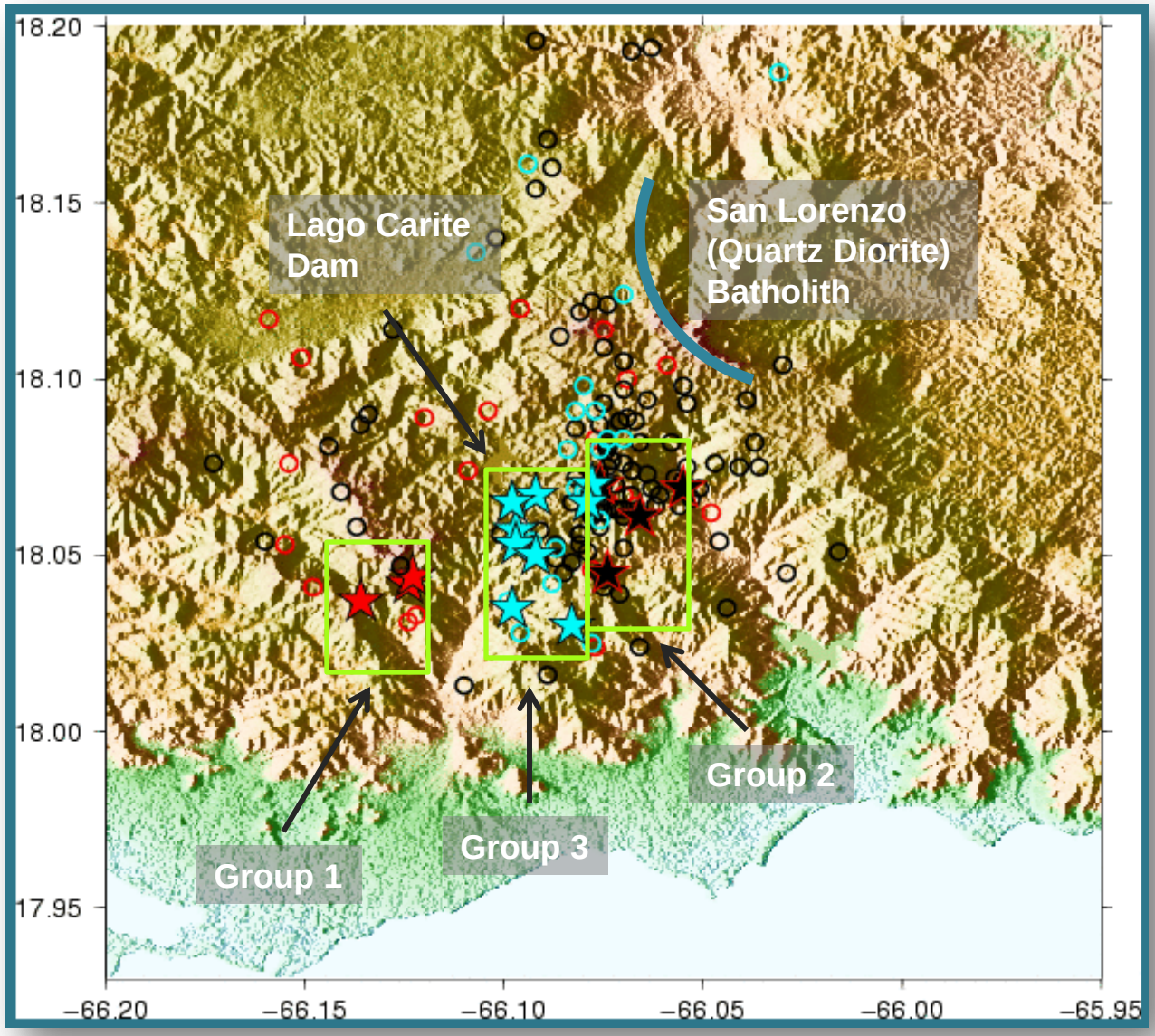


Group 1 **Group 2** **Group 3**

Time-Frequency Analysis

Time-Frequency Distribution Plots (T-F) were also generated for the same data set using a Reduced Interference Distribution (RID).

When comparing the results of these two (2) methodologies we found that the events were independently grouped in a similar manner.



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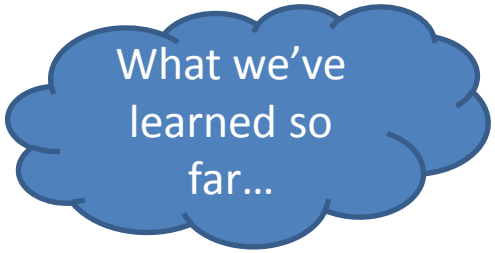

Summary

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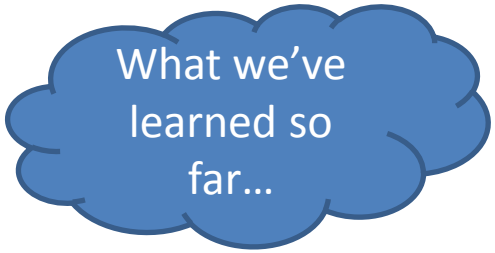

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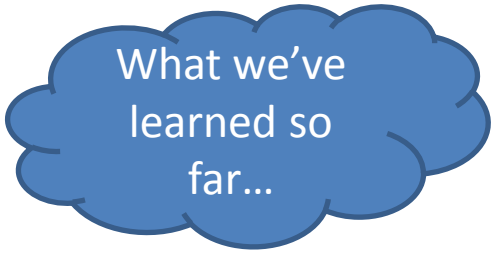
- Seismic activity seems to be confined to the least competent (pyroclastic) materials while the San Lorenzo Batolith appears to be controlling the northern extend of the seismicity.



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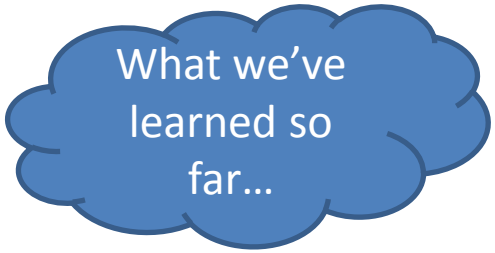

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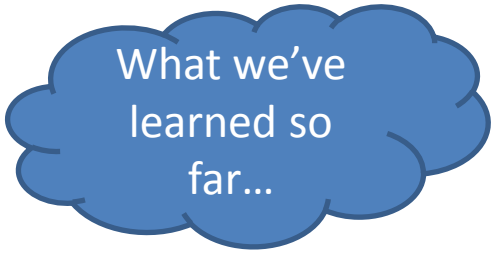
➢The study area is undergoing an extensional regime characterized by NNE-SSW trending normal faults with a strike slip component.



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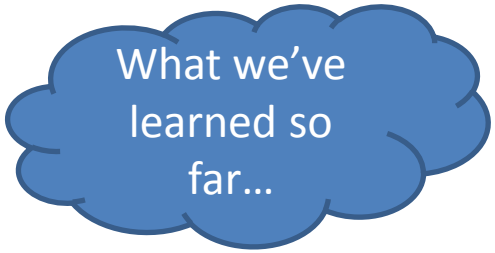
➢Waveform and T-F analysis suggest two (2) distinct normal fault systems present in the study area.



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➢Waveform cross-correlation and T-F techniques could be effective for further analysis of data set.

Future Work

❖Better constrain the area of seismicity, determine fault parameters & stress regime:

- ➢Waveform Cross-Correlation & Time-Frequency Analysis (T-F) of complete data set
- ➢High precision earthquake relocation technique →reduce the location errors.
- ➢S/P amplitude ratios to better constrain focal mechanisms

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- ➢ShakeMap Scenario based on fault parameters

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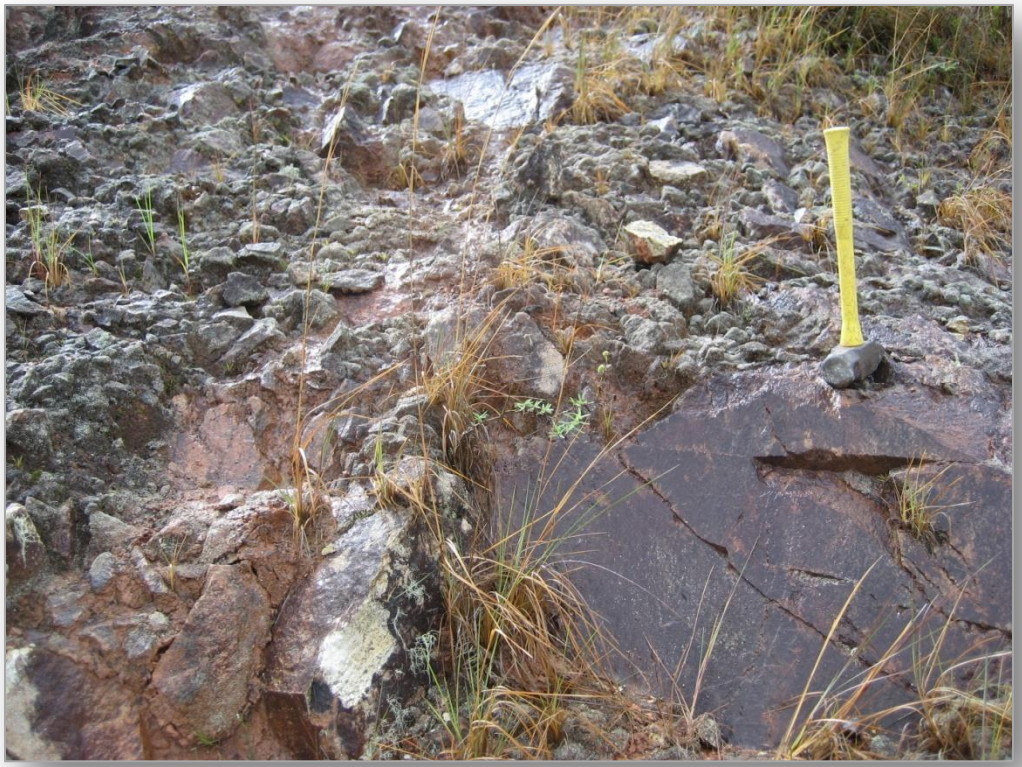
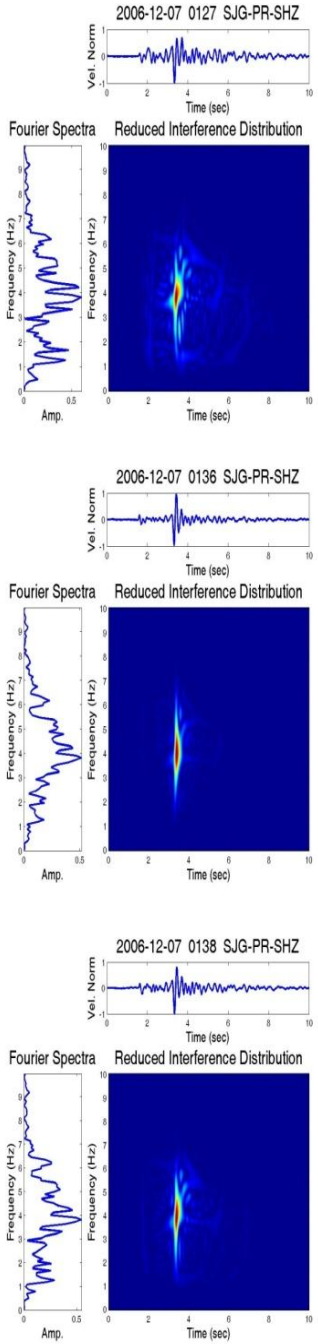
❖Improve earthquake detection & geophysical monitoring

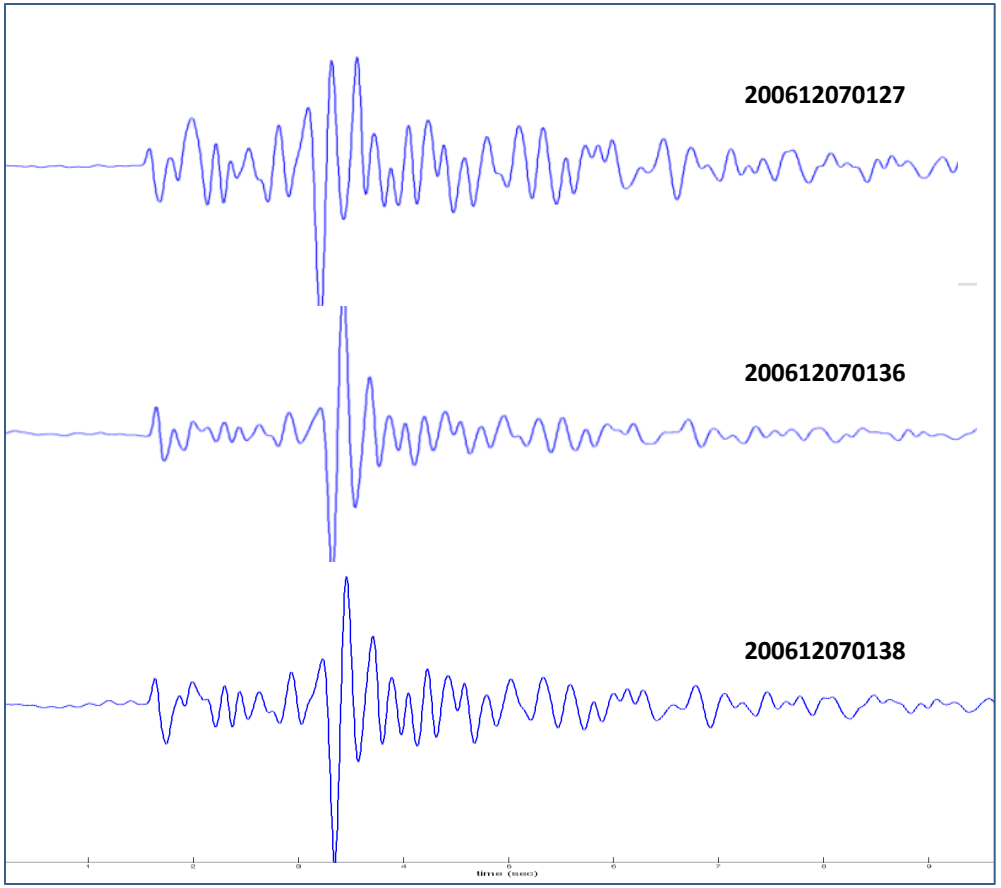
- ➢Acquisition, installation and maintenance of seismic, ground motion and GPS instruments.

Acknowledgements

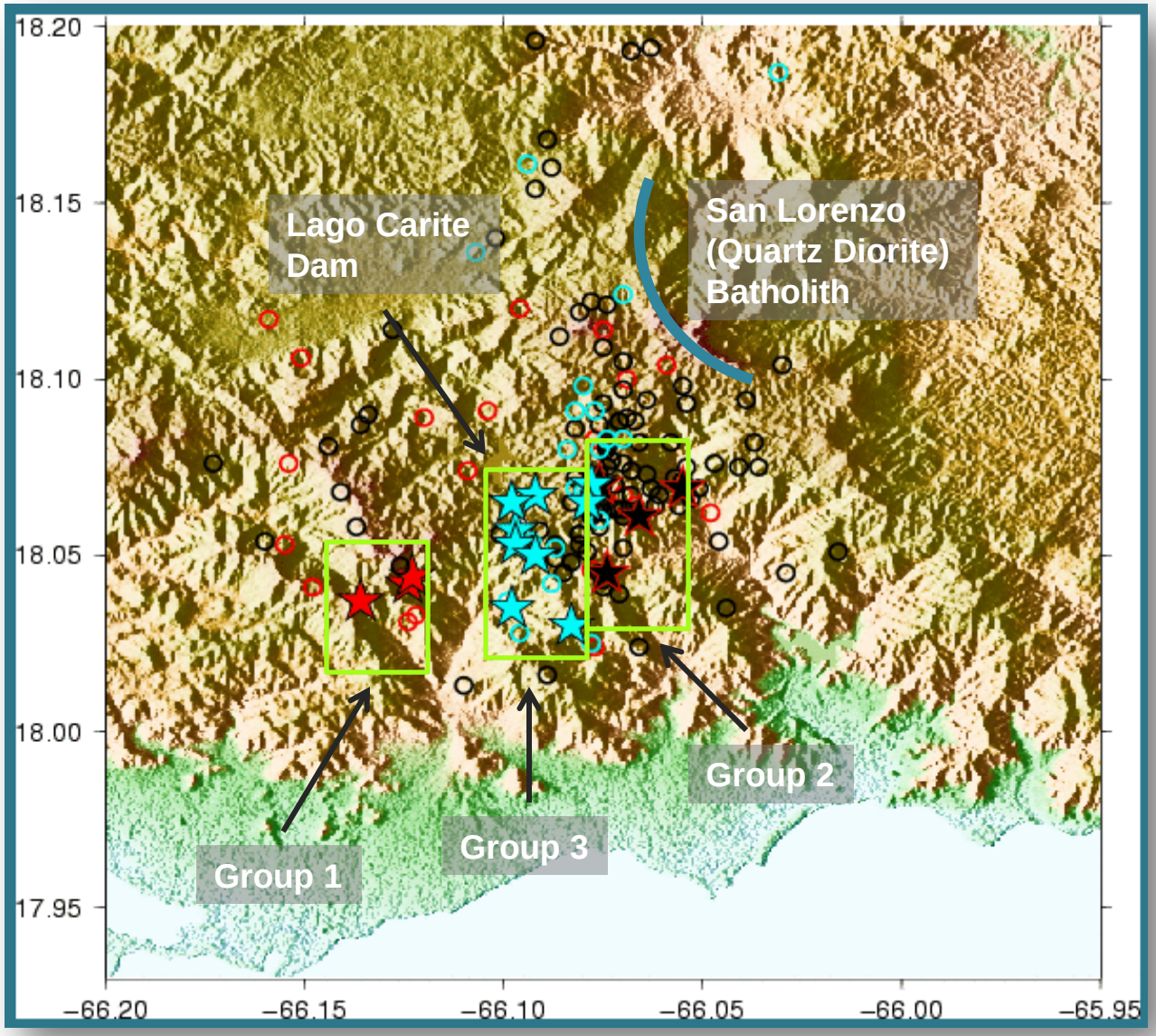
Many thanks to the PRSN staff, technicians and students for their continuous support and encouragement.







Group 1: Normal faulting microseisms that occurred in 2006 and are located to the SW of the swarm area. They are characterized by low amplitude P-wave arrivals almost imperceptible on the T-F plots. The stronger S-wave arrives at approximately 3 seconds with a frequency ranging between 2-6 Hz.



Epicentral locations

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Groups of events identified by waveform and T-F similarity

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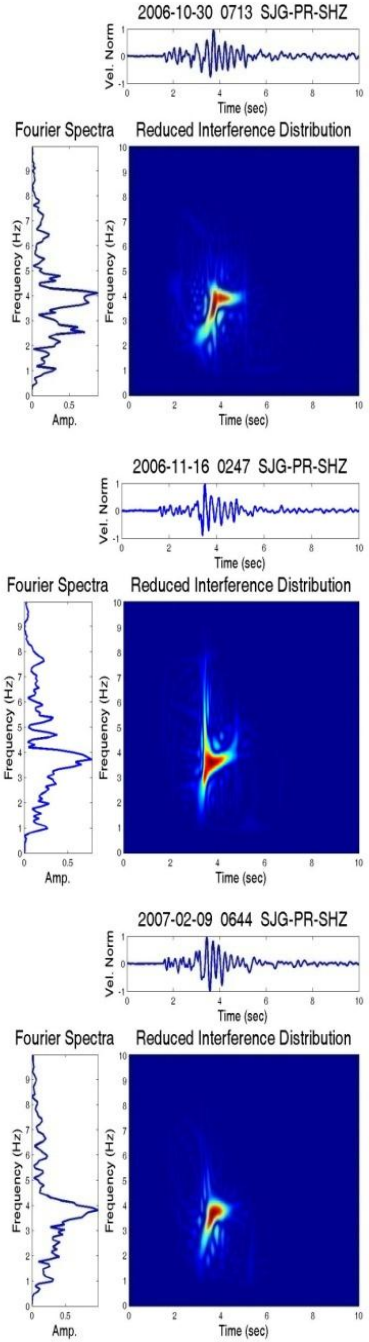
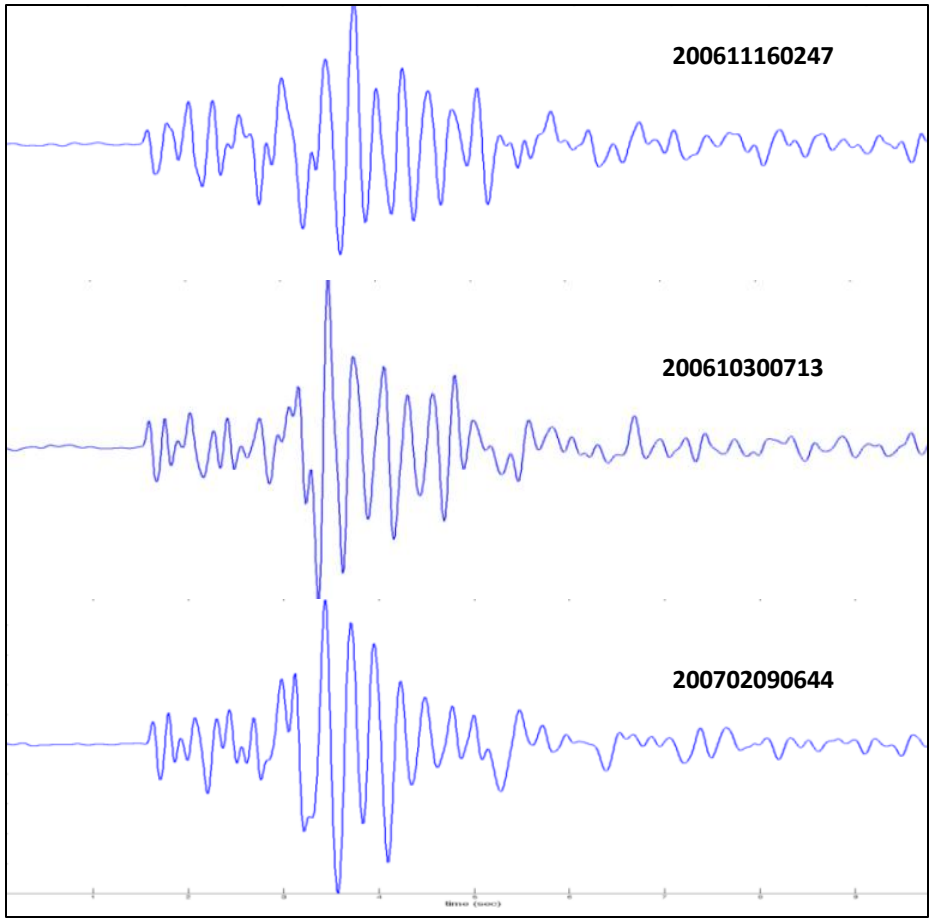
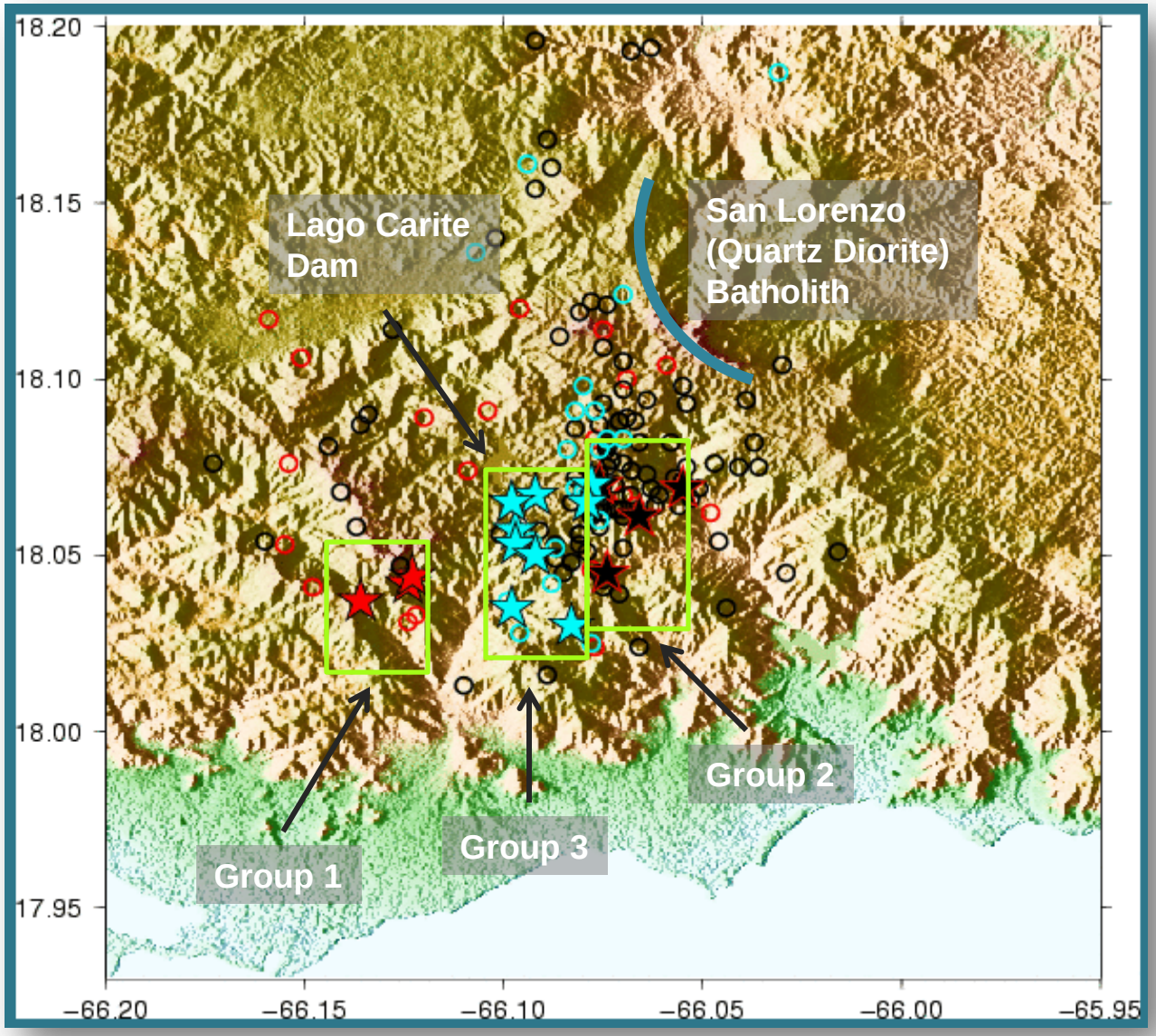




Group 2 Low amplitude P-wave of swarm earthquakes is almost imperceptible on the T-F plots. The S-wave arrives at approximately 2.8 seconds with a frequency range of 2.5 to 4 Hz. The strongest energy signals extend from 3 to 5 seconds.



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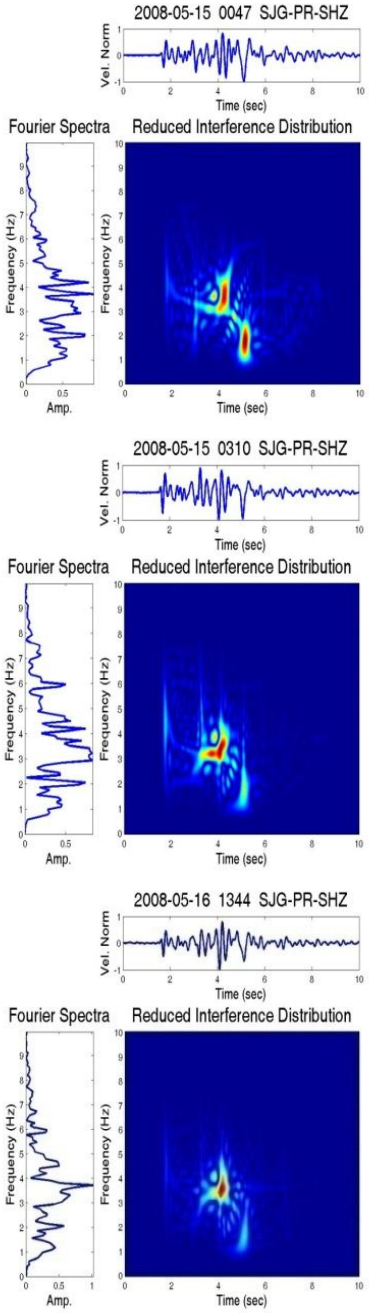

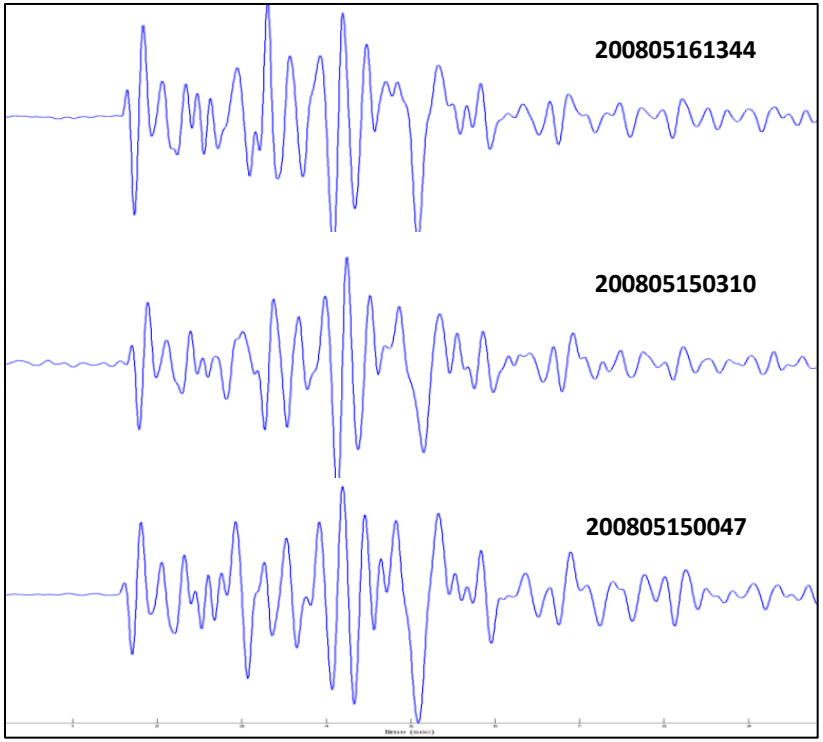

Group 3 It comprises only events that occurred on 2008 in the swarm area. The P-wave signal is clearly observed on the T-F plots arriving at 1.5 sec. The strong signal of the S-wave is observed between 3.5 and 4.5 seconds with the highest amplitude occurring at frequencies 3-5 Hz. These events are also characterized by a longer period, high amplitude, dispersive phase that arrives about 2 seconds after the S-wave. This phase can be clearly distinguished on the T-F plots as a low frequency signal at around 5 seconds. Its frequency content ranges from 1 to 2.5 Hz. It could be related to the geological characteristics of the study area.