Submarine landslide as the source for the October 11, 1918 Mona Passage tsunami:

New geological evidence, observations and tsunami modeling results.

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On Friday, October 11, 1918 at 10:14 am local time, Puerto Rico experienced an (M_L 7.5 Gutenberg & Richter, [1954], M_W 7.2 Doser et al. [2005]) earthquake originating in the Mona Passage between Puerto Rico and the Dominican Republic.

Seismic waves were followed by a tsunami that affected first the northwest coast of Puerto Rico and progressively south along the coast.

Approximately 110 lives were lost due to the earthquake and the tsunami, with approximately $4 M estimated in damages.

Tectonic or landslide? Exact cause of the tsunami was unclear.

Repeat of such an event today would be catastrophic and damages estimated in the tens of millions.

Field survey documented tsunami observations at seven locations in western Puerto Rico.

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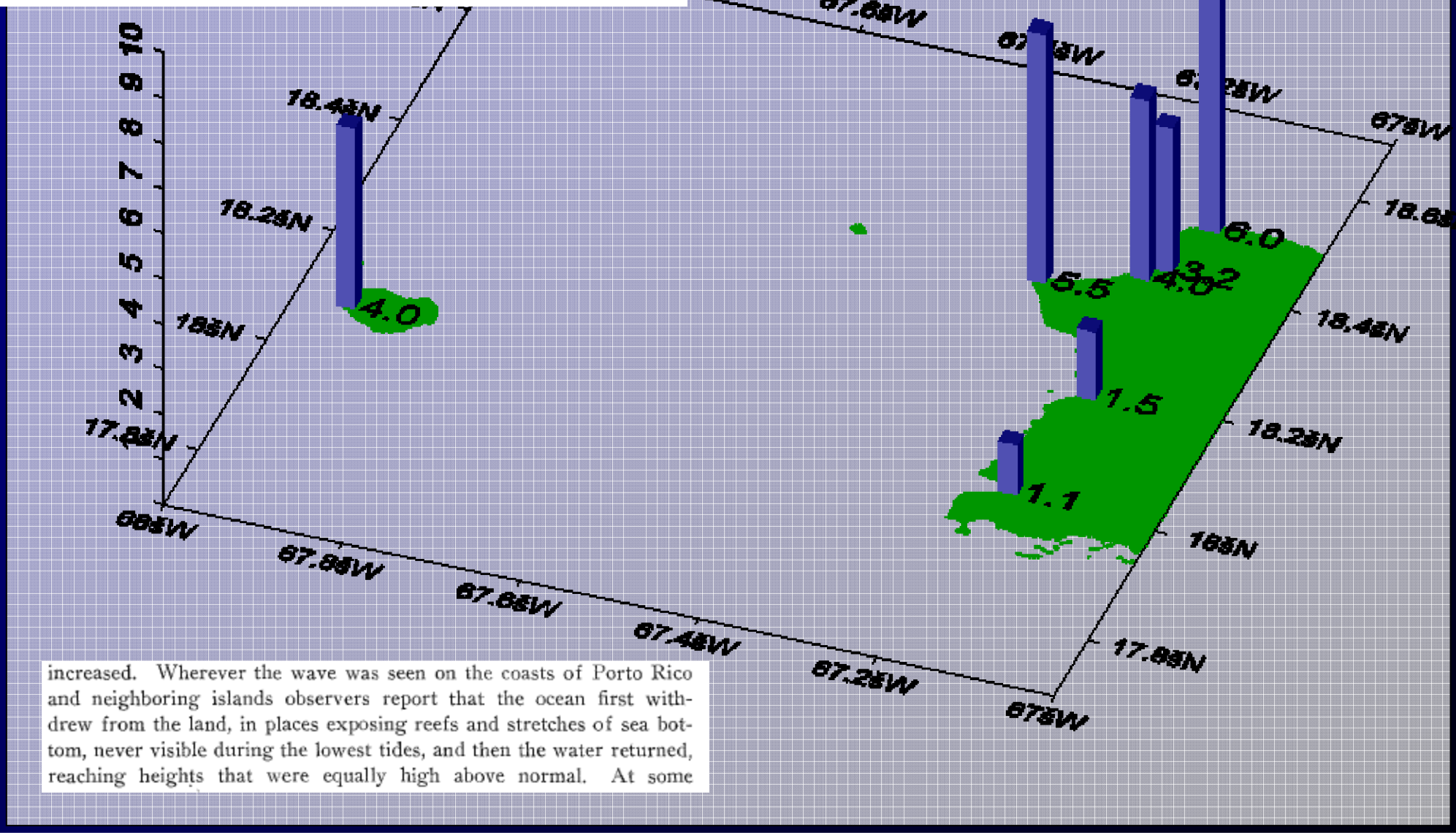
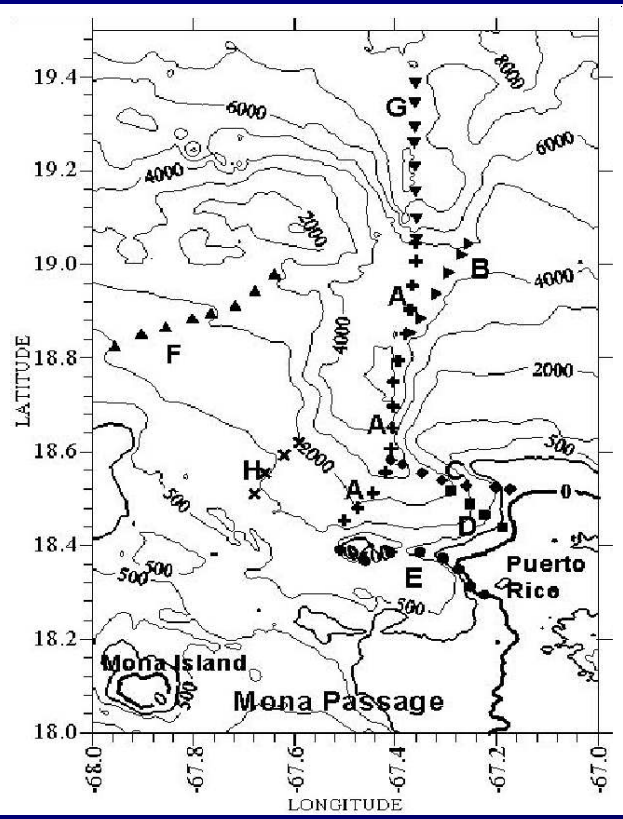
THE PORTO RICO EARTHQUAKES OF OCTOBER-NOVEMBER, 1918.

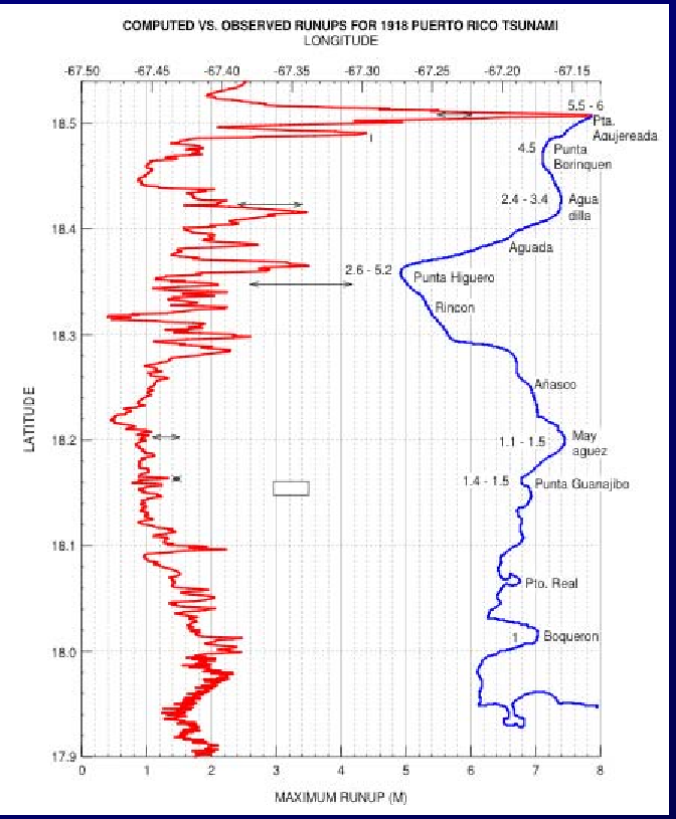
By Harry Fielding Reid and Stephen Taber



increased. Wherever the wave was seen on the coasts of Porto Rico and neighboring islands observers report that the ocean first withdrew from the land, in places exposing reefs and stretches of sea bottom, never visible during the lowest tides, and then the water returned, reaching heights that were equally high above normal. At some

Previous Work:





Mercado and McCann (1998):

-Mona Canyon fault (A): 4 segments

-Nested grids to obtain run-up and inundation values at coastal areas.

-Overall good arrival times

-Leading elevated wave

-Computed maximum wave amplitudes agree only at certain locations.

Doser et. al. (2005) waveform inversion:

-Epicenter: 18.28°N, 67.62°W

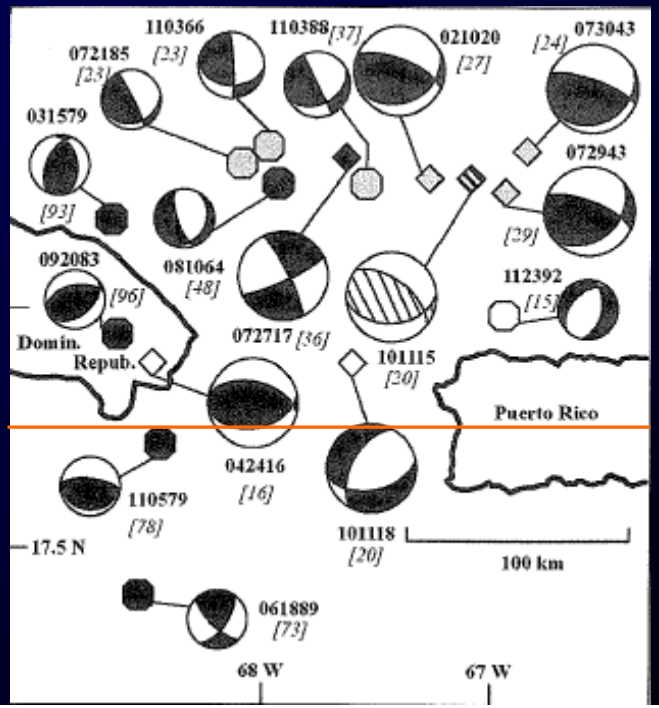
-Focal mechanism: 207, 54, -127

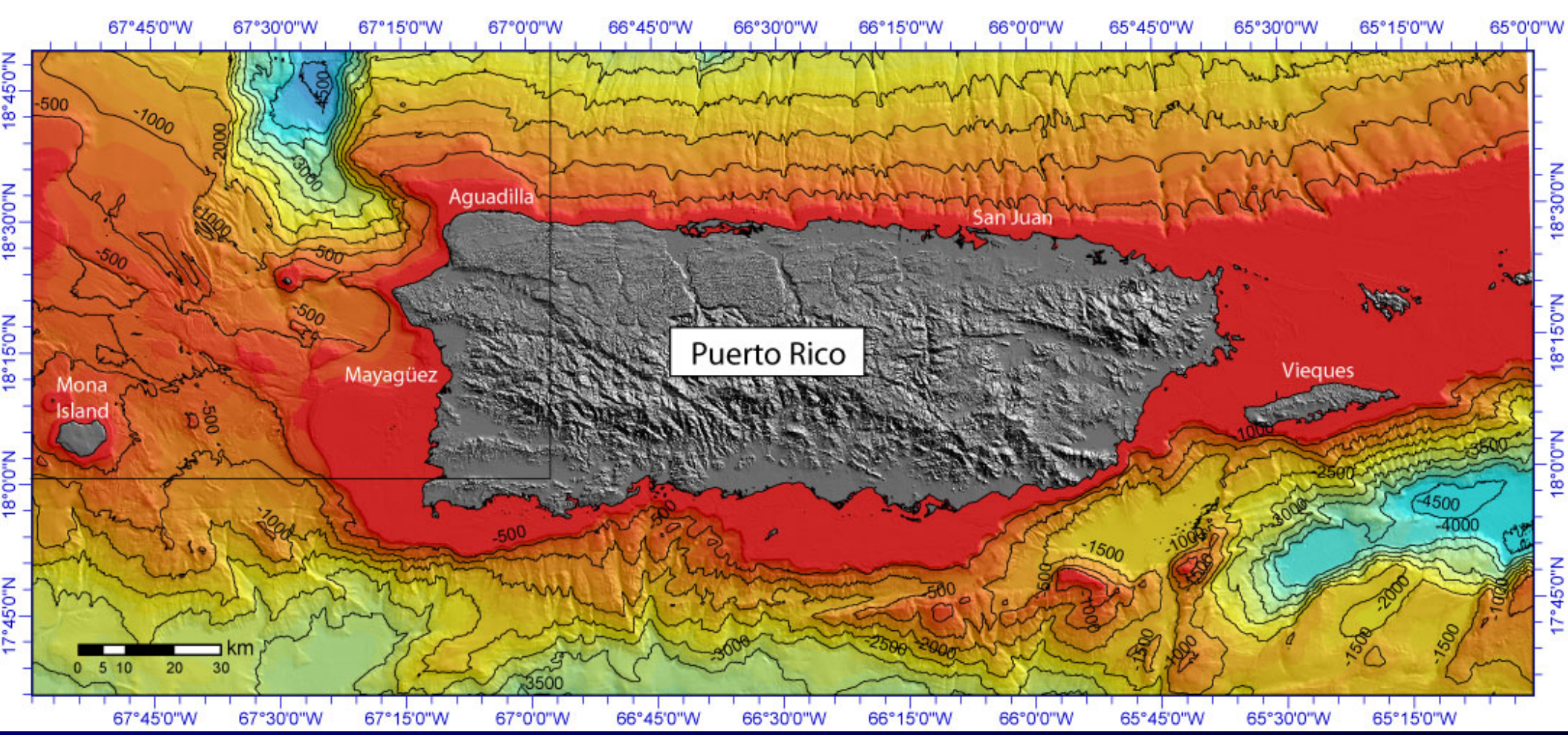
-Depth: 20±7 km (intraplate?)

-M_W=7.2 M_0=64±7 x 10^{25} dyne-cm

-Complex source-time function

-Error in map projection led to erroneous interpretation?





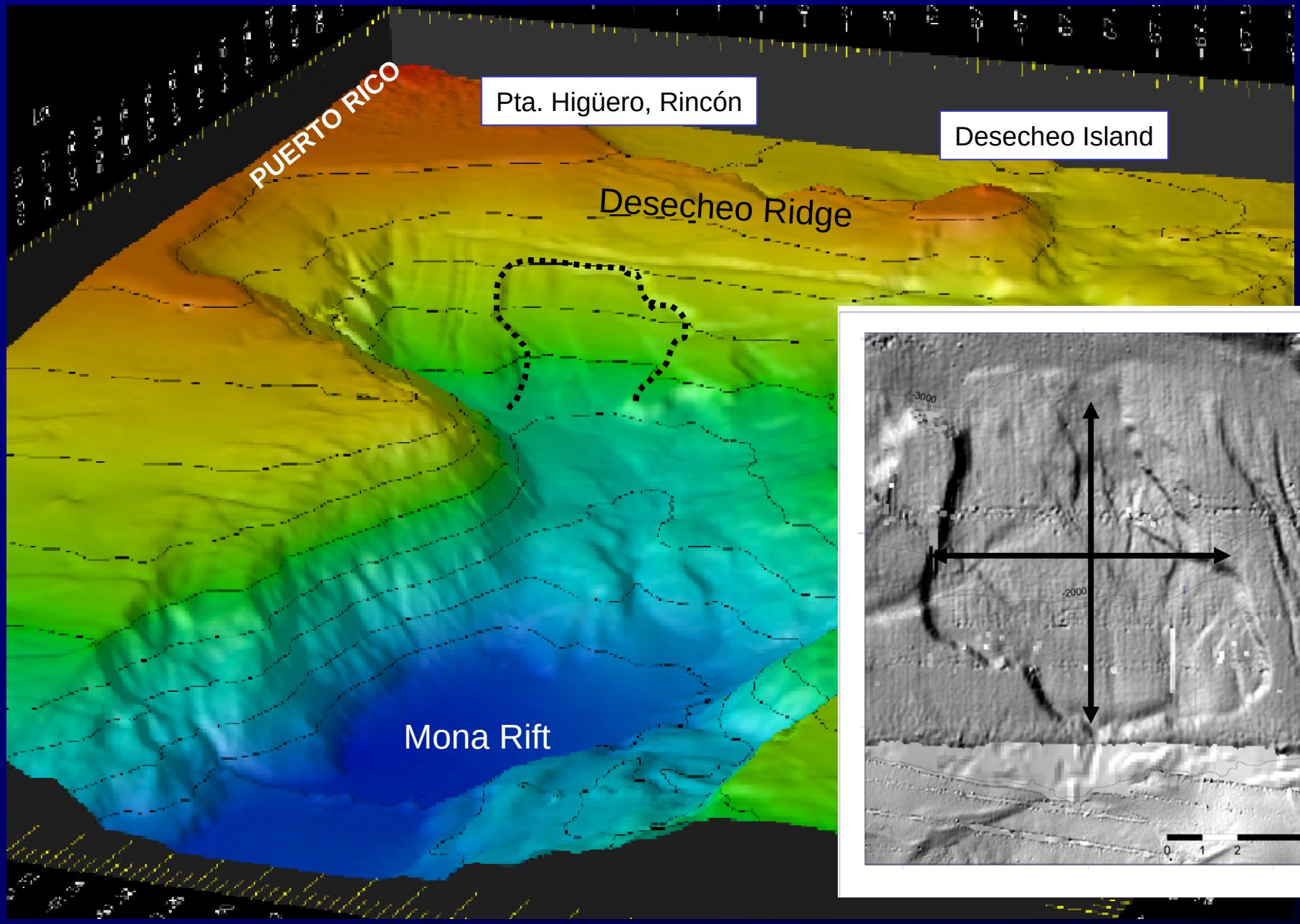
Previous studies are limited and inconclusive.

Outcome of such event today?

Advantages: Inspect available USGS high-resolution bathymetry to identify a potential source.

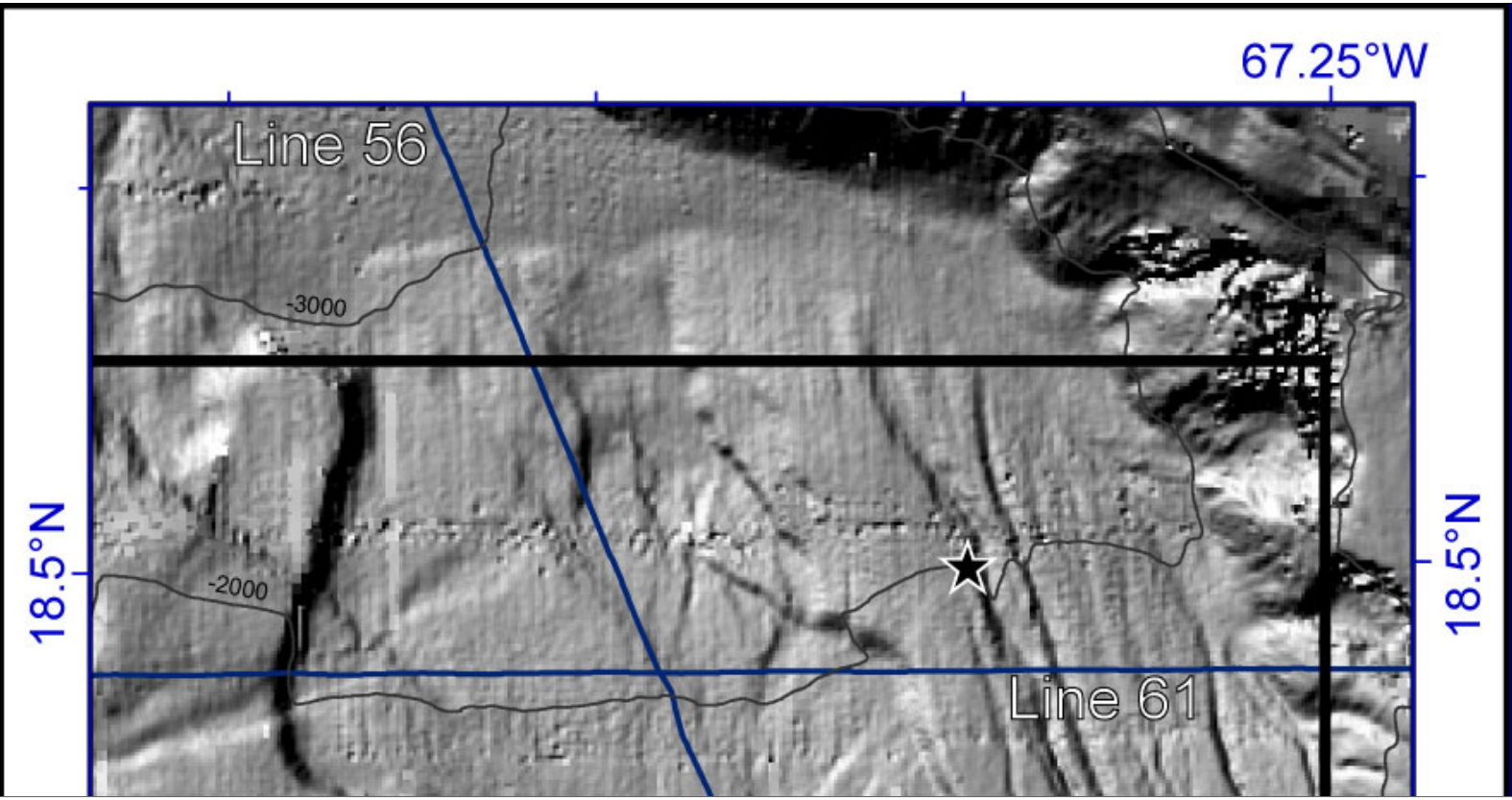
Confirm with multi-channel seismic profiles

Once the candidate source has been found, model it and then compare results with observed data.

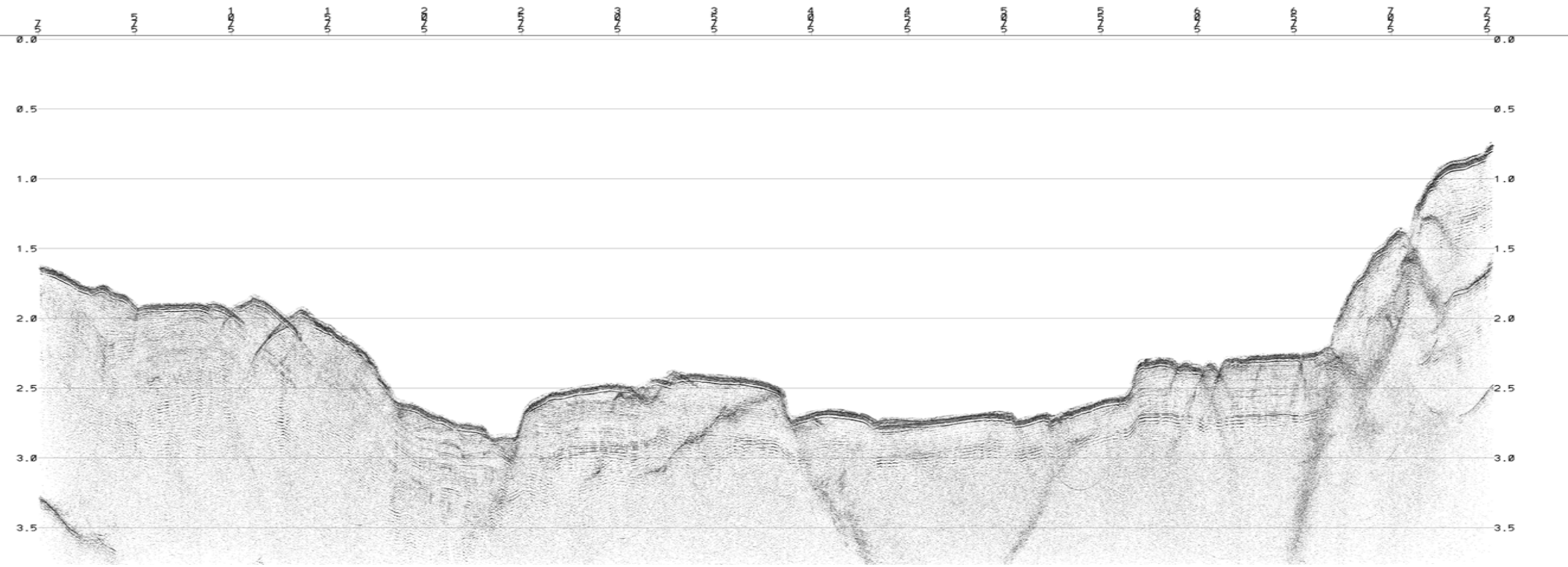


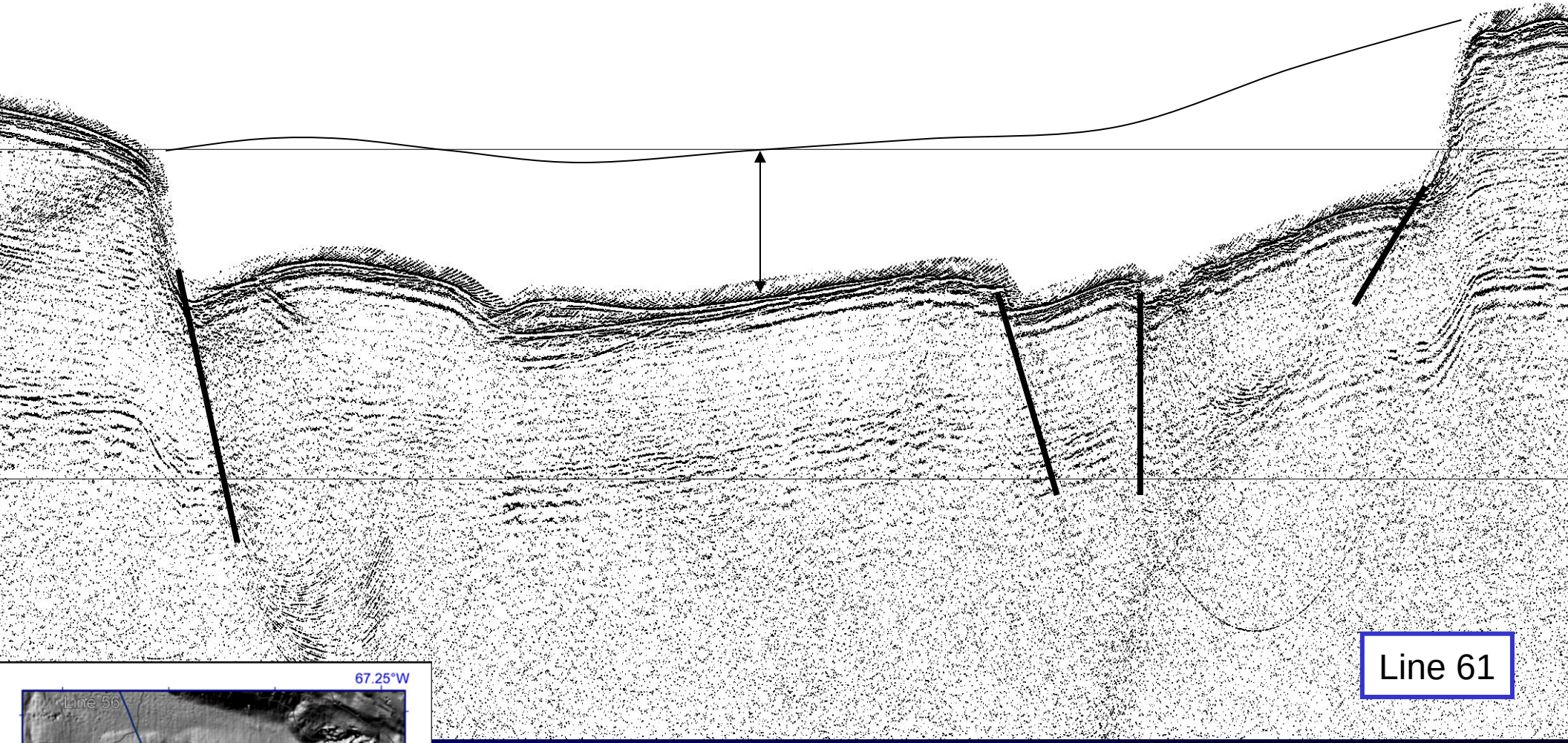
Landslide scarps north of the Desecheo Ridge seen on multibeam bathymetry.

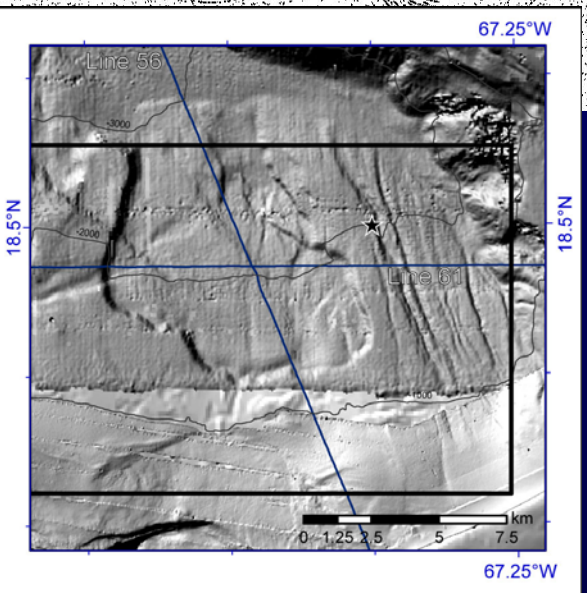
Area of landslide is approximately 76 km^2 and estimated volume is ~10 km^3



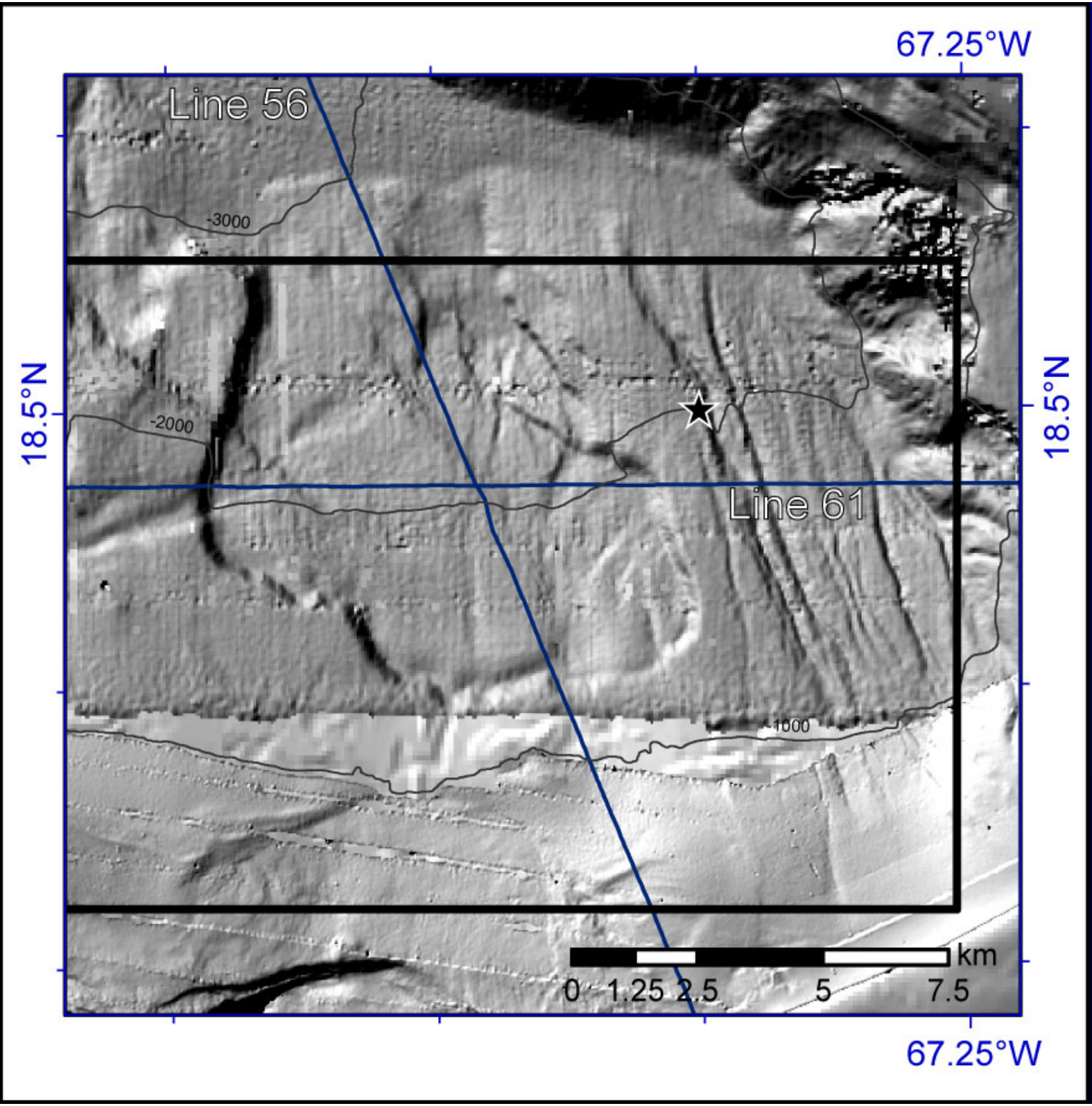
Seismic line 61 (East to West) shows landslide scarps



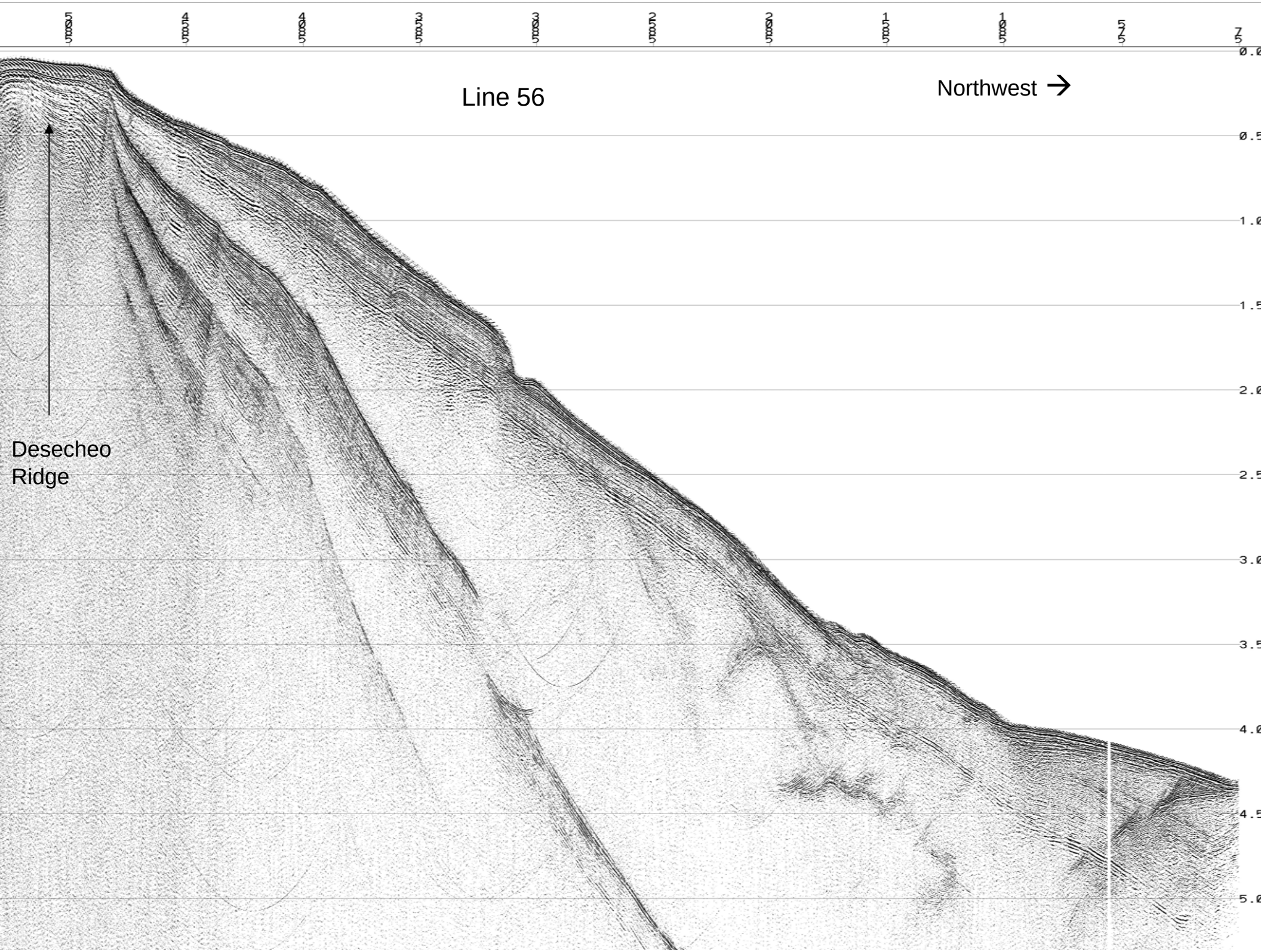


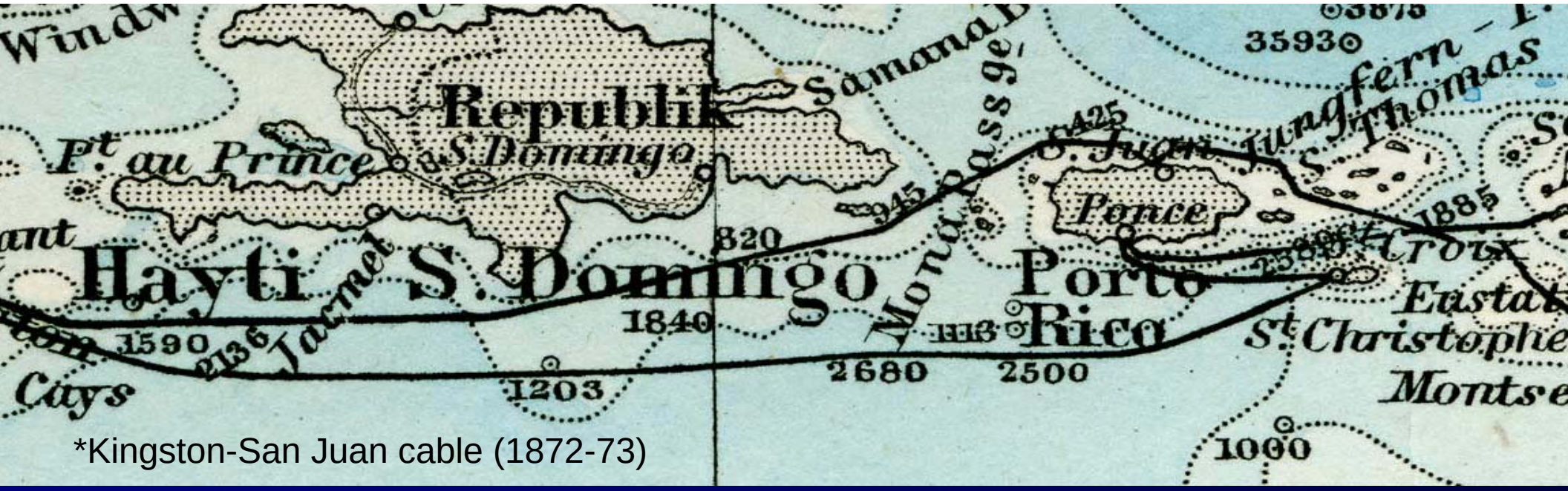


Vertical offset: ~150 meters



Seismic line 56 (NW to SW) shows landslide headscarp and show carbonate platform failed internally, probably along a weaker interface.


Line 56
Northwest →
Desecheo
Ridge
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0



*Kingston-San Juan cable (1872-73)

Reid and Taber (1919)

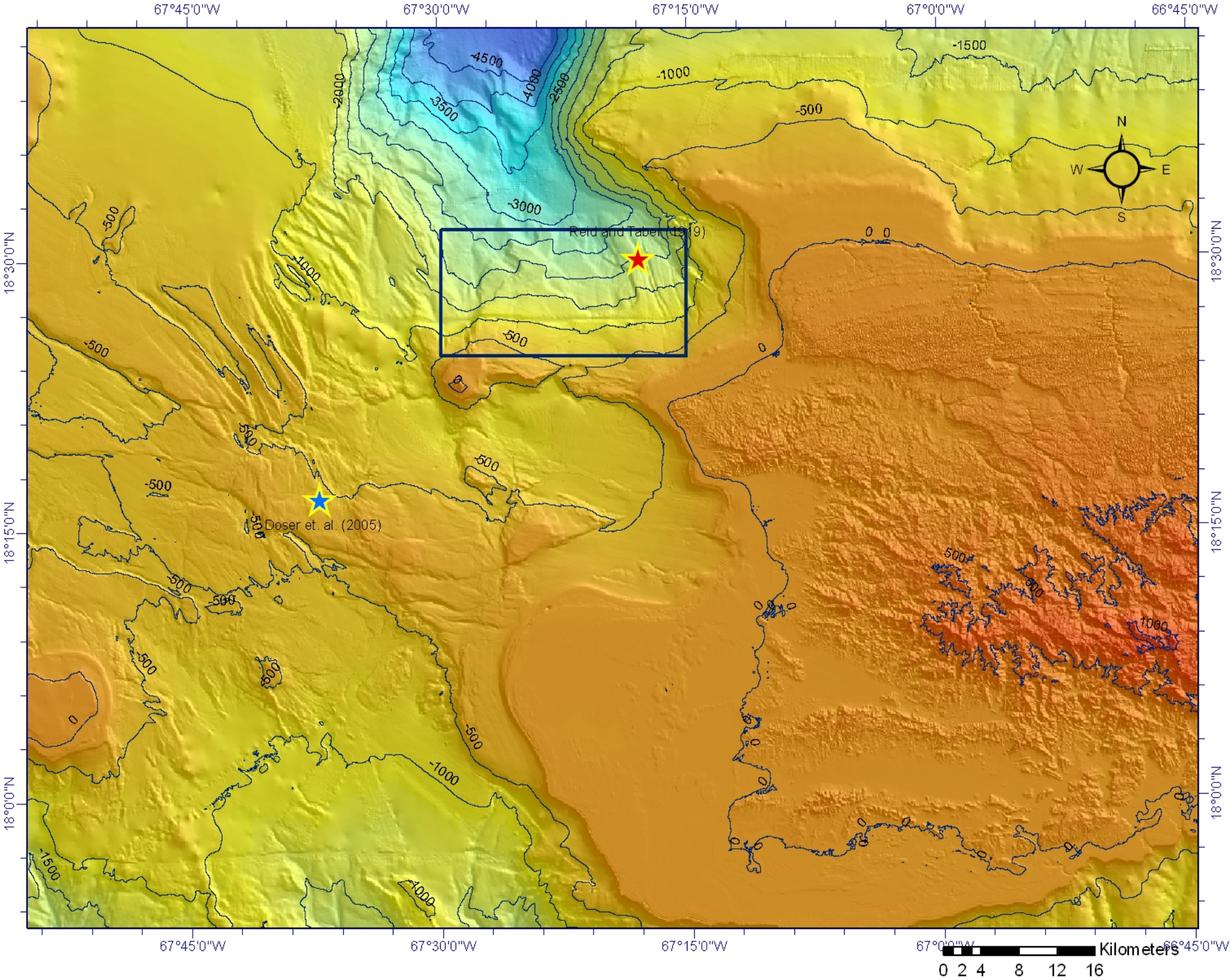
EFFECTS OF THE EARTHQUAKE ON SUBMARINE CABLES

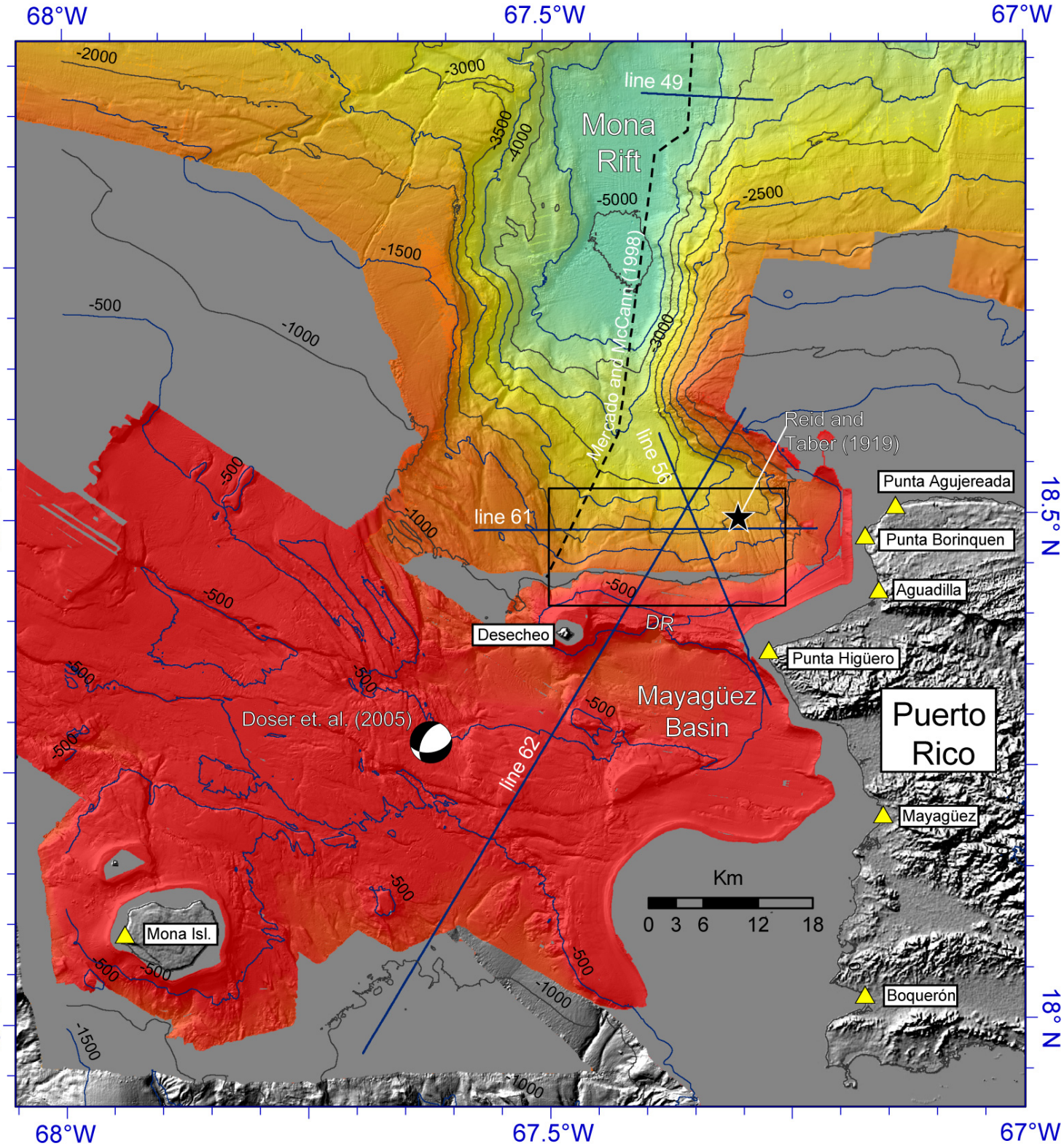
The cable of the West India and Panama Telegraph Company, connecting San Juan with Kingston, Jamaica, and the cable of the Compagnie Française des Cables Télégraphiques, from St. Thomas to Puerto Plata, Santo Domingo, were both broken at several places during the earthquake of October 11th. All of these breaks were within the area bounded by the parallels 18° 25′ and 18° 35′ north and the meridians 67° 15′ and 67° 30′ west. The cable of the French company between San Juan and Mayagüez, which runs closer inshore, was not affected.

Commander Morrell (*CS Henry Holmes*) describing the damage to the Kingston-San Juan cable:

the other cable, writes: "At the first rupture, the cable itself was not broken, but it would seem that it had been crushed by a very heavy landslide, for it was here found buried for two or three miles. The

*Source: Bill Burns http://www.atlantic-cable.com

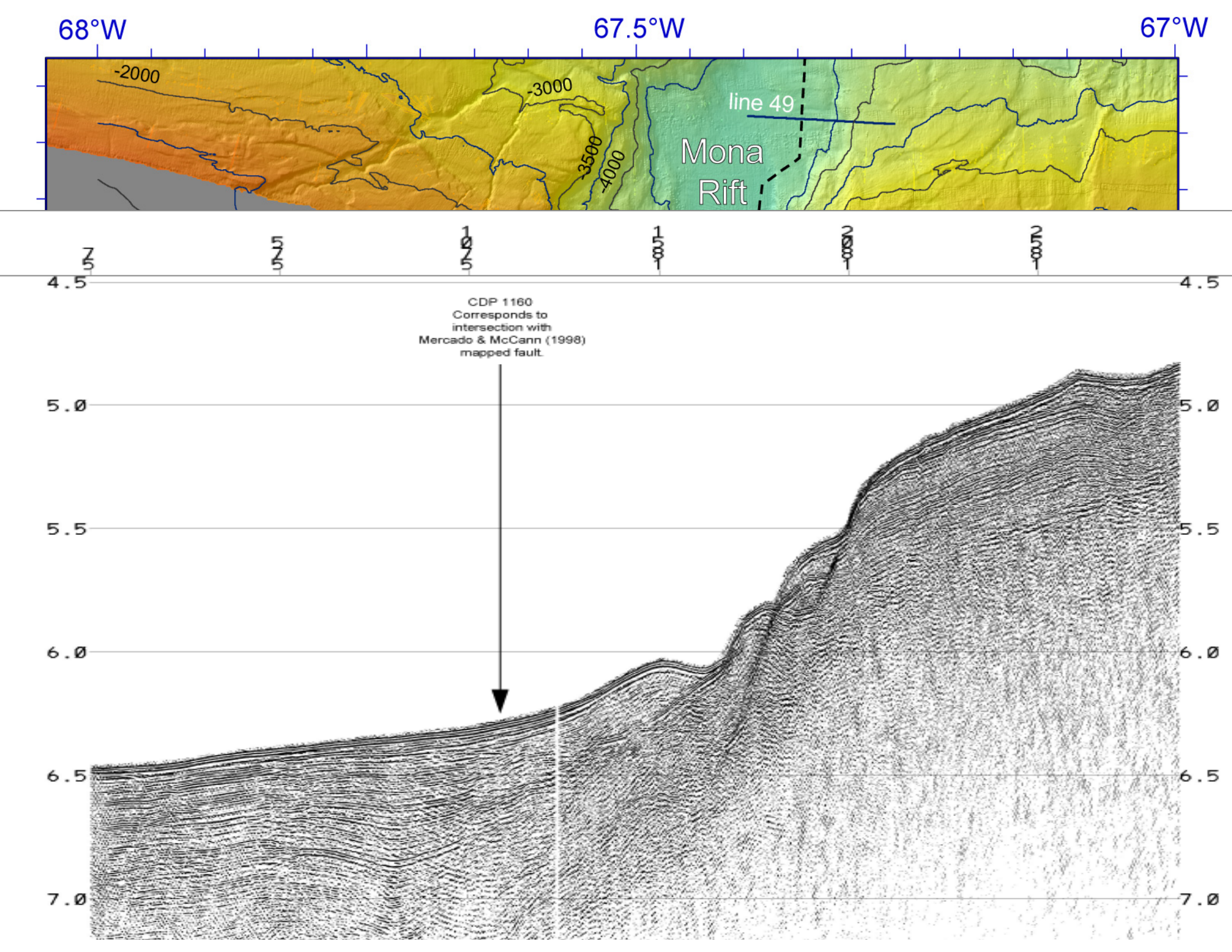

67°45'0"W
67°30'0"W
67°15'0"W
67°0'0"W
66°45'0"W
18°30'0"N
18°15'0"N
18°0'0"N
-4500
-4000
-3500
-3000
-2500
-2000
-1500
-1000
-500
0
500
1000
N
S
W
E
Reid and Taber (1919)
Doser et. al. (2005)
Kilometers
0 2 4 8 12 16

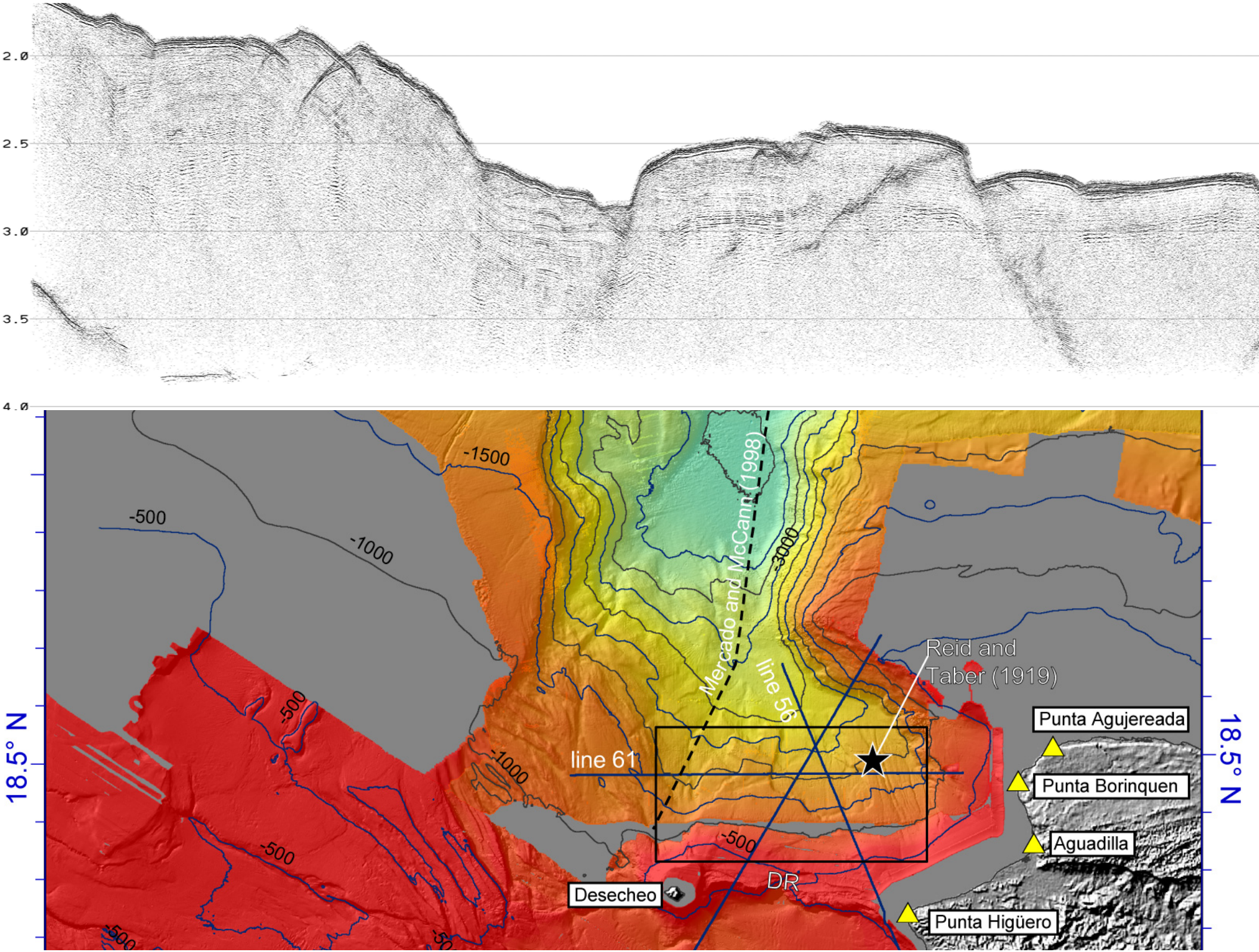


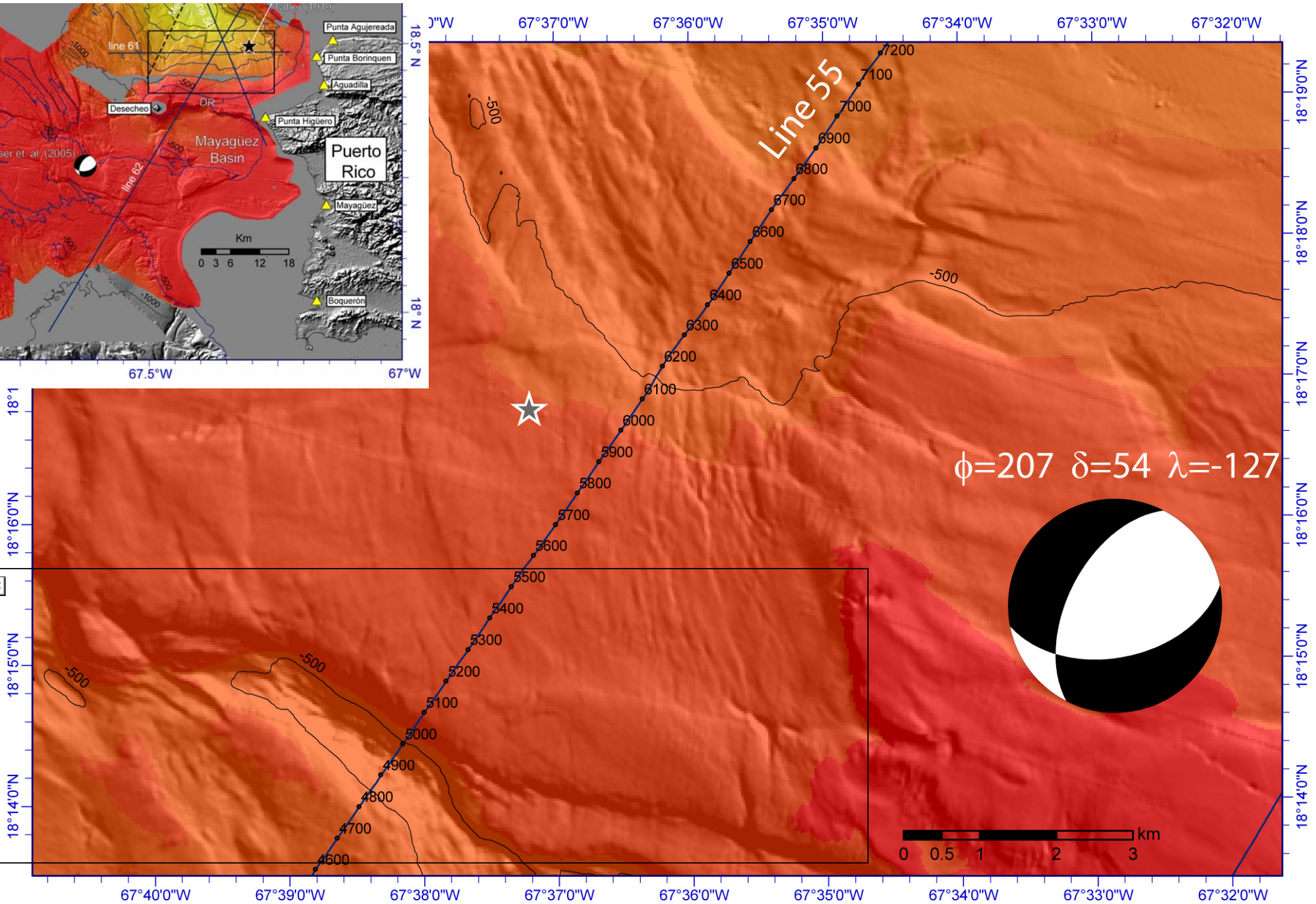
-Mercado & McCann (1998) fault starts on eastern wall of Mona Rift.

-Doser et al. (2005) epicenter plots outside this area.

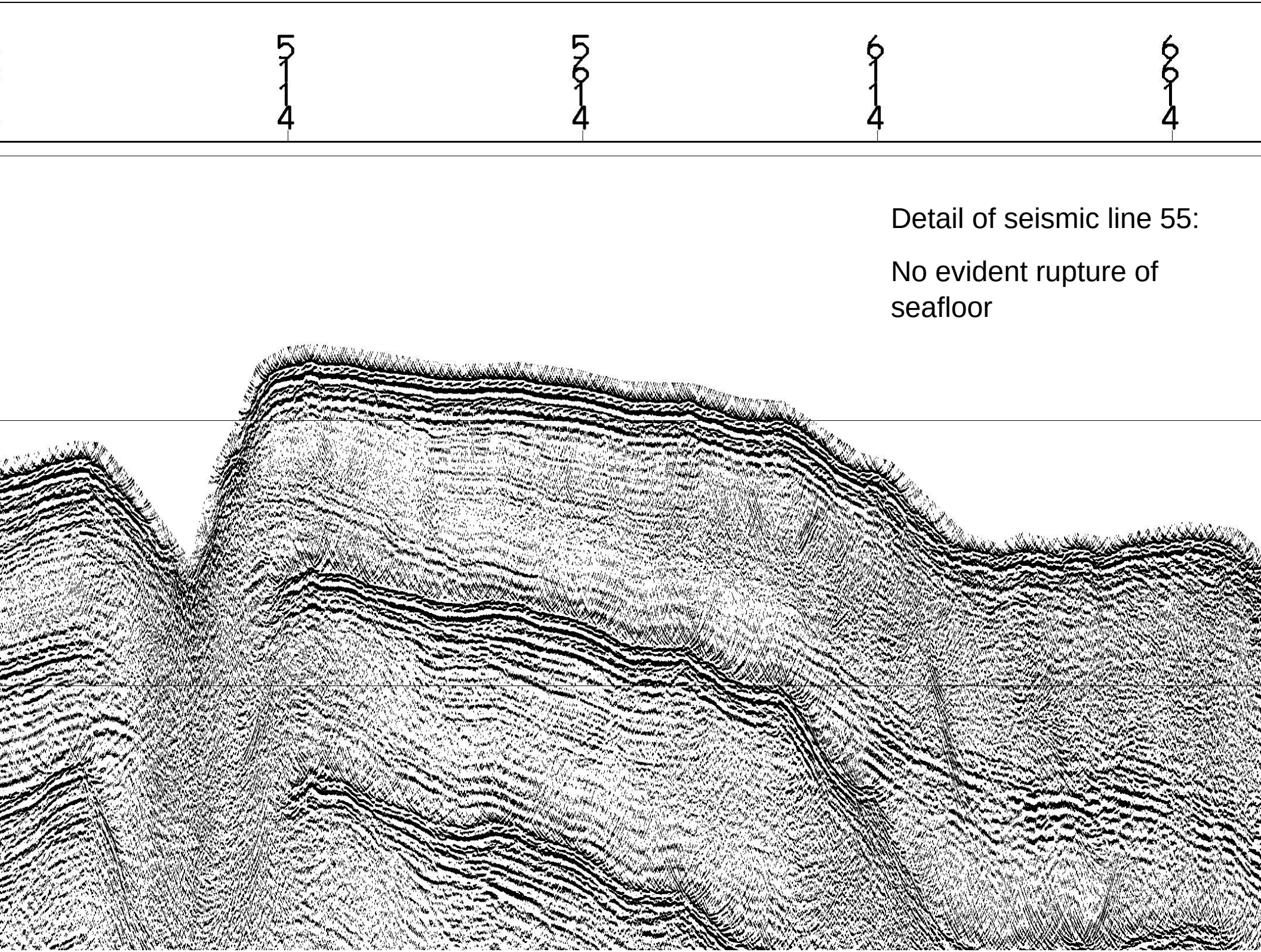
-Seismic profiles.


68°W
67.5°W
67°W
-2000
-3000
-3500
-4000
line 49
Mona
Rift
4.5
5.0
5.5
6.0
6.5
7.0
CDP 1160
Corresponds to
intersection with
Mercado & McCann (1998)
mapped fault.


2.0
2.5
3.0
3.5
4.0
-1500
-500
-1000
-3000
Mercado and McCann (1998)
line 56
Reid and Taber (1919)
Punta Agujereada
Punta Borinquen
Aguadilla
Punta Higüero
line 61
-500
-1000
-500
-500
-500
DR
Desecheo
18.5° N
18.5° N



Seismic line 55 and bathymetry does not show rupture of seafloor.



Detail of seismic line 55:

No evident rupture of seafloor

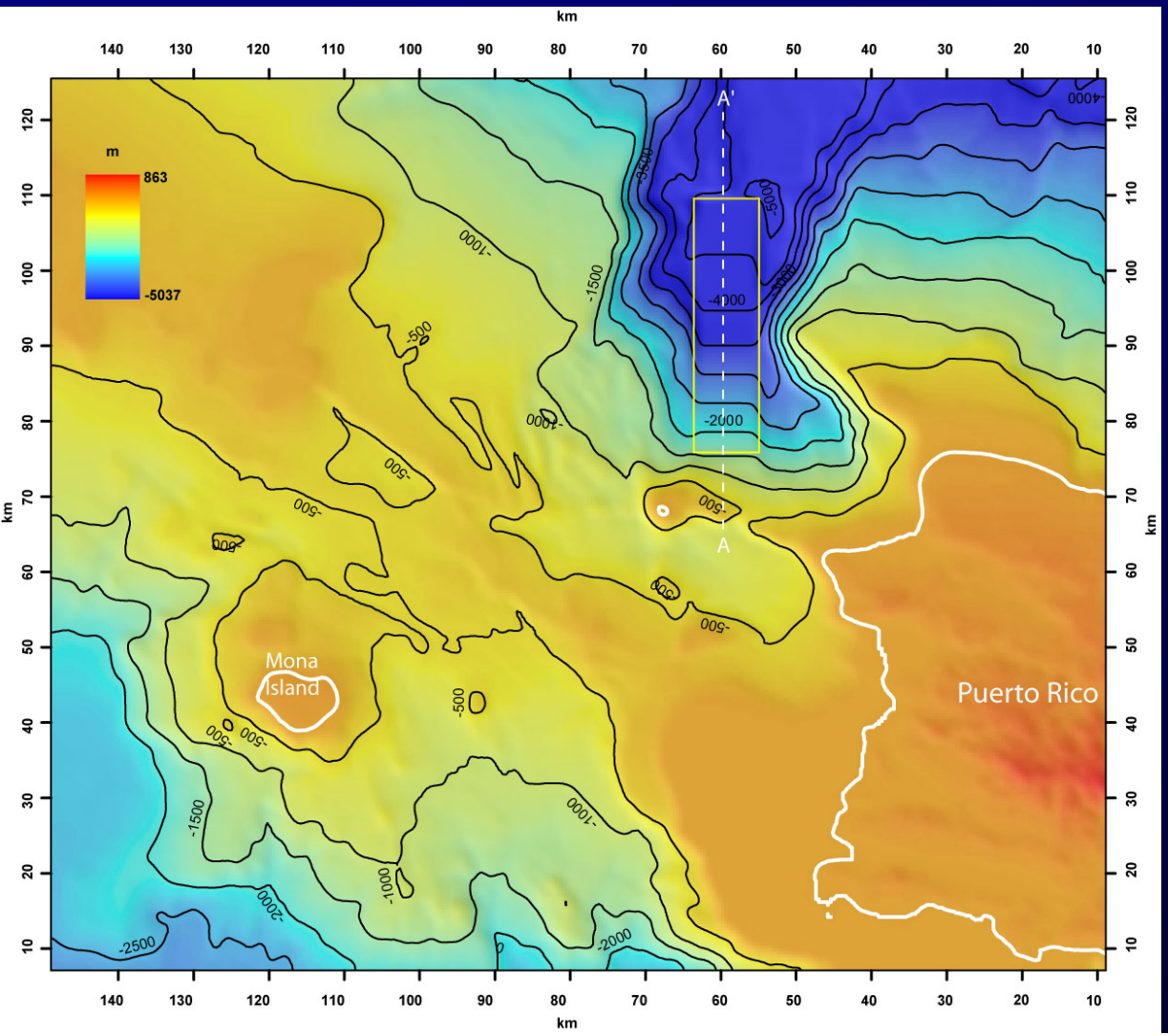
Tsunami Modeling:

-NOAA PR-1sec bathymetry grid → 200 meters resolution

-Grid dimensions: 134 x 157 km

-Rotated grid 10 degrees (landslide motion true North)

-Landslide source placed 8 km west to avoid Mona Rift eastern wall

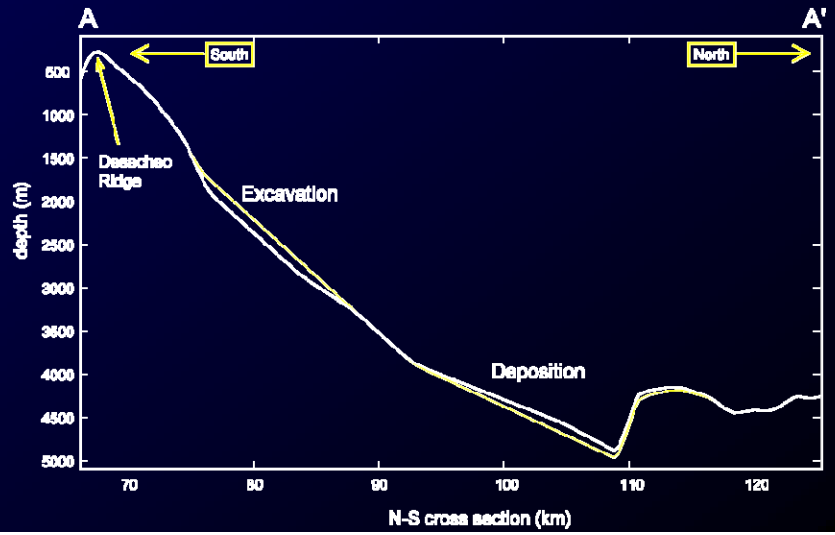


COULWAVE tsunami package
(Lynett and Liu, 2002)

-Model rotational slides with user-specified slide duration.

-Computes free-surface as the landslide progresses.

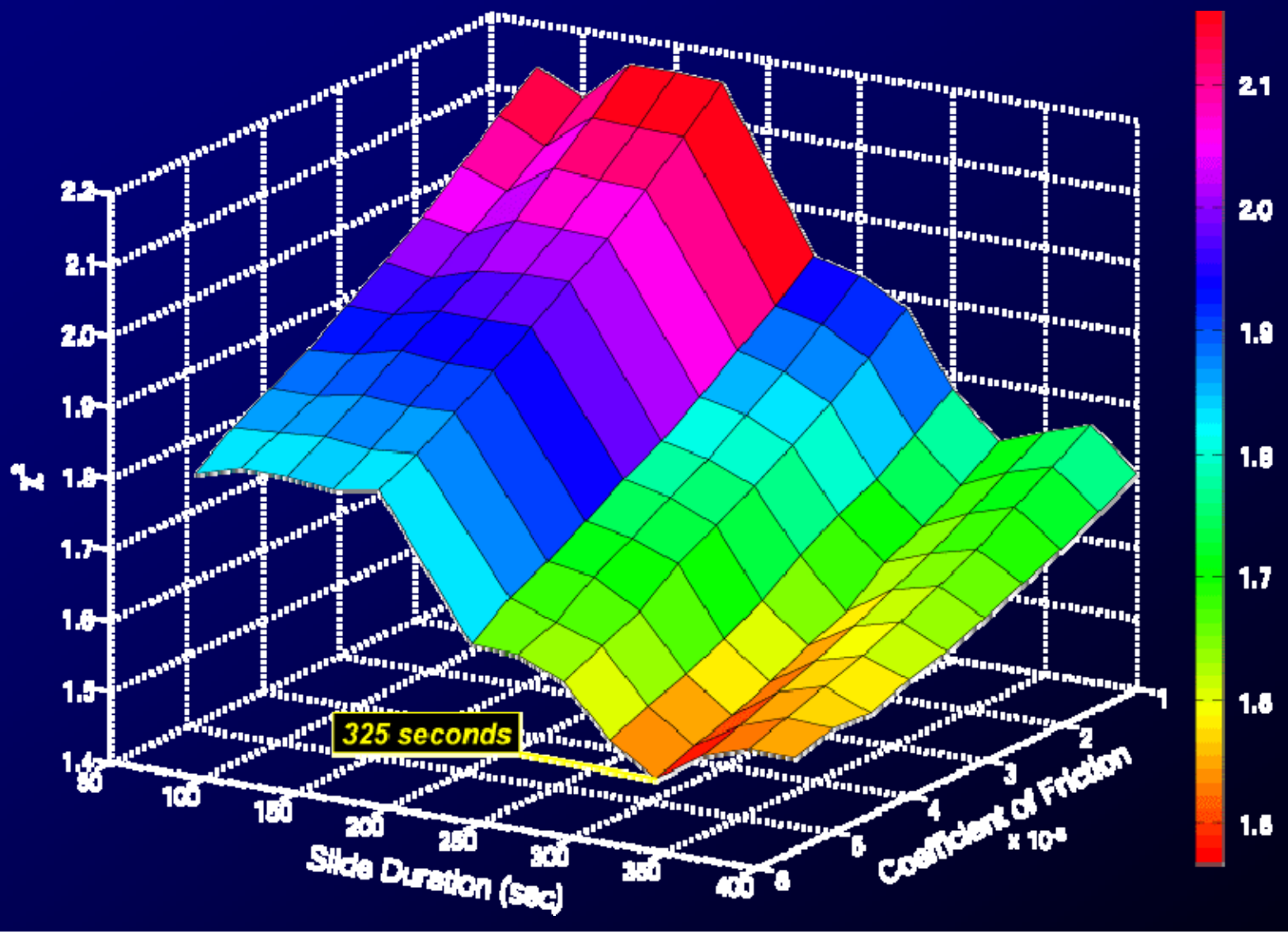
-Employs linear and non-linear terms



-Known variables: landslide area, location and thickness.

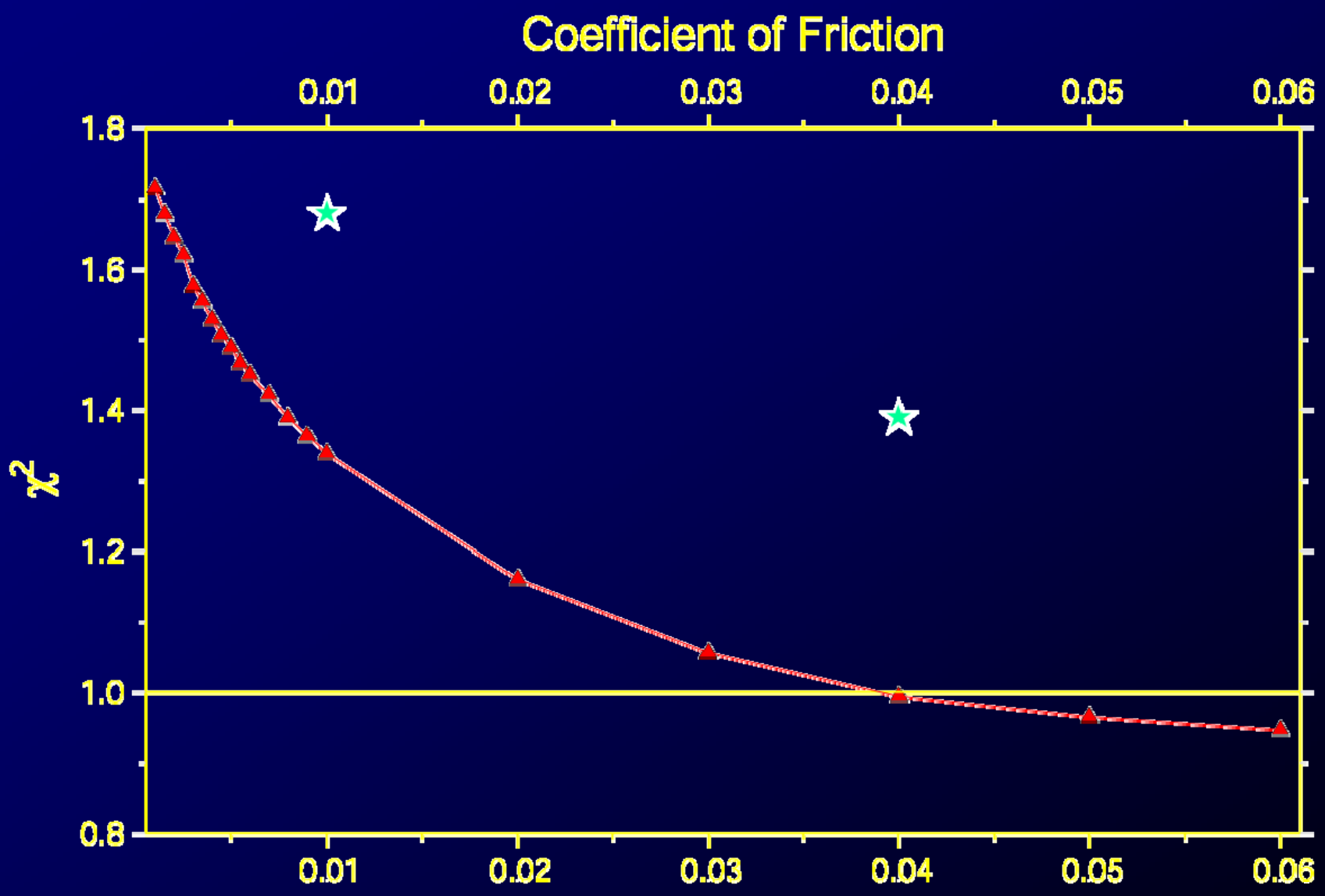
-Unknown variables: landslide duration and bottom friction coefficient.

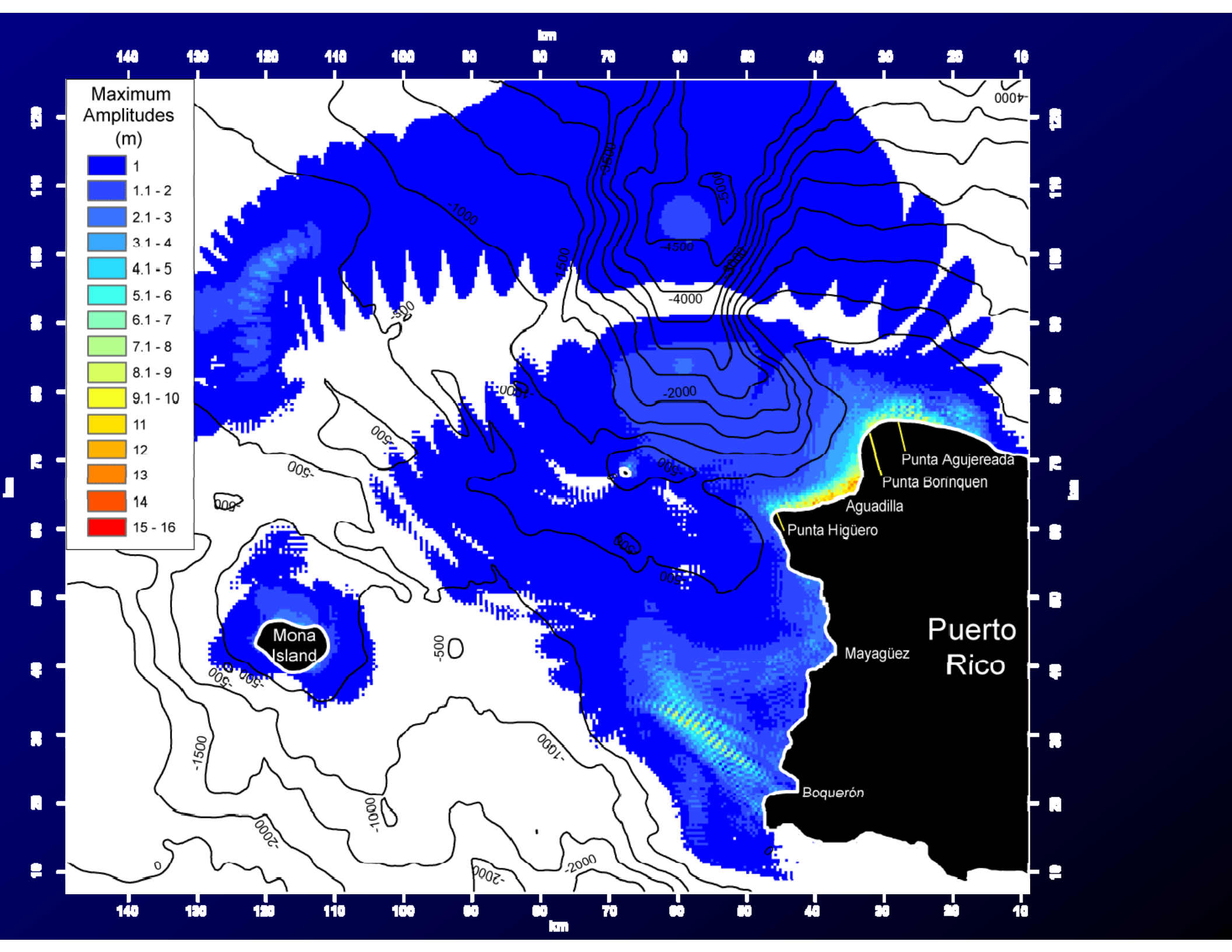
-χ^2 test was used to obtain these unknown variables by comparing Reid & Taber (1919) flow depth observations with simulations using a coarse grid of 1600 meters.

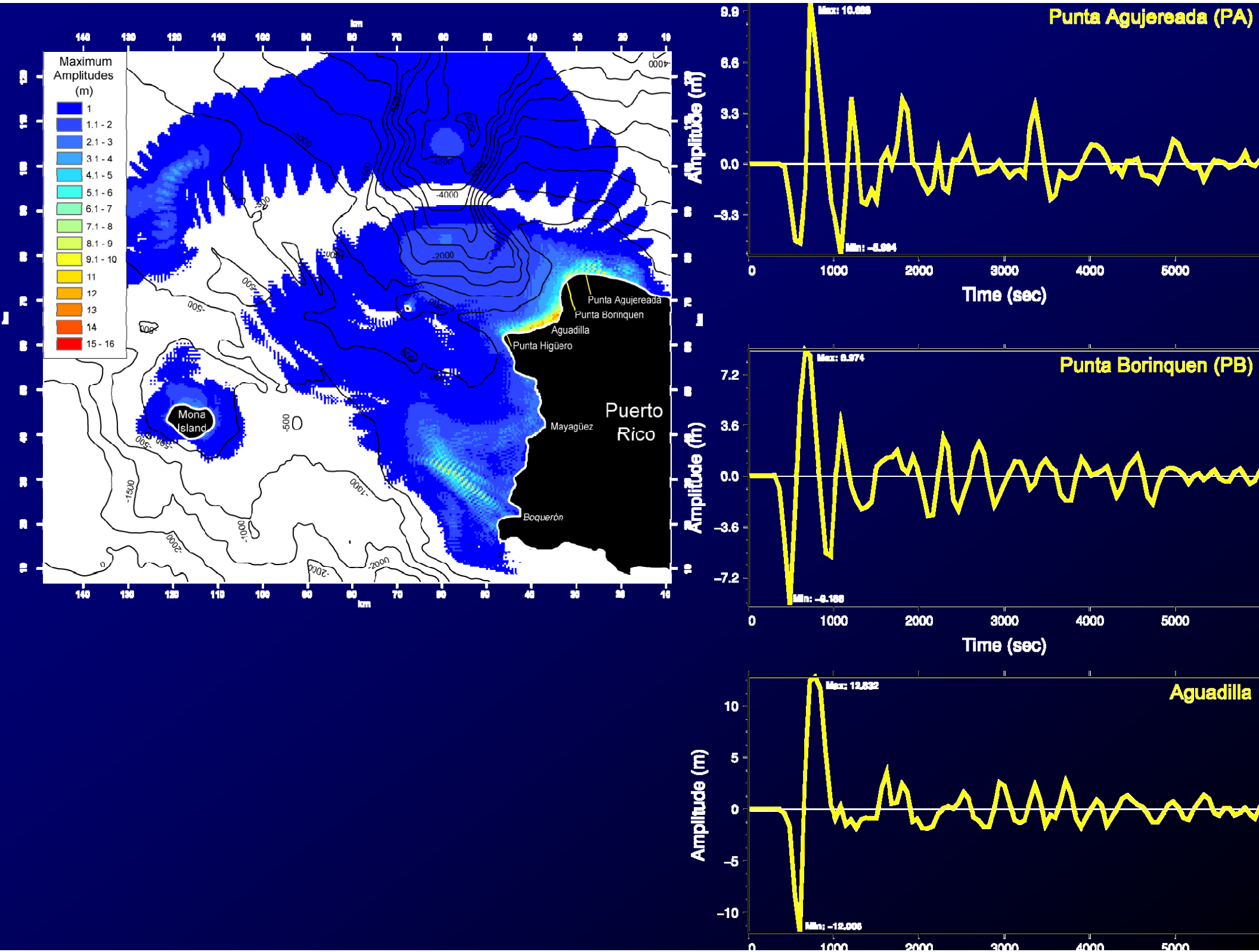


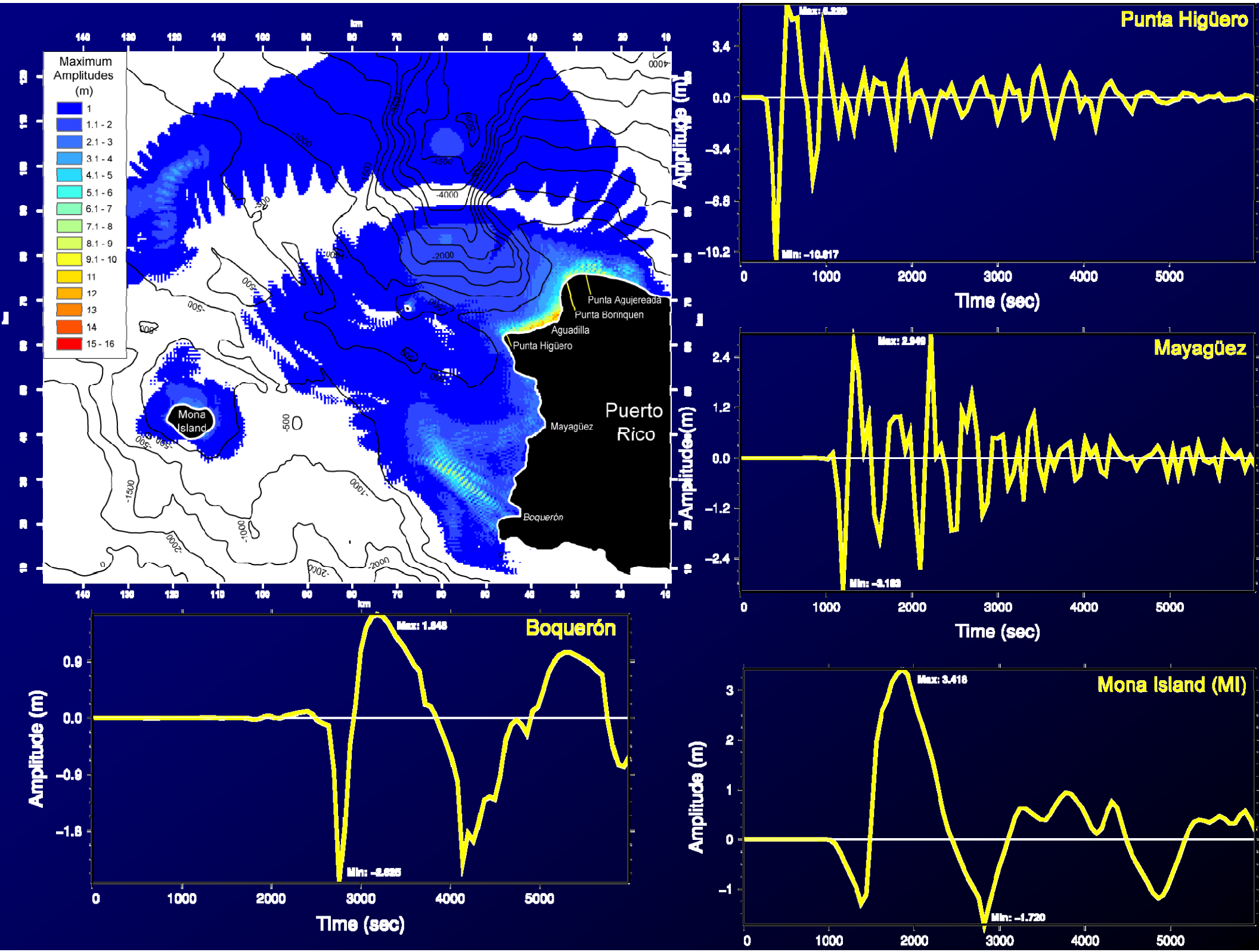
-The best fit-bottom coefficient of friction yields 0.04, but the predicted wave amplitudes are not much different for a more conservative value of 0.01.

-Used the finer resolution grid (400 m) with our best-fit parameters for final simulations.




Maximum Amplitudes (m)
1
1.1 - 2
2.1 - 3
3.1 - 4
4.1 - 5
5.1 - 6
6.1 - 7
7.1 - 8
8.1 - 9
9.1 - 10
11
12
13
14
15 - 16
km
Mona Island
Puerto Rico
Punta Agujereada
Punta Borinquen
Aguadilla
Punta Higüero
Mayagüez
Boquerón
-4000
-4500
-2000
-1000
-1500
-500
0


Maximum Amplitudes (m)
1
1.1 - 2
2.1 - 3
3.1 - 4
4.1 - 5
5.1 - 6
6.1 - 7
7.1 - 8
8.1 - 9
9.1 - 10
11
12
13
14
15 - 16
km
Mona Island
Puerto Rico
Punta Agujereada
Punta Borinquen
Aguadilla
Punta Higüero
Mayagüez
Boquerón
Punta Agujereada (PA)
Max: 10.688
Min: -5.994
Punta Borinquen (PB)
Max: 8.974
Min: -8.188
Aguadilla
Max: 12.832
Min: -12.006
Amplitude (m)
Time (sec)


Maximum Amplitudes (m)
1
1.1 - 2
2.1 - 3
3.1 - 4
4.1 - 5
5.1 - 6
6.1 - 7
7.1 - 8
8.1 - 9
9.1 - 10
11
12
13
14
15 - 16
km
Mona Island
Puerto Rico
Punta Agujereada
Punta Borinquen
Aguadilla
Punta Higüero
Mayagüez
Boquerón
Punta Higüero
Max: 4.225
Min: -10.617
Mayagüez
Max: 2.949
Min: -3.169
Boquerón
Max: 1.948
Min: -2.625
Mona Island (MI)
Max: 3.418
Min: -1.720
Amplitude (m)
Time (sec)

Model results:

Location	Observed		Computed		
	FD	AT	Max Wave Height (m)		AT
	(m)	(min)	$C_f = 0.01$	$C_f = 0.04$	(min)
Punta Agujereada	5.5-6	No Data	10.67	8.22	7
Punta Borinquen	4.6	"immediately"*	8.97	8.27	5
Aguadilla	> 4.0	5-6	12.83	13.69	7
Punta Higüero	5.5	∼ 2‡	6.23	5.89	5
Mayagüez	1.1-1.5	25-30	2.70	2.63	18
Sardinera, Mona	> 4.0	No Data	3.42	2.27	18
Boquerón	1.1	45	1.65	0.74	44
Volume (km^3)		10	8.85		
Slide thickness (m)**		130-140	155		

-Arrival times are in good agreement.

-Maximum wave amplitudes higher in the northwest but in overall good agreement south of Aguadilla.

-Good agreement in displaced volume and landslide thickness.

Conclusions:

-High-resolution bathymetry shows a submarine landslide lies 15 km off the northwest coast of Aguadilla with an approximate area of 9 x 9 km for the excavation area.

-Seismic lines confirm the existence of the landslide and suggest ~150 meters of material being removed.

-Location, rupture and burial of submarine telegraph cables confirm landslide occurrence.

-Estimated total volume displaced of ~10 km^3.

-Waves generated at the location of the identified slide propagate within the range of observed arrival times.

-The landslide geometry produces leading depression wave at all seven sites where it was observed.

-The landslide most probably had a source duration of 325 seconds, which translate in an average slide velocity of 27 m/s over the 9 km long excavation area.

-The best fit-bottom coefficient of friction yields 0.04, but the predicted wave amplitudes are not much different for a more conservative value of 0.01.

-Using a maximum slide thickness of 150 m yields a total volume displaced of 8.8 km^3 and maximum wave amplitudes in agreement with observed data.

Acknowledgments:

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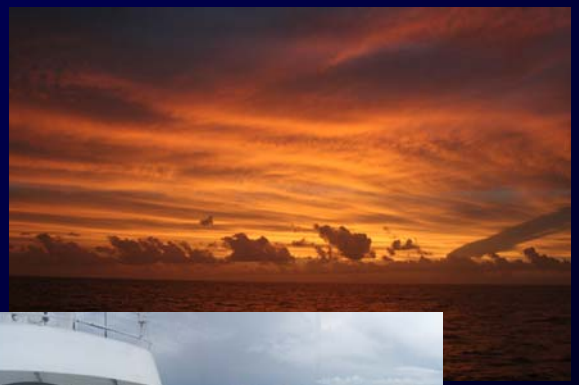
P. Lynett (UT A&M)

NOAA

LUMCON