Neotectonics and paleoseismology of a previously unmapped reverse fault in central Philippines—Insights from the Magnitude M_w 7.2 Bohol Earthquake of October 15, 2013

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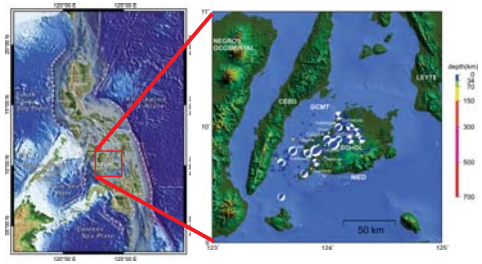
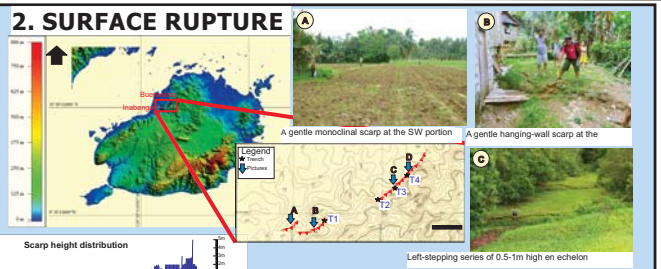


1. BACKGROUND OF STUDY

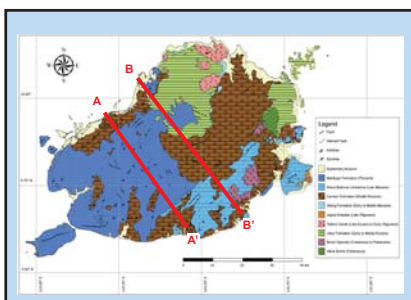
This earthquake is considered, historically, the strongest to hit the island of Bohol. It is also very significant because it is associated with a previously unmapped fault and because there is a rarity in documented ground rupture associated with earthquakes generated by reverse faulting mechanism in the Philippines.

The primary interest of this research is to determine the nature of the fault associated with the October 15, 2013 M7.2 Bohol Earthquake, to investigate its relation to the pre-existing morphotectonic and structural features in the area, and to study its history of movement. This study also relates these features to the overall tectonic regime operating in the region.

2. SURFACE RUPTURE

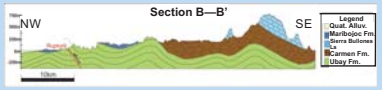


- ~ 6km-long, N40-60E-trending, fault trace on the northeastern sector of the island, along a pre-existing NE-trending hillslopes in the municipalities of Inabanga and Buenavista.
- Scarp heights are generally higher in the NE and lower in the SE and these taper toward both ends of the mapped surface rupture.
- Scarp morphologies include mostly monoclinal scarps, simple reverse fault scarps and hanging-wall collapse scarps.



Cross section A—A' shows gentle folding in the southeast portion of this section, and a steep anticline in the northwest portion of this section. This cross-section emphasizes on the steeper limbs of the anticline seen in the northwest portion of this cross section which has a fold axis oriented northeast-southwest. This fold axis is similar in trend to the reverse fault associated with the October 15, 2013 earthquake.

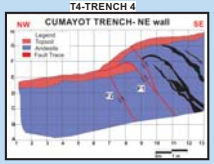
5. GEOLOGICAL TRANSECTS

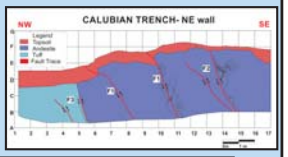


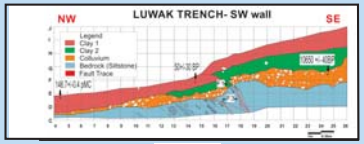
Cross-section B—B' shows that the rupture coincides with the steeply-dipping beds of folds in the Ubay Formation in the northwest sector of the island. This section also highlights the extensive folding in the southeastern sector of the island. Most of the aftershocks were generated first in the northeastern portion of the 90 km long fault rupture inferred from seismicity and then propagated southwest all the way to the Bohol Strait. It was observed that the northeast terminus of the rupture coincides with the boundary between the folded sedimentary sequences and the volcanic rocks of the Ubay Formation.

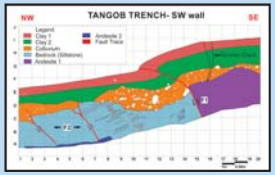
3. TRENCHES

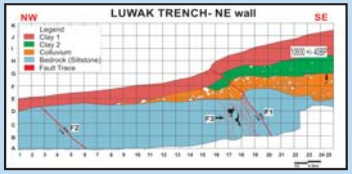
- At least 3 nearly-similar magnitude earthquakes (including the 2013 event) in the last ~12,000 years—possibly translating to a 6000-year recurrence interval.
- There could possibly be more than 2 pre-2013 surface-rupturing earthquakes, but it is hard to tell due to the general lack of stratification in the area and because of the relatively wider deformation zone of reverse faults. Considering the limited length of the trenches (maximum of 17m), some events may have been missed out.

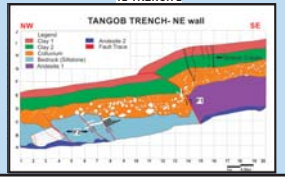






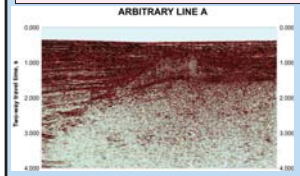


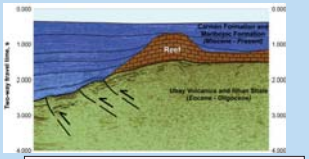




4. SEISMIC REFLECTION PROFILES

- The population of aftershock epicenters shows a 30-km wide by 90-km long belt trending east-northeast from the northern sector of Bohol, down to the offshore area in the Bohol Strait, and all the way to the southeastern shores of Cebu Island.
- This suggests that the earthquake most probably occurred due to movement along a structure which extends offshore in the Bohol Strait.
- The Bohol Strait was investigated by examining pre-earthquake 3D seismic profiles to see structures most likely associated with the earthquake-generator. These provide cross-sectional views beneath the ocean/sea bottom.





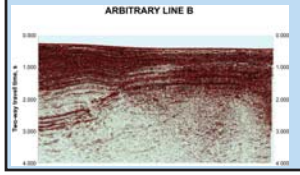
- Preliminary analysis of offshore seismic reflection profiles between Cebu and Bohol suggests the presence of NE-striking active folds rooted on bifurcating reverse faults dipping SE.

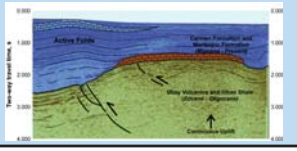
Arbitrary line A

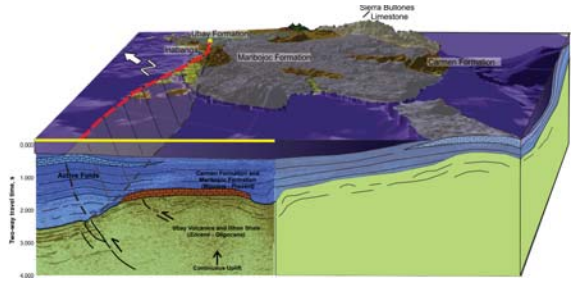
- Faults appear to cut through the erosional surface of the Ubay Formation. It can also be observed that these faults produced multiple event scarps of similar morphology with those found onshore. A reefal limestone growth is also seen on the hanging wall of the faulted block system.

Arbitrary line B

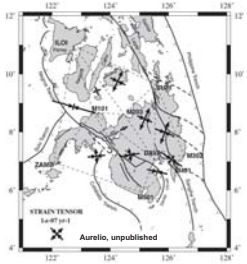
- Fold-thrust structures were observed in this section. Faults cutting through the erosional surface of the Ubay Formation seem to cause folding in the sedimentary units of the Carmen and Maribojoc formation above and are similar to fold-fault structures of the Loon-Maribojoc Peninsula.







- Based on the trend of the ground rupture found in Inabanga, plot of aftershock epicenters, and the projection on the seafloor of the reverse fault as seen in the seismic reflection profiles, a SW offshore fault continuation is possible.
- A possible explanation why there might not be a southwest continuation of the ground rupture is the accommodation of slip by folding.
- However, more ground surveys will help constrain this model further as the trace of a reverse fault can be very complex.



6. CONCLUSIONS

The previously unmapped North Bohol Fault is a NE-trending, SE-dipping reverse fault which is aligned to east-northeast—trending foothills in the Municipalities of Inabanga and Buenavista in NE Bohol.

Its recent rupture is associated with pre-existing morphotectonic features (e.g., multiple-event fault scarps). The geomorphic expression, of this fault, however, is subtler compared to other known active faults in the Philippines. This may be due to a wide-spacing of earthquake events (6000-year recurrence interval for nearly-similar magnitude earthquakes) as suggested by the results from paleoseismic trenching at four representative sites along the 6km-long (end-to-end) ground rupture.

Wide-spacing of surface faulting events can be explained by accommodation of slip by along northeast-southwest trending fold-fault structures which result from northwest-southeast horizontal compressive tectonic stress governing the actively deforming Visayan Sea Basin (Rangin, 1989).

The North Bohol Fault and the Negros trench both appear to be crustal features accommodating the overall regional east-west compression governing the Visayan Sea Basin and the entire Philippine archipelago.

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