Coastal hazards assessment in Central Visayas: The puzzling effects of active tectonics, isostatic rebound, sea-level changes and anthropogenic activities

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ABSTRACT

The coastal regions of Central Visayas show geomorphologic indications suggestive of significant compression related to the Palawan Microcontinental Block (PCB)-Philippine Mobile Belt (PMB) collision. In northeastern Negros Oriental, compressional regime brought about by such collision is expressed by the recent uplift of Quaternary coastal sediments and coral reefs, a co-seismic, reverse faulting event causing the Mw 6.9, February 6, 2012 earthquake. Deformation is also manifested by the tilted orientation of the Cenozoic clastic and carbonate rocks exposed along the coast or road cuts in northeastern Negros Oriental. Regionally, this may be related to the deformation of the Visayan Sea Basin resulting from the aforesaid collision. Similarly, in Bohol, the most recent uplift of carbonates is attributed to the 15 October Mw7.2 North Bohol Fault (NBF) earthquake, also resulting from reverse fault movement. The seismic event caused uplift of the coral reefs by as much as 2.5 meters (or more) in several coastal sections of western Bohol. Smaller islands consisting of uplifted carbonate platform between Bohol and Cebu are aligned southwesterly, consistent with the PMB-PCB collision.

The uplift of carbonate platform resulted in the formation of cliffy karstic coast most prominent in western Bohol and islands west of the province. This translates to lower vulnerability to coastal hazard, particularly coastal inundation. However, while a compressional regime would relate to a seaward retreat of the shoreline, a landward retreat is being witnessed in many areas in Negros Oriental and Bohol mainland following the most recent earthquakes. Isostatic rebound of the land following the seismic event, alongside the general rise in relative sea-level based on the 5-year data, has slowly caused a landward shift of the shoreline in recent years. In Negros Oriental, the restricted area of the Tañon Strait between Negros Oriental and Cebu island could also be an influential factor. The resultant influences of the Visayan Sea in the north and the Bohol Sea in the south could create a complex tidal activity in which high tide can be out of sync for a number of days with those areas just outside of this strait. The passage of Typhoon Odette in 2021 demonstrates how wave impacts and storm surges within the Tañon Strait could cause dramatic changes to the coastal morphology and significant erosion of beach sediments as demonstrated in northern Negros Oriental. On a local scale, anthropogenic activities have enhanced coastal erosion in both Negros Oriental and Bohol. These activities include (1) the extraction of beach sands; (2) the extraction of coral reefs (also serving as beach sediment sources) which enhances wave impacts alongshore; (3) the destruction of mangroves which are vital for trapping sediments and; (4) the erection of structures (port, coastal defenses, perimeter fences; community growth along the foreshore area) that interferes with the sediment transport alongshore. Clearly, coastal hazards studies in an actively deforming region requires a combined output of vertical geologic movement, relative sea level change and anthropogenic activities.

Keywords: co-seismic event, coastal hazards, isostatic rebound

1.0 Introduction

Climate change related hazards such as accelerated sea level rise and coastal erosion are steadily becoming an alarming threat to coastal communities and other land developments. A diverse set of strategies that entail coastal engineering works and/or ecosystems based approaches have been implemented in some areas in the Philippines and other countries worldwide, apparently in reaction to the coastal hazards already experienced by the communities.

Understanding coastal hazards in the Philippines is somehow complicated by the country's tectonic setting. Active tectonic activities and their effects on coastal morphology are marked by recent seismic activities usually resulting from fault movements, volcanic eruption and local uplift and/or subsidence of Quaternary morphologic features. In view of this, understanding coastal morphologic changes and attendant coastal hazards in the Philippines would require a look at the interplay between local vertical motion and global relative sea-level rise, as well as the anthropogenic activities that could interfere with natural transport of sediments toward the coast and alongshore. This paper demonstrates this need, by presenting results of the geological and geohazards assessment results in Central Visayas.

2.0 Regional geologic setting

Central Visayas is in the active deformation front of the collision between the terrane of Philippine Sea Plate (PSP) affinity and that of the Palawan Microcontinental Block of Eurasian/Sunda plate affinity (**Figure 1**).The deformation is manifested by the NE-SW orientation of the islands (e.g., Negros, Cebu and islands west of the Bohol) and the uplift of the young carbonate platform observed in these islands and in Bohol mainland itself. Part of the PSP-Sunda Plate collision is absorbed by subduction zones almost exclusively surrounding the Philippine Mobile Belt. These subduction zones are the Manila Trench-Negros Trench-Sulu Trench to the west, and the East Luzon Trough-Philippine Trench to the east. Between northern Luzon and Taiwan, however, the East Luzon Trough seemingly connects with the Luzon-Okinawa Fracture Zone, a non-transform discontinuity of the Philippine Sea Plate (Lallemand, 2016). The oblique subduction of the bounding plates is also partly absorbed by sinistral Philippine Fault. This structure transects the Philippine archipelago for at least ~1200-km and has offshore extensions to the northwest of Luzon and south of eastern Mindanao (Aurelio et al., 1991; Barrier et al.,1991; Armada et al.,2012).

On a basin-scale, Central Visayas is within several interconnected sub-basins between the Negros volcanic arc and the chain of Quaternary volcanoes extending from southeastern Luzon to Leyte Island along the Philippine Fault. These sub-basins consist of an ~4-km-thick carbonate and volcaniclastic deposits (Tamesis, 1981; Rimando et al., 2020). The collision of the Palawan Microcontinental Block (PCB) of Sunda Plate affinity with the Philippine Mobile Belt (PMB) in Central Philippines during the Miocene attributes for the NNE-SSW deformation features such as folds and thrusts observed in the Visayan Basin.

3.0 Results

As earlier noted, Central Visayas is generally under a compressive regime, being at the deformation front of the arc-continent collision between the Palawan Microcontinental Block (PCB) and the Philippine Mobile Belt (PMB). Uplifted carbonate platforms that span the Pliocene to Recent are manifestations of the aforesaid deformation, alongside the series of folds that characterize the Visayan Basin. In Bohol, the most recent uplift of carbonates is attributed to the 15 October Mw7.2 North Bohol Fault (NBF) earthquake. Bacolcol et al. (2019) reported that the epicentral region covers areas of Buenavista, Inabanga, Clarin, Tubigon, Calape, Loon, Maribojoc, Antequera, San Isidro, Catigbian, Sagbayan and Danao. The NBF had a reverse fault movement, consistent with a compressional regime related to the PCB-PMB collision. The seismic event caused uplift of the coral reefs by as much as 2.5 meters (or more) in several coastal sections of western Bohol, as also noted during the field survey.

Shoreline position determined from geo-referenced Google Earth images suggested that the shoreline immediately following the Bohol 2013 earthquake retreated seaward (**Figure 2**). This is consistent with the uplift of recent coral reefs related to the movement of the North Bohol Fault. Such a trend continued until 2014. It should be noted, however, that some coastal areas in western Bohol seemingly subsided following the 2013 earthquake. A landward retreat of the shoreline, however, is being reported in many areas surveyed in western and northern Bohol in the years succeeding 2014. Although such retreat is not clearly reflected in the shoreline shift maps generated for the province (due to dataset limitations and map scale), it is supported by the mean-sea level data provided by NAMRIA and by observations gathered during the field survey. The NAMRIA data show a relative mean sea-level increase starting in 2015 to cause landward retreat of the shoreline, including high tide levels. This recent trend in mean-sea-level rise could be a result of isostatic adjustment or rebound of the land following the 2013 earthquake.

In Negros Oriental, the compressional regime brought about by the arc-continent collision in Central Visayas is also expressed by the recent uplift of Quaternary coastal sediments and coral reefs. The most recent uplift is related to a co-seismic event in northeastern Negros Oriental attributed to the Mw 6.9, February 6, 2012 earthquake. PHIVOLCS (2015) reported that the earthquake resulted from a dominantly thrust-faulting movement along a NE- SW, and NW-dipping thrust fault at 10 km depth. The restricted area of the Tañon Strait between Negros Oriental and Cebu island resulting from the clockwise rotation of Negros island with respect to Cebu island (which are consequential to the arc continent collision) could be an influential factor. As a note, the Tañon Strait fronts Bais City and the northern cities/municipalities of the province. The resultant influences of the Visayan Sea in the north and the Bohol Sea in the south could create a complex tidal activity in which high tide can be out of sync for a number of days with those areas just outside of this strait. The recent passage of Typhoon Odette in 2021 demonstrates how wave impacts and storm surges within the Tañon Strait could cause dramatic changes to the coastal morphology and significant erosion of beach sediments as demonstrated in northern Negros Oriental.

On a local scale, anthropogenic activities have enhanced coastal erosion in Bohol and Negros Oriental **(Figure 3**). These activities include (1) the extraction of beach sands; (2) the extraction of coral reefs (also serving as beach sediment sources) which enhances wave impacts alongshore; (3) the destruction of mangroves which are vital for trapping sediments and; (4) the erection of structures (coastal defenses, pier; perimeter fences; community growth along the foreshore area) that interferes with the sediment transport alongshore). Hard engineering structures including makeshift coastal defenses (riprap; breakwater) are almost present everywhere along the coast of Negros Oriental and in some areas in Bohol. Many defenses were put up by property owners, apparently not in close coordination with other property owners, the LGU and/or relevant government agencies (e.g., DENR) and/or without a thorough understanding of the environmental consequences related to the installation of the structures. Unfortunately, in southern Negros Oriental, some of these hard engineering structures are causing a slow, but persistent, long-lasting effect in eroding the coast as observed in several barangays. Land developments that include port construction in Dauin-Bacong, reclamation activities in Dumaguete and construction of groins in Zamboanguita disrupted the southerly to southwesterly sediment transport alongshore. The construction of seawalls adjacent to reclamation areas as well as those affected by coastal erosion could have also played a role in enhancing the coastal erosion. While hard engineering structures and reclamation may be important in the land development of the province, their erection should consider how they would impact adjacent areas in terms of beach sediment budget, using information that should be based strongly on science. In so doing and given a coordinated approach among different stakeholders, adaptive measures can be implemented by the affected individuals/entities. At the same time, land use and development plans can be reviewed by the affected LGUs to minimize impacts of such developments to the physical and socio-economic conditions of their city or municipality.

Some makeshift engineering structures that are ill-designed are also present in many areas and are just contributing to the coastal erosion. Destruction of mangrove forests and coral reefs which are natural buffers against wave action also exacerbate the deterioration of coastal regions. Clearly, rehabilitation, enhancement and protection of mangroves and coral reefs are among the crucial ecosystem based strategies for minimizing the effects of coastal erosion.

The results of the coastal hazards assessment and mapping in the region clearly calls for an understanding of the interplay among various factors and processes, both natural and man-induced. The lack of foresight on climate change effects and the implementation of strategies to combat coastal hazards that are not based on sound scientific principles are often the cause why coastal management programs and strategies fail. To this end, it is strongly recommended that all local government units review their coastal management plans that also consider establishing a “Setback” or “No Build Zone”. While the required minimum easement/setback zone is already stipulated under Presidential Decree 1067, the LGUs are advised to consider the setback or “No

Build Zone" recommended by the Marine Geological Survey Division of the Mines and Geosciences Bureau for the communities assessed in Central Visayas.

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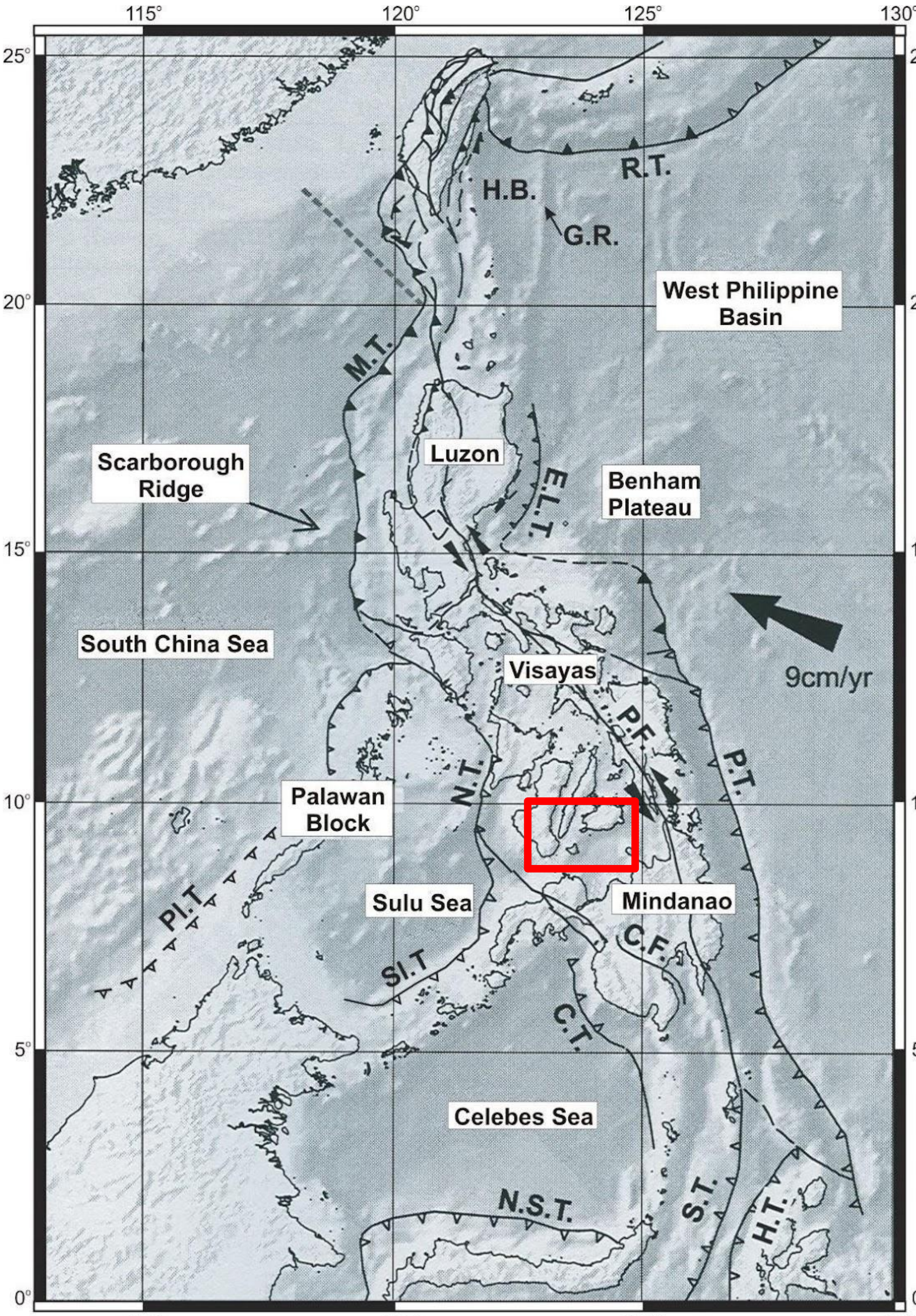

Figure 1. Geodynamic setting of the study area (in red box). MT=Manila Trench; NT=Negros Trench; SlT=Sulu Trench; .PT=Philippine Trench; ELT=East Luzon Trough; CT=Cotobato Trench;

CF=Cotobato Fault; PF=Philippine Fault; PIT=Palawan Trough; ST=Sangihe; HT=Halmahera Trench; GR=Gagua Ridge; HB=Huatung Basin; R.T=Ryuku Trench. Source: Queaño (2006).

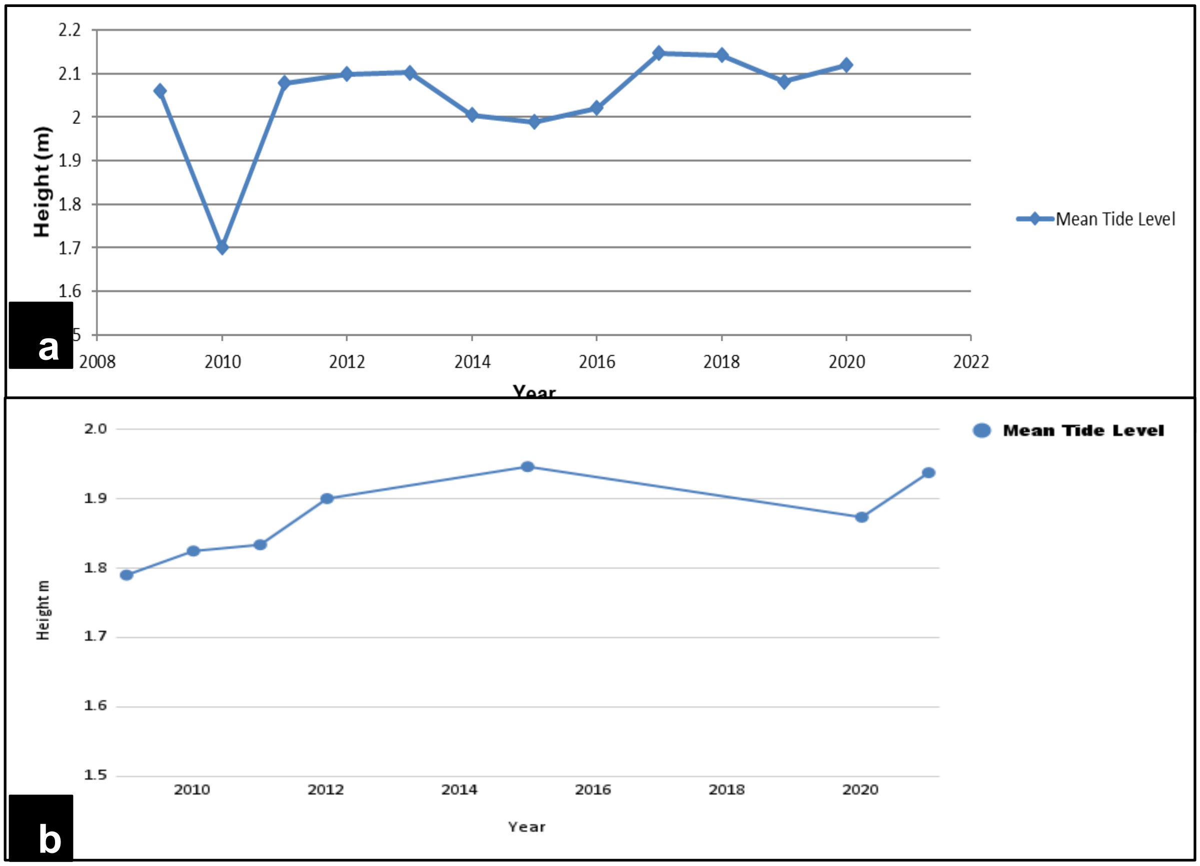

Figure 2. Sea level trends for Bohol and Negros Oriental**:** a) Mean tide level of Bohol from 2008 to 2020 (Data Source: NAMRIA); b) Mean tide level of Negros Oriental from 2009 to 2021 (Data Source: NAMRIA).

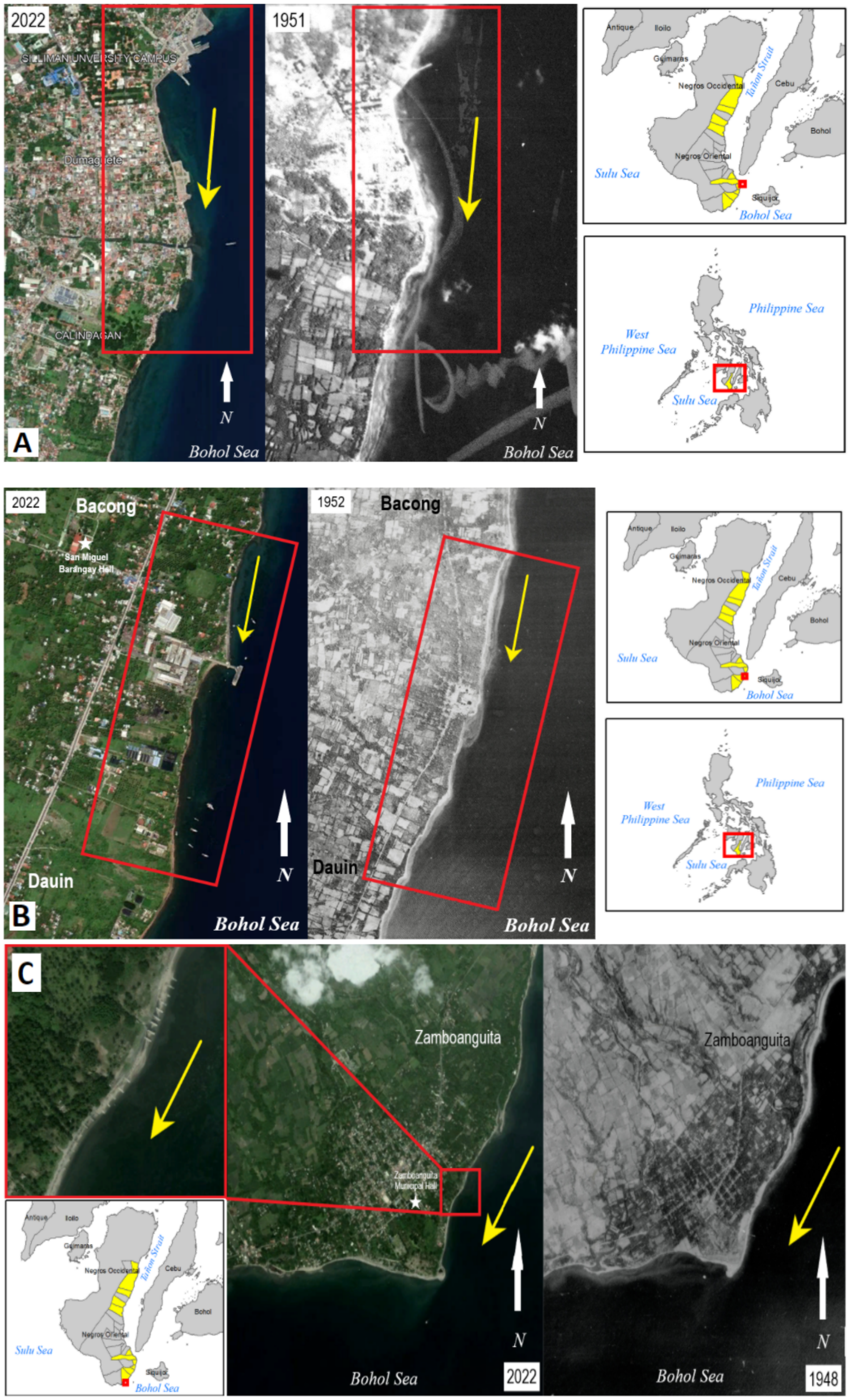

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Figure 3. Anthropogenic activities that enhance coastal erosion in Bohol and Negros Oriental: A) Comparison of the 1951 and 2022 aerial photos of Dumaguete City, Negros Oriental indicating the occurrence of coastal erosion after the reclamation activity; B) Comparison of the 1952 and 2022 aerial photos of the municipalities of Bacong and Dauin suggest that the construction of the port may have resulted to sediment deprivation and consequent coastal erosion in areas south of the port; C) Comparison of the 1948 and 2022 aerial photos of the coast of Zamboanguita which suggest that the installation of the groins may have resulted to the deprivation of sediments; D) Damaged pier and makeshift riprap seawall made out of coral fragments.