SOUTHWESTERN LUZON EARTHQUAKE HYPOCENTER AND DEPTH DISTRIBUTION MODELING USING QGIS AND LEAPFROG GEO

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INTRODUCTION

The Manila Trench (Fig. 1) is a subduction zone within the Philippine Mobile Belt formed by the active convergence of the Sunda Plate (a portion of the Eurasian Plate) and the Philippine Sea Plate (Bautista et al., 2001). Having a depth of over 5000 m and a subduction rate of about 5 cm per year, the trench is associated with volcanic activity and frequent massive earthquakes in the Philippines (Rangin et al., 1999). However, owing to the country's complex tectonic setting, the zone's proximity to several other seismically active structures such as strike-slip faults and active volcanoes often render difficulties in determining the sources and nature of these earthquakes.

From April to August 2017, the province of Batangas and nearby areas experienced a series of moderate-magnitude tectonic earthquakes which devastated buildings and even induced landslides (Cinco & Lesaba-Rabe, 2017). Stress transfer modeling suggests that this earthquake swarm transferred a significant amount of stress towards the Taal Volcano, which could have initiated its most recent major eruption in 2020 (Aurelio et al., 2021). Just this year, the same area was jolted by several magnitude-5.0 or greater earthquakes which were determined to be of tectonic origin, i.e., due to Manila Trench subduction and unrelated to Taal Volcano's recent activities (Aguilar, 2021).

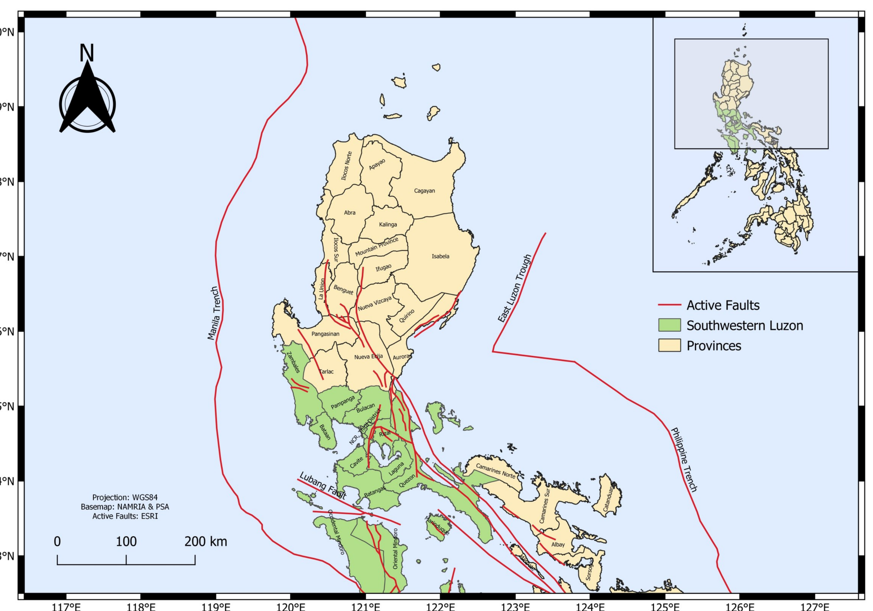

Fig. 1. Luzon island map showing active faults (red) and southwestern Luzon, the region of interest in the study (green)

In this study, hypocenter and depth data from 2011 to 2021 in Batangas and nearby areas (collectively termed southwestern Luzon here) were used to characterize the distribution and nature of these earthquakes. In particular, the earthquakes were categorized in terms of magnitude ranges and depth (shallow, intermediate, deep) using QGIS and subsequently 3D modeled using Leapfrog Geo to delineate the corresponding Wadati-Benioff zone. The delineated zone trace was then compared to USGS' Slab2, a comprehensive subduction zone geometry model generated via seismic tomography.

METHODOLOGY

Data Acquisition
- Philippine administrative boundaries shapefiles from NAMRIA
- Active Philippine faults shapefile from ESRI
- Bathymetric map SRTM from OpenTopography
- 2011-2021 hypocenter and depth data in southwestern Luzon from the International Seismological Centre (ISC) catalogue
- Slab2 seismic tomography model from USGS

Data Pre-Processing
- Classification of hypocenter data based on depth (shallow, intermediate, deep) and magnitude ranges (produced three separate CSV files)
- Modification of bathymetric map SRTM slope visualization using Global Mapper (including brightness and contrast values)

2D Data Processing
- Delineation of study area via Merge Vector Layers Data Management tool (combination of individual provincial shapefiles)
- Using Intersection Geoprocessing tool to show fault-intersected areas
- Utilization of combined symbology to comprehensively depict magnitude and depth differences (data-defined size for depth and graduation by color for magnitude)

Data Conversion
- Conversion of shapefile and CSV file coordinate reference system (CRS) from WGS84 to UTM using Global Mapper

3D Data Processing
- Creation of bathymetric surface using XYZ point data
- Categorization of imported hypocenter points by magnitude

Surface Modeling
- Color modification according to 2D map symbology
- Rendering of lateral extent surfaces (New Lateral Extent from Points) to show subducting slab (and comparing with that of Slab2 later)

Formatting and Output Presentation
- Southwestern Luzon hypocenter and depth distribution map
- Manila Trench Wadati-Benioff Zone model (with presentation video)

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RESULTS

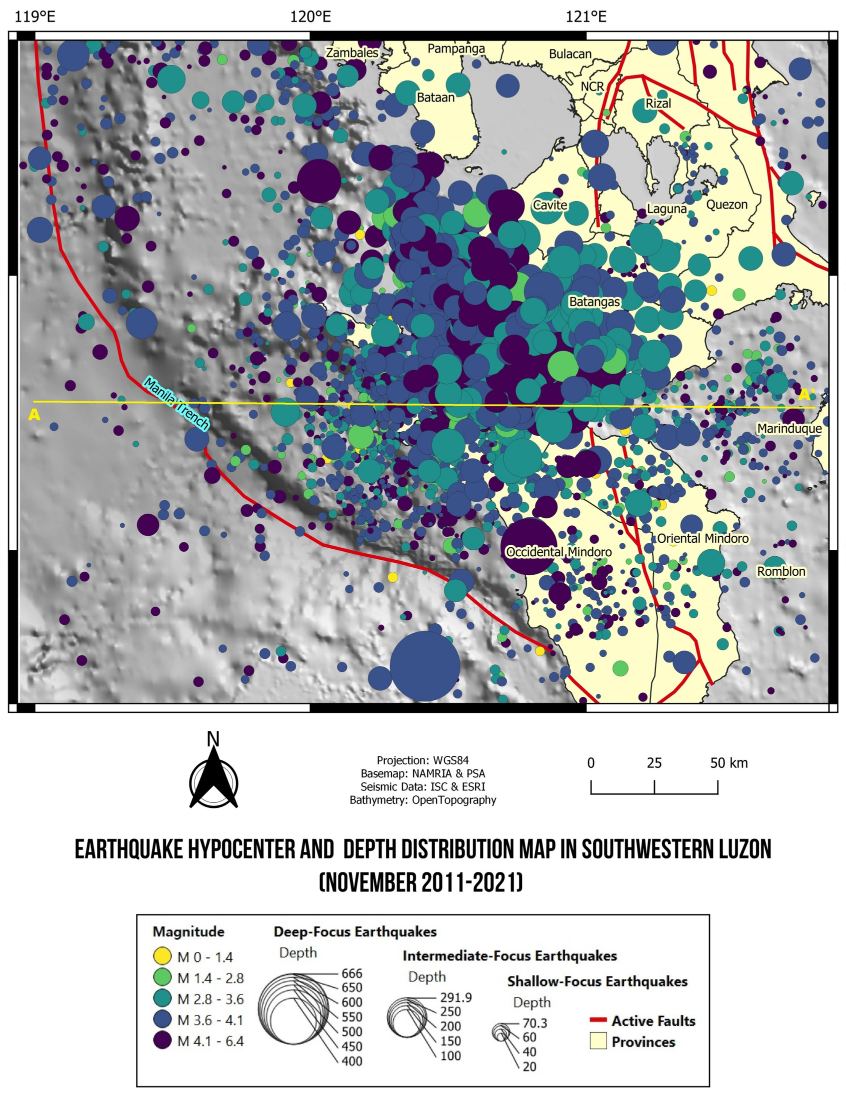

Fig. 2. Distribution of earthquake hypocenters (circles) and their corresponding depth (size-defined) and magnitude range (color-graduated) in southwestern Luzon from 2011 to present. *Generated in QGIS.*

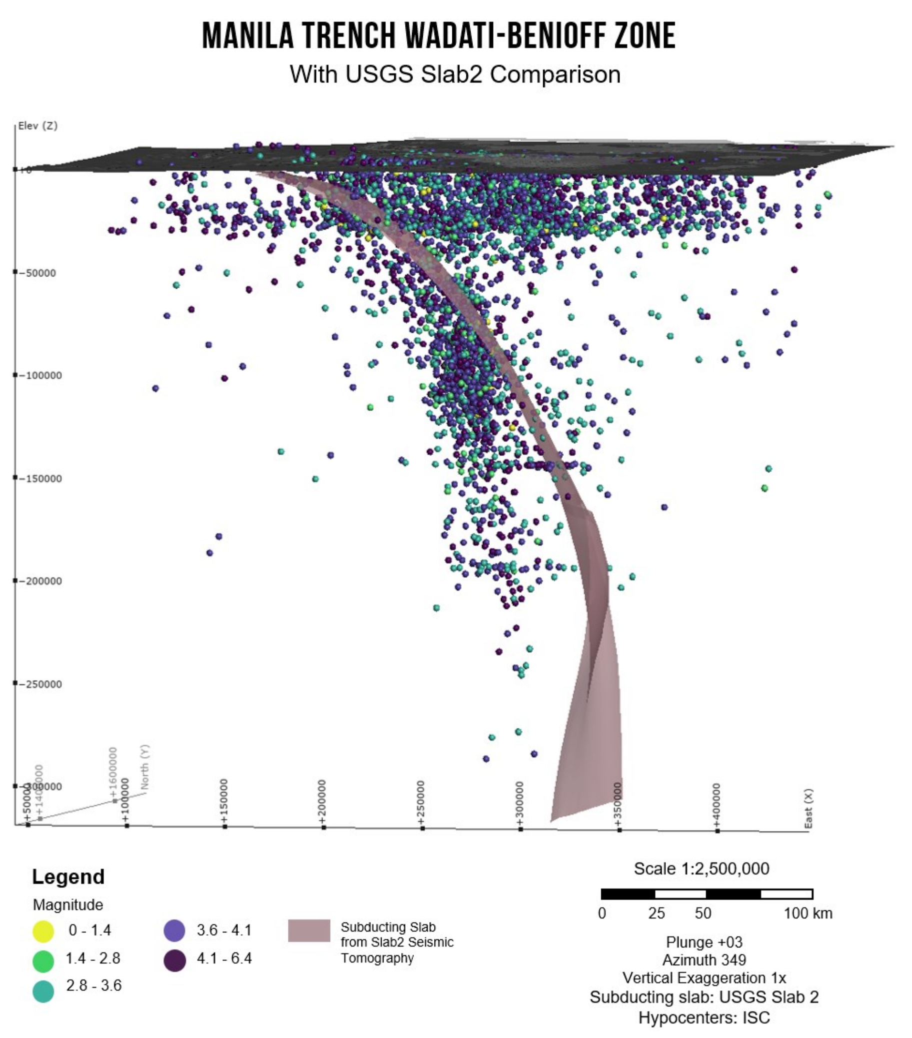

Fig. 3. Leapfrog-generated 3D model of Manila Trench Wadati-Benioff Zone in comparison with Slab2 (from USGS). Video presentation: https://youtu.be/iD05V6c7o-4

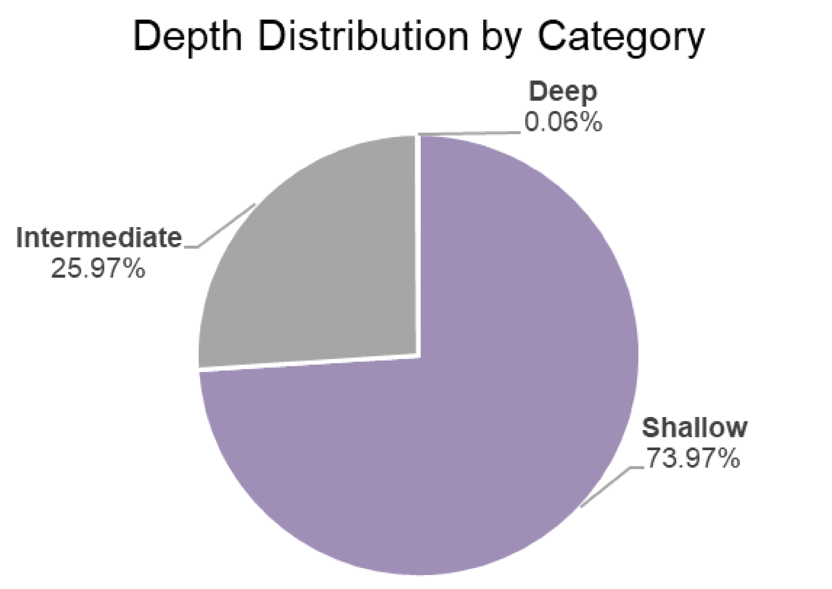

Fig. 4. Earthquake hypocenters categorized in terms of depth (after USGS in Fowler, 2012)

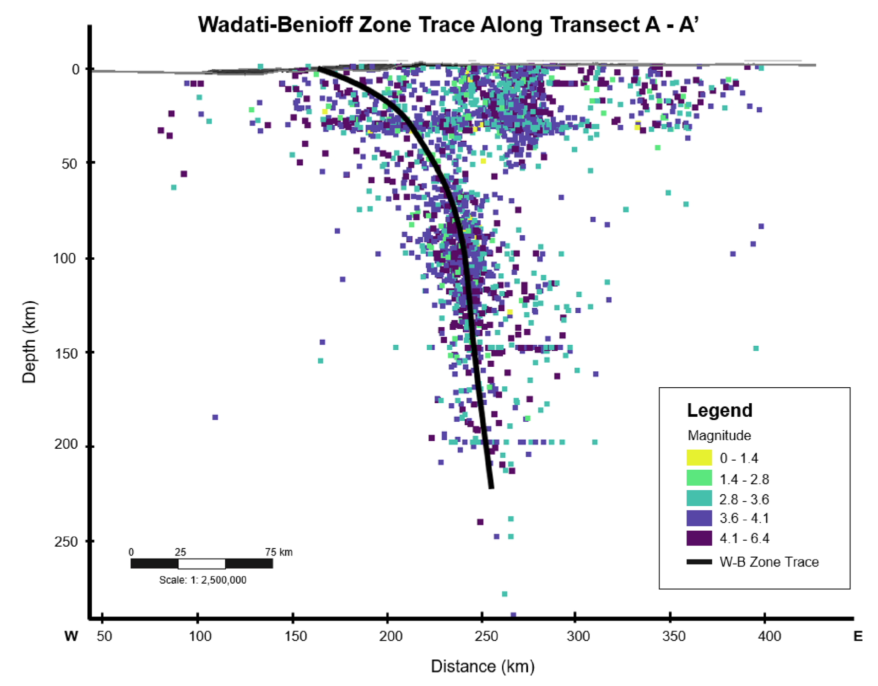

Fig. 5. Cross section of 3D model along transect A-A' (see Fig. 2) showing the Wadati-Benioff Zone trace (black)

The map (Fig. 2) and 3D model (Fig. 3) show the notable abundance of deeper hypocenters within the western portion of Verde Island Passage, Balayan Bay, and surrounding areas in Batangas. Such earthquakes can be categorized into three: shallow-focus (0-70 km), intermediate-focus (70-300 km), and deep-focus (>300 km). Majority of the earthquakes in the study area are shallow-focus at 73.97%, 25.97% are intermediate-focus, while deep-seated hypocenters are insignificant at 0.06%, as shown in Fig. 4.

The Wadati-Benioff zone, on the other hand, can be seen dipping almost vertically towards the east with depth values ranging from 0 to almost 300 km (see Fig. 5). In the 3D model, Slab2 seismic tomography model from USGS shows dip deviation in depths deeper than 100 km.

DISCUSSION

Shallow-focus earthquakes with low magnitudes are usually related to volcanism or deformation on the overriding plate boundary, while intermediate and deep ones occur within the subducting slab (Fowler, 2012). The abundance of shallow-focus earthquakes may be attributed to heavy volcanic activity, i.e, due to Taal Volcano or seismic activity of surrounding faults. Some of the shallow-focus earthquakes, however, follow the trace of the Wadati-Benioff zone, and are possibly associated with subducting mechanisms. Intermediate-focus hypocenters show the distinct trace of the W-B zone, indicative of the subducting slab's high seismic activity.

Moreover, the generated subduction zone from Slab2 yielded slightly different results due to the difference in variables used. While the generated W-B zone in this study relied on earthquake hypocenters, seismic tomography models use traveling seismic waves in between receivers (Saccorotti & Lokmer, 2021). Seismic tomography imaging, however, can generate deeper slabs even with coarse global datasets, like those used in Slab2.

In the future, using other GIS and 3D modeling software may prove to be more useful for the intents and purposes of this study. Other portions of the Manila Trench or other trenches and similar structures may also be explored and paired with higher level spatial, structural, or geomorphological analysis to further improve the study output.

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