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MAPPING SUBMARINE GEOMORPHOLOGY OF THE PHILIPPINE AND MARIANA TRENCHES BY AN AUTOMATED APPROACH USING GMT SCRIPTS

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This paper presents a geospatial analysis of two oceanic trenches using a GMT (Generic Mapping Tools) cartographic method that exploits the scripting approach to visualisation of their geometric shapes. To this end, the research applies the high-resolution datasets GEBCO and ETOPO1 and ETOPO5 for modelling of the submarine relief. This allows taking into account the 2D and 3D shape deviations in the geomorphology of the two selected segments of the trenches by transecting a series of the cross-section profiles. A scripting algorithm of spatial data processing based on the GMT techniques visualised the topography of the submarine objects in 2D and 3D forms and extracted the topographic data from raster grids for statistical analysis of depth using the cross-section transect profiles of both trenches. The bathymetry of the Mariana Trench was evaluated in the southern segment located near the Challenger Deep area, southwest of Guam Island, in comparison with the segment of the Philippine Trench, which was transected in the surroundings of Mindanao Island. The study presented a comparative submarine geomorphic modelling and spatial analysis of the Philippine Sea basin area. The bathymetric analysis of the relief in the Mariana and Philippine trenches showed effective performance of the GMT scripting toolset in advanced cartographic data analysis and visualisation.

Keywords: GMT, seabed, cartography, Philippine Sea, topography, Pacific Ocean.

INTRODUCTION

The geomorphology of the oceanic trenches has been mapped and visualised in insufficient detail, compared to the terrestrial areas the Earth. This is mainly explained by the complex submarine relief and technical difficulties of seabed observations. However, rapid development of new cartographic techniques, as well as advanced methods of data modelling and visualisation have largely contributed to general progress in mapping. Using these methods, the interpretation of submarine geomorphology by GIS methods of spatial and statistical analysis became possible and have been regularly reported in relevant studies (Hillier, 2011; Harris *et al.*, 2014a; 2014b; Lemenkova, 2019a; 2019b; Brothers *et al.*, 2020; Idárraga-García *et al.*, 2021).

Deep-sea trenches mostly have a V- or U-shape in their cross-section profiles, yet can have a more complex form (Dong *et al.*, 2018; Jamieson *et al.*, 2020; Lemenkova,

2020a; 2020b; Zhang *et al.*, 2021): trough-form, asymmetric, oblique, displaying a riverine-like geometric system in a plain 2D (Figs. 1 and 2), oblique or 3D view (Figs. 3 and 4). Generally speaking, the geomorphology of the oceanic trenches varies in slope steepness, curvature and depth, shaped as a result of the tectonic evolution of the submarine relief in the process of tectonic plate subduction. The geomorphology and development of subducting slabs are complex (Christensen, 1996), on either mantle flow or convective layering at 660 km depth. Slabs can deflect horizontally in the upper mantle transition zone beneath some convergent margins, whereas penetration to the lower mantle depths occurs beneath the other island arc segments. As a result, different patterns of the subduction across the upper mantle transition zone affect the formation of the trenches, which is well reflected in their submarine geomorphology.

Philippine Trench. Currently, the Philippine Trench has been studied with respect to geophysical processes and geo-

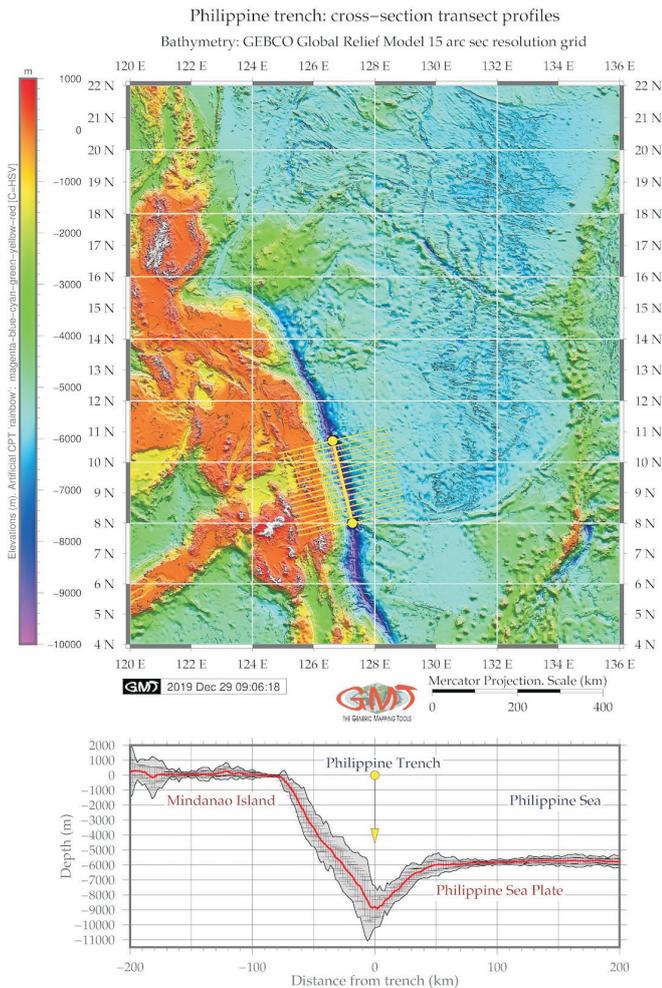


Fig. 1. Cross-section transect profiles of Philippine Trench. Data source: GEBCO (GEBCO Compilation Group, 2020). Map source: author.

logical settings at selected sample point margins. Such interest can be explained partially due to the correlation that exists between tectonic plate movements and the long-term evolution of the geological processes (Hilde *et al.*, 1984; Seno and Maruyama, 1984; Deschamps and Lallemand, 2003; Chadwick *et al.*, 2018). There is also evidence of deep-sea species existing on the seafloor of the Philippine Trench. For instance, it provides habitat to species of the hadal crustacean shrimps, such as amphipods (Hessler *et al.*, 1978). The Philippine Trench supports geomorphic evidence of tectonic deformation resulting from the westward Philippine Sea Plate (PSP) subduction along the trench, as well reconstructed previously (Ramos *et al.*, 2012) with detected raised marine platforms and terraces along the 80-km-long coastline of the Philippine coasts. The heterogeneous nature of its submarine geomorphology resulting in depth and steepness variation at the local level (ca 1200 km) is affected by crustal deformation along the Philippine Fault at Luzon, which geologically originated in the Eocene (Suzuki *et al.*, 2017).

Specifically, the fault reveals a left-lateral slip of the Philippine archipelago from the northwest corner of the Luzon Island to the southeastern end of Mindanao Island. Therefore,

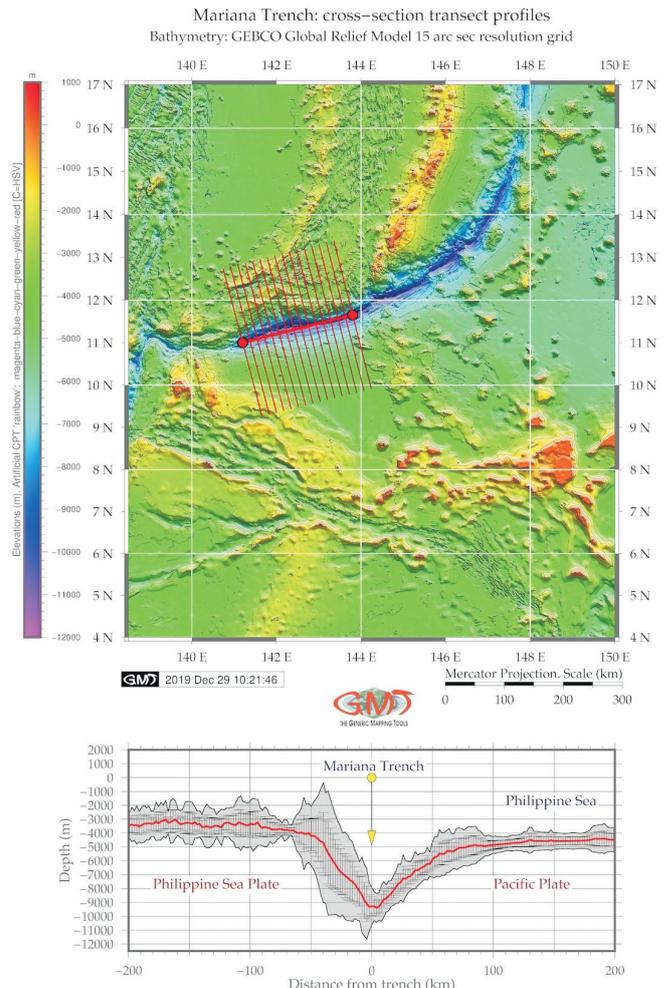


Fig. 2. Cross-section transect profiles of tMariana Trench. Data source: GEBCO (GEBCO Compilation Group, 2020). Map source: author.

it is often challenging to distinguish the multiple spatial variables of the tectonic and geological factors with those of depth distribution and gradients in deep-sea trenches. Some more studies of the PSP have investigated its geophysical settings with a special focus on magnetism and reconstruction models, highlighting its complex tectonic history, origin and motion development (Hall *et al.*, 1995). Other efforts have been focused on interpretation of the geophysical and tectonic settings of the PSP. For instance, Yu and Chang (1991) discussed lateral fluctuations in the upper mantle structure of the Philippine Sea Basin (PSB), as studied in detail in previous work (Yu *et al.*, 2000) with a focus on the geophysics of the PSB area.

Recent surveys revealed the presence of peridotites, gabbros, and massive and pillowed flows of the Mesozoic ophiolite belt in this region. Major, trace, and rare earth elements of volcanic rocks show the subduction-related impact on the formation of the island arc (Guotana *et al.*, 2017). Mixed sedimentary consolidated rocks were formed by submarine erosion from the abyssal plain area located near the Philippine Trench and transported to the trench, as well as submarine canyons followed by the water currents (Stern, 2021; Lemenkova, 2020c; 2020d; Das *et al.*, 2021). The tec-

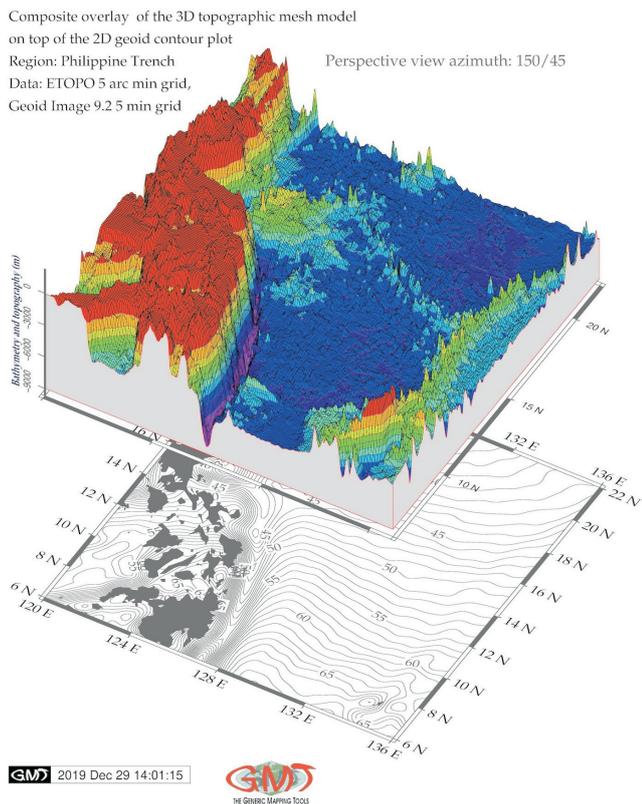


Fig. 3. The 3D relief model: Philippine Trench, southern segment. Data source: ETOPO5 DEM (US Naval Oceanographic Office, USA). Map source: author.

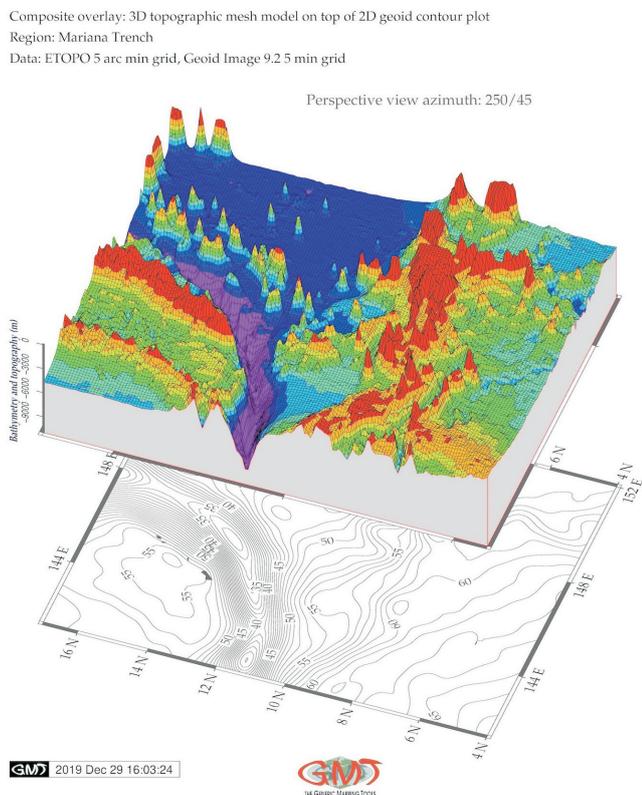


Fig. 4. The 3D relief model: Mariana Trench, southern segment. Data source: ETOPO5 DEM (US Naval Oceanographic Office, USA). Map source: author.

tonic evolution of southern Japan was simulated earlier (Hashima *et al.*, 2016), which suggested that it was caused due to the subduction of the Pacific Plate and the PSP and the collision of the Izu–Bonin–Mariana arc. Thus, the geomorphological and geological data on plate movements suggest that subsidence affected the entire PSB, after which the area of subsidence narrowed until the basin's uplift.

Previous studies (Fan and Zhao, 2019) identified the geodynamic processes in the crust and mantle of the Philippines archipelago, which induce the geographic differences in the azimuthal tomographic anisotropy between the central and southern Philippines. Thus, recorded earthquake events here can be divided into three groups of depths: 0–60, 60–350 and above 350 km, demonstrating active volcanism and seismicity around the Philippine archipelago, in general. Further reading on the tectonics and geologic settings of the Philippine Trench region can be found in relevant publications, with detailed discussions on spatial variation in seismic earthquake data (Besana *et al.*, 1997), shape form of the subducting slabs (Bautista *et al.*, 2001), tectonics of the Parece Vela Basin (Okino *et al.*, 2009), subduction system of the PSP (Holt *et al.*, 2018), questions of fault topography patterns and quaternary faulting along the Philippine Fault zone, Central Luzon (Hirano *et al.*, 1986), and accreted terranes in the northern part of the Philippines (Karig, 1983).

Mariana Trench. The submarine relief of the Mariana Trench is marked by complicated steps of various shapes and sizes, which are caused by active tectonic processes and sedimentation. The steepness of its geomorphic depth averages 4–5°, yet individual parts might be limited to the steeper slopes as subjects to the gravitational flow system of the submarine canyons and valleys (Kawabe, 1993; Normark and Carlson, 2003; Harris and Whiteway, 2011).

As a result, complex distribution of various material on the abyssal plains contributes to the formation of the geomorphic features in a particular region of the Mariana Trench. The arc of the Mariana Trench can fit into a square with coordinates 140° E–148° E, 11° N–25° N (Fig. 5). Its geomorphologic development took place in several phases shaped by the impact of various factors: geologic conditions, volcanic submarine areas, and inner ocean currents and sedimentation.

The seafloor bathymetry of the trench varies seaward of the trench axis: the Challenger Deep area, southwest of the Guam Island, is associated with the deepest relief sounding of 10 984 m (95%) at 11.33°N / 142.20°E, and axial vertical loading (Gardner *et al.*, 2014). The Challenger Deep is up to 2 km deeper than the average depth along the axis of the Mariana Trench (Fryer *et al.*, 2003). The areas with seamounts at the trench axis are marked by the gentle trench morphology, smaller axial vertical loading, and bulgy topography at the outer-rise. The Mariana Arc and the West Mariana Ridge border the trench on its west side. The Caroline Ridge and a group of the Caroline Islands are located southwards of the trench axis at a distance of about 0–250 km. A prominent trench-parallel belt of seamounts with a

Bathymetry: ETOPO1 Global Relief Model 1 arc min resolution grid

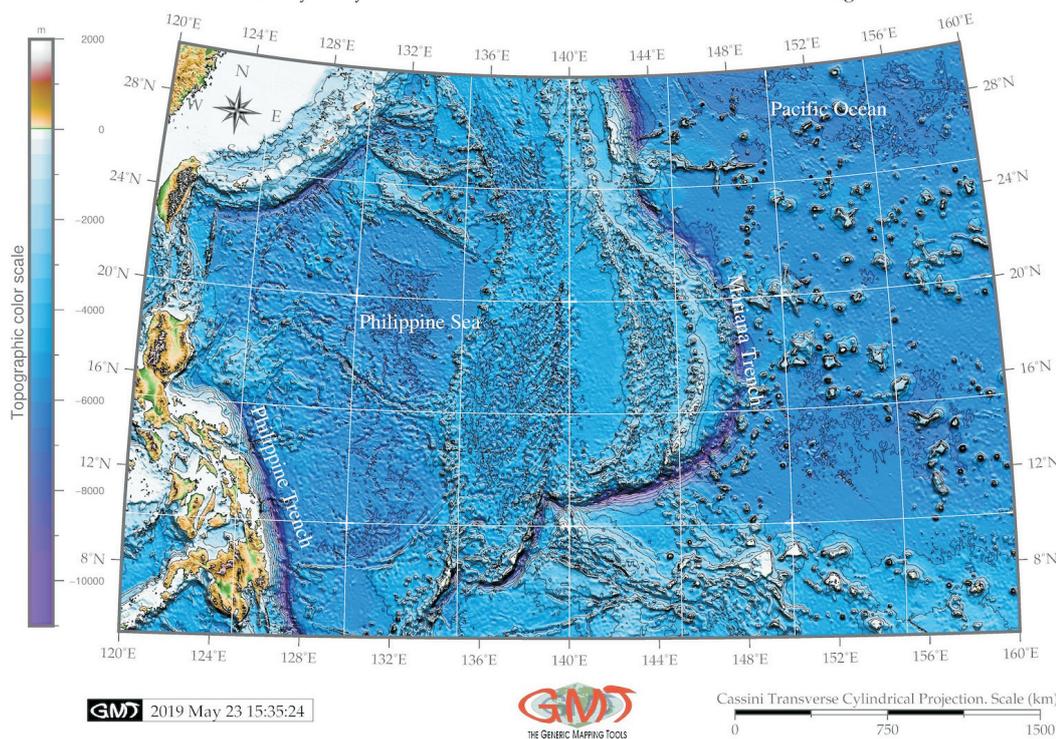


Fig. 5. Geographic location of the study area: Philippine Sea basin. Data source: ETOPO1 DEM (Amante and Eakins, 2009). Map source: author.

trench-perpendicular width of about 250 km is located at around 1350 km below sea level (BSL). Another notable group of the wide seamounts intersects the trench at a distance of 1600–2000 km BSL. The Mariana Arc lavas are enriched in Molybdenum (Mo) and have $\delta^{98/95}\text{Mo}$ greater than the Mid-Ocean Ridge Basalt (MORB). This implicates the addition of the Mo-rich fluid with $\delta^{98/95}\text{Mo}$ ca. $+0.05\%$ to $+0.05\%$ to the mantle wedge beneath most of the islands (Freymuth *et al.*, 2015).

The seafloor geomorphology with a very steep escarpment of the narrow Mariana Trench does not play a crucial role for ocean water mixing, as recently found (Haren *et al.*, 2017). Instead, the interplay between the topography and the turbulence of the ocean waves highlights the impacts of the inertial and meridionally directed tidal inertio-gravity waves, responsible for the turbulence and variation of the water mass mixing, according to the depth stratification in the Mariana Trench area.

This study aims to compare the geomorphology of the two deep-sea trenches, the Mariana Trench and the Philippine Trench, using modelling performed by scripting cartographic techniques. For that, transecting profiles of the both trenches, 3D visualization and 2D mapping of the study area were carried out. Due to variations of the bathymetry between the trenches, the statistical comparison was done additionally using the plotted histograms of depths. The goal of the comparison between the topographic transects of the trenches is to assist highlighting the impact of the complex tectonic and geophysical setting in various regions of the Pacific Ocean which affects and shapes the submarine geomorphology of the trenches.

MATERIALS AND METHODS

Study data. This study area covered the two selected submarine regions of the Philippine Sea basin: the Mariana and Philippine trenches (Fig. 5). A subset of the regional geological settings was collected from the unified catalogue of the Scripps Institution of Oceanography. The data sets included the following resources, grids and datasets:

- General Bathymetric Chart of the Oceans (GEBCO) gridded bathymetric data set (GEBCO Compilation Group, 2020), by IHO, Data Centre for Digital Bathymetry (DCDB) (Mayer *et al.*, 2018).
- ETOPO5, ETOPO1 DEM (Amante and Eakins, 2009).
- Global Self-consistent Hierarchical High-resolution Geography Database (GSHHG) GMT (Generic Mapping Tools) embedded dataset (Wessel and Smith, 1996).
- Gazetteer of IHO (IHOIOC2012) (IHO, 2012).
- Global Volcanism Program (GVP) database by Smithsonian Institution.
- Geologic datasets (tectonic plates boundaries, slabs, lineaments, trench lines, ophiolites, volcanoes, etc) from Scripps Institution of Oceanography.

The cartographic mapping and data analysis were performed in GMT (Wessel and Smith, 1991) using described methods (Gauger *et al.*, 2007; Grad *et al.*, 2009; Lemenkova, 2019c; 2019d; 2021c). The topographic descriptions of the submarine features were referenced to the existing IHO database. The geologic lineaments, ridges, volcanic spots, seafloor fabric, tectonic plates boundaries, rate of

movements and fracture zones were mapped through the batch use of several GMT modules ('psbasemap', 'psxy', 'grdcontour', 'grdcut' and 'grdimage', etc.) and converted via the 'psconvert' module.

Transecting profiles. To analyse the geomorphology of the trenches, the developed method of GMT for modelling terrains was adapted and modified (Lemenkova, 2021a; 2021b). The transect method was selected because the oceanic trenches have in general similar geomorphic setting with reverse general shape form. Specifically, using this method, the observed elevations, Z, along the cross-section transects were read into a table, using the GMT 'grdtrack' module along the selected segment of the trench with a track 400 km long, spaced 20 km and samples taken 2 km along the corresponding transect line. Then, the recorded bathymetric measurements were read into an input table from which a graph was plotted denoting the profile shapes (Figs. 1 and 2).

The target area for the Philippine Trench was selected off the Mindanao Island, which is the 2nd largest island in the Philippines, situated in the southern part of the archipelago. The Area of Interest (AOI) square was 126.62° E 10.7° N 127.27° E 8.0° N. The AOI for the Mariana Trench was located in the south-western part of the crescent (Fig. 5) and was bounded on the east by Guam Island and on the south by the Yap Trench encircled by the target square of 141.2°E 11.0°E 143.8°E 11.65°N, capturing the Challenger Basin. A sequence of the GMT codes were used for plotting the transects as follows (here with the example for the PT). A 'cat' Unix utility has been used to plot the target coordinates:

```
cat << EOF >> trenchP.txt 126.62 10.7 127.27 8.0 EOF
```

The line of transect was plotted using the 'psxy' module:

```
gmt psxy -Rpt_relief.nc -J -W2p,yellow trenchP.txt -O -K >>ps
```

Start and end points of transect were plotted using the 'psxy' module:

```
gmt psxy -R -J -Sc0.1i trenchP.txt -Gyellow -Wblack -O -K >>ps
```

Generation of the cross-track profiles was done using the 'grdtrack' module. The parameters were selected as follows: 400 km long, spaced 20 km, sampled every 2 km. The results of the cross-sectioning were saved in a table (here: tableP.txt)

```
gmt grdtrack trenchP.txt -Gpt_relief.nc -C400k/2k/20k+v -Sm+sstackP.txt > tableP.txt
```

Then, the crossprofiles were added using the 'psxy' module:

```
gmt psxy -R -J -Wthin,yellow tableP.txt -O -K >>ps
```

```
gmt convert stackP.txt -o0,5 > envP.txt
```

```
gmt convert stackP.txt -o0,6 -I -T >>envP.txt
```

RESULTS

The resulting profiles were visualised as two segments on Figures 1 and 2, below the maps. Here the red line shows the values of the median depth for both trenches. The samples received through the transecting were compared for the analysis of the variability in depth for both trenches. On the cross-section graphs, gradient slopes of the trenches have markedly symmetric accurate 'V'-shape form in their deepest parts, where the Mariana Trench has in general a steeper gradient slope on the northern flank off archipelago compared to the Philippine Trench. The statistical histograms showing frequency of data distribution for the transecting profiles of the Mariana and Philippine trenches bordering the PSB are visualised in Figure 6. The shape of the histogram varies for the two trenches, reflecting their geomorphology. The descriptive statistics on the topography and interpolation approaches shows the following results.

The west Mariana Ridge (Fig. 2) is located north off the trench axis at a distance of 0–50 km, while the northern part of the Caroline Ridge is intersected by the southern transects of the trench profiles at a distance of about 180–200 km. A prominent trench-parallel belt of the seamounts visualised on the 3D graph (Fig. 4) appears at 148°–149° E. The 3D relief map of the Mariana Trench shows the selected segment of Challenger Deep to the north-west (left on the figure) off the trench at Mariana Ridge, to the north-east a chain of seamounts, and to the south shows sediment accretion.

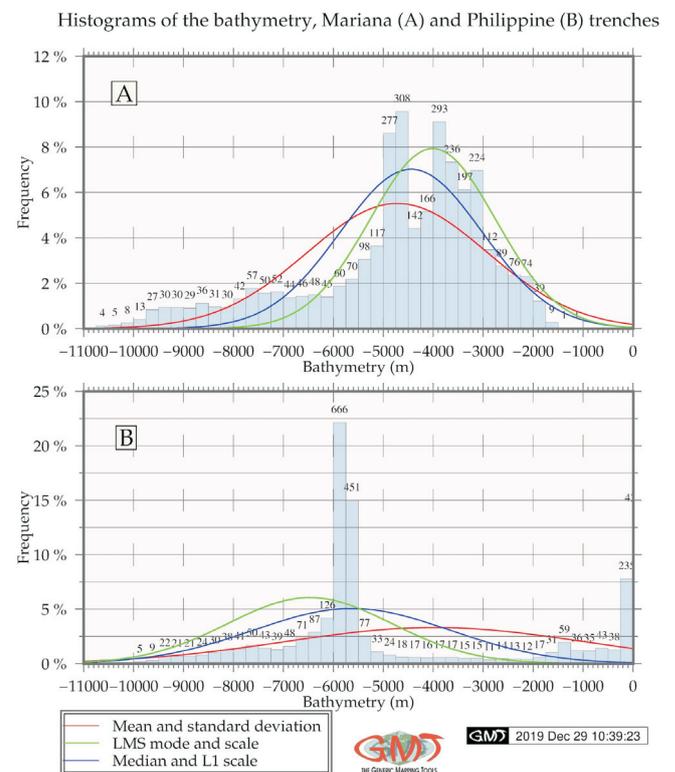


Fig. 6. Frequency histograms of depths: Mariana and Philippine trenches. Graph source: author.

The automatic digitising of the perpendicular transects cross-sectioning Mariana and Philippine trenches demonstrated that the geomorphology of the Mariana Trench had a steeper gradient slope on the northern flank on the archipelago's side (Fig. 2, left part of the graph). More specifically, the slope steepness on the left flank of the selected segment of the trench is $33,10^\circ$ at 0–15 km from the centre of the vertical plummet. A segment on 15–25 km has a steepness of 45° , and a segment of 25–40 km has a steepness of $30,75^\circ$. The last segment located 40–50 km before the start of the shelf area has a steepness of 28° . On the right flank of the trench its gradient steepness varies as follows. The segment at distance 0–28 km has a steepness of $40,5^\circ$ from the vertical plummet. A segment of 28–37 km from the start point has a $43,33^\circ$ steepness. It then gradually becomes gentler with $30,43^\circ$ until the 50th km on the transect profile. Finally, the segment at 50–90 km has an arc shape with gradual increase of elevation that stabilises after 100 km, not exceeding –4000 BSL (Fig. 4).

The results of statistical data processing of data distribution are shown on Figure 6. The data distribution for the Mariana Trench (Fig. 6, A) demonstrates a bimodal peak on a histogram for the depths from –5000 m to –3000 m with sample observations not exceeding 10% of the selection. In this interval, the 1st peak covers an interval of –4500 to –5000 m BSL and the 2nd one is for the –3800 to –3000 m. A gradual decrease in data samples below 5000 m indicate a uniform data distribution for the depth range of –5000 to –6500 with a frequency ranging from 4% to 2% for the 285 samples in total.

The next interval of elevations covers the remaining samples with depths from –6200 to –10800 BSL and a data frequency below 2%. Shallower areas with dominating depths between the 3000 and 1500 m BSL have a data frequency not exceeding 4%. In total, there are 400 samples with data frequency below 4%. In general, the relief surrounding the left flank slope of the Mariana Trench is a more uneven submarine terrain compared to its right part with a more complex submarine relief. The Philippine Trench has a more accurate and steep relief form on the right flank.

The Philippine Trench (Fig. 1) has a classic symmetric bell-shape histogram form showing depth distribution with a notable sharp increase in data frequency at the interval of –5000 to –6000 m BSL, with together 1117 samples (22% and 15% of the data pool, i.e. 37%). This indicates an abrupt gradual decrease of depth, which can also be seen on Figure 1. The cross-sections of the selected segment have a strongly asymmetric view caused by the Philippine Islands (Mindanao) located on the west. Therefore, the western part of the cross-sections has a smooth gradual decrease in depth in a uniform way from –75 up to 40 km in the left flank with a slope of 31° .

The 2nd segment stretches from 40 until 10 km of the left cross-section with a gradient slope of $40,60^\circ$. The last and short segment on the left (10–0 km) has a steepness of 28° . The right flank of the profile has the following variation in

steepness. A segment of 0–20 km has a slope of 44° , following by the fragment of 20–35 km ($41,70^\circ$) and 35–50 km ($25,0^\circ$). A long segment on the right (50–200 km) has a very uniform geomorphology with almost no significant variation and dominating depth is around –6000 BSL. The deepest segment of the Philippine Trench, that is, 10–0 km on the profile from the centre line, has a more gentle slope with a steepness 28° vs 44° on the right flank for the same segment.

Unlike the Mariana Trench, the cross-sections of the Philippine Trench have asymmetric profile caused by the adjacent Mindanao Island. However, both trenches have a V-shape form in their deepest parts. Figures 1 and 2 show vertical cross-section transects perpendicular to the segment for Philippine and Mariana trenches. The lower placed graph shows a median stacked cross-section profile (red line) and an interval of error bars for the measurements. A comparison of these two graphs clearly shows the existing variation in the gradient of the angles, steepness and elevation from the western and eastern flanks of the trenches. The 3D bathymetry model of the selected segment of the Philippine Trench (Fig. 3) shows a margin characterised by the adjacent steep slope close to Mindanao Island to the south (left) of the trench, to the north by sediment accretion, and to the north-west by tectonic erosion.

Comparing the Philippine and Mariana Trenches, the bathymetry varies more notable westward of the trench axis by the Mariana Trench. A group of seamounts east of the Philippine Trench, stretching in a south-east direction with narrow seamount bases and shallow apices appears east of the archipelago at the trench axis at 130°E – 135°E (Fig. 3). However, at the area of plate subduction (127°E – 129°E), seamounts are absent and the seafloor has a more unified landform pattern. Starting at 16°N – 126°E , a ridge can be noted near the trench axis (Fig. 1). The geometric differences between the shapes of the trenches are explained by the context of geologic evolution and tectonic development and actual sedimentary processes affected their formation and structure.

DISCUSSION

The locations of the cross-sectional transects of the Philippine and Mariana Trenches were selected in the southern regions, due to the representativeness of these regions and important features, such as deep valley, slopes, moraines in the Philippine Sea Basin, and adjacent shelf. Mapping and modelling of the submarine geomorphology of the Philippine and Mariana Trenches revealed a relatively consistent pattern of their structural and morphological features. These include a deep abyssal valley, steep slopes, bounded by submarine deep basin moraines at the outer limits of the trenches. The submarine ridges can be explained as a series of small moraines, stacked behind larger moraines. The functional GMT-based framework for cartographic mapping and modelling of the ASCII datasets, raster and vector data enabled to quantify the variability of the bathymetry in spa-

tially distributed segments of the Mariana and Philippine Trenches.

This paper proposed a scripting cartographic method based on the GMT to transect the bathymetric raster grid for cross-sectional analysis and 2D and 3D cartographic modelling. The submarine relief is formed under complex interactions of the geophysical setting and geological formation in this study area. This research demonstrated a scripting method for visualisation of the submarine objects, otherwise non-reachable for direct detailed analysis. Compared to the traditional GIS techniques, GMT improves the speed and accuracy of mapping through significant automation of data processing, which is achieved by code written in GMT structured syntax. The scripting method of GMT based on using the console exploits the elevation values in the initial raster grid through the discriminative cartographic processing of the datasets performed by various modules of GMT. In such a way, it enabled to separate the submarine features in the deepest parts of the oceanic seafloor for the statistical analysis of depths in order to separate them from the surrounding relief and detect variation in bathymetry between the Mariana and the Philippine trenches.

A detailed cartographic analysis was evaluated for the two trenches using publicly available datasets (GEBCO, ETOPO1, ETOPO5) with extensive use of the GMT modules and comparison of the bathymetry of the two trenches. The effective performance of GMT for semi-automated mapping using scripts is reported in both cases: Mariana and Philippine trenches. The performed analysis showed that the appearance of the topography of the trenches differs, even for the two trenches located within the Philippine Sea. These results might appear useful for further studies and further evaluation of the submarine trenches of the Pacific Ocean.

In contrast with many other GIS, the GMT scripting approach is not designed for using Graphical User Interface (GUI) to perform an easy and conventional mapping, but permits instead complex data modelling using a sophisticated scripting approach. From the results reported above, it was shown that GMT is capable of cartographic plotting of most of the complex shapes of submarine bathymetry by 2D and 3D data modelling with performance superior or equal to the traditional GIS mapping with the current cartographic data processing. Finally, there are some aspects of the proposed GMT methods that deserve further study, for instance applied for other marine and oceanic regions. This study proves that the GMT can be successfully applied for mapping complex bathymetric regions using high-resolution datasets, quality visualisation, and data retrieval from the raster grids. In fact, the cross-section profiling can be extended to different trenches with various curvature and complexity using GMT, which can be recommended for future similar studies.

CONCLUSION

The two deep-sea trenches dissecting the PSB margins were the target of the presented research, which investigated spa-

tial variability of their submarine geomorphology, as well as highlighted impact factors that control their formation. The transect profiling was exemplified using sampling of the two case segments of the Area of Interest (AOI) in topography of the Mariana Trenches as a modelling goal. The semi-automated methods of cartographic digitising presented previously (Schenke and Lemenkova, 2008) was driven largely by the developed algorithms of machine learning (ML). Application of the ML in the cartographic routine significantly minimises the manual routine and subjectivity and increases the speed of mapping. Also, it increases the overall precision of data processing and accuracy of visualisation. The GMT presents a more advanced solution in the automatising of the cross-sections through ML-based digitising that results in a series of profile transects across the trench.

The functionality of several GMT modules used for the cartographic data analysis enabled to perform automated sampling of the orthogonal transects crossing trenches in a perpendicular direction. The GMT based modelling enabled to visualise and compare the shape of the submarine landforms, and the steepness gradient of the trenches for west and east flanks of the trenches. The two trenches were visualised, compared and statistically analysed using the GMT 'pshistogram' module. In general, the GMT-based ML method for automation of mapping largely improved modelling accuracy and reliability. In contrast to the traditional mapping techniques with standard user menu, e.g., ArcGIS, SAGA GIS (Hilst and Seno, 1993; Suetova *et al.*, 2005; Klaučo *et al.*, 2013; 2017; Lemenkova, 2020e; 2021d; 2021e), GMT is notable for scripting algorithm as a core methodology, as demonstrated in this paper.

This paper approached the problem of visualisation, modelling and statistical evaluation of the bathymetric data, otherwise unreachable to the analysis due to the remote location. The cross-section profiling by the GMT scripting techniques is mainly designed for plotting profiles of complex regions of the seafloor formed in the influence of several factors, such as tectonics and geology. While being valuable as a classic cartographic instrument, GMT enables to perform cross-sectioning of the complex relief forms as well.

Complex bathymetric landforms are common on the oceanic seafloor and can only be studied using advanced profiling and modelling, as demonstrated in this study by GMT. The profiling and 3D visualisation also implies that we need to select the representative segments in order to model and visualise the part of the oceanic relief for further geomorphological analysis. The presented research considers the GMT approach as a promising extension of the cartographic techniques that combine scripting and machine learning algorithms and geospatial analysis. In this paper, it was demonstrated that the performance and obtained results of the GMT are comparable or superior to GIS-based mapping. The presented 2D and 3D models and maps and other results of this study verify the usefulness of the GMT approach for both research goals: topographic analysis and cartographic visualisation.

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FILIPĪNU UN MARIANAS TRANŠEJU ZEMŪDENS ĢEOMORFOLOĢIJAS KARTĒŠANA, IZMANTOJOT AUTOMATIZĒTU PIEEJU UN GMT SKRIPTUS

Šajā rakstā sniegta divu okeāna tranšeju ģeotelpiskā analīze, izmantojot *GMT* kartogrāfisko metodi, kas izmanto skriptu pieeju to ģeometrisko formu vizualizēšanai. Šim nolūkam zemūdens reljefa modelēšanai tiek izmantotas augstas izšķirtspējas datu kopas GEBCO un ETOPO1 un ETOPO5. Tas ļauj ņemt vērā 2D un 3D formas novirzes divu atlasīto tranšeju segmentu ģeomorfoloģijā, pārģiežot virkni šķērsriezuma profilu. Telpisko datu apstrādes skriptu algoritms, kas balstīts uz *GMT* metodēm, vizualizēja zemūdens objektu topogrāfiju 2D un 3D formās un ieguva topogrāfiskos datus no rastra režģiem dziļuma statistiskai analīzei, izmantojot abu tranšeju šķērsriezuma transektu profilus. Marianas tranšejas batimetrija novērtēta dienvidu segmentā, kas atrodas netālu no *Challenger Deep* apgabala, uz dienvidrietumiem no Guamas salas, salīdzinot ar Filipīnu tranšejas segmentu, kas ir transektēts Mindanao salas apkārtnē. Pētījumā tika piedāvāta Filipīnu jūras baseina apgabala salīdzinoša zemūdens ģeomorfoloģiskā modelēšana un telpiskā analīze. Papildus reljefa batimetriskai analīzei Marianas un Filipīnu tranšejās šajā rakstā ziņots par *GMT* skriptu rīku kopas efektīvu veiktspēju uzlabotajā kartogrāfisko datu analīzē un vizualizācijā.