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Python libraries matplotlib, seaborn and pandas for visualization geospatial datasets generated by QGIS

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Abstract: This work aim is to perform modelling and spatial analysis of the marine geological data using combination of the QGIS and Python programming. Selecting proper cartographic software is important part of the geospatial research. QGIS provides organizing data in a GIS project for mapping and spatial visualization through vector and raster layers stored in GIS. Study area is Mariana Trench, west Pacific Ocean. A series of cross-section profiles were digitized in QGIS and used for further data processing in Python. Mariana Trench has complex geomorphic structure and unevenness in profiles stretching south-westwards. The geomorphology is subjected to various phenomena that affect its shape. These include bathymetry, geodesy, gravimetry, tectonics plates and geological settings, studied in this paper. To understand the structure of the trench, a data modelling using bathymetric analysis was performed by combination of QGIS mapping and statistical analysis in Python's library Seaborn. Statistical data modelling aimed at the analysis of the spatial variation of the geomorphology of the trench using following methods: multiple facet grids, area charts for the data frames, regression analysis, letter-value plots, hexagonal and Kernel density estimation. The results of the geospatial data analysis show spatial unevenness of the geomorphic structure, gravimetric, geodetic and bathymetric settings of the Mariana Trench. The study demonstrated effectiveness of Python application in geographic data analysis with Python codes provided for repeatability.

Keywords: *Quantum GIS, Python, Matplotlib, Geospatial Analysis*

I. INTRODUCTION

The study focuses on the area of the Mariana Trench (Figure 1), the deepest place on the Earth. Bathymetry of the Mariana Trench is well studied and has uneven shape in its various regions (Gardner et al., 2014; Lemenkova, 2019a;

2019b). Thus, East Mariana Basin is notable by prevailing depths of -5500 – -6000 m, however, in some local depressions of the seafloor they may reach up to -6300 – -6400 m. Central and southern parts of the Mariana basin are presented by a wavy plain. Small trenches directed northeastwards are presented in this area. Northern part is complicated by many seamounts (e.g., Mount Zubova, -5000 m) and blocky uplifts, especially in the north-west. An external rise extends along the Mariana Trench with individual blocks raised to a height of up to 2000 m above the seafloor, while the rest of the seafloor has local elevations ca. 500 m. Mariana Trench is located in the west part of the Pacific Ocean on the border of the two major tectonic plates: Pacific and Philippine (Figure 2), with additional two minor tectonic plates, Mariana and Carolines which results in complicated geological structure of the region (Figure 3).

Mariana Trench is located on the eastern margin of the Philippine Sea, which is bounded from the east by a chain of the island arcs (Nampo, Mariana, Yap, Palau) and associated deep-sea trenches (Rodnikov 1979). The uniqueness of the Philippine Sea in its submarine relief seafloor of the Philippine Sea is distinct from the typical marginals seas and is similar to the ocean seafloor (Peyve, 1980). The Philippine Sea is divided by the underwater ridges into several basins: Philippine, Nampo and Western Mariana. The prevailing depths in the Philippine basin are 5500–5800 m, in the Nampo and Western Mariana – from 4800 to 5200 m, although individual depressions in the geomorphology of the seafloor reach deeper values. Unlike in the basins of the marginal seas, the seafloor of the Philippine Sea is strongly dissected, hilly, with amplitudes of depths from 100 to 500-700 m. The orientation of the ridges is mainly sub-meridional and north-western, corresponding to the directions of the large submarine morphostructures.

The Mariana Islands are a crescent-shaped archipelago consisted of 15 mostly dormant volcanic mountains along the arc of the Mariana Trench. Such volcanic arcs are zones of volcanic activity along the borders of the Philippine Sea (Lemenkova, 2020a). Most of the active volcanoes are concentrated in the volcanic arcs. For the continental margins, the relief-forming role of the volcanic processes has a subordinate importance compared to the tectonic plate subduction. For the volcanic island arcs, on the contrary, volcanism is important geomorphic factor.

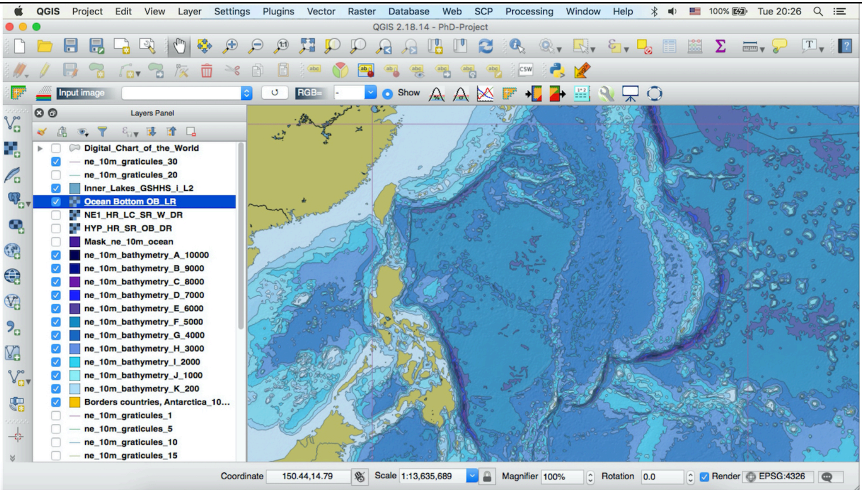

Fig. 1 Study area: crescent arc of the Mariana Trench (Source: author).

Based on the age of the constituent rocks, the Mariana island arc (as well as the Aleutian and Kuril-Kamchatka arcs) was formed in the Oligocene. During the Oligocene, an independent axis of extension existed in the Philippine Sea basin, which continued southwards in the direction of the Carolina basin (Monin & Lisitsyn, 1980). Its existence is proved by the corresponding magnetic anomalies (Litvin, 1987). Obviously, this local expansion of the seafloor of the Philippine Sea basin, caused by tectonic plate movements, induced the formation of the Mariana island arcs with associated deep-sea Mariana Trench (Rudich 1983).

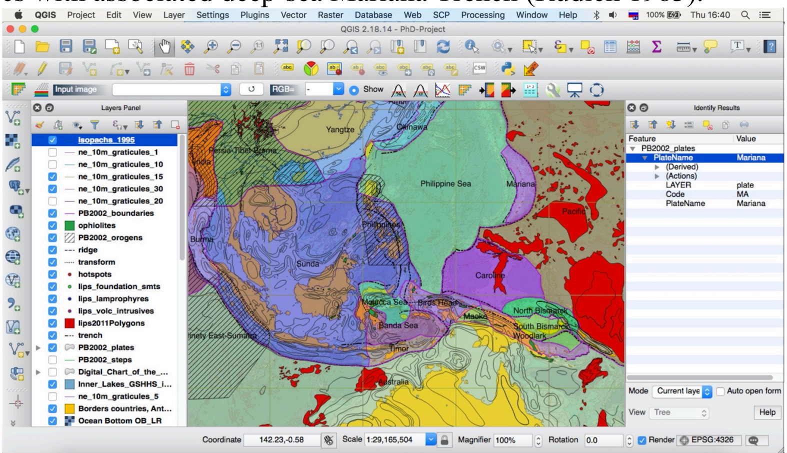

Fig. 2 Tectonic plates boundaries, QGIS project (Source: author).

Sediment cover in the Pacific Ocean is rather thin comparing to the Atlantic or Arctic (Heezen & Fornary, 1975; Neprochnov, 1979).

The sedimentation of the seafloor in the Mariana Trench shows that sediment samples taken from the lagoon of Saipan Island (group of Mariana Islands) are dominated by fragments of coral, calcareous algae and coral-algal rocks (Cloud, 1959).

Geological provinces of the study area. GIS project Mariana Trench.

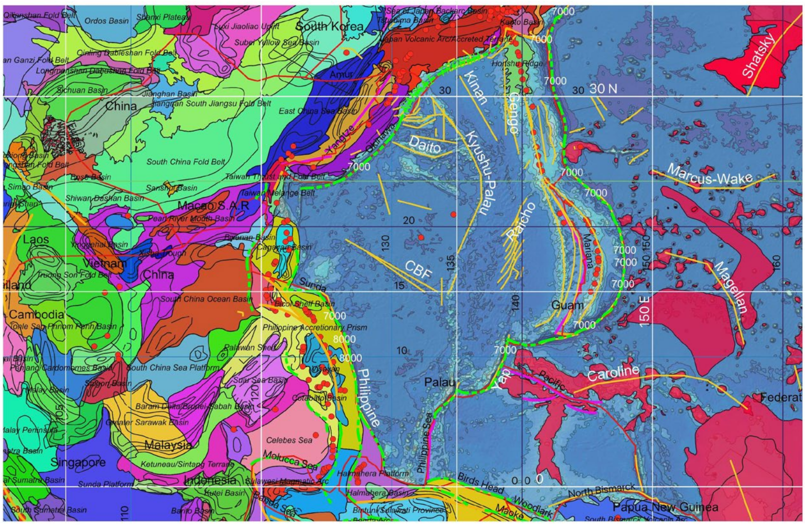

Fig. 3 Geological provinces and ophiolites (Source: author).

In smaller quantities, they also contain shells of foraminifer and fragments of the skeletons of mollusks. There is very small amount of needles and shells of hedgehogs, although they are very widespread in this area. Among fragments of algal, predominating are whole and fragmented segments of the green alga (Bezrukov, 1957). Andesites predominates on the Mariana Islands followed by basalts (Bezrukov, 1979).

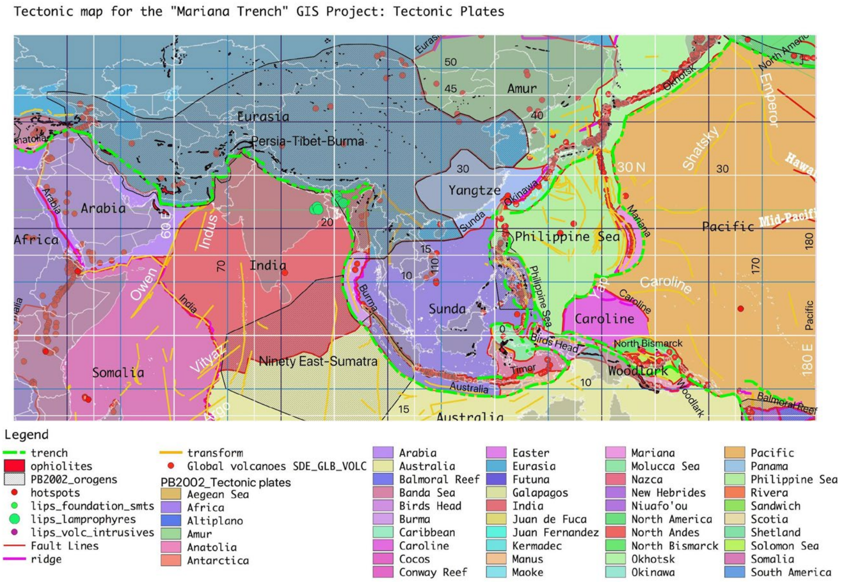

Fig. 4 Tectonic provinces and minor tectonic plates (Source: author).

The Izu-Bonin-Mariana island arcs and associated with them deep-water trenches which include Mariana Trench, were formed in the process of the subduction of one tectonic plate under another (Figure 4). The arcs were uplifted to a height of 2-3 km, and the inter-basin (depressions) remained at about the same bathymetric level of the seafloor.

II. METHODOLOGY

Methodology of the current research included following parts in QGIS and Python:

1. initialized project in QGIS (Figure 2);
2. organizing data and visualizing layers: geology, sediments, bathymetry (Figure 5);
3. geoprocessing, thematic mapping for spatial analysis using QGIS (Figure 6);
4. digitizing cross-section profiles by center points and lines (Figure 7 and Figure 8);
5. saving data as table and converting to .csv format;
6. data analysis using Python programming (Figure 9, 10, 11, 12, 13).

The QGIS project data plotting and vectorization is described in previous research (Lemenkova, 2018a; 2018b). The data covering study area included raster and vector thematic layers on following clusters: geology, bathymetry and topography vector layers. Vector layers were downloaded from the available sources online. Print screen of the fragment of the Quantum GIS project is presented on the Figure 6.After all the data were uploaded to the GIS project, the 25 cross-section profiles were digitized in QGIS for data sampling. The cross-section profiling was performed in Quantum GIS. A large dataset consisted of 12.950 observations and 25 profiles digitized across the trench with a 100-km distance in-between. The available vector layers were uploaded into the GIS and the attribute tables imported into the .csv tables.

Further data processing was implemented by Python. The data for the Python processing included coordinates and thematic data in numerical of string format.

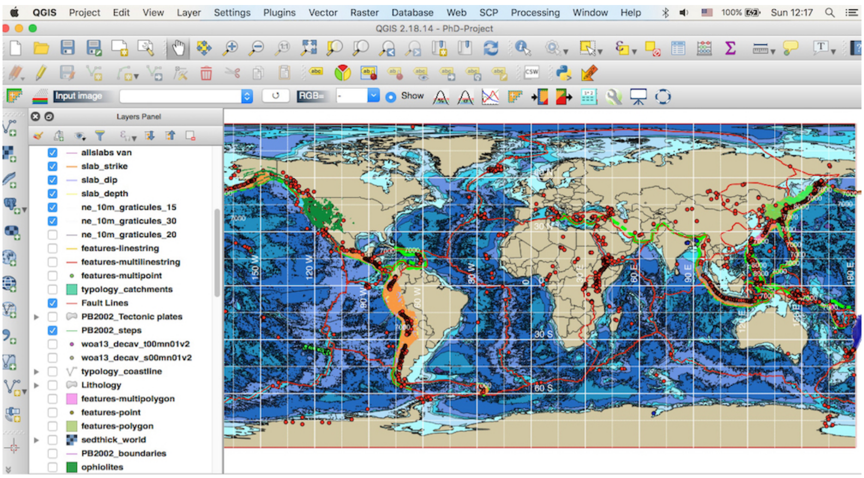

Fig. 5 QGIS project showing map layers visualization (Source: author).

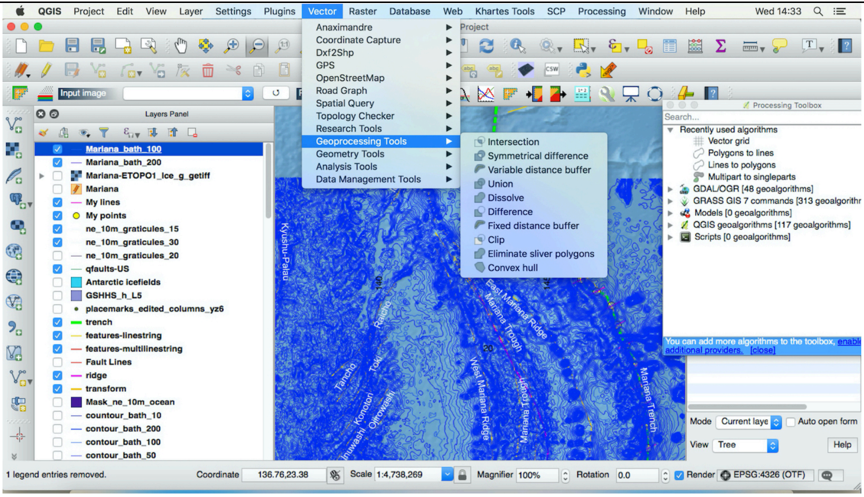

Fig. 6 Geoprocessing of bathymetric layer in Quantum GIS (Source: author).

The methodology of the data analysis in the current research is supported by the open-source programming language Python, initially released in 1991 by Guido van Rossum. There are various significant advantages of the Python that make it a stand-alone language among the others among them applicability for the oceanological data processing (Lemenkova, 2019c). The polymorphism embedded to the Python syntax enables to seamless overload standard operators to adjust their behavior in the context of the current task. Since Python is a very-high-level evolving language, it has flexible arrays built in (Rossum at al., 2018). Another feature of Python comparing to other applications in data science, e.g. R, Gretl, SPSS, AWK (Lemenkova, 2019f; 2019d; 2019e; 2019h; 2019m; 2019n) is its inheritance that scripts lets create subclasses containing qualities of their upper-level classes. The statistical analysis and programming algorithms were widely applied from the existing descriptions of the mathematical methods and computing approaches (e.g., Roberts et al., 2018; Vermeesch et al., 2016; Rossum G., van and the Python development team, 2018; Halterman, 2011; Harrington, 2015; Kuhlman, 2013).

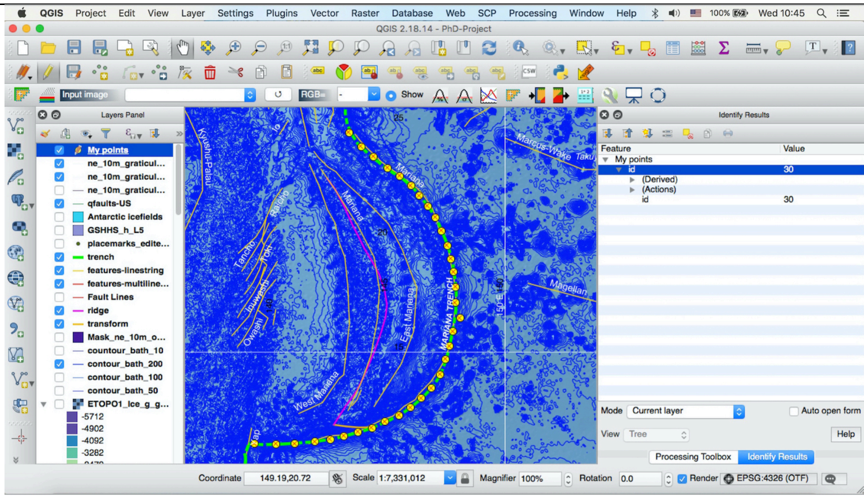

Fig. 7 Digitizing central points of 25 profiles in Quantum GIS (Source: author).

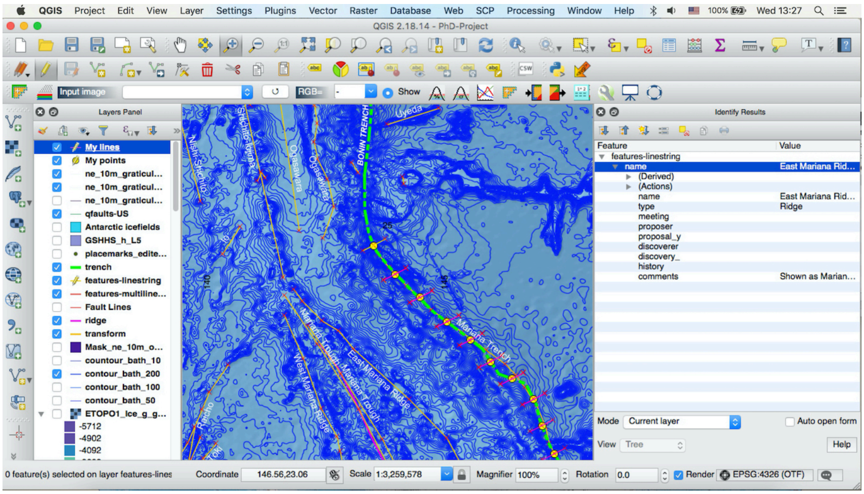

Fig. 8 Fragment of drawing cross-section profiles in QGIS (Source: author).

The statistical data processing was performed using Integrated Development and Learning Environment (IDLE), a Python editor and interpreter. Processing tables was done using multi-module NumPy fundamental library for fast computing and effective operating with arrays and matrices (NumPy community, 2019). The data were read-in to Python as a table in a .csv format and processed by statistical algorithms in Python libraries: Pandas for reading and processing tables, NumPy for array analysis, Matplotlib and Seaborn for large dataset modelling, analysis and visualization.

III. RESULTS

3.1. Regression Analysis

Regression analysis shows ground statistical modelling, such as data distribution, mean, median, quantiles and outliers. First, the 25 profiles were visualized by area chart and facet grid (Figure 9) from the exported .csv table that contained XYZ data (coordinates and depths in every sample points along each of the 25 profiles).

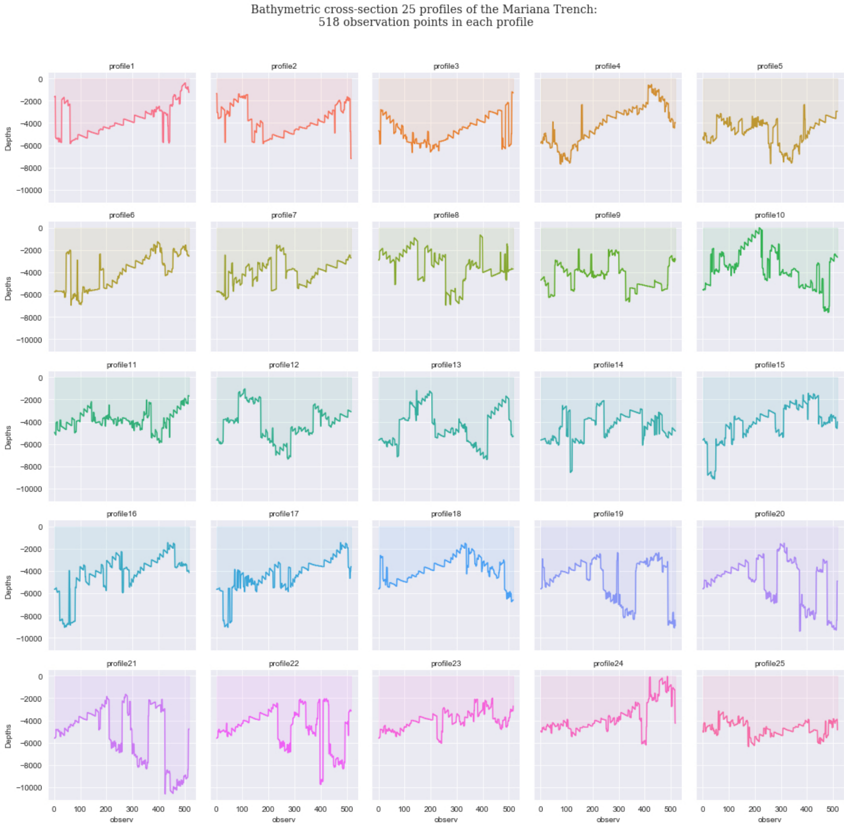

Fig. 9 Area chart and facet grid of the 25 cross-section bathymetric profiles of the Mariana Trench. Plotting visualization: Seaborn library, Python. (Source: author).

This gives an overview of the geometry (shape and steepness) and bathymetry (depths) of the profiles. Second, the regression analysis for the 25 profiles (Figure 10) has been done using lmplot() function which is a figure-level function that combines regplot() and FacetGrid() functions of the Matplotlib, Python. The regression analysis was done using Python code (1):

Code (1): Regression Analysis

```
import os
import numpy as np
import seaborn as sb
import pandas as pd
import matplotlib.pyplot as plt
sb.set_style('darkgrid')
sb.set_context("paper")
sb.set(font_scale = 3)
os.chdir('/Users/pauline/Documents/Python')
dfM = pd.read_csv("Tab-Bathy.csv")
# Defining loop sequence
profiles_nrs = list(map(lambda x: x, range(25)))
profiles_list = []
for i in profiles_nrs:
    profiles_list.append('profile{}'.format(i + 1))
# Defining variables
df = dfM.melt(id_vars = ['observ'],
              value_vars = profiles_list,
              var_name = 'Profiles', value_name = 'Depths')
# Plotting
g = sb.lmplot(data = df, x = "observ", y = "Depths",
              col = "Profiles", hue = "Profiles", col_wrap = 5,
              fit_reg = True, truncate = True,
              x_jitter = True, y_jitter = True,
              scatter = True, markers = '.', order = 2, height = 6)
g.set_axis_labels("Observation points",
             "Depths, m").fig.subplots_adjust(wspace=.04)
# Visualizing and saving picture
plt.tight_layout()
plt.subplots_adjust(top=0.92, bottom=0.08,
             left=0.10, right=0.95, hspace=0.25,
                 wspace=0.35)
plt.savefig('plot_FacetGrid.png', dpi=300)
plt.show()
```

3.2. Letter-value plots

The features shown on the letter-value plot (Figure 11) are distribution of the bathymetric data observations across 25 profiles. The statistical approach is derived from the Tukey's original box plot principle (Hofmann et al., 2011). Letter-values plot shows a large number of quantiles in the bathymetric observation set, defined as “letter values”. The layout of this plot is similar to a box plot, however it is modified and improved.

Besides plotting a nonparametric representation of a depths distribution across bathymetric profiles, where the data distribution corresponds to the observations, it plots more quantiles. Therefore, the letter-values plot gives more deep inside into the shape of the bathymetric data distribution. Hence, it can be seen clearly that the maximal depths of the Mariana Trench are located in the south-western part of its crescent.

Comparing to the box plot, the letter-value plot provides more detailed information in the ‘tails’ using letter values. Comparing to the box plots, letter-value plots on the bivariate big real data sets demonstrate to be more useful due to the more detailed approach on data analysis. The Letter-value plot was visualized by Python Code (2).

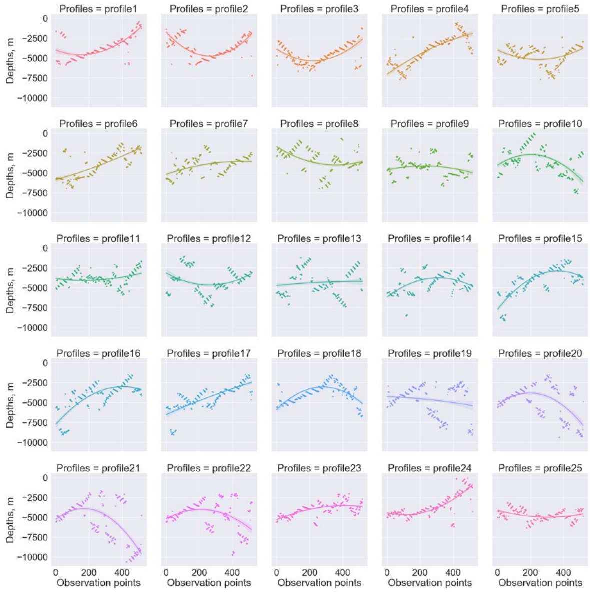

Fig.10 Regression analysis: facet grid of the 25 cross-section bathymetric profiles of the Mariana Trench. Plotting visualization: Seaborn library, Python. (Source: author).

Python Code (2). Letter-value plot:

```
import seaborn as sb
from matplotlib import pyplot as plt
import pandas as pd
import os
os.chdir('/Users/pauline/Documents/Python')
dfM = pd.read_csv("Tab-Bathy.csv")
dfM.head(5)
sb.set_style('darkgrid')
sb.catplot(data=dfM, kind="boxen",palette='Paired',
    orient="v", legend=True, legend_out=True, margin_titles=True)
plt.xticks(rotation=45)
plt.title('Letter-value plots for the Mariana Trench bathymetry', fontsize=12,
fontfamily='serif')
plt.subplots_adjust(bottom=0.15,top=0.85)
plt.show()
```

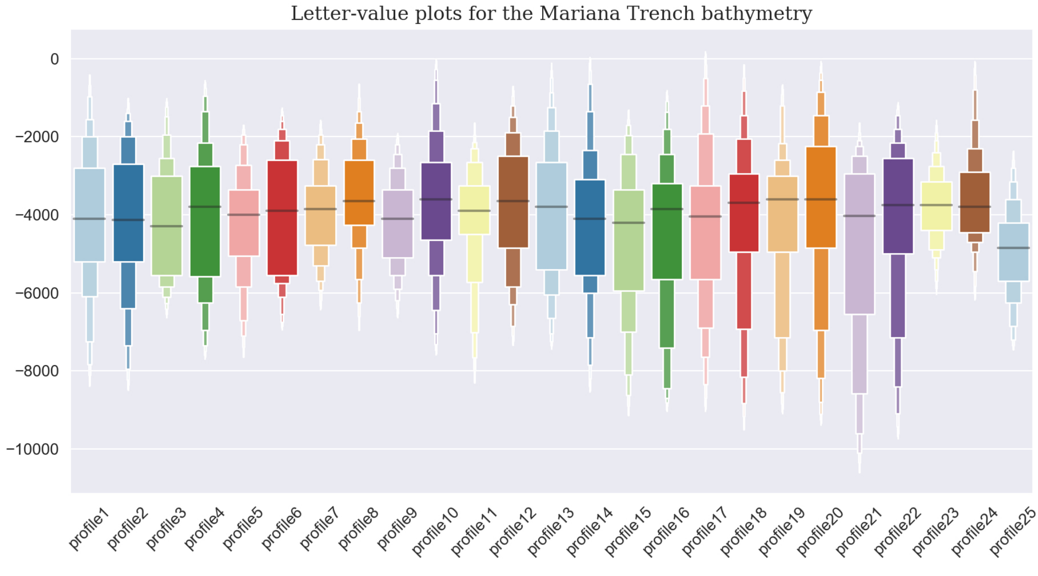

Fig.11 Letter-value plot for data distribution, Mariana Trench bathymetric profiles. Plotting: Seaborn library, Python. (Source: author).

3.3. Cluster heatmap, hexagonal data distribution and KDE

Hexagonal mapping is another useful approach for analysis of the big data sets when there are many observation points that may overlap. In this case, the data set comprised 25 profiles with 519 observation points in each, which in total gives 12.950 points. In this case, hexagonal binning that plots density, rather than points shows the concentration of data values in the specific profiles (Figure 12, right). Depth points are binned into gridded hexagons and distribution (the number of depths ranges per hexagon). As a result, it is displayed (Figure 12, right) using the density of color within the hexagons. The kernel density estimation is a non-parametric approach that visualized the probability of the density of a depth variables by profiles (Figure 12, left). The hexagonal and KDE plots were visualized by Python Code (3).

Python Code (3) for the Hexagonal and KDE plots:

```
import seaborn as sb
from matplotlib import pyplot as plt
import pandas as pd
import os
os.chdir('/Users/pauline/Documents/Python')
profiles_nrs = list(map(lambda x: x, range(25)))
profiles_list = []
for i in profiles_nrs:
    profiles_list.append('profile{}'.format(i + 1))
dfB = pd.read_csv("Tab-Bathy.csv")
df = dfB.melt(id_vars = ['observ'], value_vars = profiles_list,
            var_name = 'Profiles', value_name = 'Depths')
#print(df.head)
sb.set(style = "white")
sb.set_color_codes()
sb.jointplot(x = 'observ',y = 'Depths',data = df, kind='kde',
        dropna = True, color = "m")
sb.jointplot("observ", "Depths", data = df, kind = "hex", dropna = True)
plt.subplots_adjust(bottom = 0.15,top = 0.85, right = 0.90, left = 0.10)
plt.show()
```

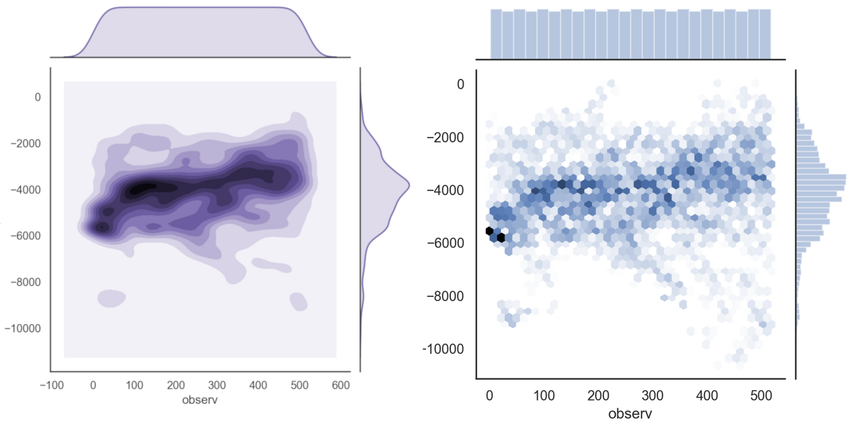

Fig.12 Hexagonal and KDE plots. Plotting: Python. (Source: author).

IV. RESULTS AND DISCUSSION

This study demonstrates variability between the geomorphology, slope angle steepness, geographic location depth of the bathymetric profiles cross-sectioning Mariana Trench. The geomorphology gives a response towards the geodetic location, gravimetric properties of the place by steepness of the gradient and depth. The shape of the submarine trench changes in space gradually due to the preconditioning by diverse factors.

Oceanic trench is highly sensitive to the different triggering factors, such as ocean deep currents that contribute towards the hadal sedimentation, as well as accounting for the topographic variability observed in the cross-section profiles. More importantly is that the effects of those factors that increase gradient steepness, that is location of the profile, crossing four tectonic plates in the places of slab movements may hidden other environmental triggers underlying the geomorphic responses induced, for instance, by the plankton biomass accumulation in the deep layers of the trench.

The novelty of this research consists in its cross-disciplinary approach that combines traditional approaches of the geospatial research performed in Quantum GIS with statistical analysis performed in Python programming language. The mix combination of the geological and mapping GIS visualization with statistical analysis and Python coding is schematically represented on the word cloud used to visualize text semantics of the crucial keywords for this research (Figure 13). Various categories of the approaches, methods, and data are show in a fish-formed word cloud. The area taken by each word proportionally to its importance for this study.

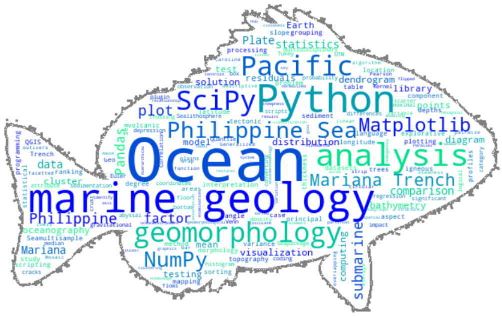

Fig.13 Word cloud plotted by Python. (Source: author).

GIS methods are used to perform spatial analysis, cartographic visualization and geoprocessing by various approaches (Gauger et al., 2007; Klaučo et al., 2013a; Klaučo et al., 2013b; Klaučo et al., 2017; Klaučo et al., 2014; Kuhn et al., 2006; Lemenkova, 2020b). These examples include land cover types analysis, geological mapping, geographic visualization of datasets using various projections and satellite image analysis. However, it is well known that classic GIS menu does not include advanced methods of statistical data analysis which is necessary for estimation of data distribution, assessment of data range and accuracy. Python statistical libraries can be effectively used for the post-GIS data processing as demonstrated in this paper. To date, most studies investigating, for example, land cover types analysis or geologic investigations, or land cover change measurements by raster image processing have utilized traditional GIS methods. However, precise statistical data analysis and visualization is still a major technique for Earth sciences. Combination of statistical data analysis with GIS enables to obtain visual models of data distribution received from GIS, to highlight correlation between data groups and variables, to perform factor analysis, data grouping, sorting and ranking, and to use other methods of statistical data processing. In this study, geological and bathymetric mapping was performed in QGIS environment followed by Python-based statistical data processing and plotting which contributes to the development of technical methods of data processing in geosciences.

V. CONCLUSION

Progress in methods of spatial data processing recently grown across a variety of geoscience disciplines. However, the use of high-level programming languages in marine geology require special focus and attention as lacking comprehensive introduction of the machine learning algorithms. Scripting languages applied for GIS analysis is a necessity in Earth sciences nowadays. Although this is the case, the programming languages are still not common in the GIS analysis today and are mostly restricted by plugins. The reasons for this can be the time required for learning and to some extent, lack of well-described applications specifically for GIS. In the presented research, a sequential use of QGIS and Python (Matplotlib, Pandas, Seaborn) is proposed to overcome these disadvantages.

Current state of the research in Earth science domains includes various computing methods supported mainly by GIS. While some work fragmentary include Python-written script as plugins directly embedded in GIS, relatively few works use programming languages in full (e.g. Skøien et al, 2014). On the other hand, supporting GIS methods by computer modelling contributes significantly towards our understanding of the structure of the oceanic seafloor (Suetova et al., 2005; Schenke & Lemenkova, 2008; Lemenkova, 2015). The aim of this research was to fill the gap between the 'pure' programming and Earth science research by demonstrating the advantages and power of the Python language in marine geology. This work introduced application of the programming based visualization specifically applied towards studies of the submarine geomorphology using statistical methods of data analysis and processing.

The novelty of this approach consists in the highlighting the functionality of the high-level language, such a Python, and applicability of the machine learning algorithms towards Earth science, doing a step apart from the traditional GIS. The practical purpose of this work is to test statistical package Seaborn built on the Python's Matplpotlib library for the geospatial data analysis, modeling and visualization using existing approaches (Lemenkova, 2019g). Effective and precise plotting supported by Python, demonstrates the indisputable advantages of the machine learning in Earth sciences.

The study has both scientific and practical implications for the understanding of submarine structure of the Mariana Trench through spatial analysis of its morphology. Being the deepest place on the Earth with unique environment, Mariana Trench constantly deserves attention of the scientific world (Chadwick et al., 2018; Curtis & Moyer, 2005; Faccenna et al., 2018; Fujioka et al., 2002; Theberge, 2008; Taira et al., 2005; Taira et al., 2004). It has potential for the application at other oceanic trenches. This study contributed to better understanding of the Mariana Trench geomorphology through spatial analysis combining QGIS and Python technical tools.

As a recommendation for future studies could be testing and applying more advanced cartographic tools developed and described previously, e.g. Generic Mapping Tools (GMT), a fully console-based cartographic toolset with extended functionality for print-quality mapping (Lemenkova, 2019i; 2019j, 2019k; 2019l). Both programming scripts and graphical outputs (maps, plotted graphs) are presented in this paper. In addition, application of QGIS was implemented for digitizing of the cross-section profiles and the results are presented as screenshots of the maps (QGIS menu and map layouts).

As final remarks, it can be noted that the workflow of the developed application can be applied in similar research. Thus, thematic vector layers of the QGIS project (bathymetry, sediments, geological settings, tectonic lines and geomorphology) were obtained based on GIS analysis. Each layer in QGIS has an attribute table with geographic coordinates and respective values. These data were stored and saved as .csv tables and then processed by Python, as demonstrated in this paper. This logical scheme for data processing can be recommended for future similar research and advised as a flowchart for combined use of GIS and Python.

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