Shelf width and slope canyon channel spacing: example from the Black Sea

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Introduction

Submarine canyons are linear and curvilinear conduits that downcut into the continental slope mud, and act as conduits for sediment delivery. Amount of sediment that arrives at the head of the submarine canyons depend on the width of the shelf (Porebski and Steel, 2006) and the process on the shelf (e.g. Stevenson et al., 2015). With increasing quality of worldwide bathymetric data, several efforts have been made to map the distribution and geomorphology of submarine canyons (e.g. Harris & Whiteway 2011). In this project, I conduct a brief mapping and analysis of the bathymetry of the Black Sea, where the shelf width varies 140 km near the Danube Delta (Popescu et al 2004), to only a couple of kilometers offshore western Pontides (Fig 1), making it perfect to compare shelf width with submarine canyon spacing.

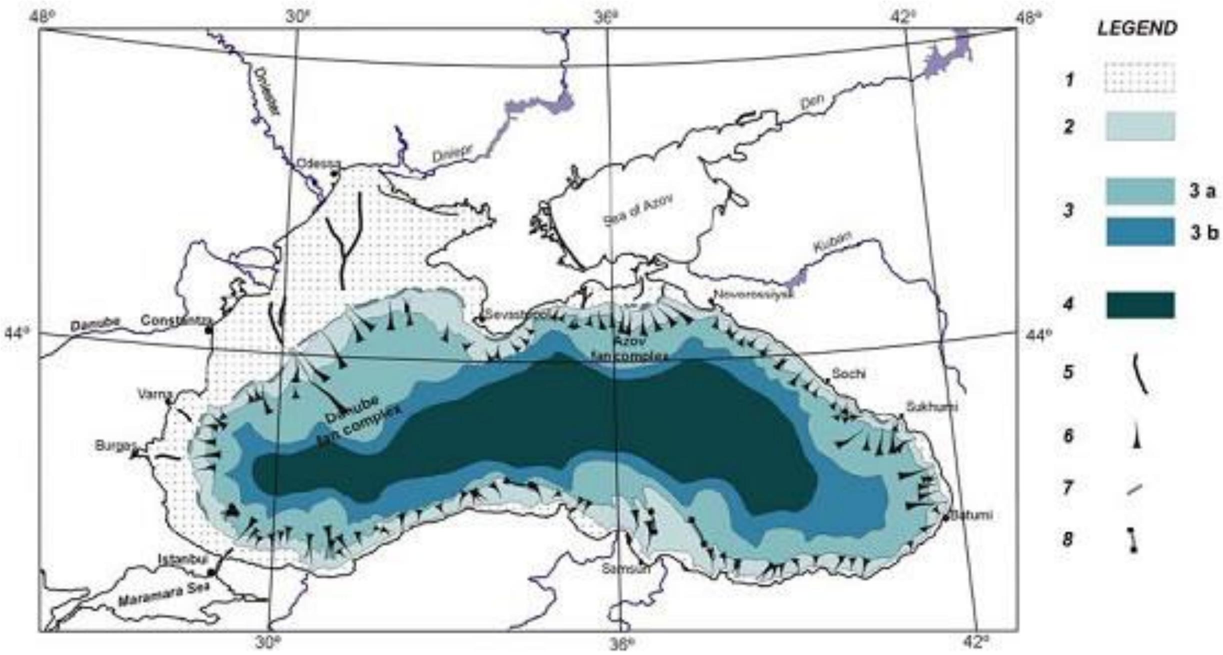

Figure 1 Geomorphologic zonation of the Black Sea (after Panin & E. and G. Ion, 1997). 1, continental shelf; 2, continental slope; 3, basin apron: 3 a - deep sea fan complexes; 3 b - lower apron; 4, deep sea (abyssal) plain; 5, paleo-channels on the continental shelf filled up with Holocene and recent fine grained sediments; 6, main submarine valleys - canyons; 7, paleo-cliffs near the shelf break; 8, fracture zones expressed in the bottom morphology. Source: http://archive.iwlearn.net/bsepr.org/Text/ESP/GeologyArchaeology.htm

Dataset

The bathymetric data of the Black Sea and its surround DEM is obtained from The Global Multi-Resolution Topography (GMRT) Data Synthesis, a multi-resolution compilation of edited multibeam sonar data collected worldwide, along with Digital Resolution Models (DEM) (https://www.gmrt.org/index.php). The data is downloaded from website as a geotiff file and projected at UTM zone 36N, the UTM zone that covers the middle of the Black Sea (Fig 2). The resolution is about 200m (Fig 3, 4).

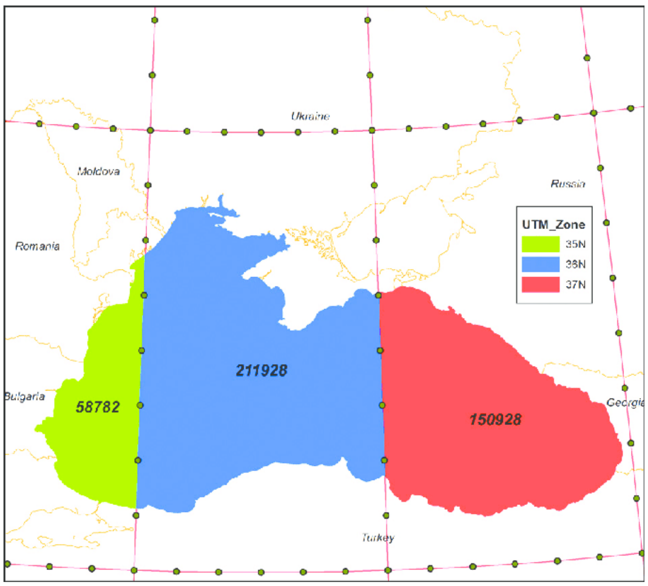

Figure 2 UTM zones of the Black Sea and the surface area calculated with such projection. From Stanchev et al 2011.

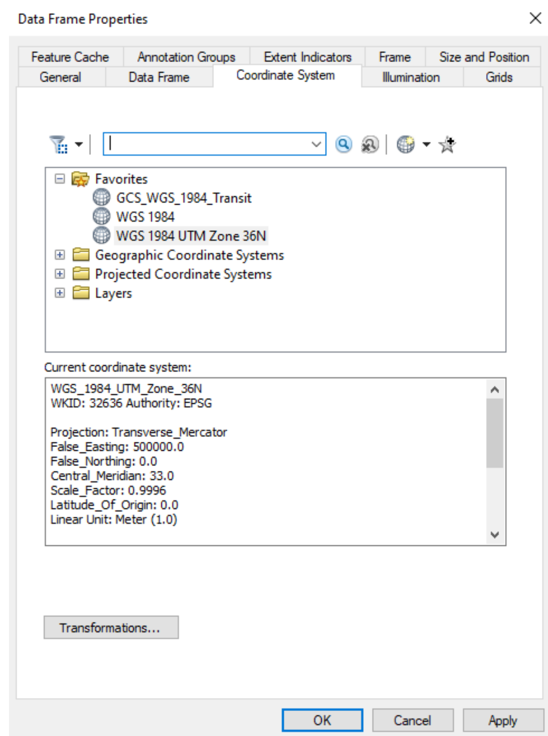

Figure 3 Data frame property

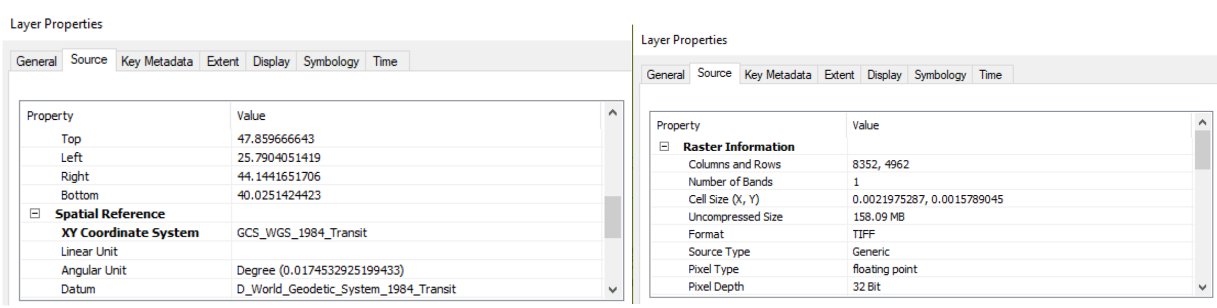

Figure 4 Property of the main DEM used.

Method

All subsequent data are extracted from the aforementioned dataset. **Methods are in bold** and data are underlined. In ArcToolbox:

Firstly, to examine the data and map the bathymetry of the Black Sea:

1. Use **Spatial Analysis/Surface/Contour** to map the controls of the DEM at 100 M. Examine the DEM and contour density.
    a. 0m contour is extract as the coastline, -300m contour is extracted as the shelf edge, -2100m is extracted as the base of slope. (Fig 5)
    b. In **Editor**, clean three contours in a. respectively.
2. Use **Data Management/Features/Feature To Polygon** to produce a mask of the Black Sea.
3. Use **Spatial Analysis/Extraction/Extraction by Mask**, a bathymetry-only Black Sea is produced combining the complete geotiff data and the Black Sea mask.

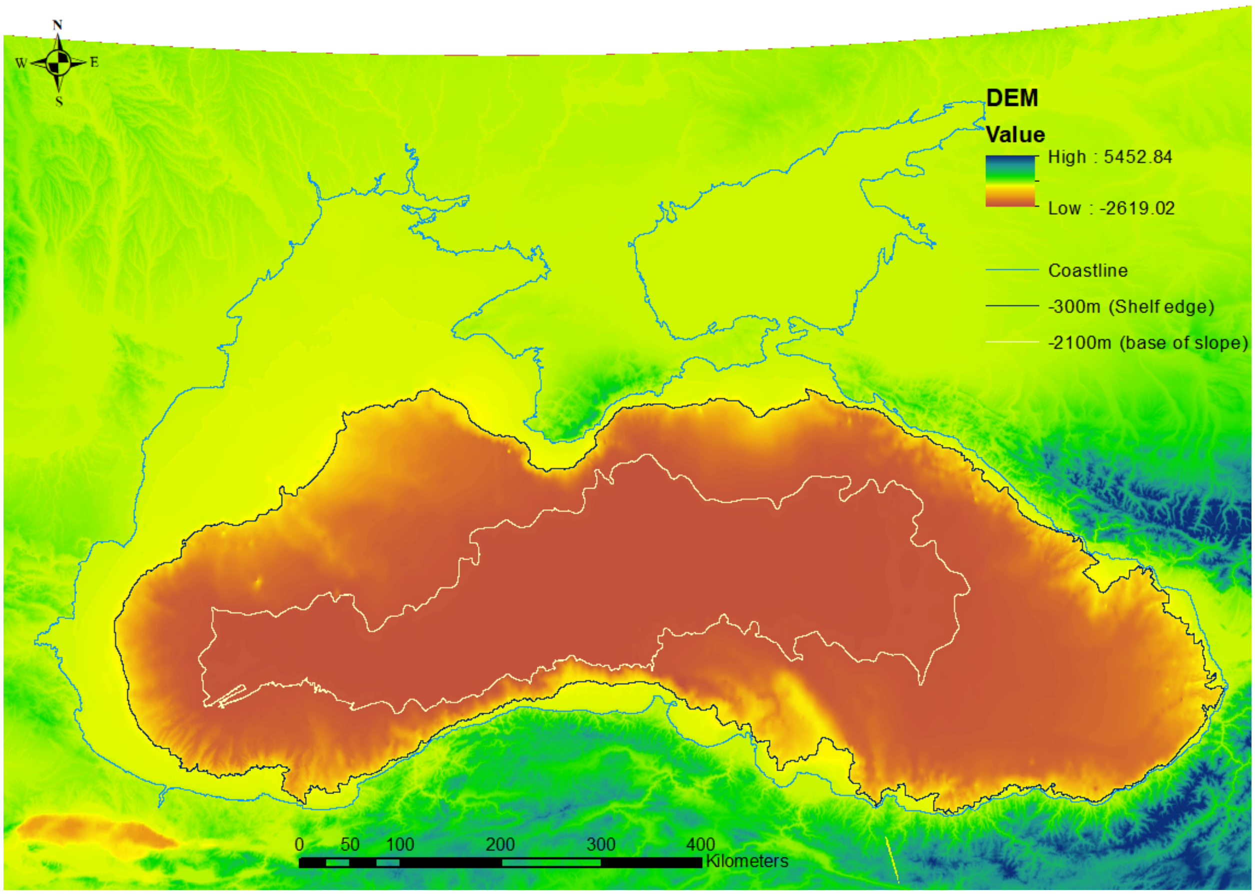

Figure 5 Basic geography of the Black Sea.

Secondly, to map the submarine canyons

4. Use **Spatial Analysis/Hydrology**
    a. **Fill** the bathymetry to -2100m. Since the max depth is -2619.02, the z limit is 519.02m.
    b. Use **Flow Direction** followed by **Flow Accumulation** to map accumulated flows, which is interpreted to follow the submarine canyons.
    c. Obverse the Flow Accumulation pattern. Change the **symbology** to 'clasfified' and use 1000 as the threshold: flow accumulation is greater than 1000 is highlighted. They suggest the submarine canyons where flow would accumulate.
    d. Use **Spatial Analysis/Map Algebra**. Areas with flow greater than 1000 is given a value of 1.
    e. Use **Stream Order** to obtain a raster ordering all the streams.
    f. With **Stream to Feature**, a shapefile of all the streams with flow accumulation greater than 1000 is obtained. This is used as the map for all submarine canyons on the Black Sea continental slope.

Third, find the position of the canyonheads.

5. The intersection between the canyon and the shelf edge ('canyonhead') is mapped using **Analysis/Overlay/Intersect**. The output is in points.
6. Separated into the Northern Shelf Points and Southern Shelf Points by the west-most point, in the **Attribute Table** of two Canyonhead points, fields are added for 'longitude' and 'latitude' and obtained in **Calculate Geometry**.

Fourth, to find the straight-line distance between the canyonheads

7. The attribute tables are then exported into Excel to sort the Northern Shelf Points from east to west and Southern Shelf Points from west to east. Combining the two sorted point sets, all the canyonhead points are now sorted in an anticlockwise manner. Add a column called 'rank' ranking the points in their anticlockwise positions.
8. Import the anticlockwise-sorted canyonhead points back into ArcGIS. In **Data Management/Features/Points To Line**, join all the points into a line connecting all canyonheads, and check if there's any not following the coastline.
    a. There are a couple. So in **Attribute Table** of canyonhead points, **Edit** the 'rank' column to rearrange the canyonhead ranks to match the coastline.
9. With **Data Management/Features/Split Line At Vertices**, the straight-line distance between the canyonheads are obtained.

Fifth, the minimum shelf width is calculated for each canyonheads

10. Apply **Analysis/Proximity/Near** to the canyonhead points
11. Apply **Data Management/Features/XY To Line**, joining the canyonhead points to their near points. (Fig 6)

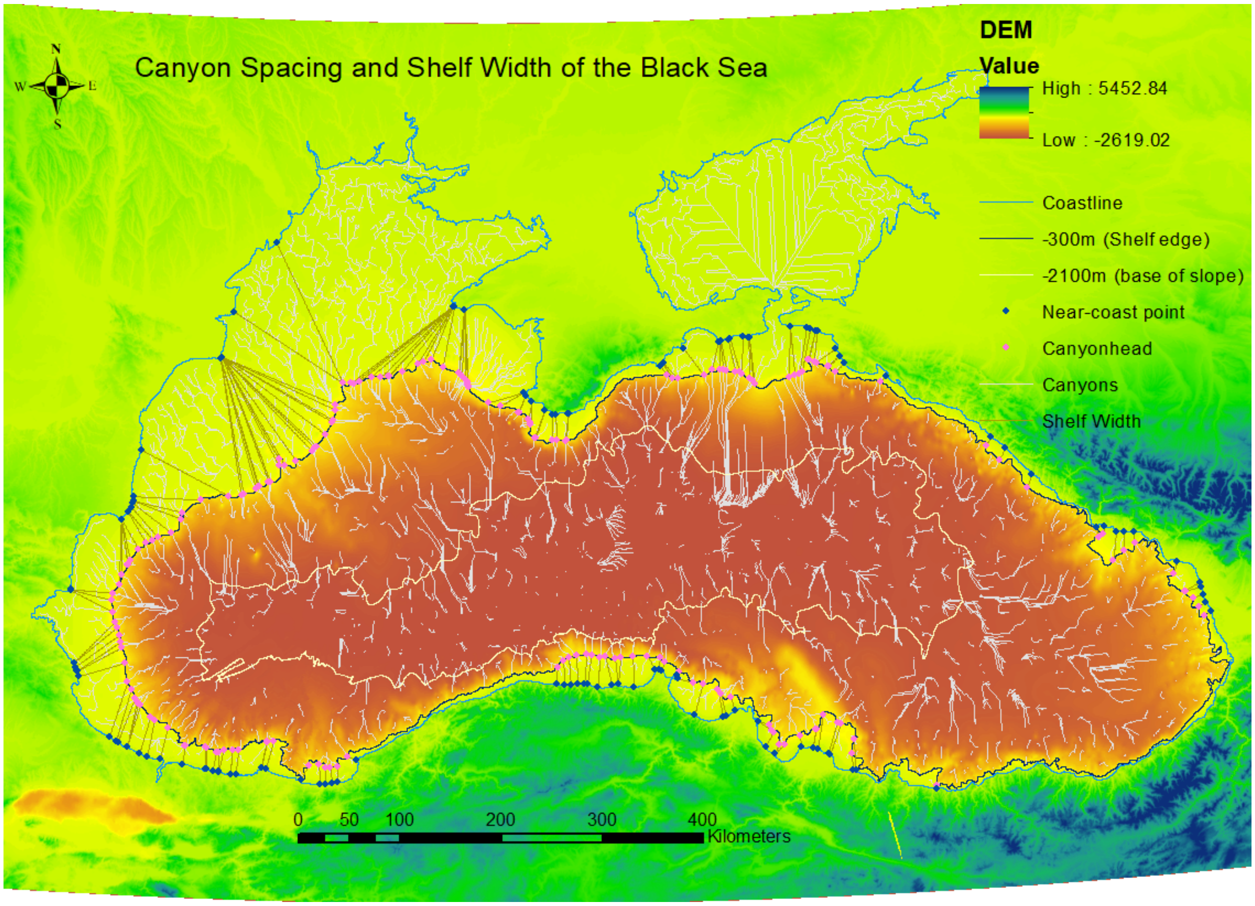

Figure 6 Results after Step 11.

Sixth, the canyon density is calculated for the western Black Sea

12. Using **Selection by Attribute**, select <u>points with shelf width in a certain range</u> (e.g. >100km, 60-70km etc).
13. With **Spatial Analyst/Density/Point Density**, calculate the <u>point density</u> with radius = 0.45degress (diameter=100km) (Fig 8)
14. In **Symbology** of the <u>point density</u>, record the mean and mode of values.

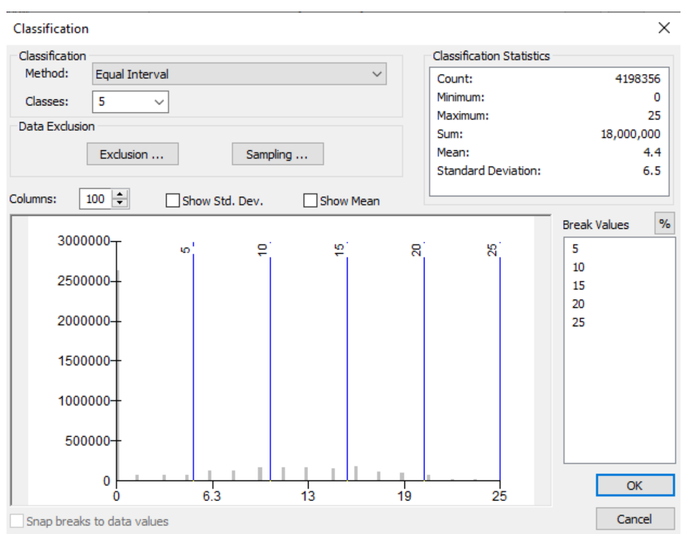

Figure 7 Classification in Symbology, where the mean and mode can be read.

Results

For this study, based on the distribution of the mapped submarine canyons, the Black Sea continental shelf is divided into the following regions, and shelf width in histogram is shown for each region (Fig 7):

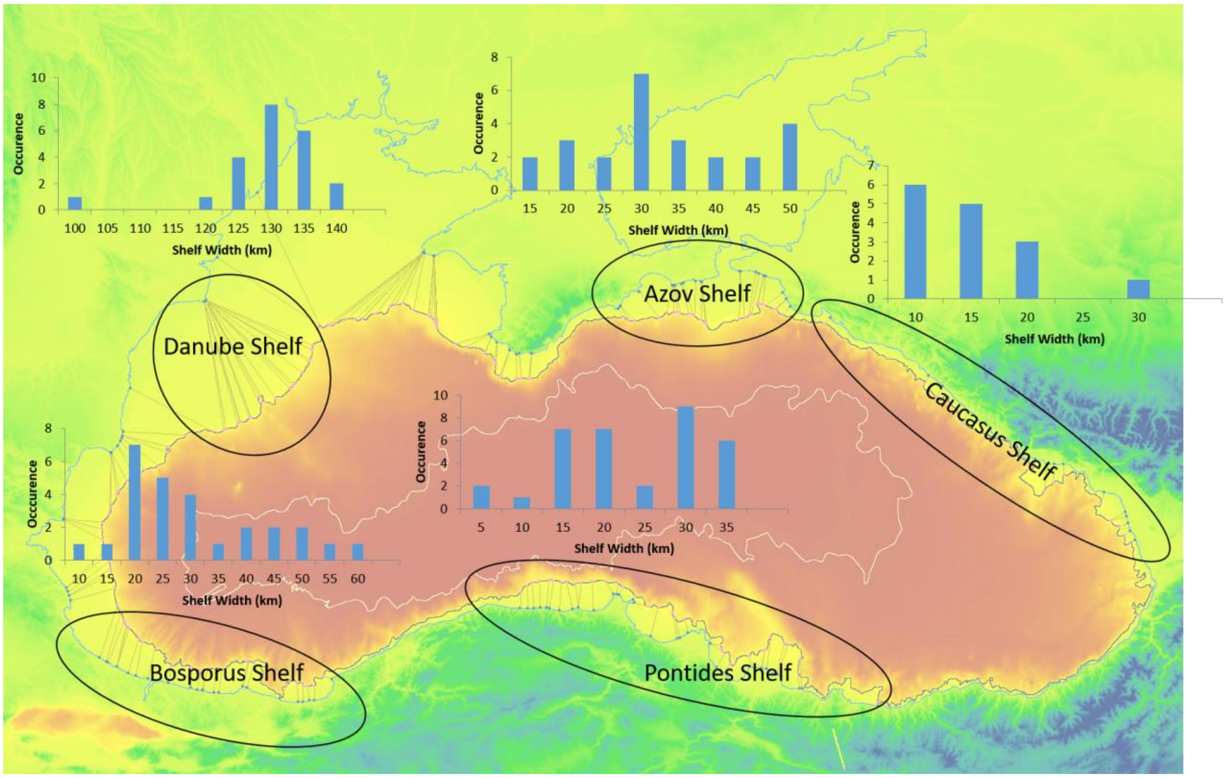

Figure 7 Shelf width measured at the canyonhead, bin size is 5km. For example, in Caucasus shelf, there are 6 canyonheads that are 5-10km away from the coast.

For the western Black Sea (excluding Pontides Shelf, Azov Shelf, and Caucasus Shelf), the canyonhead density for each shelf width range is as follows:

Shelf Width Range (km)	Number of Canyonheads per 50km radius	Canyonhead per 50km radius mode
0-30	7.9-18.9	9.4
30-60	1.6-18.9	1.6
60-90	1.6-22.0	1.6
90-120	1.6-7.9	1.6
120-155	12.57-18.9	14.1

Table 1 Statistical result of the canyonhead density per 50km radius in relation to shelf width.

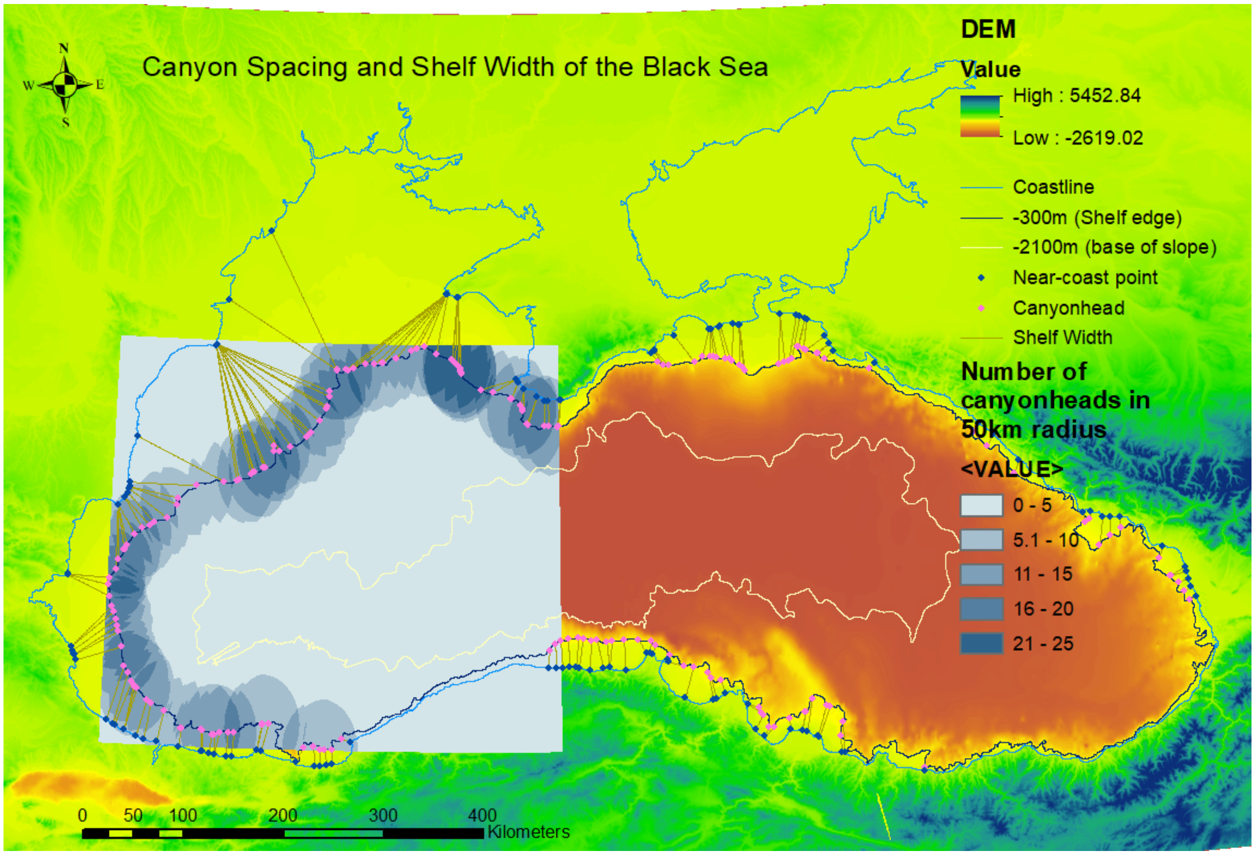

Figure 8 Canyonhead density for the western Black Sea.

Discussion

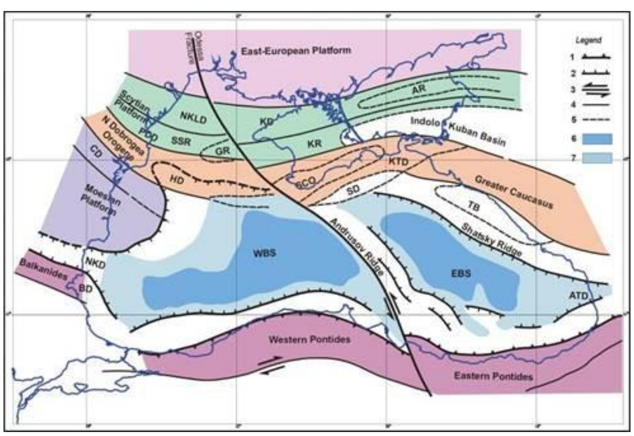

Figure 10 Tectonic sketch of the Black Sea Region (after Dinu et al., 2003; Panin et al., 1994).

Fig 7 and Fig 10 shows that the width of the continental shelf of the Black Sea is strongly dependent on the tectonics and geography of the coast. The shelf is wide in front of delta (Danube Shelf) or seaways (Bosporus Shelf and Azov Shelf), but narrow close to mountains (Pontides Shelf and Caucasus Shelf). The narrow shelf along the Turkish coast is also linked to the thrust faults.

As for the density of the submarine canyonheads, Table 1 clearly shows that canyonhead density decreases with increasing shelf width, which is what we expected as a wider shelf makes it harder for sediments to arrive at the shelf edge, hence produce less sediment density flow-relate erosions, which is essential for formation of submarine canyons.

The exception is for canyons at shelf width greater than 120km. They locate exclusively close to the Danube Delta and give the highest canyon density at 23 canyons per 50km radius (Fig 11). However, this is not unexpected: the large amount of sediments brought by the Danube river means that in spite of the wide shelf which is built by the sediment itself, a significant proportion is still able to arrive at the shelf edge.

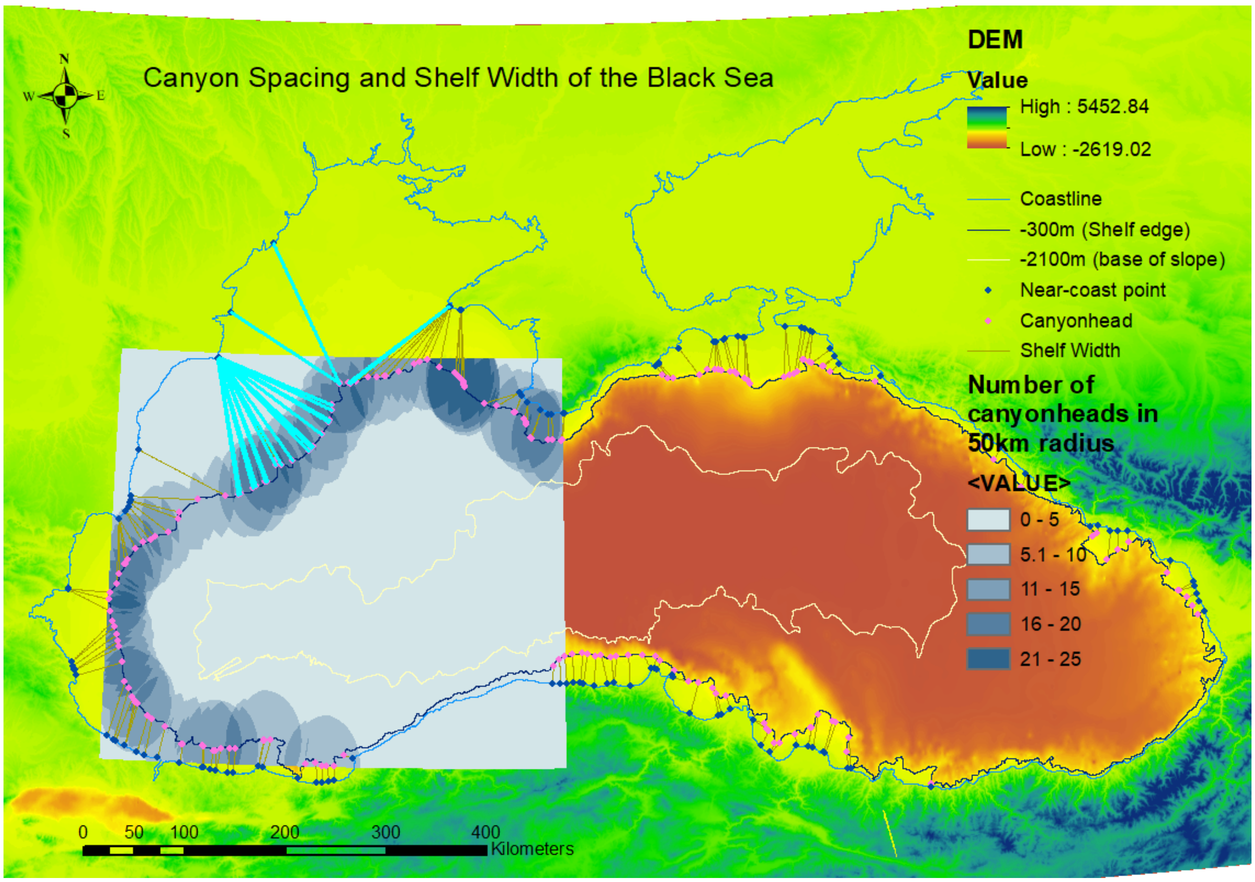

Figure 11 Shelf width greater than 120km.

Source of Error

The greatest source of error comes from the hydrological study, and hence the number and position of 'canyonheads'. In this study, it is simply obtained through **Flow Accumulation** tool without considering the difference between subaerial and subaqueous flows, and also not cross-compared with the bathymetry itself. As we can see in Fig 11, some rather obvious canyons are not picked up, especially towards the eastern part of the Black Sea.

Secondly, the position of the shelf edge is approximated by the -300m contour, however, it is likely to vary +/- tens of meters across the region. In a more rigorous study, the maximum gradient should be used to obtain the position of the shelf-edge.

Thirdly, the shelf width is obtained using **Near** toolbox for each individual canyonhead. For more precise measurements, the tangent distance between the coast and the shelf edge should be obtained.

Reference

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