A NEW INTERPRETATION OF THE EXISTENCE OF THE PANJANG REGIONAL FAULT BASED ON DEM AND FIELD OBSERVATIONS IN LAMPUNG, SUMATRA, INDONESIA

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Abstract. Referring to the regional geological map sheet of Tanjung Karang, the existence of the Panjang regional fault in the Sukarame area (the research area) is still debated. This can be seen from the dashed line on the map, which indicates that the existence of the fault is still unclear. The objective of this research is to ascertain the existence of the Panjang Fault, together with information on its type and direction. The method used was to integrate the tectonic geomorphological sections through Digital Elevation Model (DEM) interpretations and field observations result. Field observations were made to confirm the existence of these structures. We found that the Panjang regional fault in the research area does exist. From the south of research area, the fault apparently continues into the research area. It is a normal fault in a northwest-southeast direction. The existence of the fault is also supported by the discovery of water springs during the field observations. The fault has cut aquifers so that the groundwater appears on the surface as water springs.

Keywords: *regional, Lampung, Panjang Fault, Sumatra, geomorphology*

1 INTRODUCTION

The regional geological map of Tanjung Karang was produced by a geological survey in 1993, meaning it is 27 years old, but still used as a reference for academic research, mining material exploration, and natural disaster mitigation in Lampung. It therefore needs to be updated with the latest Digital Elevation Model (DEM) data. In addition, the scale of the geological map sheet of the headland is very small, namely 1: 250,000. This significantly affects the map resolution in presenting geological data. From the aspect of geological structure, there remain many regional and local structures that have not been well mapped. This can be seen in the research area, which is indicated by a dashed line in Figure 1-2. The dotted line means that the position of the fault is uncertain. In the research area, the Lampung Formation is the youngest rock formation (quaternary age). The formation consists of tuff lithology with an acidic to medium composition and a thickness of up to 200 m (Mangga et al., 1993).

The research area is located in the southern part of Lampung province, and includes Bandar Lampung, the capital of the province. Its location is about 100 km from the Sumatran fault (Figure 1-1). The study area is 63,736 km^2.

Sumatra is located at the western end of the Indonesian archipelago and is subject to active subduction, with the Australian Plate moving beneath the continental Sunda Shelf (Barber et al., 2005). The arc extends from the Andaman Islands south into Indonesia, past Sumatra, then east past Java, and onwards to Flores (McCaffrey, 2009). The dextral strike-slip Sumatran Fault

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System has been generated by oblique subduction (McCaffrey, 2009). The fault runs the length of the island for over 1600 km, from northwest to southeast, becoming active during the Miocene (Barber et al., 2005), with a current slip rate of 5.5 ± 1.9 mm/yr (Bellier et al., 1999). Another regional fault besides the Sumatran one is the Panjang fault. This runs in same direction as the Sumatra fault (NW-SE), and is located around Lampung Bay. The Panjang fault began with strike slip fault movement, which then became normal fault movement (Pramumijoyo & Sebrier, 1991). There are very few references to this fault when compared to the Sumatran one. It is relatively young and has the potential to move at any time.

Referring to data from the Central Statistics Agency of Lampung Province from 2020, the population of Bandar Lampung City is 1,071 million. This makes it the second largest in Lampung Province after Central Lampung Regency (BPS Lampung, 2020). Geographically, some of the research locations are in the capital of Lampung. Therefore, research on disasters, especially those related to geological structures, is vital, and should be conducted as part of geological disaster mitigation.

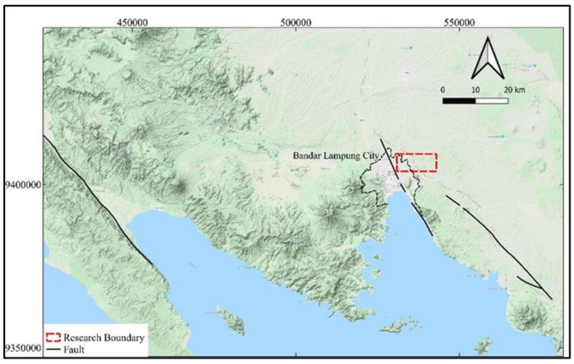

Figure 1-1: Position of research area (red dashed line) about 100 km from Sumatra (western part of the map)

This study aims to examine the existence of faults more definitely, with information about their type and direction The methods used involved integration of the tectonic geomorphological cross section through Digital Elevation Model (DEM) interpretations and field observations. It is an inexpensive method for analyzing the presence of faults, in contrast to geophysical methods, which are relatively expensive.

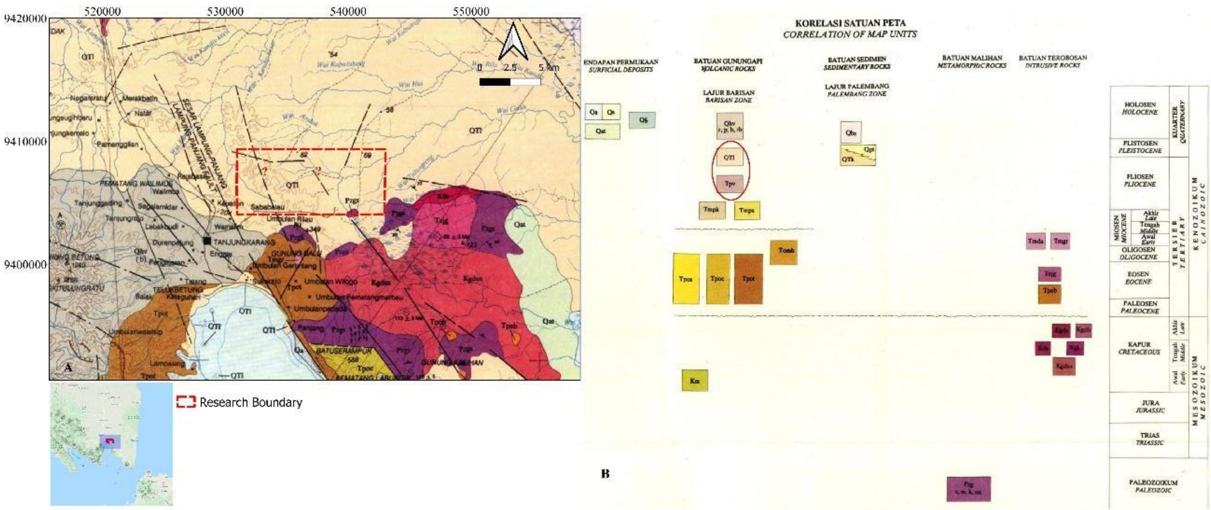

Figure 1-2: The left side shows the research area overly to the Tanjung Karang regional geology map and the right side shows the regional stratigraphy of the map. The question marks indicate the aim of the research and the red oval shows the formations which exist in the research area.

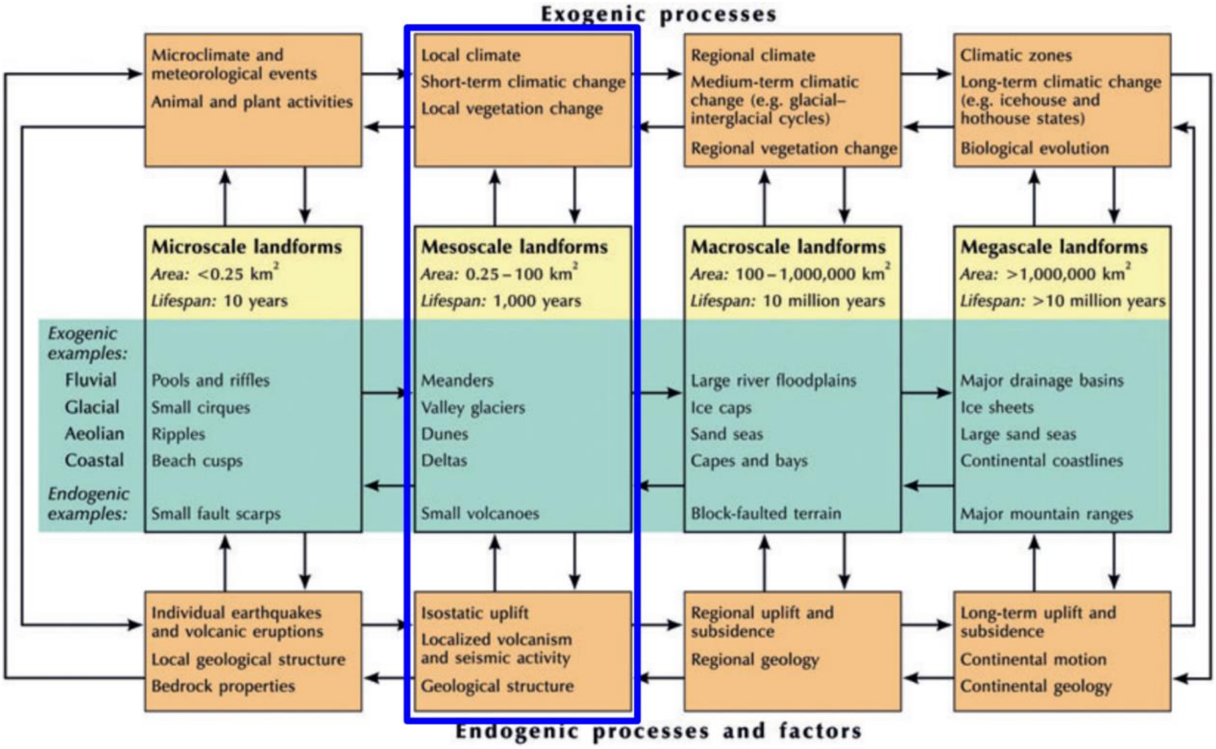

Figure 2-1: Landforms at different scales and their interactions with exogenic and endogenic processes. The blue box shows the location of the research area. Modified from Hugget (2016).

2 MATERIALS AND METHODOLOGY

Geomorphology is used to understand the processes of the earth's surface, the system response, and landscape evolution (Keller et al., 2019). Geomorphic processes refer to the various chemical and physical means by which the Earth's surface undergoes modification. They are driven by geological forces emanating from inside the Earth (endogenic or endogen processes); by ones originating at or near the Earth's surface and in the atmosphere (exogenic or exogen); and by forces from outside the Earth (extraterrestrial processes, such as asteroid impacts) (Huggett, 2016). The research area is 63,736 km^2 and is included in the mesoscale landform category, based on Hugget (2016) (Figure 2-1). In this type, the endogenous force that forms the morphology is geological structure activity.

The final fault interpretation is to establish the existence of the Panjang fault in the research area using Digital Elevation Model (DEM) and field observations (Figure 2-2). Field observations were made to obtain very accurate results. The fault analysis was made using geomorphological concepts, including interpretation of the morphology/shape of the three cross sections (DEM processing results) which were made diagonally and parallel to each other (Figure 3-1).

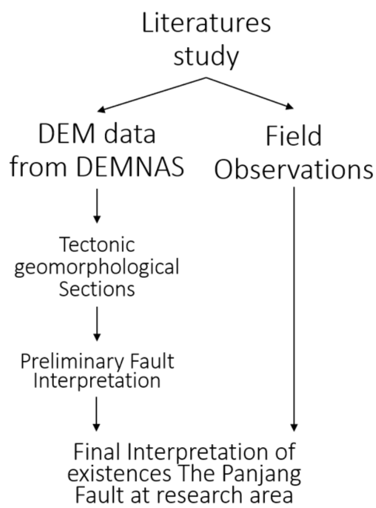

Figure 2-2: The flowchart of the research

Geomorphological analysis aims to find initial indications of the existence of faults (the preliminary stage). The cross sections are presented diagonally because based on the Tanjung Karang geological map, the faults that are expected to exist are in a northwest-southeast direction. Based on this information, the cross section must be made perpendicular to the expected fault so that the morphological changes caused by the fault can be seen appropriately.

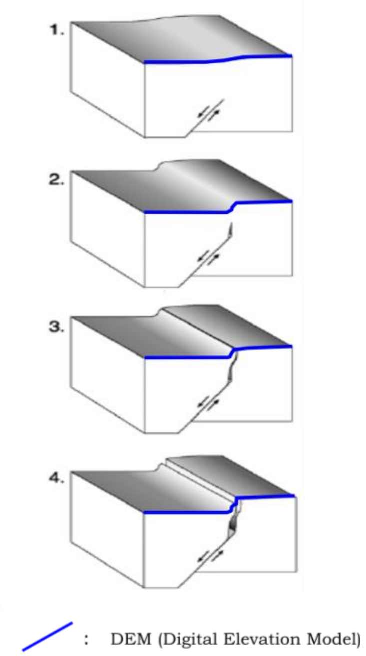

Figure 2-3: The DEM reflects the morphology/shape of the surface of the Earth. The fault model was modified from Grant (2004).

Besides conducting geomorphological analysis through DEM, field observations are also performed to observe the geological phenomena as validation of the existence of faults in the study area. Geomorphological analysis based on DEM data refers to DEM reflection of the surface of the Earth (Fig 2-3). Figure 2-3 shows an example how a normal fault is formed, starting from the ductile stage, followed by the brittle stage. In addition, the DEM data will tend to follow morphological changes. Therefore, the preliminary interpretation of the existence of geological structures in an area can be based on DEM data.

Digital Elevation Model (DEM) data use sources from the DEMNAS (Digital Elevation Model and National Bathymetry) website. The data can be downloaded free by first registering. The DEMNAS data are built from several sources, including IFSAR (5 m resolution), TERRASAR-X (5m resolution) and ALOS PALSAR (11.25 m resolution), by adding mass point data from stereo-plotting results. DEMNAS spatial resolution is 0.27-arcsecond, using the EGM2008 vertical datum (DEMNAS, 2020). The program used in processing the DEM data is QGIS 3.10.4.

3 RESULTS AND DISCUSSION

3.1 Geomorphology Cross Section

The geological structure like faults is easily identified from the landscape or events in nature. Recognizable landscapes are exemplified by changes in extreme elevation, river lineaments, valley lineaments, springs, waterfalls, and triangular facets (Burbank & Anderson, 2001). Three geomorphological sections were created to reflect the geomorphology of the study area: the A-B section, C-D section, and E-F section, which are parallel to one another (Figure 3-1). The three sections stretch from the southwest to the northeast. In analysing the expected presence of faults, we focused on significant differences in elevation (Burbank & Anderson, 2001; McCalpin et al., 2020). The fault plane lines were drawn at the boundary between morphological blocks with a high elevation and those with a low elevation. At the front of the fault plane a gradual topography is often found (Figure 3-1). We interpret that in this case the topography is an avalanche or loose material resulting from the movement of the fault.

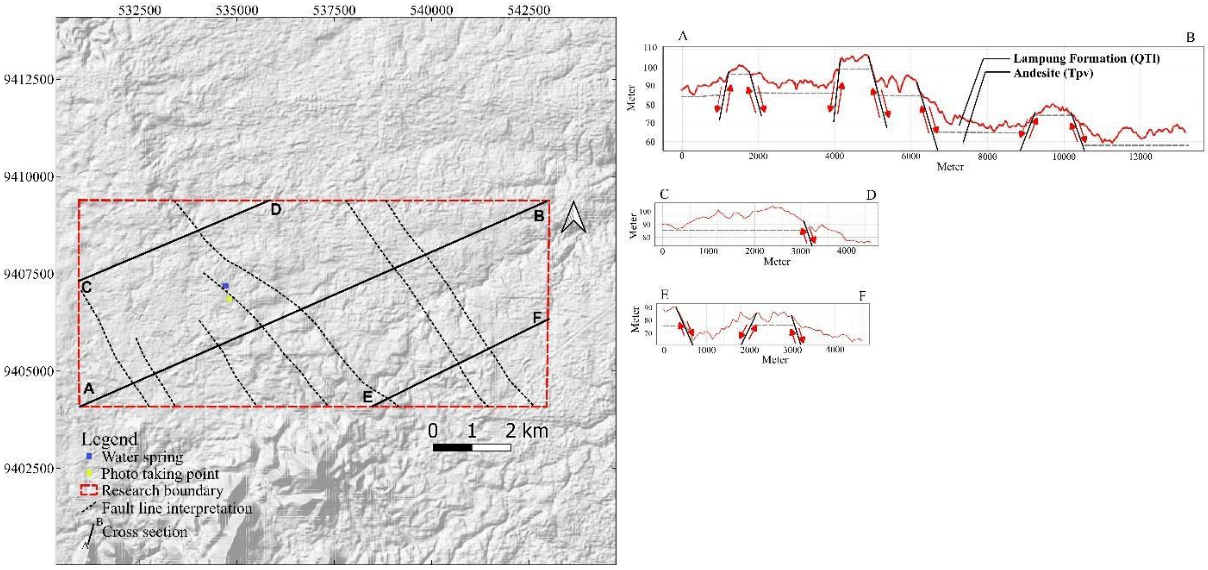

Figure 3-1: The three parallel cross section applied to the research area with result are existences of normal faults in every cross section.

Figure 3-2: A) View of a water spring as an indication of the existence of a fault; B) Thickness of the tuff reaching 8 meters; C) Landscape of half the research area showing a hilly morphology (hummocky)

In A-B section, it is estimated that there are seven faults in the C-D section only one fault; while in the E-F section three faults. All the faults formed in the three sections are normal ones, in a relatively northwesterly-southeasterly direction.

The drawing of the boundary between the Lampung Formation and the Andesite is based on the thickness of the tuff in the outcrop, which reaches 8 meters. Therefore, in total, the thickness of the Lampung Formation is estimated to be more than 8 meters over the whole study area.

3.2 Field Observation

To validate the results of the interpretation of the three sections, we conducted field observations. From these, we found a naturally occurring water spring. Water springs can be used as an indication that the area around them has developed a fault. One type of water spring can be caused by an aquifer that is faulted by the fault plane (Springer & Stevens, 2009). The types of water spring in the study area are classified as Helocrene (Springer & Stevens, 2009). Water that should be able to flow through aquifer rocks cannot do so because the aquifer is faulted by the fault plane, which causes the groundwater to appear on the surface as springs.

Apart from the emergence of such springs, we observed the geomorphology of the study area. The research area does not appear flat, but hilly (hummocky) (Figure 3-2). The hilly morphology (avalanche or debris deposits) can be created by the development of faults (Keller et al., 2019). In addition, hilly morphology can also be created by pyroclastic rock falls (fall deposits) or a combination of both. On the other side of the study area, Tuff lithology was found, which was up to 8 meters thick.

3.3 Final Structural Geology

To obtain the final interpretation of the geological structure, we integrated the results of the analysis of the geomorphological sections with the results of the field observations. The faults that have developed in each section are connected to each other (Figure 3-3). The criteria for drawing the fault lines are based on the similarity in the type of structure, morphology, and direction of each section. However, not all the sections display fault continuity with the other sections, especially the C-D section. We expect that this is due to the location of this section, which is further away from the Sunda Strait. Since the Miocene age, this strait has developed a Horst-Graben structure as a result of the process of its opening up. This opening has implications for the movement of the Semangko and the Ujung Kulon faults (Susilohadi et al., 2009). We expect that the development of the Horst-Graben structure in the study area is still influenced by the opening of the Sunda Strait. In addition, the rigidness factor of the Lampung Formation is more ductile than the andesite rock, so is not easily faulted.

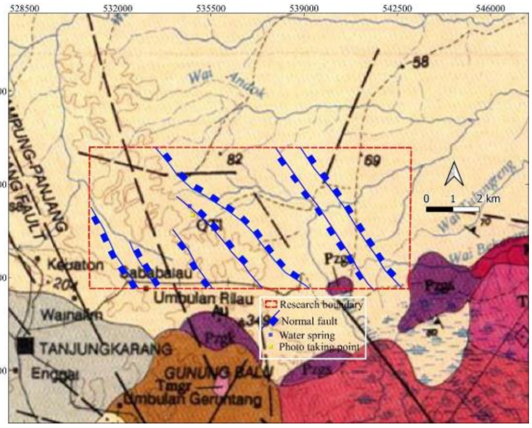

Figure 3-3: Final interpretation of research area shows the existence of seven normal faults resulting from Horst-Graben morphology.

We plotted the coordinates of the spring, which showed a location close to the fault as a result of the geomorphological cross-section analysis. This further strengthens the analysis showing that the study area has developed relatively young faults.

Seven faults were identified. These are in a northwest-southeast direction, extending with dip slip movements of the normal fault type. By observing the distribution of normal faults with fields facing each other and backwards, Horst-Graben morphology was developed. This was created when the outer brittle crust was stretched and fractured (Kandie, 2015). From a tectonic aspect, morphological occurrences like this characterise tensional tectonic events. When compared with regional geological maps, it emerges that the developed faults are more numerous and the direction of the fault is relatively similar to the direction of the Panjang fault on the regional geological map.

We realise that this study has many limitations, one of which is that it does not use geophysical methods to identify faults more accurately. However, we believe that the research makes a significant contribution to understanding the geological structure patterns in the study area and its surroundings.

4 CONCLUSION

Based on the study results, it can be concluded that the geological structures in the study area are indeed clear. The faults that developed are normal ones, extending northwest-southeast, thus creating Horst-Graben morphologies. These normal faults faulted the Lampung Formation, which can be an indication that during the Quaternary age tensional tectonics developed in the study area and its surroundings. The application of geomorphic principles leads to a better understanding of the geomorphic history and active tectonics of normal faults (Topal et al., 2016). This discovery can be the basis for determining the direction of settlement development or the basis for further geological research to reveal the evolution of the geological structures and tectonics of Lampung. Geophysical methods need to be used in further research to observe the subsurface images clearly.

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AUTHOR CONTRIBUTIONS

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of result, and manuscript preparation.

REFERENCES

Barber, A., Crow, M., & Milson, J. (2005). Sumatra: Geology, Resources and Tectonic Evolution. The Geological Society.

Bellier, O., Bellon, H., Sébrier, M., Sutanto, & Maury, R.C. (1999). K-Ar age of the Ranau Tuffs: Implications for the Ranau caldera emplacement and slip-partitioning in Sumatra (Indonesia). Tectonophysics 312, 347–359. https://doi.org/10.1016/S0040-1951(99)00198-5

BPS Lampung (2020). Perkembangan Indikator Makro Sosial Ekonomi Lampung Triwulan I 2020.

Burbank, D.W., & Anderson, R.S. (2001). Tectonic geomorphology. Blackwell Science.

DEMNAS (2020). Demnas [WWW Document]. URL http://tides.big.go.id/DEMNAS/ (accessed 8.12.20).

Grant, J. V., & Kattenhorn, S.A. (2004). Evolution of vertical faults at an extensional plate boundary, southwest Iceland. J. Struct. Geol. 26, 537–557. https://doi.org/10.1016/j.jsg.2003.07.003

Huggett, R.J. (2016). Fundamentals of Geomorphology. Routledge. https://doi.org/10.4324/9781315674179

Kandie, R.J. (2015). Eastern Rift Structural Geology-Tectonics, Volcanology and Geothermal, in: Short Course X on Exploration for Geothermal Resources.

Keller, E., Adamaitis, C., Alessio, P., Anderson, S., Goto, E., Gray, S., Gurrola, L., & Morell, K. (2019). Applications in geomorphology. Geomorphology 1–19 https://doi.org/10.1016/j.geomorph.2019.04.001

Mangga, S.., Amirudin, Suwarti, T., Gafoer, S., &Sidarto, 1993. Peta Geologi Lembar TanjungKarang, Sumatera.

McCaffrey, R. (2009). The tectonic framework of the Sumatran subduction zone. Annu. Rev. Earth Planet. Sci. 37, 345–366. https://doi.org/10.1146/annurev.earth.031208.100212

McCalpin, J.P., Gutierrez, F., Bruhn, R.L., Guerrero, J., Pavlis, T.L., & Lucha, P. (2020). Tectonic geomorphology and late Quaternary deformation on the Ragged Mountain Fault, Yakutat microplate, south coastal Alaska. Geomorphology 351, 106875. https://doi.org/10.1016/j.geomorph.2019.106875

Pramumijoyo, S., & Sebrier, M. (1991). Neogene and quaternary fault kinematics around the Sunda Strait area, Indonesia. J. Southeast Asian Earth Sci. 6, 137–145. https://doi.org/10.1016/0743-9547(91)90106-8

Springer, A.E., & Stevens, L.E. (2009). Spheres of discharge of springs. Hydrogeol. J. 17, 83–93. https://doi.org/10.1007/s10040-008-0341-y

Susilohadi, S., Gaedicke, C., & Djajadihardja, Y. (2009). Structures and sedimentary deposition in the Sunda Strait, Indonesia. Tectonophysics 467, 55–71. https://doi.org/10.1016/j.tecto.2008.12.015

Topal, S., Keller, E., Bufe, A., & Koçyiğit, A. (2016). Tectonic geomorphology of a large normal fault: Akşehir fault, SW Turkey. Geomorphology 259, 55–69. https://doi.org/10.1016/j.geomorph.2016.01.014