Δελτίο της Ελληνικής Γεωλογικής Εταιρίας τομ. XXXVII, 194 - 200, 2005
Bulletin of the Geological Society of Greece vol. XXXVII, 194 - 200, 2005

THE TROY FAULT

Tutkun S.Z.[1], S. B. Pavlides[2]

[1] *Çanakkale Onsekiz Mart University, Engineering and Architecture Faculty, Department of Geophysical Engineering* (sztutkun@comu.edu.tr / 17020 CANAKKALE)
[2] *Department of Geology, Aristotle University of Thessaloniki, Greece (pavlides@geo.auth.gr, 54124 THESSALONIKI)*

ABSTRACT

The Troy (Troia) fault is an E-W oriented normal – oblique slip fault located at the eastern part of Biga peninsula in northwestern Turkey (fig.1). It extends for about 8 to 10 km with clear topographic expression affecting the Neogene-Quaternary sediments and extends possibly for 2-4 km westwards of the Hisarlik hill under the recent late Holocene deposits of the Troy plain. It is part of a large NE-SW trending zone that includes several other active fault. Although it is not associated with known historical or instrumental strong earthquake activity, taking into account known empirical relationships of fault length versus Ms (or Mw) and the length of segments, the seismic potential is of Mw = 5.5-6.1. However, taking the total length in the order of 10 km and the possible westward extension (for another couple of Km an earthquake of magnitude 6.2 to 6.5 is possible in case of reactivation of the entire length of Troy Fault.

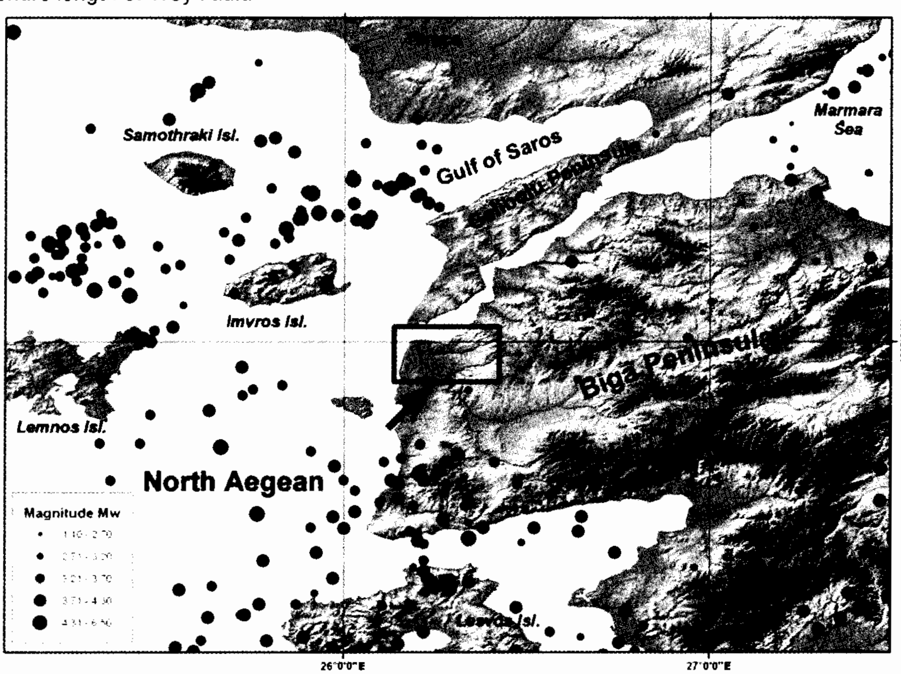


Figure 1. Relief map of Northeastern Aegean and Biga peninsula. Black rectangle shows study broader area (Troad). Dots are earthquake epicentres occurred during 2001-2005. (*Earthquake data source: Seismological Station - Lab of Geophysics, Department of Geology, Aristotle University of Thessaloniki, 2005*).

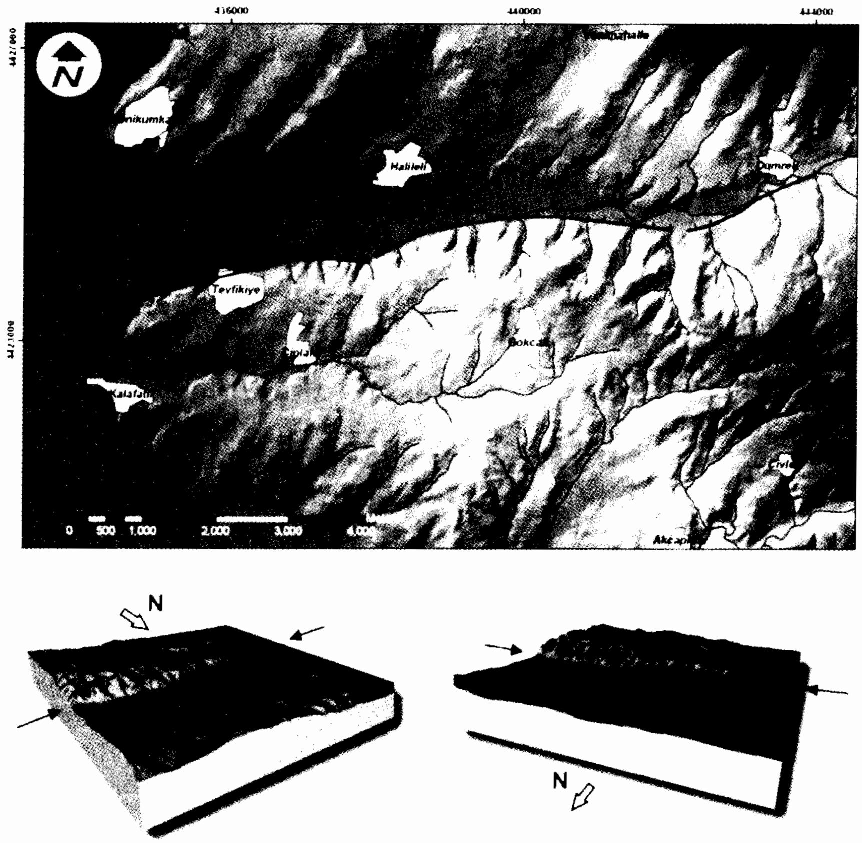


Figure 2. Troy fault segments: from east to west Tevfikiye, Halileli and Dómrek. 3D visualizations created from 5m Digital Elevation Model. Elevation exaggerated by 2x.

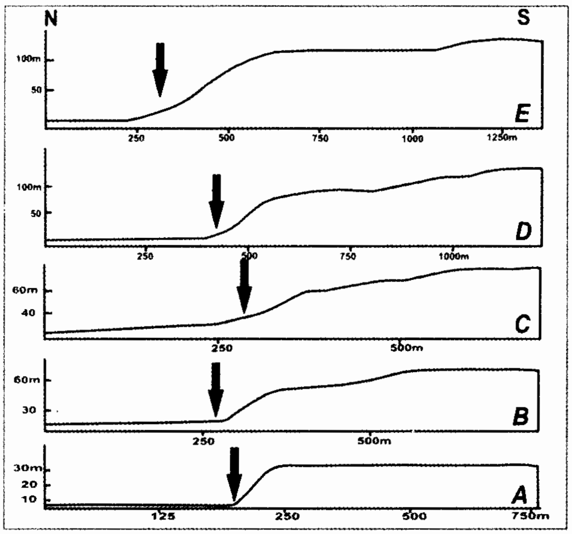
INTRODUCTION

Troia (Troy), a myth and reality, is a remarkable archaeological site with geological interest as well (Wagner et al., 2003). It lies at the northwestern edge of Biga peninsula, 30 km southwest of Çanakkale, located between two of the most active fault branches of the North Anatolian Fault system, the Ganos (Calipolis -Gelibolu) and Yenice-Gonen branches respectively. The Biga area is influenced by the N-S Aegean extension, as well (e.g. Taymaz et al. 1991; Yilmaz 2003, Kurcel et al., 2005).

The morhotectonics of the southern part of Dümrek (Simois) river valley give a rather strong evidence for an E-W trending, north dipping normal fault, which extends along the northern foothills of the archaeological site, which is the acropolis of Troy. According to Homer (Iliad) landscape description ".... There is a steep-side hill in front of the city apart in the plain..." (*Έστι δε τις προπάροιθε πόλις αιπεία κολώνη, εν πεδίω απάνευθε...*), or there is a city named Thryoessa, a steep-sided hill..." (*Έστι δε τις Θρυόεσσα πόλις αιπεία κολώνη* ...) (Ομήρου Ιλιάδα). Apparently this description fits quite well the north dipping fault scarp of the Troy fault. The morphology and geology of Troy broader area have evolved under strong neotectonic control. Major morphological features supporting this notion are the Dardanelles strait (Çanakkale Bogazi), Dumrek low, Truva-Tevfikive high, Ciplac river low, Kalafatli high, and Bayramic low. All these features are controlled by young structures of post-early Pliocene age formed by the transtensional tectonic regime affected the broader Aegean region (Kayan 1996; Kraft et al., 2003; Yilmaz 2003).

TROY FAULT TECTONICS

Troy Fault is a normal fault located at Biga Peninsula, NW Turkey. Its structural setting is roughly associated with the westernmost splaying of the North Anatolian Fault Zone, although there are no significant indications of lateral displacement along the Troy Fault (Sengor 1985; Koukouvelas and Aydin 2002; Taymaz et al. 1991). Troy fault is a typical normal active fault, which strikes N80-100^0, dips 60-50^0 NNW and the striation pitch angle range 70-80^0 E (rake), that is it implies a small dextral component and could be characterizes as oblique fault as well, but although strike and dip values are average for the whole fault striation is from a single locality.



Troy fault is a structure that deforms the Neogene in age Hanakkale Formation, consisting of conglomerates, fossiliferous sandstone and siltstone, while at its northeasternmost end it deforms the Upper Cretaceous Denizgφren ophiolitic mιlange. The fault shows a clear topographic length signature with *ca.* 10 km, but it is possible that it extends for another 2-3 km to the west its, being covered by Karamenderes (Skamandros) river deposits (see also Kayan 1996; 2002; Kraft et al., 1980; 2003) up to Kesiktepe hills. The fault scarp is not very prominent

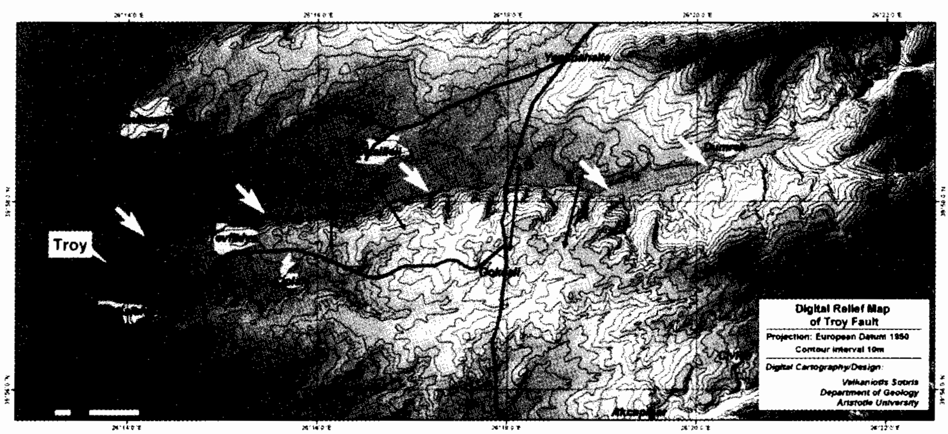


Figure 3. (Top) Digital Relief map of Troy Fault. White arrows indicate fault trace. (Down) Morphological cross sections (A - E) along Troy fault scarp are shown below. Black arrows indicate fault trace. Fault scarp height varies from 100 to 20m along its trace.

Figure 4 . Panoramic view of Troy E-W trending fault scarp, where Canakkale-Izmir national road, the Tevfikiye village and Truva (Troy-Hisarlik hill) are shown. (View to the South)

but defines the boundary between rocks of the Neogene Hanakkale formation to the south and quaternary fluvial deposits to the north (fig. 2). A series of mature occasionally overlapping, alluvial fans is formed along the fault scarp, due to the deep footwall erosion of transversal streams. Along the foothills of the fault scarp, an elongated valley is formed, through which river Dómrek (Simois) is flowing. Flow of the river is seasonal, with local pods and marshes, while present and older river-bed morphology seems to be controlled by the fault. Three distinct segments can be identified according to geological mapping and geometric criteria: Tevfikiye, Halileli and Dómrek segments from West to East (fig. 2). Boundaries between the segments are defined by jogs and slightly change of strike.

MORPHOTECTONICS

The geomorphological structures such as small young alluvial fans, triangular faces, sag-ponds and marshes along the fault scarp shows the present morphology is controlled by fault. In the course of this study the fault segments of Troy Fault have been also studied by the digital elevation models (DEM), field cartography, drainage patterns analysis and the morphotectonic indices like mountain front sinuosity, drainage basin asymmetry, knick points and stream length-gradient indexes. Due to its specific morphotectonic features Troy fault shows typical and recognizable normal fault features, that are high angle slopes, scarplets, etc.

A number of morphotectonic indices have been calculated along the total length of the fault and especially for the three segments. According to the fault scarp sinuosity index (mountain front Smf=L/l see Keller & Pinter 1996/2002), which indicates the level of recent fault activity, Tevfikiye and Halileli segments are the most active ones (Smf 1.15 and 1.49 respectively), while Dümrek corresponding to the eastern most segment is far less active showing Smf =2.52. The normalized fault scarp height vs distance from the start graph, shows clearly that there is a distinct discontinuity between Halileli and Dümrek segments, while Tevfikiye and Halileli show no so clear evidence while their boundary is a weak step-over. They could also behave in a continuous manner. Furthermore, the transversal valley floor width/ Valley height ratio shows that while Tevfikiye (western) and Halileli (eastern) have similar characteristics. Dümrek segment shows far higher values, indicating a mature stage of erosion (i.e. less fault activity). Thus, based on morphotectonic quantitative characteristics, Tevfikiye and Halileli segments, of about 4 km long and 5 km long respectively, may be considered as one, uniformly behaving segment (hereby called "Troy segment"), while Dümrek segment is a much less active one. So, for seismic hazard assessment only the Troy segment and its westward extension have been taken into account.

CONCLUSION

Due to its typical morphotectonic characteristics Troy fault can be characterized as an active fault, although it is not associated with any historical or instrumentally recorded earthquake. It is recorded that Homer Troy VI (1800-1275 BC), was destroyed by an earthquake and/or earthquakes. However, there are no studies related to dating of these earthquakes.

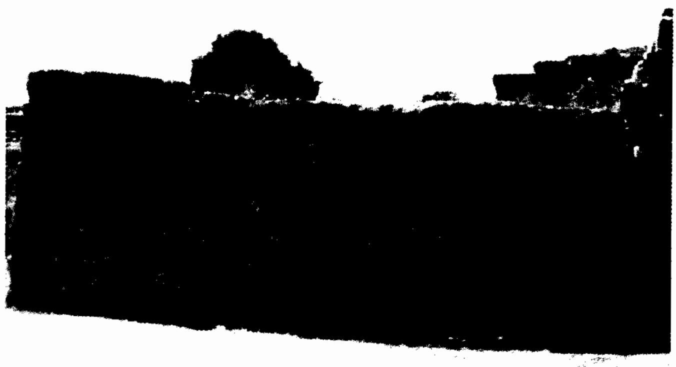


Figure 5. Troy city ancient walls (Hisarlik archaeological site) with indications of probable tectonic displacement during an unknown paleoearthquake event. The wall is deformed because of flexure of footwall

Excluding the easternmost inactive Dómrek segment Troy fault it was divided into two main geometrical, morphological and seismic behavioral segments. So, taking into account known empirical relationships of fault length versus Ms (or Mw) and the length of segments, such as Wells & Coppersmith (1994), Ambraseys & Jackson (1998), Pavlides & Caputo (2004), the seismic potential of the Troy Fault is Mw = 5.5-6.1. However, suggesting that the total length of the fault is in the order of 9 km and its possible westward extension 10 to11 Km in the plain, an earthquake of magnitude 6.2 to 6.5 is probable, in case of reactivation of the total length of Troy Fault. Based on this fault length, its estimated highest probable earthquake magnitude is $M_{s\ max} = 6.5$.

Palaeoseismological studies based on trenching investigation of fault colluvial tecto-stratigraphy (McCalpin 1996; Pavlides 1996; Pavlides et al., 1999; 2004, 2006; Kurcel et al., 2005) could help to understand the Holocene seismic history of Troy. These type of analyses can also facilitate to the understanding chronological order of past events ant to provide crucial data regarding the occurrence of destructive palaeoearthquake (s), because there are some preliminary initial findings of paleoseismologic features on Troy fault, which was thought to be the main motive for the earthquake (s) that destroyed the VIth layers of Troy. This kind of research will be the next promising step of Troy Fault study.

ACKNOWLEDGMENTS

This preliminary work on the geometry and morphotectonics of Troia Fault has been done in the framework of bilateral Scientific Cooperation of the Aristotle University of Thessaloniki and the Onsekiz Mart University of Çanakkale. The second author express his sincerely thanks to the university of Canakkale, and especially the Rector, for the great hospitality and "Pythagoras II" programme of the Greek Ministry of Education for travel expenses. Thanks are also due to our colleagues A. Chatzipetros, S. Valkaniotis, A. Zervopoulou A. Kürçer and Ö. Ates for their help during field work and Map digitting. Thanks are also due to A. Ganas and I.Koukouvelas for their review of the manuscript and for constructive comments.

REFERENCE

Ambraseys, N. & Jackson, J. A. (1998). "Faulting associated with historical and recent earthquakes in the Eastern Mediterranean region". Geophysical Journal International, vol. 133, p. 390 - 406.

Kayan, I. (1996). Holocene stratigraphy of the lower Karamenderes-Dumrek plain and Archaeological material in the Alluvial sediments to the north of Troia ridge. STUDIA TROICA Band 6, 239-249

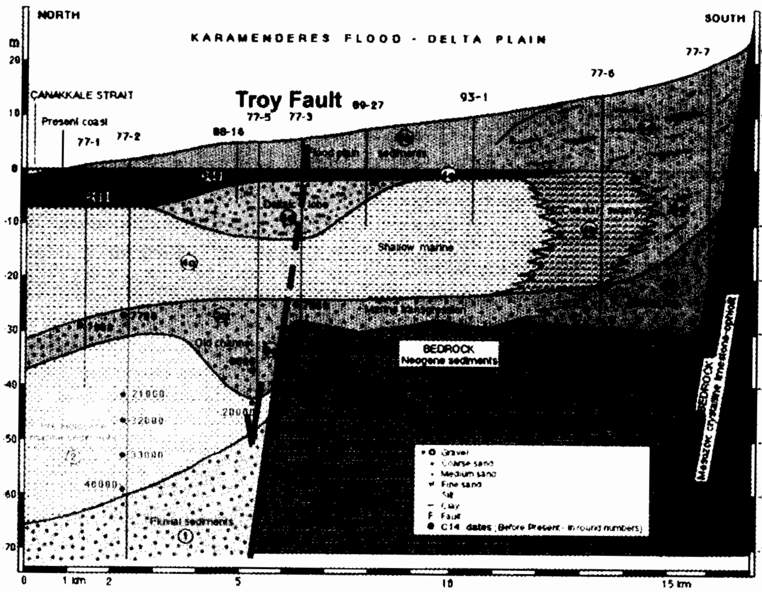


Figure 6. North-South cross-section of the Karamenderes plain with interpretation based on drilling evidence. (Please indicate location of Figure 6 inside Figure 2 Troy fault is shown buried by the sediments of the Karamenderes plain. Modified after *Kraft, et al., (1980).* and *Kayan I. (1999).*

Kayan I. (1999). Holocene stratigraphy and geomorphological evolution. Quat. Sci. Reviews, 18, 541-548.

Kayan I. (2002). Paleogeographical reconstruction on the plain along the western footslope of Troy. Mauer Schau Festschrift fur M. Korfmann, R. Aslan et al. (Eds) B3, 993-1004

Keller, a. E., Pinter, N., (1996). ACTIVE TECTONICS, Earthquakes, Uplift and Landscape. Prentice Hall (ISBN 0-02-304601-5) N. Jersey -pp. 377. (Second Edition 2002).

Koukouvelas I.K. and Aydin A. (2002): Fault structure and related basins of the North Aegean Sea and its surroundings. Tectonics, 21, 1046, doi:10.1029/2001TC901037.

Kraft, J. C., Kayan, I., & Erol, O. (1980). Geomorphic reconstructions in the environs of Ancient Troy. Science, 209, 776-782.

Kraft, J. C., Rapp, G., Kayan, I.,Luce, V. J. (2003). Harbor areas at ancient Troy: Sedimentology and Geomorphology complement Homer's Iliad. Bull. Geol. Soc. Am. V31, 163-166.

Kürçer A., Pavlides S., Tutkun S.Z., Chatzipetros A. and Ates Ö (2005). Preliminary paleoseismological results from the 1953 Yenice-Gönen earthquake (Mw 7.2) fault, *58th Geological Congress of Turkey,* Ankara, Turkey, 11-17 April 2005, Abstract book, 123-124.

McCalpin J.P. (1996): *Paleoseismology.* Academic Press, New York, 583 pp.

Pavlides S. (1996): First palaeoseismological results from Greece. *Ann. Geofisica*, 39, 545-555.

Pavlides S., Zhang P. and Pantosti D. (Eds.) (1999): Earthquakes, active faulting, and paleoseismological studies for the reconstruction of the seismic history of faults, *Tectonophysics.*, 308.

Pavlides S., Chatzipetros A., Tutkun Z. and Özaksoy V. (2004). Paleoseismological indications for Holocene earthquake activity along the 1999 Izmit, Turkey, earthquake rupture, *5th International Symposium on Eastern Mediterranean Geology,* Thessaloniki, Greece, 14-20 April 2004.

Pavlides S., Tutkun S.Z., Chatzipetros A., Kürçer A., Ates Ö. and Valkaniotis S. (2005). Palaeoseismological investigation of the 1953

(M_w 7.2) Yenice – Gönen earthquake fault (NW Turkey), *International Symposium on the Geodynamics of Eastern Mediterranean: Active Tectonics of the Aegean,* Istanbul, Turkey, 15-18 June 2005.

Pavlides S., Chatzipetros A., Tutkun S.Z., Özaksoy V. and Dogan B. (2006). Evidence for late Holocene activity along the seismogenic fault of the 1999 Izmit earthquake, NW Turkey, *Geological Society of London, Special Publication 260 (Roberson & Mountrakis eds).635-647.*

Pavlides S. & Caputo R. (2004). Magnitude versus faults' surface parameters: quantitative relationships from the Aegean region, *Tectonophysics,* 380, 159-188.

Sengör A.M.C., Gorur N. and Saroglu F. (1985): Strike-slip faulting and related basin formation in zones of tectonic escape: Turkey as a case study, *Soc. Econ. Paleont. Miner.*, Spec. Publ. 37, 227-264.

Taymaz T., Jackson J. and McKenzie D. (1991): Active tectonics of the North and Central Aegean Sea. *Geophys. J. Intern.*, 106, 433-490.

Yilmaz, Y. (2003). Seismotectonics and Geology of Troia and surrounding areas, North Anatolia, in Wagner, A.G., Penicka, E., Uerpmann, H. P. (Eds). (2003). Troia and the Troad. Springer, 55-75.

Wagner, A.G., Penicka, E., Uerpmann, H. P. (Eds). (2003). Troia and the Troad. Springer, 448pp.

Wells, D. L., & Coppersmith, J. K., (1994). "New empirical Relationships among Magnitude, Rupture Length, Rupture Width, Rupture Area and Surface Displacement". Bulletin of the Seismological Society of America, vol. 84, p. 974 - 1002.

ΠΕΡΙΛΗΨΗ

ΤΟ ΡΗΓΜΑ ΤΗΣ ΤΡΟΙΑΣ

Tutkun S. Z.[1], Σ. Β. Παυλίδης[2]

[1] *Çanakkale Onsekiz Mart University, Engineering and Architecture Faculty, Department of Geophysical Engineering* (sztutkun@comu.edu.tr / 17020 ÇANAKKALE)

[2] *Department of Geology, Aristotle University of Thessaloniki, Greece (pavlides@geo.auth.gr, 54124 THESSALONIKI)*

ΠΕΡΙΛΗΨΗ

Το ρήγμα της Τροίας είναι ένα κανονικό - πλαγιοκανονικό ρήγμα Α-Δ διεύθυνσης που εκτείνεται για 8-10 km στο βορειοδυτικό άκρο της χερσονήσου Biga στη Βορειοδυτική Τουρκίας. Αποτελεί τμήμα του συστήματος ΒΑ-ΝΔ διεύθυνσης ρηγμάτων της ευρύτερης περιοχής Παρουσιάζει τυπικά και σαφή τοπογραφικά χαρακτηριστικά επηρεάζοντας τα Νεογενή και Τεταρτογενή ιζήματα της περιοχής. Διαμορφώνει την κοιλάδα του ποταμού Σιμόη (Dómrek) και την πεδιάδα της Τροίας, όπου εκτείνεται για 2-4 km ακόμη δυτικότερα και επηρεάζει τα Ολοκαινικά ιζήματα. Έχει γεωλογικά χαρακτηριστικά ενεργού ρήγματος, ιδιαίτερα μορφοτεκτονικά, όπως δαντέλωση πρανών, κλίσεις πρανών, ασυμμετρία λεκάνης κ.α. αν και δεν συνδέεται με κανέναν γνωστό ιστορικό σεισμό. Από εμπειρικές σχέσεις μήκους ρήγματος-μεγέθους σεισμού τα διάφορα επί μέρους τμήματα εκτιμάται ότι έχουν δυναμικότητα γένεσης σεισμού της τάξης επιφανειακού μεγέθους του 5.5-6.1, ενώ στην ακραία περίπτωση ενεργοποίησης στο σύνολό του μπορεί να ξεπεράσει το μέγεθος 6,2 και να προσεγγίσει το 6,5.