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Re-Assessment of Seismic Risk Associated with the Furthest East of the Düzce-Kaynaşlı Segment of the North Anatolian Fault (Türkiye) Utilising Data Derived From 12 November 1999 Earthquake in the Bolu Basin (NW Anatolia)

Kuzey Anadolu Fayı Düzce-Kaynaşlı Segmentinin Doğusunda Sismik Riskin Yeniden Değerlendirilmesi; 12 Kasım 1999 Depreminde Bolu Havzasında (KB Anadolu) Gözlenen Etkiler

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Abstract: During the 17 August 1999 Marmara earthquake in Türkiye, the surface rupture became indistinct north of Aydınpınar village in the southeast of Düzce Basin at the eastern end of the rupture. The surface rupture of the 17 August 1999 earthquake propagated towards the west, but it also propagated towards the east reaching the southeast of Düzce Basin. Thus fault propagation after 17 August developed towards the east to cause the later Düzce-Kaynaşlı earthquake on 12 November 1999 where the surface rupture propagated reaching Asarsuyu valley in Kaynaşlı county. Although an İstanbul earthquake is expected in the near future, we aim to draw attention to the segment in the furthest east of this zone. In this area, increasing earthquake risk is indicated by the development of a series of tensional gashes in the north of the Bolu Basin and an M=4.8 earthquake that occurred in this region on 16 March 2023.

Keywords: *1999 earthquakes, Bolu Basin, North Anatolian Fault, seismic risk.*

Öz: *17 Ağustos 1999 Marmara depreminde meydana gelen yüzey kırığının doğudaki ucu Düzce havzasının güneydoğusunda Aydınpınar köy yolunun kuzeyinde belirsiz hale gelmişti. 17 Ağustos Adapazarı-Gölcük depreminin yüzey kırığı batıya ilerlerken doğuya doğru Düzce ovasının güneydoğusuna kadar da ilerlemişti. Doğuya ilerleyen yüzey kırığı 12 Kasım 1999 da Düzce –Kaynaşlı depremine yol açmış ve yüzey kırığı Kaynaşlı ilçesini geçerek Asarsuyu vadisine kadar ilerlemişti. Her ne kadar yakın gelecekte bir İstanbul depremi beklenmekteyse de yer bilimcilerin dikkatini bu yüzey kırığının daha doğusunda artan deprem tehlikesine çekmek istemekteyiz. Bu tehlike söz konusu deprem sırasında Bolu havzasının kuzeydoğusunda beliren bir seri tansiyon çatlağı ile ve 16.03.2023 tarihinde bu noktada meydana gelen M=4.8 depremi ile kendini belirtmiştir.*

Anahtar Kelimeler: *1999 depremleri, Bolu Havzası, Kuzey Anadolu Fayı, sismik risk.*

INTRODUCTION

The broadly northwards-convex North Anatolian Fault System (NAFS) extends for approximately 1100 km from Karlıova in eastern Türkiye to Saros Bay and beyond in the west (Figure 1; Gökten et al. 2011). Following the pioneering work of Ketin (1948), who first recognised its strike-slip character, this lineament is now recognised as one of the most important seismically-active structures in this region and has been the object of numerous

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publications (e.g., Ketin, 1948, 1969; Tokay, 1973; Şengör, 1979; Şaroğlu, 1988; Barka, 1996; Emre et al. 1999, 2000, 2003; Demirtaş, 2000; Gökten et al, 2000, 2011; Çemen et al., 2000; Akyüz et al. 2002; Barka et al. 2002; Koçyiğit, 2003; Çakır et al. 2003; Hitchcock et al. 2003; Şengör et al., 2004; Herece, 2005; Özden et al., 2008; and the references there in).

There is broad consensus that the NAFS has been active since the Late Pliocene (Koçyiğit, 2003; Şengör et al., 2004; Gökten et al., 2011; and others), facilitating the westward movement of the Anatolian Block along the right-lateral strike-slip North Anatolian Fault and the conjugate left-lateral strike-slip East Anatolian Fault. These movements can ultimately be attributed to the crustal-scale compressive forces associated with northwards movement of the Arabian Plate, in classic Prandtl triangle style.

One consequence of this geodynamic situation is that over the past century many earthquakes have occurred and been recorded along the ca. 1100 km length of the NAFS, from Erzincan in the east (1939) to the Marmara region in the west (1999). Along this segmented fault zone, earthquakes with magnitudes of seven or more appear to have migrated from east to west in the 1939 to 1999 time-interval. This is due to the stress within each segment loading onto the westward-adjacent segment, with the exception of the 1912 Tekirdağ and 1992 Erzincan earthquakes.

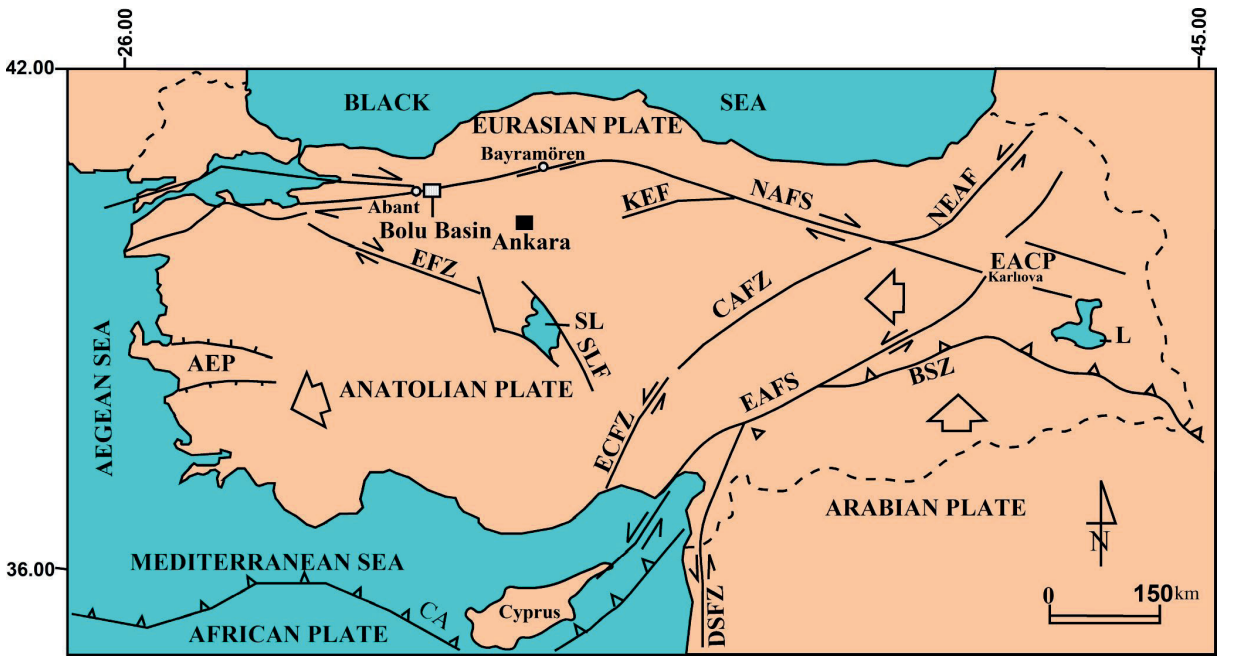

Figure 1. The principal neotectonic structures of Türkiye: AEP: Aegean extensional province, BSZ: Bitlis Suture Zone, CA: Cyprus Arc, CAFZ: Central Anatolian Fault Zone, DEFZ: Dead Sea Fault Zone, EACP: East Anatolian contractional Province, EAFZ: East Anatolian Fault Zone, ECFZ: Ecemiş Fault Zone, EFZ: Eskişehir Fault Zone, KEF: Kırıkkale-Erbaa Fault, LV: Lake Van, NAFS: North Anatolian Fault System, NEAFZ: Northeast Anatolian Fault Zone, SL: Salt Lake, SLF: Salt Lake Fault (from Gökten et al. 2011).

Şekil 1. *Türkiye'nin başlıca neotektonik yapıları: AEP: Ege genişleme bölgesi, BSZ: Bitlis Sütür Zonu, CA: Kıbrıs Yayı, CAFZ: Orta Anadolu Fay Zonu, DEFZ: Ölü Deniz Fay Zonu, EACP: Doğu Anadolu sıkışma bölgesi, EAFZ: Doğu Anadolu Fay Zonu, ECFZ: Ecemiş Fay Zonu, EFZ: Eskişehir Fay Zonu, KEF: Kırıkkale-Erbaa Fayı, LV: Van Gölü, NAFS: Kuzey Anadolu Fay Sistemi, NEAFZ: Kuzeydoğu Anadolu Fay Zonu, SL: Tuz Gölü, SLF: Tuz Gölü Fayı (Gökten vd. 2011'den).*

During the Adapazarı-Gölcük earthquake (17 August 1999: M=7.4), a surface rupture developed in the southern part of Düzce Basin, starting from the area east of Gölyaka (near Aydınpınar village: Fig, 2) and traceable into the southern part of the Marmara Sea, offshore of Yalova and Çınarcık (Gökten et al., 2000). On 12 November, 1999, a further tremor (M=7.2) propagated the existing surface rupture affecting the southern margin of the Düzce Basin (the Adapazarı-Gölcük segment) toward the east. This propagation began from the north of Aydınpınar village as far as the Asarsuyu valley, north of Kaynaşlı, where the fracture became indistinct (Figure 2) (Emre et al. 1999; Akyüz et al. 2002; Gökten et al., 2011).

Further Fault Propagation Towards the East:

During the 12 November earthquake, an east-west trending strained zone developed in the northwest sector of the Bolu Basin (Figure 2 Loc. 1), east of the Asarsuyu valley. The arrays of tensional cracks (gashes) observed in this zone are typical of Reidel fractures created in this type of high-strain field. This strain occurs in the western sector of Bolu Basin, around 100 m north of the D 100 state highway. The zone is about 50-60 m long, with individual tension-gashes that range in length from 2-3 m with widths of a few cm (Figure 2; inset).

The observed E-W trend of the surface rupture associated with the 12 November 1999 Düzce-Kaynaşlı earthquake suggests that it may continue to the east along the northern margin of Bolu Basin in an east-west direction, utilising a zone of weakness that controls the northern boundary of that basin (Figure 2: MF). Most previous studies agree that the main strand of the North Anatolian Fault zone forms the southern boundary of the Bolu Basin (Öztürk, 1968, Tokay, 1973; Demirtaş, 2000,

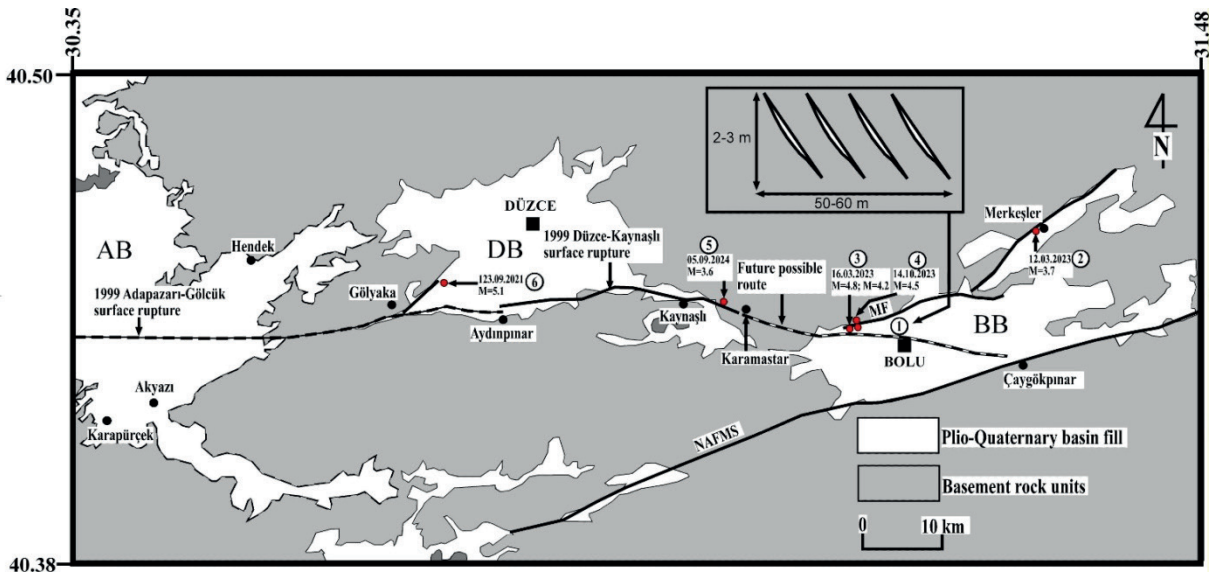

Figure 2. 1999 Düzce-Kaynaşlı earthquake surface rupture and the course of the North Anatolian Master Fault (NAFMS). AB: Adapazarı Basin; BB: Bolu Basin; DB: Düzce Basin; MF: Musluklar Fault (Northern Boundary Fault). NAFMS: North Anatolian Fault Master Strand. Inset: The array of tensional cracks at Loc. 1; Numbers 1 to 6: Earthquakes; red circles: epicentre locations.

Şekil 2. 1999 Düzce-Kaynaşlı depreminin yüzey kırığı ve Kuzey Anadolu Ana Fayı üzerindeki depremler. AB: Adapazarı Havzası, BB: Bolu Havzası, DB: Düzce Havzası, MF: Musluklar Fayı (Kuzey Sınır Fayı), NAFMS: Kuzey Anadolu Ana Fay Hattı. Küçük dikdörtgen içindeki şekil: Gerilme çatlaklarının yeri; 1'den 6'ya rakamlar: Depremler; Kırmızı Daireler: Deprem dış merkezlerinin yeri.

Gökten et al. 2011, and others). However, it was also suggested (e.g., Hitchcock et al., 2003) that the Düzce splay of the NAFS enters the Bolu Basin from the west, in the vicinity of Karamastar, and may continue eastwards through the central part of the basin before rejoining the main southern strand of the NAFZ near Çaygökpınar (Figure 2). The existence and behaviour of the Musluklar Fault (and parallel minor fractures) forming the northern boundary of the basin and the strain-zone that developed during the 12 November earthquake all support the pull-apart character of the Bolu Basin, as previously determined by Gökten et al. (2011**).** However Gürbüz and Gürer (2009) claimed that during the extinction period of pull-apart basins the faults causing the pull-apart development migrate from the edges of the basin toward the centre, as is likely seen in the Bolu Basin.

CONCLUSION

In brief, the segment of the North Anatolian Fault traceable from the Düzce-Kaynaşlı surface rupture in the northern sector of the Bolu Basin poses an earthquake risk comparable to that predicted for the central Marmara or İstanbul region. The concentration of stress manifested by the strain-zone documented in the north-central sector of the Bolu Basin may ultimately be transferred to the main fault that forms the southern boundary of the basin. In general, strike-slip faults exhibit an initial concentration of stress near both ends of the structure and this stress then propagates along the fracture. An example of this was seen during the 1995 Kobe earthquake in Japan (Bolt, 2004). This is why, following the 17 August 1999 Adapazarı-Gölcük earthquake, the eastern tip of the surface rupture of the segment, which ended in the area north of Aydınpınar village (southeastern sector of Düzce Basin: Figure 2) at that point, propagated further east during the later (12 November 1999) Düzce-Kaynaşlı earthquake. This situation implies that the region to the east of this point is now a critical part of the North Anatolian Fault Zone in terms of potential earthquake risk. This conclusion is confirmed by the recent development of a localised strain-zone in the northwest sector of the Bolu Basin, as described above. A recent earthquake with magnitude 5.1 affected the region on 23rd of September 2021 and the epicentre was localized on the bifurcated eastern end of the Adapazarı-Gölcük segment (Loc. 6 in Figure 2). There were later earthquakes on the 16th March 2023 and 14th October 2023 in the northwest of Bolu Basin (Locs. 3 and 4 in Figure 2), in addition to some other events in the region with magnitudes between 3.5 and 4.1. A very recent event had an epicentre localized on the western end of the surface rupture of the 12 November 1999 earthquake (Loc. 5 in Figure 2). The identified strain-zone and recent earthquake activity contribute to the conclusion that there is increased earthquake risk in this area.

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REFERENCES

Akyüz, H. S., Hartleb, R., Barka, A. A., Altunel & E. Sunal, G. (2002). Surface rupture and slip distribution of the 12 November 1999 Düzce earthquake (M 7.1), North Anatolian Fault, Bolu, Turkey. *Bulletin of the Seismological Society of America*, *92*(1), 61-66. https://doi.org/10.1785/0120000840

Barka, A. (1996). Slip distribution along the North Anatolian Fault associated with the large earthquakes of the period 1939-1967. *Bulletin of the Seismological Society of America*, *86*(5), 1238-1254. https://doi.org/10.1785/BSSA0860051238

Barka, A.A., Akyüz, H.S., Altunel, E., Sunal, G., Çakır, Z. … & Page, W. (2002). The surface rupture and slip distribution of the 17 August 1999 İzmit earthquake (M 7.4), North Anatolian Fault. *Bulletin of the Seismological Society of America*, *92*(1), 43-60. https://doi.org/10.1785/0120000841

Bolt, B.A. (2004). *Earthquakes – Depremler* (Çev: Ü. Tansel, 2008). W.H. Freeman and Company, New York. Tübitak Popüler Bilim Kitapları, 273, 485 s.

Çakır, Z., Barka, A. A., De Chabalier, J. B., Armijo, R. & Meyer, B. (2003). Kinematics of the November 12, 1999 (Mw=7.2) Düzce earthquake deduced from SAR interferometry. *Turkish Journal of Earth Sciences*, *12*(1), 105-118.

Çemen İ. Gökten E. Varol B. Kılıç R. Özaksoy V. Erkmen C. & Pınar A. (2000). Turkish earthquakes reveal dynamics of fracturing along a major strike-slip fault zone. *EOS, 81*(28), 309-313. https://doi.org/10.1029/00EO00233

Demirtaş, R. (2000). *Kuzey Anadolu Fay Zonu'nun Abant-Gerede arasında kalan bölümünün neotektonik özellikleri ve paleosismisitesi (Paleoseismicity and neotectonics of the Abant-Gerede region of the North Anatolian Fault Zone)*. Doktora Tezi (PhD Thesis), Ankara Üniversitesi Fen Bilimleri Enstitüsü, 191 p.

Emre, Ö., Duman, T. Y., Doğan, A., Ateş, Ş. & Keçer, M. (1999). *12 Kasım Düzce depremi saha gözlemleri ve ön değerlendirme raporu*. M.T.A. Gen. Müd. Jeol. Et. Dairesi, 16 Kasım Ankara, 27 p.

Emre, Ö., Duman, T. Y., Awata, Y., Dogan, A., & *Özalp, S. (2000). Surface r*upture of November 12 1999 Düzce earthquake, NW Turkey. *XXVII General Assembly of the European Seismological Commission (ESC-2000). Book of abstract and papers*, (p.: 247-252), 10-15 September 2000, Lisbon, Portugal.

Emre, Ö., Awata, Y. & Duman, T. Y. (Eds). (2003). 17 Ağustos 1999 İzmit depremi yüzey kırığı (surface rupture of the 17 August 1999 İzmit earthquake). *Spec. Publ. of the Gen. Direc. Min. Res. Explor.*, *280 p.*

Gökten, E., Çemen, İ., Varol, B., Pınar, A. & Özaksoy, V. (2000). The 17 August 1999 Gölcük (Kocaeli)-Arifiye (Adapazarı) and 12 November 1999 Düzce earthquakes, NW Turkey; Their mechanisms and tectonic significance. In N. Görür, G. A. Papadopoulos & N. Okay (Eds.), *Integration of Earth Science Research on the Turkish and Greek 1999 Earthquakes, NATO Science Series: IV: Earth and Environmental Sciences, vol 9. Springer, Dordrecht.* https://doi.org/10.1007/978-94-010-0383-4_1

Gökten, E., Demirtaş, R., Özaksoy, V., Herece, E., Temiz U. & Varol, B. (2011). Faulting, Stress Distribution in the Bolu Pull-Apart Basin (North Anatolian Fault Zone, Turkey): The significance of new dates obtained from the basin fill. *Turkish Journal of Earth Sciences, 20*(1), 1-26. https://doi.org/10.3906/yer-0803-6

Gürbüz, A. & Gürer, *Ö.* F. (2009). Middle Pleistocene extinction process of pull-apart basins along the North Anatolian Fault Zone. *Physics of the Earth and Planetary Interiors, 173*(1-2)*,* 177-180. https://doi.org/10.1016/j.pepi.2008.10.021

Herece, İ.E. (2005). *Kuzey Anadolu Fay Zonu batı kesiminin neotektonik özellikleri (Neotectonic features of the western part of the North Anatolian Fault Zone)* [Yayımlanmamış Doktora Tezi]. Ankara Üniversitesi Fen Bilimleri Enstitüsü, Ankara 228 p.

Hitchcock, C., Altunel, E., Barka, A. I., Bachhuber, J., Lettis, W., Kozaci, Ö., Helms, J. & Lindvall, S. (2003). Timing of Late Holocene earthquakes on the eastern Düzce Fault and implications for slip transfer between the southern and northern strands of the North Anatolian Fault System, Bolu, Turkey. *Turkish Journal of Earth Sciences*, *12*(1), 119-136.

Ketin, İ. (1948). Uber die tectonische-mechanischen folgerungen aus den grosse Anatolischen Erdbeben des letzten dezenniums. *Geologische Rundschau*, *36,* 77-83. https://doi.org/10.1007/BF01791916

Ketin, İ. (1969). Kuzey Anadolu Fayı hakkında (About the North Anatolian Fault). *Maden Tetkik Arama Enstitüsü Yayını, 72*, 1-27. https://izlik.org/JA77KA26JK

Koçyiğit, A. (2003). *The Gerede-Kaynaşlı Fault Zones of the North Anatolian Fault System (NAFS),*

Turkey- A Post International workshop excursion guidebook. Middle East Tech. Univ. (METU), Ankara, Turkey, 27 p.

Özden, S., Över, S., Kavak, K. Ş. & İnal, Ş. S. (2008). Late Cenozoic stress state around the Bolu basin along North Anatolian Fault, NW Turkey. *Journal of Geodynamics, 46*(1-2), 48-62. https://doi.org/10.1016/j.jog.2008.04.004

Öztürk, A. (1968). *Çerkeş-Eskipazar-Gerede Bölgesinin Jeolojisi (The Geology of the Çerkeş-Eskipazar-Gerede Region)* [Unpublished PhD Thesis]. Ankara University.

Şaroğlu, F. (1988). Age and offset of the North Anatolian Fault. *METU J. App. Sci., 21, 65-79.*

Şengör, A. M. C. (1979). The North Anatolian transform fault: its age, offset and tectonic significance. *Journal Geological Society London, 136,* 269-282. https://doi.org/10.1144/gsjgs.136.3.0269

Şengör, A. M. C., Tüysüz, O., İmren, C., Sakınç, M., Eyidoğan, H., Görür, N., Le Pichon, X. & Rangin, C. (2004). The North Anatolian Fault: A new look. *Annual Review of Earth and Planetary Sciences, 33,* 1-75. https://doi.org/10.1146/annurev.earth.32.101802.120415

Tokay, M. 1973. Kuzey Anadolu Fay Zonu'nun Gerede ile Ilgaz arasındaki kesiminde jeolojik gözlemler. (Geological observations on the North Anatolian Fault in the part between Gerede and Ilgaz). Kuzey Anadolu Fayı ve Deprem Kuşağı Sempozyumu, *Maden Tetkik Arama Enstitüsü Yayını*, 12-29. Ankara.