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Evolution of the Duzce segment of the North Anatolian Fault Zone (Turkey)

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West of the town of Bolu, the North Anatolian Fault splays into two main strands, the Duzce and the Mudurnu fault segments. On November 12, 1999, three months after the Mw 7.4 earthquake that struck the Izmit region, a Mw7.1 event ruptured the Duzce fault and produced a 40-km-long, E-W trending, surface rupture zone, with predominant right-lateral coseismic slip up to 5.0 meters. The 1999 ruptures are still well-preserved, making the Duzce segment a natural laboratory where coseismic deformation, landforms and long-term geological structures can be analyzed and integrated in order to image the fault evolution. The 1999 rupture geometry and its peculiar complexity were mapped in detail, revealing mole-tracks organized in a en-échelon pattern of left-stepping Riedel shears, right-stepping P-shears and parallel Y-shears. This pattern of coseismic fault trace (CFT) is recognized at different scales of observation: from single outcrop to kilometric subsections of the rupturing fault. Analysis of the broader geologic and geomorphic setting was performed extending the observation in a wider area around the CFT and shows that the trace of coseismic ruptures is associated with a consistent pattern of landforms indicating that the Duzce fault ruptured with similar style of deformation (location, geometry, kinematics) during several seismic cycles. However, the CFT is not the unique expression during time of the Duzce fault zone. In fact, the collected structural data and the recognized morphotectonic elements describe a long-term kilometric structural system (KSS) composed by a much wider (up to 5 km) en-échelon pattern of left-stepping, WNW-ESE striking, Riedel shears and of right-stepping, SW-NE striking, P-shears. This similarity in the arrangement among fault systems at different scales of observation is evidence for scale-independent deformational pattern. The relevance of the role of KSS during the Quaternary deformational history of the Duzce Fault is clearly expressed by the two

main left-stepping Riedel shears that are responsible for the opening of the Kaynasli pull-apart basin to the east. Similarly, the other elements of the KSS have participated in the development of the Duzce fault zone during time. The comparison of the KSS and the 1999 CFT provides the insights to recognize how the Duzce fault zone evolved through time. In general, at the whole fault scale, the present expression of the fault (i.e. CFT) shows a general E-W trend, and a much less complexity with respect to KSS; this is suggestive of a tendency of the fault to simplify its trace with time and evolve from a geometric complexity towards a straighter trace. This is in agreement with the combination of displacement along Riedel and P-shears that leads to the formation of Y-shears, oriented parallel to the general direction of movement that is presumably a mechanically more favorable setting. According to its relations with KSS, CFT can be subdivided into two sections with: (1) the western one following a staircase trajectory, reactivating both left-stepping Riedel shears and right-stepping P-shears of the KSS; (2) the eastern one cross-cutting the en-échelon pattern of the KSS. This suggests that to the east the CFT has totally overcome the KSS that now is inactive or experiences negligible activity. Conversely, the imprint of the KSS is still relevant in the western section of the fault. The KSS arrangement and the two distinct settings of CFT sections describe well different stages of the evolution of the Duzce fault zone from a complex to a simpler, mature trace. This implies also that the whole structural setting, at surface, is not evolving exactly at the same time. The understanding of the fault zone evolution both in time and geometry is of critical importance for developing segmentation models and, at the same time, highlights the importance of strain partitioning amongst shallow transtensional and transpressional structures, and a deeper single structure, at seismogenic depth.