Short communication

Middle Pleistocene extinction process of pull-apart basins along the North Anatolian Fault Zone

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A B S T R A C T

Numerous basins that present in northern Turkey formed in Plio-Quaternary period by the strike-slip tectonics of the North Anatolian Fault Zone. These pull-apart basins isolated from their surrounding topographies by major scarps of faults along their margins that mapped as active faults. But the mapped recent traces in the pull-apart basins are in disagreement about these marginal faults and commonly characterized by the faults that pass through basin floors in the cases of surface rupturings in great earthquakes during the last century. These faults have migrated from the basin rims to the center of the basins in agreement with the extinction model of pull-apart basins. Here we review observations about numerous basins along the North Anatolian Fault Zone to show that the migration of these faults in Middle Pleistocene related with the maturity of basins through their evolution. © 2008 Elsevier B.V. All rights reserved.

1. Introduction

Pull-apart basins are structural depressions controlled by strike-slip faults within intraplate and interplate settings (Reading, 1980; Mann et al., 1983; Christie-Blick and Biddle, 1985). They caused by the crustal extension in domains where the sense of fault overstepping or bending coincides with the fault motion sense (Chen et al., 2001). Pull-apart basins are generally displayed as in rhomb-shapes isolated by two vertical, offset strike-slip faults that are linked by two step, parallel, oblique-slip extensional faults from their surrounding topographies (e.g. Christie-Blick and Biddle, 1985; Aydın and Nur, 1985). However, the real geometry of this basin type in nature is more variable due to initial separation and increasing offset of strike-slip faults (e.g. Mann et al., 1983; Rodgers, 1980). Numerous studies about the theoretical (e.g. Aydın and Nur, 1982; Mann et al., 1983), numerical (e.g. Rodgers, 1980; Bertoluzza and Perotti, 1997) and analog (e.g. Dooley and McClay, 1997; Rahe et al., 1998; Basile and Brun, 1999) modelling in the last three decades guide the understanding of pull-apart basins.

The analog models are the best matchable method to understand the evolution of pull-apart basins through a period. They are useful to present the other structural features that appear in basin floors associated with the master strike-slip faults. According to analog model results, pull-apart basins evolve through three stages: incipient, early and mature (Rahe et al., 1998). The incipient stage characterized by normal faults bounding the pull-apart basins dip steeply basinward. Forming of cross-basin strike-slip faults as separate and in small forms marks the beginning of the early stage in the evolution of pull-apart basins. Into the mature stage of development the active portions of cross-basin faults are located toward the center of the pull-apart basins. The migration of boundary faults toward the basin center as cross-basin strike-slip faults can be considered a contributing factor to the extinction process of a pull-apart basin. The formation of these new strike-slip faults probably represents a tendency to straighten itself and causing a cessation in the development of pull-apart basin (Rahe et al., 1998).

The current tectonics of northern Turkey are controlled mainly by the dextral strike-slip tectonics exerted by the North Anatolian Fault Zone (NAFZ) (Fig. 1). The NAFZ extends from the town of Karlova in eastern Turkey to Gulf of Saros in northern Aegean Sea in an approximately E–W direction between the Eurasian and Anatolian plates with about 1600 km long and 100 km wide. 900 km of this length is a very definite fault trace between the Karlova and town of Dokurcun. To the west of Dokurcun, the NAFZ bifurcates into two major subzones; northern and southern strands (Bozkurt, 2001). Its very high seismic activity between 1939 and 1999 and the westward migration of this activity with a succession of eight large earthquakes made this fault one of the best-known tectonic structures in the world.

Numerous depressions are aligned along the NAFZ and its major splays and defined within classical pull-apart basin or rhomb-graben models by numerous scientists in literature due
Fig. 1. Location and geological maps of studied pull-apart basins along the NAFZ. (A) Simplified tectonic map of northern Turkey. (B) Erzincan pull-apart basin and the rupture of the 1939 earthquake (modified from Yoshioka, 1996). (C) Suşehri–Gölova pull-apart basin and the rupture of 1939 earthquake (modified from Yoshioka, 1996). (D) Erbaa–Niksar pull-apart basin and the ruptures of the 1942 and 1943 earthquakes (modified from Yoshioka, 1996). (E) Bolu–Yeniçağa pull-apart basins and the rupture of the 1944 earthquake (modified from Herece and Akay, 2003). (F) İzmit–Sapanca pull-apart basin and the rupture of the 1999 earthquake (modified from Herece and Akay, 2003).

to the remarkable surface expressions of faults that bounds the rims of basins. However only some of workers (Yoshioka, 1996; Bozkurt and Koçyigit, 1996; Le Pichon et al., 2001; Gürbüz and Gürer, 2008) have discussed forming mechanisms of these basins based on recent active traces that pass straight basin floors.

Here we review the geometric features that presented by numerous writers about the recent traces of the main strand of the NAFZ in Erzincan, Suşehri–Gölova, Erbaa–Niksar, Bolu–Yeniçağa, İzmit–Sapanca and Marmara Sea pull-apart basins to explain the recent stages of these basins through their structural evolution.

2. Pull-apart basins along the NAFZ

Here we describe some of the main pull-apart basins related to the activity of the main strand of the NAFZ from east to west (Fig. 1A).

Although Neogene-Quaternary successions are different in each of these basins, Late Pliocene–Early Pleistocene deposits that generally consist of fluviolacustrine sediments overlying the older deposits and bedrocks with an angular unconformity due to initiated dextral tectonic activity of the NAFZ (Barka and Hancock, 1984). These deposits followed by the fluvial Middle Pleistocene–Holocene sediments.

2.1. Erzincan basin

This basin is located at an altitude of 1150 m above sea level (a.s.l.) with a size of 50 km in length and 15 km in width and surrounded by mountains of more than 3000 m a.s.l. Recent active traces are those of 1939 (M = 7.9) surface rupture, and the eastern extent of this breaks runs from the NW corner of the basin, into the basin (Fig. 1B). The existence of non-buried volcanic cones by recent deposits that aged to 0.246 ± 0.026 Ma (Hempton and Linneman, 1984) shows the basin floor has not subsided since at least 0.2 Ma (Yoshioka, 1996).

2.2. Suşehri–Gölova basin

The basin is a narrow pull-apart structure and actually consist of Suşehri and Gölova subbasins. Its full size is 50 km long and 5 km wide and situated at an altitude of 840 m a.s.l. The surrounding mountains which are more than 2000 m a.s.l. isolated from the basin floor by subparallel marginal faults along both rims of the basin (Koçyigit, 1989, 1990). However there is no evidence of recent activity of these marginal faults. The recent active traces reactivated during the 1939 earthquake pass almost straight through the center of the basin (Fig. 1C) (Yoshioka, 1996).

2.3. Erbaa–Niksar basin

The basin is in rhomboidal shape with a size of 75 km in length and 13 km in width and consists of Erbaa and Niksar subbasins. The altitudes of these subbasins are 190 m a.s.l. for the Erbaa and 260 m a.s.l. for the Niksar. Margin-bounding faults that display well-preserved scarps between the pre-Neogene bedrocks.

2.4. Bolu–Yeniçağa basin

This basin consists of Bolu and Yeniçağa subbasins as a narrow structure with a total size of 50 km long and 10 km wide. The Bolu subbasin is located at an altitude of 700 m a.s.l. and the Yeniçağa subbasin is at 900 m a.s.l. Margin-bounding faults that display well-preserved scarps between the pre-Neogene bedrocks.
basins with the altitudes of \( \sim \) width. It consists of two subbasins called as İzmit and Sapanca subbasins of Marmara Sea with a full size of 50 km in length and 10 km in width. It was generally assumed that the northern Marmara Sea is a pull-apart basin that lies on the eastern side of Marmara Sea with a full size of 50 km in length and 10 km in width. It consist of two subbasins called as İzmit and Sapanca subbasins with the altitudes of \( \sim \) 10 m a.s.l for İzmit and 35 m a.s.l. for Sapanca subbasins. The İzmir–Sapanca basin is bounded by marginal faults from its northern and southern sides. As expressed by the morphology, the southern side indicates a tectonic high activity of margin-bounding fault, but the 17 August 1999 earthquake \( (M = 7.4) \) generated a ground rupture that cut-across the center of the basin with a straight trace \( \) (Gürbüz and Gürer, 2008).

2.6. Marmara Sea pull-apart basin system

The Marmara Sea is located between the Black Sea in the north and the Aegean Sea in the south, with a size of 280 km in length and 80 km in width and consist of three subbasins; Çınarcık, Central and Tekirdağ basins, each of which is more than 1000 m deep \( \) (Fig. 2). The 17 August 1999 earthquake was the last in the series of westerly migrating major shocks along the NAFZ leaving the segment in the Marmara Sea as the only portion of the western NAFZ that has not been broken during the 20th century \( \) (Le Pichon et al., 2001). So the Marmara Sea is prone to a new earthquake in the chain of westward migrated earthquakes.

It was generally assumed that the northern Marmara Sea is a pull-apart basin \( \) (Barka and Kadinsky-Cade, 1988; Armijo et al., 1999, 2002). After the 17 August 1999 earthquake detailed studies on the bottom surface and subsurface of the Marmara Sea suggested that the pull-apart structure is not active any more and there is a pure strike-slip on a single through-going fault that cut across the subbasins \( \) (Le Pichon et al., 2001, 2003). The bathymetry of the Central Basin is appears to have been dextrally offset by about 4 km along the trace of this fault. It has also been asserted that this fault is geologically recent with about \( 0.2 \) Ma \( \) (Le Pichon et al., 2001, 2003; Imren et al., 2001) whereas the pull-apart basins are generally assumed to be Plio-Pleistocene \( \) (Armijo et al., 1999).

3. Discussion and conclusions

There have been numerous studies related to the tectonics of the NAFZ and also the Marmara Sea for the last decade \( \) (e.g. Hubert-Ferrari et al., 2002; Yaltırak, 2002; Şengör et al., 2005). However, some major questions about the geometric and kinematic features of the faults in the pull-apart basins and the age of deformation related to the NAFZ still are not clearly explained in the literature and require new views.

As recurrent features in analog models \( \) (Rahe et al., 1998; Dooley and McClay, 1997), the cross-basin faults play an important role in the extinction of pull-apart basins in nature. The extinction model \( \) (Zhang et al., 1989) successfully defined for numerous pull-apart basins along the major strike-slip faults around the world. Some of them are: the Dayinsui, Salt Lake and Liaohe-Yaxiao basins along the Haiyuan fault zone in northwestern China \( \) (Zhang et al., 1989), the Suwa basin along the Hoigawa–Shizuoka fault zone in central Japan \( \) (Yoshioka, 1996) and the Carica basin along the Moron–El Pilar fault zone in northern Venezuela \( \) (Jaimés-Carjaval and Mann, 2003).

About the pull-apart basins along the NAFZ in northern Turkey, Yoshioka (1996) mentioned about the extinction model for the first time as refereed above in the cases of Erzincan, Suşehri–Çölova and Erbaa–Niksar basins. Seven years after the 17 August 1999 great Kocaeli earthquake, Gürbüz and Gürer (2006) proposed the rupture of this shock in the İzmir–Sapanca basin was a cross-basin fault. And Kuşçu (2006) suggested that the through-going fault across the Marmara Sea is in character of a cross-basin fault. Briefly, the recent active traces that signed during the westward migration of large earthquakes in the last century, pass straight through basin floors of pull-apart basins along the NAFZ as in agreement with the extinction model of pull-apart basins and point out the inactivity of the marginal faults of the basins. So, the most suitable explanation for the mechanism on geometry and kinematics of all mentioned basins, is the extinction process of these pull-apart basins.

The age of dextral motion along the NAFZ is also controversial and there are different views. The more accepted one is that the movement along the NAFZ was initiated in eastern Anatolia during the late Miocene and propagated westwards reaching the Marmara Sea region during the Pliocene \( \) (e.g. Şengör, 1979; Şengör et al., 1985, 2005; Barka, 1992; Okay et al., 2000; Gürer et al., 2003). But according to the latest detailed studies in eastern Anatolia, the initiation age of strike-slip dominated neotectonism in eastern Turkey is late Pliocene \( \) (Kocyigit et al., 2001), as in the NW Turkey \( \) (Ünay et al., 2001; Gürer et al., 2006; Gürbüz and Gürer, 2008).

According to analog modelling results, forming of cross-basin faults in small forms mark the beginning of the early stage in the evolution of pull-apart basins and locating of these faults toward the center of the basin floor occur in the mature stage and contribute the extinction process of pull-apart basin \( \) (Rahe et al., 1998).

As mentioned above, in the east of NAFZ, the age of non-buried volcanic cones \( \sim \) 0.246 \pm 0.026 Ma \( \) (Hempton and Linneman, 1984) in Erzincan basin shows the basin has not subsided since at least 0.2 Ma \( \) (Yoshioka, 1996) and in the west the age of recent trace of fault that cut-across the Marmara Sea pull-apart basins is about...
0.2 Ma (Le Pichon et al., 2001; İmren et al., 2001) too. This shows the age of inactivation of marginal faults and extinction of pull-apart basins along the NAFZ is same as Middle Pleistocene in the east and west side of main strand. Like the extinction age, in the same evolution period, the incipient stage of pull-apart basins by dextral strike-slip motion of the NAFZ is Late Pliocene in the both side.

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References


