

Geometric characteristics of pull-apart basins

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ABSTRACT

Pull-apart basins are depressions bounded on their sides by two or more strike-slip faults and on their ends by diagonal transfer faults. As proposed by theoretical, experimental, and numerical studies in the literature, there are angular and scale relationships between these faults. Here, I compiled the major results on geometries of pull-apart basins of previous workers and then examined the geometric characteristics of pull-apart basins along the North Anatolian fault zone for a comparison of current data in two and three dimensions. According to the results of my compilation from the literature and measurements of pull-apart examples from northern Turkey, the acute angles of this type of strike-slip basin are clustered at 30°–35°. In metric scale, the consistency in their two-dimensional (2-D) geometry is well known as an aspect ratio of 3:1 between length and width. Basin length is a function of stretching associated with strike-slip displacement, and increased displacement causes the width of the fault zone to increase, resulting in wider pull-apart basins. However, the depth of a pull-apart basin is a function of stretching associated with strike-slip displacement. In this study, comparison of data related to pull-apart basin scales from the literature suggests that the depth is related to the length and width.

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INTRODUCTION

Following the definition of pull-apart basins by Burchfiel and Stewart (1966) in their interpretation of the Death Valley Basin, this basin type has been recognized numerous times along major strike-slip faults throughout the world (e.g., Aydın and Nur, 1982; Bahat, 1983), although many pull-apart basins have been adopted in the literature as synonymous with terms such as rhombochasms (Carey, 1958), wrench grabens (Belt, 1968), rhomb grabens (Freund, 1971), and releasing bends (Crowell, 1974a). Many rhomb structures previously described are considered clear examples of pull-apart basins, but their structural geometries were not well defined. As depicted by Crowell (1974a), pull-apart basins are deep, rhomb-shaped depressions bounded on their sides by two, subparallel, overlapping strike-slip faults and bounded on their ends by perpendicular or diagonal dip-slip faults, termed “transfer faults,” which link the ends of the strike-slip faults (Fig. 1). It is known that pull-apart basins along strike-slip faults are associated with geometrical irregularities of these faults (Aydın and Nur, 1982). However, many uncertainties complicate the interpretations of their geometrical aspects.

In this study, after summarizing some of the major conclusions on geometries of pull-apart basins by previous workers, I examine the geometries of clearly defined pull-apart basins

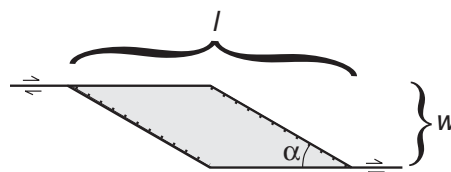


Figure 1. Geometrical model for pull-apart basins.

along the North Anatolian fault zone of Turkey, which is one of the most important strike-slip faults in the world, with its high seismic activity and descriptive morphology. My first goal will be to demonstrate the angular characteristics of Turkish pull-apart basins in two dimensions and compare them to natural, experimental, and numerical examples in published studies. The second goal of this paper will be to demonstrate the scale characteristics of pull-apart basins in three dimensions. In two dimensions, the well-defined linear correlation between the basin length and width is well known after the research by Aydın and Nur (1982). In the third dimension, the depth of the pull-apart basin is related to the length in an equation presented by Hempton and Dunne (1984). Here, I look for relationships among the basin length, width, and depth parameters in three dimensions, and I try to define this relationship by quantitative means.

Previous Conclusions on the Geometries of Pull-Apart Basins

The geometry of a strike-slip basin is one of its most obvious characteristics, and it has been

the basis for various classification schemes and for many discussions about the process of basin formation (Carey, 1958; Kingma, 1958; Lensen, 1958; Quennell, 1958; Burchfiel and Stewart, 1966; Clayton, 1966; Belt, 1968; Freund, 1971; Crowell, 1974a, 1974b, 1976; Ballance, 1980; Aydın and Nur, 1982, 1985; Burke et al., 1982; Crowell and Link, 1982; Fralick, 1982; Mann and Burke, 1982; Mann et al., 1983; Mann and Bradley, 1984; Christie-Blick and Biddle, 1985; Sylvester, 1988; Mann, 2007).

Field studies (e.g., Aydın and Nur, 1982; Bahat, 1983; Mann et al., 1983; Hempton and Dunne, 1984), experimental studies (e.g., McClay and Dooley, 1995; Dooley and McClay, 1997; Rahe et al., 1998; Basile and Brun, 1999; Sims et al., 1999; Atmaoui et al., 2006; Wu et al., 2009), and numerical studies (e.g., Rodgers, 1980; Segall and Pollard, 1980; Gölke et al., 1994; Katzman et al., 1995; Bertoluzza and Perotti, 1997; Petrunin and Sobolev, 2006, 2008) help to guide the interpretation of two-dimensional (2-D) and three-dimensional (3-D) geometry of pull-apart basins. The shape, fault system, and sedimentary structure of a pull-apart basin depend upon the geometry associated with the step in the master strike-slip fault system: fault length, depth to the main fault in the basement, fault separation, and, perhaps above all, the length of overlap (Carton et al., 2007).

Aydın and Nur (1982) proposed that pull-apart basins have an aspect ratio of 3:1 in 2-D (plan view). Plots of the log of basin length versus width for the 62 basins show a well-defined

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linear correlation between length and width, although the value of 3:1 may vary widely, depending on whether the structural, physiographic, or active dimensions of the basin are measured. The most common range of ratios determined directly is between 3 and 4. Aydın and Nur observed that this type of basin becomes wider as it grows longer with increasing fault offset. Mann et al. (1983) suggested that the rectangular form of pull-apart basins results from the lengthening of an S- or Z-shaped basin with increased master fault overlap. The basin length-to-width ratios, therefore, tend to increase. Basin width does not increase significantly and remains fixed by the width of the releasing bend. Most pull-apart basins have low length-to-width ratios, and this is a consequence of their short lives in rapidly changing strike-slip zones (Mann et al., 1983). Bahat (1983) compiled 39 natural examples of rhombic, trapezoidal, and triangular basins and suggested a mean acute angle of 35° between the master strike-slip faults and their links (oblique faults) in 2-D. Hempton and Dunne (1984) proposed that the pull-apart basin shapes are not necessarily rhomboidal but vary from the lazy-Z-shaped to almond-shaped to rhomboidal, and they suggested that the sediment thickness in pull-apart basins is related to the length of the basin. The length of a basin would reflect the amount of horizontal displacement (Eyal et al., 1986).

Experimental studies have been used to simulate the geometries of pull-apart basin development in a sedimentary cover sequence above strike-slip faults. The experimental models show many similarities to natural examples of pull-apart basins. There are many experimental modeling works investigating strike-slip faults (Cloos, 1928, 1955; Tanner, 1962; Emmons, 1969; Tchalenko, 1970; Withjack and Jamison, 1986; Hempton and Neher, 1986; Mandl, 1988; Gapais et al., 1991; Richard et al., 1991, 1995; Tron and Brun, 1991; Schreurs, 1994). Only some of the investigators attempted experimental modeling of pull-apart basins; the rest of the researchers dealt with pure strike-slip deformation. Pull-apart basins differ dramatically from simple strike-slip systems: they share properties with both strike-slip and extensional settings, resulting in complex basin structures (Rahe et al., 1998). McClay and Dooley (1995) described symmetric pull-apart basins in experimental models with varying step angles, using equal and opposite rates of displacement of opposing sides of the strike-slip system with respect to the fixed basement. Dooley and McClay (1997) presented their experimental model in 3-D. Their pull-apart basins typically form sigmoidal to rhombic deep grabens, the geometries of which are dependent upon the

offset architecture of the underlying basement faults. All of the pull-apart basins, regardless of offset geometry, evolve progressively from narrow grabens bounded by the oblique-slip link faults to wider rhombic basins flanked by terraced basin sidewall fault systems (Dooley and McClay, 1997). Rahe et al. (1998) described pull-apart basin structures as being in incipient, early, and mature developmental stages according to their sandbox experiments, and further, they categorized pull-apart basins as asymmetrical, symmetrical, and hybrid, based on the orientation of faults, pattern of displacement, and basin subsidence. Basile and Brun (1999) showed that the geometry of experimental pull-apart basins follows the same law in nature, i.e., an approximately constant length versus width ratio ($2.2 < l/w < 3.8$). In addition, from the experiments in the same study, the mean acute angle between the basin bounding faults is 30°, consistent with natural examples. Sims et al. (1999) described synthetic and antithetic strike-slip faults as controlling basin geometries, while localized normal faulting and local oblique slip on strike-slip fault accommodate basin subsidence. They showed that depth to décollement, décollement rheology, or both are controlling factors for basin morphology. The strength and thickness of the décollement zone controls the pull-apart basin geometry. Atmaoui et al. (2006) concluded that the geometry of pull-apart basins is controlled by a relatively low angle between the oblique bounding faults and the principal strike-slip segments (below 30°), as well as the high aspect ratio of the basins with a long axis, a small width, and great depth.

Numerical studies that are used to understand the geometry of a pull-apart zone at a releasing overstep along a strike-slip fault have been based on the elasticity theory (Rodgers, 1980; Segall and Pollard, 1980; Gölke et al., 1994; Katzman et al., 1995; Bertoluzza and Perotti, 1997; Petrunin and Sobolev, 2006, 2008). According to the model of Rodgers (1980), the geometry of pull-apart basins is controlled by the amount of master fault overlap, separation, and displacement since the initiation of the basin. The size of the pull-apart basins is varied and well defined by these parameters (Rodgers, 1980). Rodgers (1980) calculated the vertical displacement of a horizontal surface at a releasing overstep and showed that the axis of the depression tends to link the ends of the master fault segments (Bertoluzza and Perotti, 1997). However, the models of Rodgers (1980) and Segall and Pollard (1980) provide clues to the orientation of the different faults, which can form inside the overstep area, and to the characteristics of the stress field around and inside

a pull-apart basin: the maximum extensional axis tends to be parallel to the strike-slip faults (Bertoluzza and Perotti, 1997). Bertoluzza and Perotti (1997) indicated that the angle between the strike-slip faults and the potential normal faults bounding the pull-apart basin depends strongly on the rheological features of the material and on the overlap and/or separation ratio of the faults. The angle may vary from a few degrees in transtensional conditions to 100°–120° in transpressional conditions. This indicates that the boundary conditions are the major parameters determining the basin shape (Bertoluzza and Perotti, 1997). According to the thermomechanical model of Petrunin and Sobolev (2006, 2008), the major parameter that controls pull-apart basin length, sediment thickness, and deformation pattern beneath the basin is the thickness of the brittle layer.

The approach I present here is similar to Aydın and Nur (1982), Bahat (1983), and Hempton and Dunne (1984); I compare the geometric (angular and metric scale) characteristics of 11 well-defined pull-apart basins along the North Anatolian fault zone with the observations and predictions of previously proposed theoretical, experimental, and numerical models.

PULL-APART BASINS IN TURKEY

Tectonic Setting

The neotectonic configuration of Turkey has been shaped by the collision of the northerly moving Arabian plate and the Eurasian plate at ca. 11 Ma (Şengör and Yılmaz, 1981). Postcollisional N-S-directed contractional tectonics continued over an interval of ~9 m.y. and resulted in a series of deformations (e.g., Şengör, 1979; Şengör and Kidd, 1979; Şaroğlu and Yılmaz, 1987; Koçyiğit et al., 2001). The most important deformation resulting after this period in Turkey is strike-slip tectonism, which caused the escape regime of the Anatolian plate along the North Anatolian fault zone and the East Anatolian fault zone (Fig. 2). The initiation age of this strike-slip-dominated tectonics is late Pliocene (Şaroğlu, 1988; Koçyiğit et al., 2001; Gürbüz and Gürer, 2009).

Pull-Apart Basins along the North Anatolian Fault Zone

The North Anatolian fault zone is one of the best-known strike-slip faults in the world because of its remarkable seismic activity and its importance for the active tectonics of the Eastern Mediterranean region. It runs in an approximately E-W direction across northern Turkey, it is 1600 km long and just a few

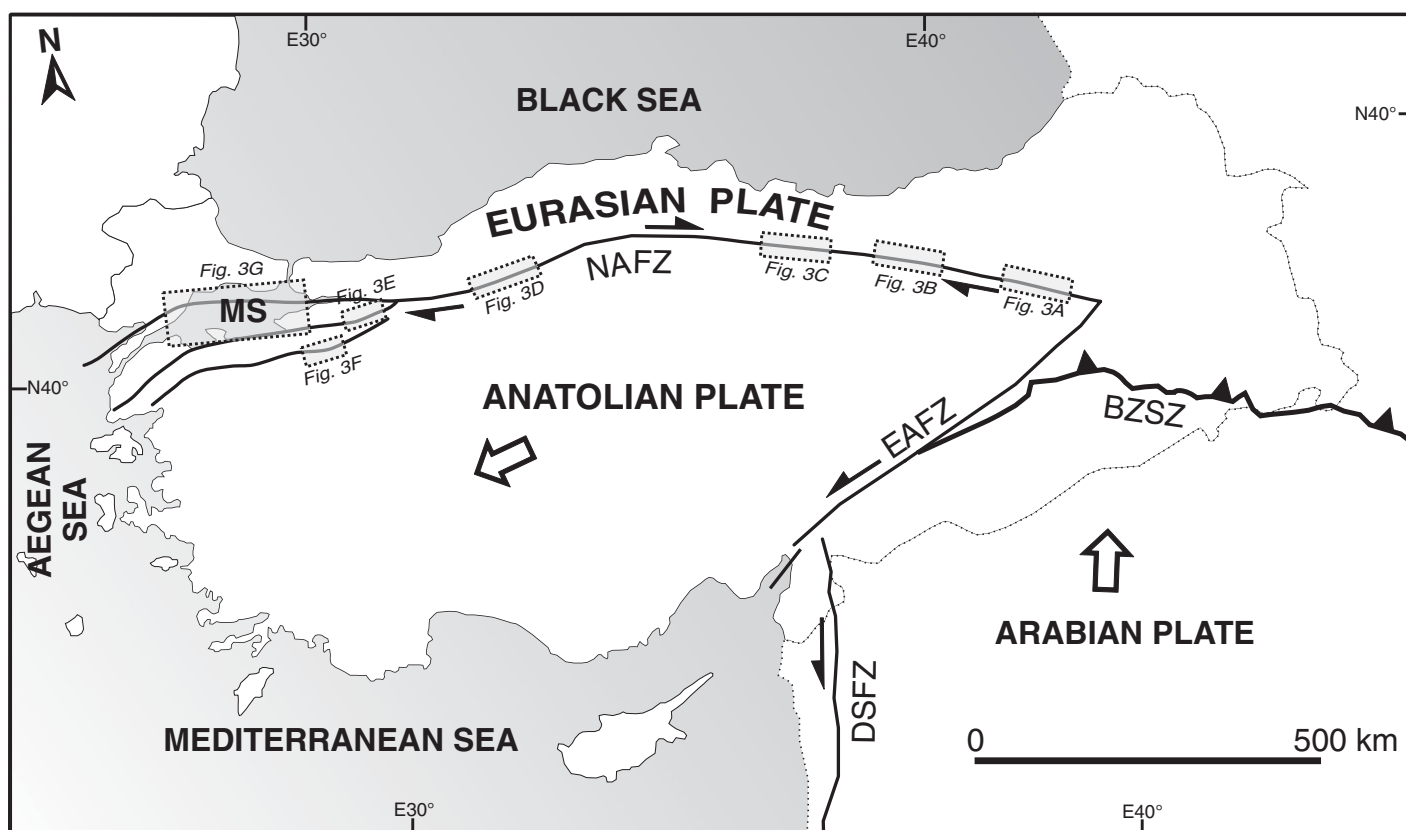


Figure 2. Tectonic outline of Turkey and locations of studied pull-apart basins along the North Anatolian fault zone. MS—Marmara Sea, NAFZ—North Anatolian fault zone, EAFZ—East Anatolian fault zone, BZSZ—Bitlis-Zagros suture zone, DSFZ—Dead Sea fault zone.

kilometers to 100 km wide, and it forms the boundary between the Eurasian plate in the north and the Anatolian plate in the south (Fig. 2). The dextral North Anatolian fault zone appears to be a relatively deep and narrow fault zone extending from Karlıova in the east to the Gulf of Saros in the west. To the west of Mudurnu Valley, the North Anatolian fault zone splits into three branches, separated from each other by a rhomb-like basin and horst complexes elongated in an approximately E-W direction (Bozkurt, 2001; Kim and Sanderson, 2006).

Several basins are aligned along the North Anatolian fault zone and its major splays. The pull-apart-originated basins of various sizes along this fault zone have been reported by many authors (e.g., Şengör et al., 1985, 2005; Barka and Kadinsky-Cade, 1988; Bozkurt, 2001; Gürbüz and Güner, 2009). Figure 2 illustrates 11 well-defined examples of these pull-apart basins from the east to the west. Table 1 reviews the geometric characteristics. This table consists of angular (acute angles that measured between the master and diagonal faults) and scale (length, width, and depth) data. These basins are mainly filled with Pliocene-Quaternary detrital and partly carbonate deposits.

TABLE 1. GEOMETRIC CHARACTERISTICS OF PULL-APART BASINS ALONG THE NORTH ANATOLIAN FAULT ZONE

Basin	Acute angle (°)	l (m)	w (m)	d^{10} (m)	d (m) (visible)	d (m) (this study)
Erzincan	30	48,000	16,000	2900	2000–3000 ¹	3895
Suşehri	30	23,000	9000	2100	750 ²	1775
Niksar	29	22,000	9000	1500	600 ³	1672
Taşova-Erbaa	39	30,000	10,000	–	850 ^{4,5}	2434
Yeniçağa	34	11,000	4500	–	600 ⁶	836
Bolu	33	35,000	9000	–	200 ⁷	3020
Pamukova	30	31,000	10,000	–	120 ⁸	2538
Yenişehir	28	33,000	11,000	–	?	2678
Çınarcık	30	53,300	16,600	–	5000–6000 ⁹	4404
Central	44	15,000	6000	–	?	1149
Tekirdağ	43	26,000	10,000	–	?	2019

Note: References: 1—Kaypak (2002); 2—Kazancı (1993); 3—Tatar (1996); 4—Irritz (1972); 5—Barka et al. (2000); 6—Arca (2004); 7—Aktimur et al. (1986); 8—Koçyiğit (1988); 9—Carton (2005); 10—Hempton and Dunne (1984).

GEOMETRIC CHARACTERISTICS OF PULL-APART BASINS

Angular Characteristics

Regarding the theoretical background of the acute angles between the master and transfer faults of the pull-apart basins, Segall and Pol-

lard (1980) examined the geometries of the faults in California and considered that the bridging path of the transfer faults is determined by the combined effects of the local tensile and shear stresses. The acute angles appear to be independent from the basin scale (Bahat, 1983). In the base model of pull-apart basin development, the strike-slip displacement results in an

oblique (transfer) fault that bridges the two en echelon faults, becoming the plane from which the two blocks detach along opposite directions parallel to the master faults; this requires equality of the two acute angles of a basin with only minor deviations due to possible block rotation (Bahat, 1983). In addition, Bahat (1983) discussed the two mechanisms that can lead to the development of pull-apart basins. According to the concept model based on fracture interaction between crack-pairs, if there is not horizontal compression, a mechanism is likely to result in basins, possibly with curved boundaries. According to another mechanism based on fracture bifurcation under extensional conditions, basin boundaries are expected to be straight with sharp angular perimeters (Bahat, 1983). In experimental studies, the analog models are compared with natural examples of pull-apart basins and show many strong similarities in structural geometries. The acute angle is one of these resemblances. Dooley and McClay (1997) demonstrated strong similarities between the 30° acute angle of their analog model and the Mesquite (California), Glynnwye (New Zealand), and Dungun (Malaysia) Basins. Rahe et al. (1998) expressed natural examples in eastern California, including central Death Valley, that represent an acute angle of 40° (e.g., Burchfiel and Stewart, 1966; Burchfiel et al., 1987); hence, it was chosen for their experiments. From the experiments of Basile and Brun (1999), the acute angle is 30° , which is comparable with the Timna graben (Dead Sea fault zone). Sims et al. (1999) prepared a model with an acute angle of 40° , like Rahe et al. (1998). They also compared them to natural examples including the Gulf of Aqaba (Elat), Gulf of Paria (Venezuela and Trinidad), and the Cariaco Basin (northern Venezuela). Atmaoui et al. (2006) represented the angle of intersection between two fault sets as being below 30° , but they expressed the bounding oblique faults of the major basins of the Strait of Sicily complex rift zone as mainly oriented at angles between 10° and 40° . In the recent work of Wu et al. (2009), they simulated a right-stepping, dextral strike-slip fault system in rigid basement; aluminum plates were cut with 30° step-over geometry, and their results show similarities with the Gulf of Aqaba (Elat) and the Vienna Basin (Austria). The numerical study of Bertoluzza and Perotti (1997) showed that the angle between the strike-slip fault and potential faults bounding the pull-apart basin depends strongly on the overall boundary conditions of the whole model and only slightly on the rheological features of the material and on the overlap and/or separation ratio of faults. In their finite-element models, the angle can vary from 10° to 65° in transensional conditions

to 100° – 120° in transpressional conditions. Briefly, according to the results of the theoretical, experimental, and numerical studies, the acute angles are clustered at 30° – 35° .

The pull-apart structures along the North Anatolian fault zone are ultimately products of similar mechanisms; alternatively, the products of shear and extensional mechanisms may give rise to comparable angular relationships. There is a narrow spread of acute angles of 11 pull-apart basins in the 28° – 44° range, with a mean angle of 33° , along the North Anatolian fault zone (Figs. 3 and 4). These angular values are in contrast with the results of other published

natural examples from the rest of the world and experimental and numerical studies as mentioned previously. This may be a result of initial overstep geometry that would be constant for basins developed in the same tectonic regimes. In contrast to the suggestion of Bahat (1983) regarding the equality of the two acute angles of a basin with only minor deviations, the basins along the North Anatolian fault zone present a deviation range of 0° – 11° . I think that these deviations are related to the counterclockwise rotation of the Anatolian plate situated on the southern side of the North Anatolian fault zone. Many of these pull-apart basins present straight

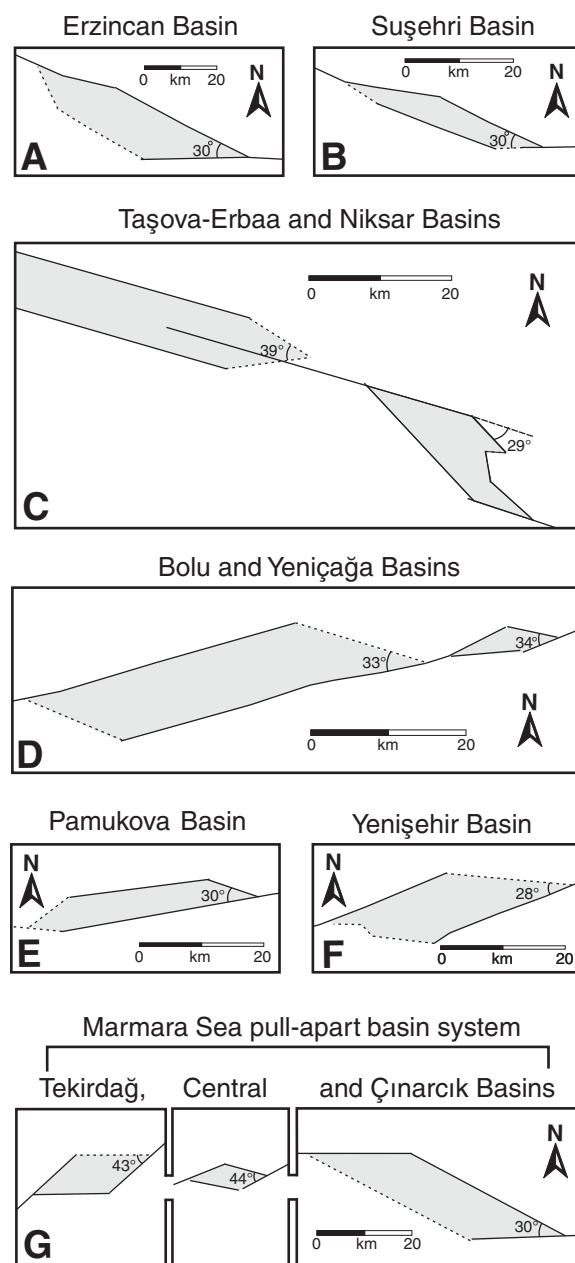


Figure 3. Pull-apart basins that were studied for angular and metric characteristics along the North Anatolian fault zone.

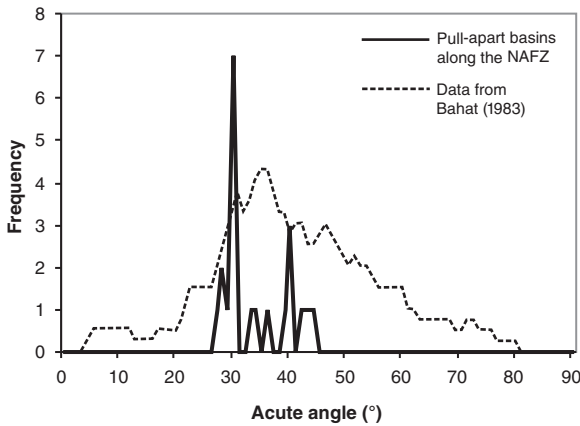


Figure 4. Frequency histogram for acute angles between border faults in pull-apart basins (data from Bahat [1983] and pull-apart basins in northern Turkey from this study). NAFZ—North Anatolian fault zone.

boundaries with sharp angles as expected by Bahat (1983) under extensional conditions. Only the basins on the eastern half of the North Anatolian fault zone appear with curved boundaries (Fig. 3). Bahat (1983) suggested that this type of boundary is developed if there is no horizontal compression. This characteristic of pull-apart basins should be explained for the eastern basins by the westward movement of the Anatolian plate in the south. This movement creates a relaxation on the eastern half and a pressure on the western half of the North Anatolian fault zone due to its northward arc geometry (Bellier et al., 1997).

Scale Characteristics

In 2-D, Aydın and Nur (1982) found a good relationship between the length (l) and width (w) of pull-apart basins after measuring the dimensions of 62 active pull-apart basins from all over the world (Fig. 5). They analyzed the metric measurement results by using a least square fit of the function:

$$\log l = c_1 \log w + \log c_2, \quad (1)$$

where $c_1 \cong 1$ and $2.4 < c_2 < 4.3$, with a mean value of 3.2.

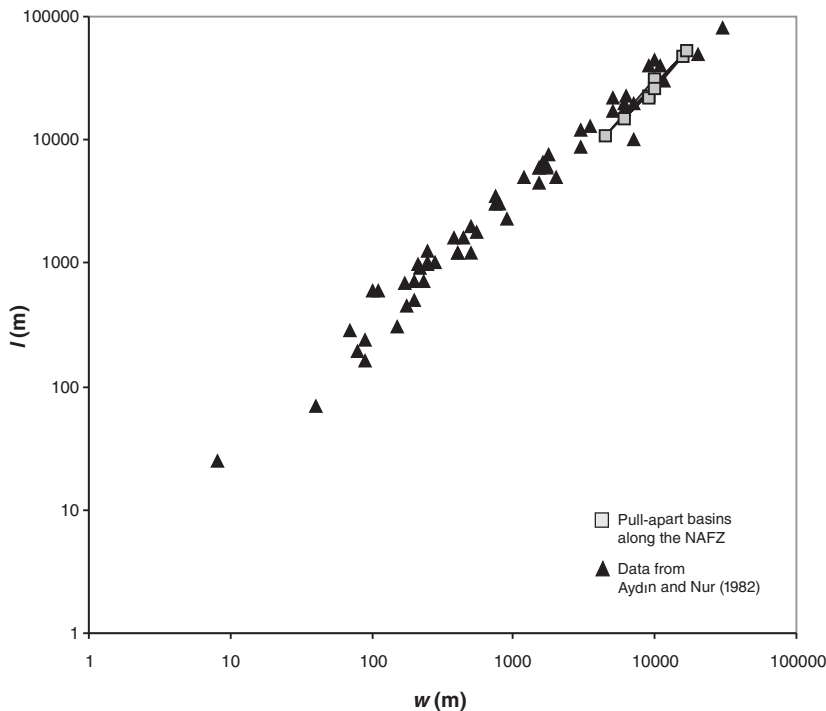


Figure 5. Length versus width plot for natural pull-apart basins (data from Aydın and Nur, [1982] and pull-apart basins in northern Turkey from this study). NAFZ—North Anatolian fault zone.

According to the experimental results of Basile and Brun (1999), this value is in agreement with a similar mean value in their 2-D analog models (Fig. 5). From another view in their study, they found a relationship between the acute angles of the basin and l/w ratios:

$$l_s/w_s = l/\tan \alpha + l/\tan \beta \quad (2a)$$

or

$$l_m/w_m = l/\sin \phi \cos \phi, \quad (2b)$$

where l_s is measured parallel to the bulk displacement, l_m is the longest diagonal of the basin, and w_s and w_m are measured perpendicular to l_s and l_m . From these equations, they suggested $l_s/w_s = 3.5$ and $l_m/w_m = 3.8$ values for an ideal pull-apart basin.

In the third dimension, a similar relationship between pull-apart basin depth and master fault displacement was first proposed by Rodgers (1980). He suggested that when the master fault overlap is more than twice the separation, the depth of the basin is ~10% of the displacement along the master faults. A similar view on the relationship between the basin length and depth (d) was suggested by Hempton and Dunne (1984). According to the measurement results of nine ancient and seven modern pull-apart basins, a linear regression of the data defines a line between the true thickness of basin deposits versus basin length:

$$d = 0.8l + 0.26. \quad (3)$$

Hempton and Dunne (1984) tried to predict the depths of some Turkish pull-apart basins by this equation. Their calculations show the Erzincan, Süşehri, and Niksar Basins along the North Anatolian fault zone have depths of 2.9, 2.1, and 1.5 km, respectively (Table 1).

There is a point in the suggestions of Aydın and Nur (1982) and more recently Basile and Brun (1999) and Hempton and Dunne (1984) that intersects. The first two studies observed that pull-apart basins become wider as they grow longer with increasing fault offset, and the third study suggested that the depth of pull-apart basin is related to the length of the basin. Basin length is a function of stretching, and basin depth is also a function of stretching associated with displacement (Hempton and Dunne, 1984). Thus, there would be a relationship that could be defined by an equation between all these dimensions of a pull-apart basin. To understand this, I plotted the metric scale data of Hempton and Dunne (1984) in Figure 6. This 2-D graph represents similar trends in the length, width, and depth of the 15 pull-apart basins. As shown

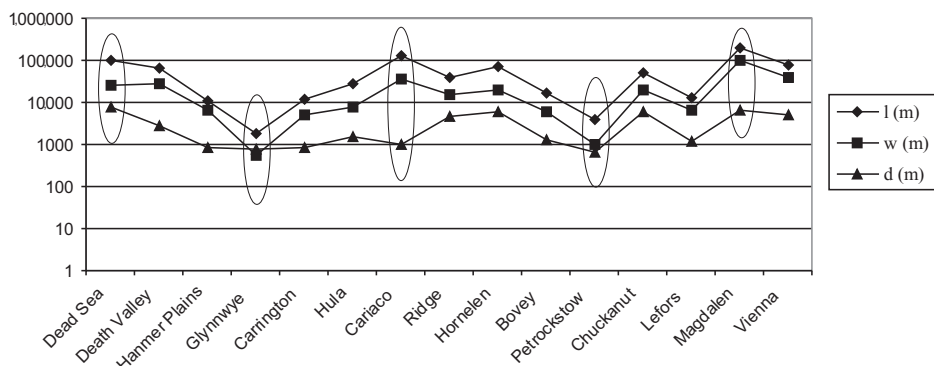


Figure 6. Metric characteristics of natural pull-apart basins and deviations determined from their trends (data from Hempton and Dunne, 1984).

in this graph, five of them, the Dead Sea, Glynwye, Cariaco, Petrockstow, and Magdalen Basins, present deviations on their third dimension. The Dead Sea Basin is a very elongated basin, with the dimensions of 130 km in length and 18 km in width ($l/w = 7.2$), and it consists of three subbasins in which depocenters have migrated northward with time (Zak and Freund, 1981). As reported by Basile and Brun (1999), each of these subbasins has an l/w ratio (2.4, 3.3, and 2.6) that is consistent with the range of Aydın and Nur (1982). This would be interpreted as follows: the increase on the elongation ratio of a pull-apart basin may be the result of the migration of depocenter from the center of the basin. Due to its migrated depocenter, the third dimension is an unknown for now. The anomalies in the third dimensions of other basins in Figure 6 would be related to the absence of reliable depth data. Figure 7 represents a good 3-D relationship of all three dimensions (l , w , and d) from

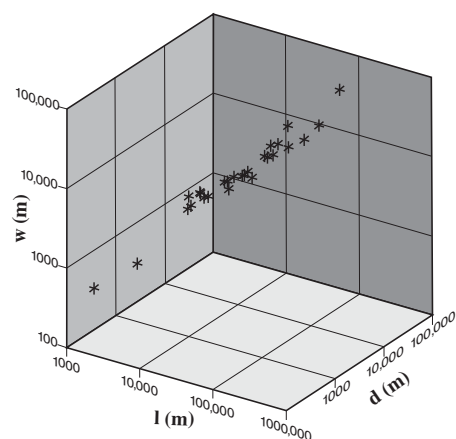


Figure 7. Three-dimensional relationship between metric parameters of natural pull-apart basins with calculated depth data in this study (length and width data from Hempton and Dunne [1984] and pull-apart basins in northern Turkey from this study).

Hempton and Dunne’s (1984) data. Here, I tried to define this relationship with an equation. By using the metric scales of 11 pull-apart basins, the regression of the data defined as:

$$d = 0.1104l - (8.7550 \times 10^{-2})w. \quad (4)$$

As more depth data become available, the reliability of the relationship will improve.

I used the equation that I calculated using the database of Hempton and Dunne (1984) for other pull-apart basins to predict the depths of pull-apart basins along the North Anatolian fault zone. According to my calculations, the Erzincan, Suşehri, Nıksar, Taşova-Erbaa, Yeniçağa, Bolu, Pamukova, Yenişehir, Çınarcık, Central, and Tekirdağ Basins along the North Anatolian fault zone have depths of 3.9, 1.8, 1.7, 2.4, 0.8, 3, 2.5, 2.7, 4.4, 1.1, and 2 km, respectively (Table 1).

As I mentioned already, there are deviations on the third dimensions of the Glynwye, Cariaco, Petrockstow, and Magdalen Basins according to the calculations of Hempton and Dunne (1984) (Fig. 6). Here, I used my equation to recalculate the questionable depth data of these basins. The predicted depth values for these basins are ~0.2, 11, 0.3, and 14 km, respectively (Table 2).

According to my results, the Cariaco and Magdalen pull-apart basins would have depths

TABLE 2. SCALE CHARACTERISTICS OF PULL-APART BASINS THAT REPRESENT DEVIATIONS IN THEIR TRENDS IN FIGURE 6

Basin	l (m)	w (m)	d^* (m)	$d^†$ (m)
Glynwye	1800	550	760	150
Cariaco	125,000	35,000	1000	10,590
Petrockstow	4000	1000	670	347
Magdalen	200,000	100,000	6700	13,969

*From Hempton and Dunne (1984).

†This study.

of over 10 km. I have not been able to find any depth data over 7500 m (Zak and Freund, 1981) in the literature. However, these data are suggested for the Dead Sea Basin, and, as previously mentioned, Zak and Freund (1981) showed that this basin is formed by the coalescence of three subbasins in which depocenters have migrated northward. Thus, the depth data could not reflect the third dimension of the whole basin within the possible relationship. I think that the depth data for the Cariaco and Magdalen Basins would be less than them due to their unknown subbasin geometries. In contrast, their 2-D scales are much larger than the other examples from the rest of the world (like the Dead Sea Basin). This could be related to their complex intrabasinal geometries.

CONCLUSIONS

This study presents a review of current literature about the angular and dimensional characteristics of pull-apart basins aimed at understanding their geometries in 2-D and 3-D, and it provides a new data set from the pull-apart basins along the North Anatolian fault zone to enrich the database.

Previously published angular data from the field, experimental, and numerical studies represent a mean acute angle of 33° between the basin margin master faults and transfer faults. Turkish pull-apart basins also present the same mean angle. This value is a result of overstep geometry and does not change except in the hybrid regimes, rotation, or extinction processes.

Scale characteristics of pull-apart basins in literature present good 2-D relationships between basin length and width, and basin length and depth. Comparison of 3-D data from the well-known active and ancient pull-apart basins suggests that there may be an empirical relationship among the length, width, and depth parameters in 3-D. This relationship would be most useful to predict sediment thickness of pull-apart basins when the 2-D data are known. The application of the proposed relationship to the pull-apart basins in northern Turkey predicts the depths of the Erzincan, Suşehri, Nıksar, Taşova-Erbaa, Yeniçağa, Bolu, Pamukova, Yenişehir, Çınarcık, Central, and Tekirdağ Basins to be 3.9, 1.8, 1.7, 2.4, 0.8, 3, 2.5, 2.7, 4.4, 1.1, and 2 km, respectively. In the future, by the addition of more depth data to current literature, the accuracy of the relationship and predicted values will increase.

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