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Polyphase tectonic evolution of the Aksu Basin, Isparta Angle (Southern Turkey)

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Abstract: The Aksu Basin, within the Isparta Angle, is located to the north of the intersection of the Aegean and Cyprus arcs and has been evolving since the Middle Miocene. Correlation of: (1) kinematic analysis of fault planes that cut the basin fill, (2) the reactivation/inversion of fault planes and (3) sedimentological data indicate that the Aksu Basin has evolved by four alternating compressional and extensional tectonic phases since its formation. The first phase was NW-SE oriented compression caused by the emplacement of the Lycian Nappe units which ended in Langhian. This compressional phase that induced the formation and the initial deformation of the basin was followed by a NW-SE extensional phase. This tectonic phase prevailed between the Langhian and Messinian and was terminated by a NE-SW compressional regime known as the Aksu Phase. The neotectonic period is characterized by NE-SW extension and began in the Late Pliocene. Correlation with the existing tectonic literature shows that the order of deformational phases proposed in this study might also be valid for the entire Isparta Angle area.

Key words: Fault slip analysis, tectonic evolution, Eastern Mediterranean, southern Turkey, Aksu Basin.

Introduction

The Isparta Angle is one of the most important morphotectonic structures exposed in southwestern Central Anatolia. This inverse v-shaped structure was first described by Blumenthal (1951) as "Courbure d'Isparta" (Isparta bend). It is located to the north of Antalya Bay in southern Turkey, where the Aegean and Cyprian arcs intersect in the eastern Mediterranean (Fig. 1a). The Isparta Angle is kinematically linked to the West Anatolian extensional province through the NE-striking Fethiye-Burdur Fault Zone to the west (Barka et al. 1997), and to the Anatolian Plateau through the NW-striking Akşehir Fault Zone to the east (Koçyiğit & Özacar 2003). It plays a balancing role between the uplifting and westward moving Anatolian Plateau and the southwestward displacing and counter-clockwise rotating west Anatolian province.

Previous studies point out three major nappe sheets as integral parts of this triangle, which were formed as linear elements in the Isparta Angle. The first one is the Antalya Nappe units which originate from the southern part of Neotethys to the east. They were emplaced onto the Tauride carbonate platform during the late Early Paleocene (Uysal et al. 1980). The second one is the Beyşehir Hoyran Hadım Nappe units, located to the east and derived from the northern branch of Neotethys. They were thrusted onto the central Tauride platform during two sequential stages (Campanian and Late Lutetian) (Piper et al. 2002). The Lycian Nappe units to the west have the same origin as the Beyşehir Hoyran Hadım Nappe units and represent a two-stage emplacement onto the western Tauride platform (Late Oligocene–Late Langhian) (Piper et al. 2002). Paleomagnetic studies introduce a 40° clockwise rotation for the eastern part of the Isparta Angle (Kissel et al. 1993) while a 30° counterclockwise rotation is calculated for the western part (Kissel & Poisson 1987; Morris & Robertson 1993). Paleomagnetic studies do not indicate any rotation from Pliocene to recent for the central part of the Isparta Angle (Kissel & Poisson 1986).

The Antalya Basin, located within the Isparta Angle, has been developing unconformably over the Antalya, Beyşehir Hoyran Hadım and Lycian nappe sheets since the Late Cenozoic. On the present day map, this basin consists of three subbasins, namely the Aksu, Köprüçay and Manavgat. The N-S striking Kırkkavak Fault and W-to SW-verging Aksu Thrust are the two major structures dividing these three basins (Dumont & Kerey 1975; Poisson 1977; Akay et al. 1985; Monod et al. 2006; Çiner et al. 2008; Poisson et al. 2011) (Fig. 1b).

Three tectonic phases have been cited in the literature in the Miocene to Recent evolutionary history of the Isparta Angle. The first one is NW-SE shortening created by the emplacement of the Lycian Nappe units that terminated in the Langhian (Hayward 1984; Flecker et al. 1998, 2005; Robertson et al. 2003). The second tectonic phase is the NE–SW shortening which is known as the Aksu Thrust (Poisson 1977; Frizon de Lamotte et al. 1995; Poisson et al. 2003a, 2011). The time interval of this shortening, which affected the study area and surrounding areas, is dated from post-Tortonian to Late Pliocene (Poisson 1977; Akay et al. 1985; Flecker et al. 1998; Poisson et al. 2003a,b, 2011). The last tectonic phase is E-W to NE-SW extension which is responsible for the opening of the Kovada Graben, located to the north of the Isparta Angle, from Late Pliocene to Recent (Price & Scott 1994; Temiz et al. 1997; Glover & Robertson 1998a,b; Hançer & Karaman 2001; Poisson et al. 2011). In the central part of the Isparta Angle, the extension direction differs

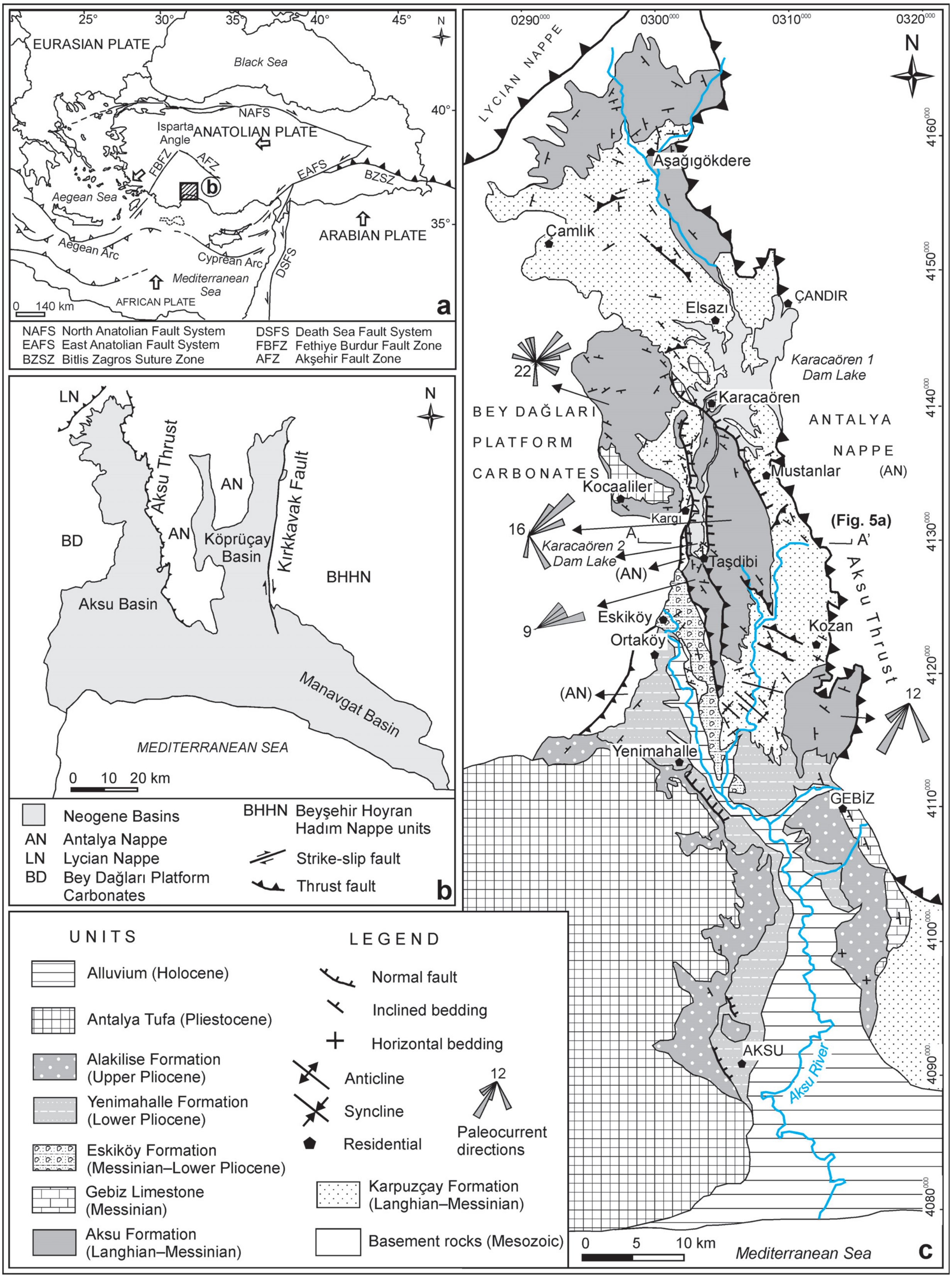

Fig. 1. a — Major neotectonic features of Turkey and adjacent areas (compiled from Koçyiğit & Özacar 2003; Zitter et al. 2003; Çiftçi 2007; Özsayın 2007) (white arrows indicate the motion of the plates); **b** — Location and boundaries of the Aksu, Köprüçay and Manavgat basins in the Isparta Angle; **c** — Geological map of the Aksu Basin (modified from Akay & Uysal 1984; Şenel 1997; Glover & Robertson 1998a; Karabıyıkoğlu et al. 2004; Monod et al. 2006; Poisson et al. 2011; Üner et al. 2011).

locally (Taymaz & Price 1992; Price & Scott 1994; Eyidoğan & Barka 1996; Temiz et al. 1997; Hançer & Karaman 2001; Koçyiğit & Özacar 2003).

We focus on the Aksu Basin because this basin is located at the center of the Isparta Angle and is adjacent to these three nappe sheets. It also contains Middle Miocene to Recent deposits controlled by marginal faults that permit study of the temporal and spatial evolution of the Isparta Angle. Here, we present new field data from the Aksu Basin that correspond to a new tectonic phase that was not defined previously. We finally suggest a new order for these tectonic phases in the light of our field measurements which are proposed not only for the Aksu Basin but also for the entire Isparta Angle area.

Stratigraphy

With a 2000 km^2 area, the N-S trending Aksu Basin is located in the central part of the Isparta Angle and it is bounded by the Bey Dağları Platform Carbonates to the west and by the Aksu Thrust to the east (Fig. 1c). The basin fill initiates with the Langhian–Tortonian Karpuzçay Formation (Akay et al. 1985; Karabıyıkoğlu et al. 2004), which is composed of shallow marine conglomerates intercalating with sandstone-mudstone alternations. It unconformably overlies the basement units consisting of the Bey Dağları Platform Carbonates, Alanya Metamorphics, Antalya and Lycian Nappe units. The Langhian-Messinian Aksu Formation interfingers with the Karpuzçay Formation (Karabıyıkoğlu et al. 2004) and is composed of five different fan deltas that are fed from the north (Kapıkaya Fan Delta), west (Karadağ, Kargı and Bucak Fan Deltas) and east (Kozan Fan Delta) of the basin. Thick bedded, consolidated conglomerates of the Aksu Formation, together with patch reefs (Karabıyıkoğlu et al. 2005a) and intercalated sandstones-marls gradually pass into the Messinian Gebiz Limestone (Poisson et al. 2011) and the Messinian–Pliocene Eskiköy Formation (Şenel 1997). The Eskiköy Formation is represented by alluvial fan and fluvial deposits and composed of poorly consolidated conglomerates, sandstones and marls (Fig. 2).

The transition from shallow marine to terrestrial environments in the basin took place during the Messinian salinity crisis. Because of rising sea levels following the salinity crisis, marine conditions recovered in the southern part of the Aksu Basin whereas northern parts remained terrestrial. The Eskiköy Formation was unconformably overlain by the shal-

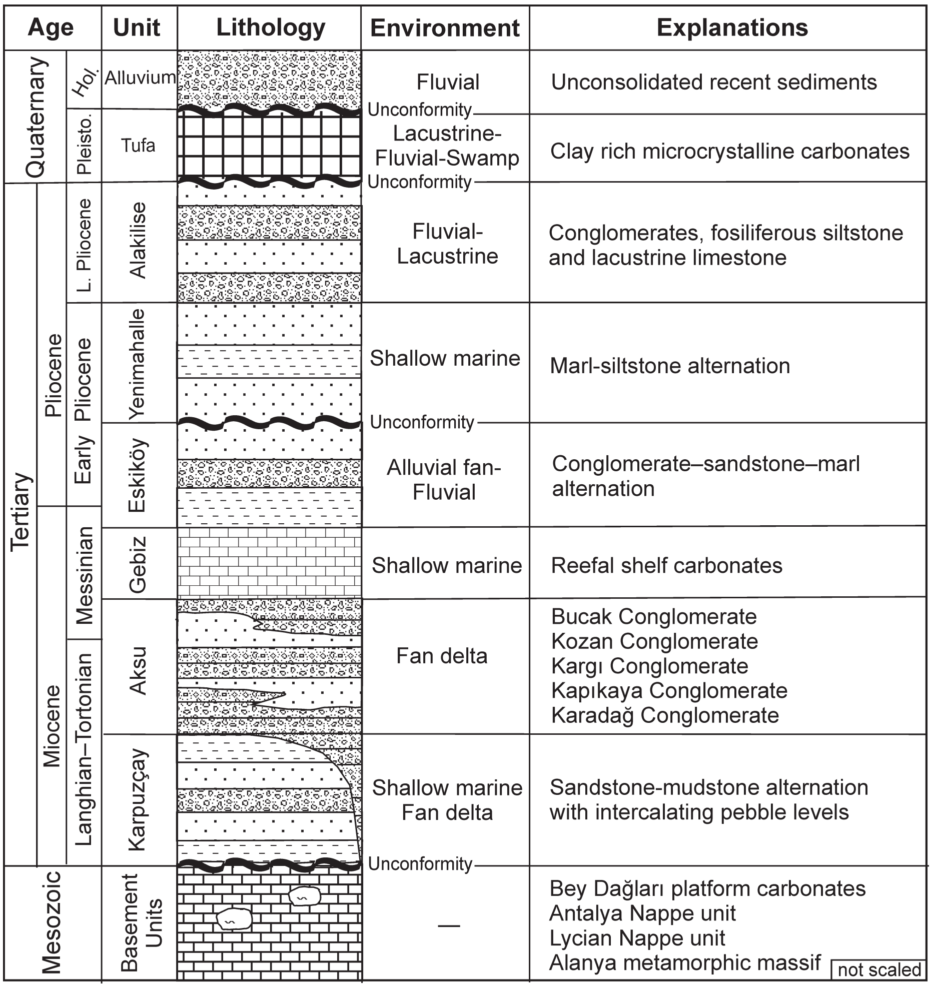

Fig. 2. Stratigraphic columnar section of the study area (modified from Poisson et al. 2003a, 2011; Karabıyıkoğlu et al. 2004).

low marine (marl-sandstone) Yenimahalle Formation during that period (Poisson et al. 2003a). These units grade into the lacustrine/fluvial Pliocene Alakilise Formation characterized by thick bedded conglomerates, lacustrine limestones and siltstones (Glover 1995; Poisson et al. 2003a). The uppermost part of the basin fill is composed of the Quaternary Antalya tufa and alluvium (Fig. 2).

Method of study

In order to determine the structural evolution of the Aksu Basin, we clarified the basement rocks/basinal deposits boundary relationships and revised the 1 : 100,000 scale geological map of the Mineral Research and Exploration Institute of Turkey (MTA). A total of 59 paleocurrent data were collected and combined with the previous studies. Imbrications of pebbles, flute casts, cross-bedding and current ripple marks are used for paleocurrent direction determinations.

We collected two types of structural data in the field: (1) strike and dip measurements of the bedding planes to elucidate both the angular relationships between older and younger units exposed in the study area and the deformation adjacent to faults; (2) strike, dip, and slip-lineation measurements from fault planes to decode different deformational phases that prevailed in the study area. Additionally, drag folds, horizontal and vertical offsets, juxtaposition of different aged units, cross-cutting relationships and reactivations/inversions observed on the fault planes are other major criteria for determining deformational phases. Timing of faulting and deformation are distinguished by the age of the stratigraphic units and cross-cutting relationships. Angelier's Direct Inversion Method version 5.42 was used to analyse fault-slip data (Angelier 1991). For the definition of the paleostress field, the nature of the vertical/sub-vertical stress axis and the value of ratio φ were taken into account (Angelier 1994). Stress fields may vary from radial extension (σ_1 vertical, $0<\varphi<0.25$), extension (σ_1 vertical) with pure extension ($0.25<\varphi<0.75$) and transtension ($0.75<\varphi<1$), to strike-slip stress fields (σ_2 vertical), with pure strike-slip ($0.25<\varphi<0.75$), transtension ($0.75<\varphi<1$) and transpression ($0<\varphi<0.25$), or to compression (σ_3 vertical), with transpression ($0<\varphi<0.25$), pure compression ($0.25<\varphi<0.75$), and radial compression ($0.75<\varphi<1$) (Delvaux et al. 1997). In order to calculate principal stress directions and to determine different deformational regimes, a total of 289 slip-data were measured from fault planes at 43 stations.

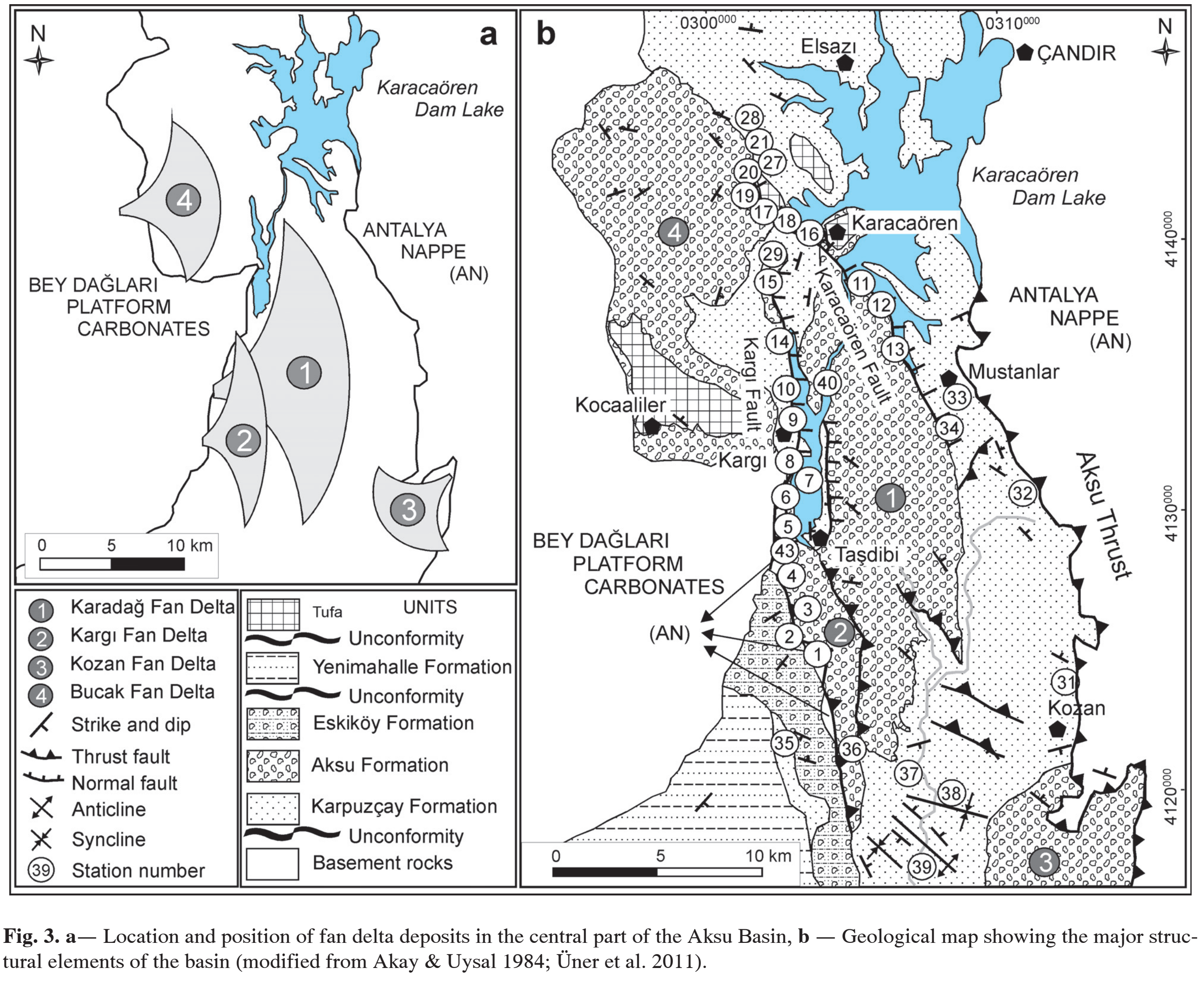

Fig. 3. a— Location and position of fan delta deposits in the central part of the Aksu Basin, **b** — Geological map showing the major structural elements of the basin (modified from Akay & Uysal 1984; Üner et al. 2011).

Structural analysis

Faults

Kargı Fault Set

The N-S trending and E-dipping Kargı Fault Set is located on both sides of the Karacaören-2 Dam Lake situated at the center of the Aksu Basin. Kargı village is the key location where the typical characteristics of this set can be determined. On the western side, fault planes of this set can be observed along 10 km from the Karacaören village to Taşdibi (Fig. 3). In the southwestern part of Karacaören village it constitutes the boundary between the Karpuzçay Formation and Karadağ Conglomerate of the Aksu Formation. To the south, the basement units and Kargı Conglomerate are juxtaposed along this fault set. On the eastern side, Kargı Fault Set comprises the tectonic boundary between the Karpuzçay Formation and Karadağ Conglomerate of the Aksu Formation.

To the north of Eskiköy, two superimposed slickenlines are observed on the Kargı Fault Set. The first slickenlines show reverse faulting (Table 1, station #5–1) where overlying ones represent normal faulting with a minor dextral strike-slip component (Table 1, station #5–2).

Table 1: Field information and kinematic analysis results of slip-data measurements.

Stat. #	Location	σ_1	σ_2	σ_3	Φ	Unit and/or boundary
1.1	$0306^{080}/4126^{450}$	348º/41º	202º/44º	094º/18º	0.949	Aksu Fm Conglomerate — basement
1.2	$0306^{080}/4126^{450}$	226º/20º	046º/70º	136º/0º	0.394	Aksu Fm Conglomerate — basement
2	$0305^{080}/4127^{809}$	078º/20º	347º/4º	247º/69º	0.654	Aksu Fm Conglomerate
3	$0305^{750}/4127^{450}$	218º/45º	040º/45º	309º/1º	0.507	Aksu Fm Conglomerate
4	$0305^{523}/4127^{564}$	148º/34º	217º/13º	355º/53º	0.576	Karadağ Conglomerate of Aksu Fm Conglomerate
5.1	$0306^{221}/4128^{580}$	072º/3º	164º/33º	338º/57º	0.498	Aksu Fm Conglomerate — basement
5.2	$0306^{221}/4128^{580}$	123º/73º	011º/6º	279º/15º	0.644	Aksu Fm Conglomerate — basement
6	$0305^{992}/4129^{476}$	13º/70º	162º/17º	255º/10º	0.793	Aksu Fm Conglomerate — basement
7	$0306^{011}/4129^{689}$	030º/88º	155º/1º	245º/2º	0.385	Karpuzçay Fm turbidites
8	$0306^{010}/4130^{392}$	048º/13º	298º/55º	146º/32º	0.645	Aksu Fm Conglomerate — basement
9	$0306^{222}/4132^{053}$	213º/17º	303º/0º	34º/73º	0.716	Karpuzçay Fm turbidites
10.1	$0306^{234}/4133^{540}$	240º/65º	047º/24º	139º/5º	0.232	Karpuzçay Fm turbidites
10.2	$0306^{234}/4133^{540}$	133º/32º	290º/56º	036º/11º	0.489	Karpuzçay Fm turbidites
11	$0308^{557}/4137^{933}$	163º/73º	335º/17º	066º/2º	0.370	Aksu Fm Conglomerate
12.1	$0309^{097}/4137^{597}$	019º/29º	242º/53º	121º/21º	0.242	Karpuzçay Fm turbidites
12.2	$0309^{097}/4137^{597}$	123º/15º	241º/61º	026º/25º	0.501	Karpuzçay Fm turbidites
13	$0309^{610}/4136^{544}$	339º/67º	139º/22º	231º/7º	0.480	Aksu Fm Conglomerate
14	$0306^{172}/4134^{425}$	050º/54º	316º/3º	224º/36º	0.814	Karpuzçay Fm turbidites
15	$0306^{232}/4137^{681}$	72º/20º	167º/13º	288º/65º	0.779	Karpuzçay Fm turbidites
16	$0306^{493}/4139^{144}$	002º/11º	092º/0º	184º/79º	0.741	Aksu Fm Conglomerate
17.1	$0306^{440}/4139^{500}$	087º/61º	290º /27º	195º/9º	0.974	Aksu Fm Conglomerate
17.2	$0306^{440}/4139^{500}$	040º/6º	301º/58º	134º/31º	0.097	Aksu Fm Conglomerate
18	$0306^{438}/4139^{470}$	053º/29º	181º/49º	307º/27º	0.294	Karpuzçay Fm turbidites
19	$0305^{977}/4139^{865}$	227º/16º	134º/9º	016º/72º	0.889	Aksu Fm Conglomerate
20	$0304^{789}/4141^{428}$	201º/13º	110º/4º	006º/76º	0.590	Aksu Fm Conglomerate
21.1	$0304^{515}/4142^{125}$	239º/75º	140º/2º	049º/14º	0.277	Karpuzçay Fm turbidites
21.2	$0304^{515}/4142^{125}$	233º/14º	347º/58º	136º/28º	0.192	Karpuzçay Fm turbidites
22	$0302^{754}/4148^{031}$	087º/20º	179º/6º	284º/69º	0.830	Karpuzçay Fm turbidites
23	$0301^{817}/4153^{415}$	009º/25º	273º/11º	162º/62º	0.991	Karpuzçay Fm turbidites
24	$0301^{534}/4153^{938}$	063º/24º	158º/11º	271º/64º	0.281	Karpuzçay Fm turbidites
25	$0301^{876}/4158^{977}$	338º/17º	247º/4º	146º/73º	0.997	Karpuzçay Fm turbidites
26	$0301^{842}/4159^{322}$	217º/17º	315º/24º	095º/60º	0.325	Aksu Fm Conglomerate
27	$0304^{855}/4142^{928}$	009º/13º	234º/72º	102º/13º	0.217	Karpuzçay Fm turbidites
28	$0304^{418}/4142^{706}$	134º/16º	256º/62º	038º/22º	0.455	Karpuzçay Fm turbidites
29	$0306^{871}/4138^{532}$	247º/2º	337º/1º	107º/88º	0.230	Karpuzçay Fm turbidites
30	$0305^{126}/4097^{000}$	027º/66º	160º/17º	255º/17º	0.447	Antalya Tufa
31	$0315^{984}/4121^{453}$	150º/13º	025º/68º	244º/17º	0.333	Karpuzçay Fm turbidites
32	$0316^{350}/4131^{083}$	146º/39º	251º/18º	0º/45º	0.583	Karpuzçay Fm turbidites — basement
33.1	$0312^{019}/4134^{043}$	050º/11º	319º/4º	211º/78º	0.499	Karpuzçay Fm turbidites
33.2	$0312^{019}/4134^{043}$	203º/75º	025º/15º	295º/1º	0.402	Karpuzçay Fm turbidites
34	$0311^{685}/4133^{255}$	334º/64º	096º/15º	192º/22º	0.394	Aksu Fm–Karpuzçay Fm boundary
35	$0305^{214}/4121^{677}$	111º/13º	000º/57º	209º/30º	0.739	Karpuzçay Fm turbidites
36	$0307^{450}/4122^{091}$	066º/15º	179º/56º	327º/30º	0.496	Aksu Fm Conglomerate
37	$0310^{787}/4120^{610}$	198º/35º	308º/26º	066º/44º	0.120	Karpuzçay Fm turbidites
38	$0311^{107}/4119^{986}$	149º/22º	240º/1º	333º/68º	0.848	Karpuzçay Fm turbidites
39	$0310^{232}/4117^{178}$	088º/55º	262º/35º	354º/3º	0.256	Karpuzçay Fm turbidites
40	$0307^{021}/4133^{352}$	171º/16º	060º/52º	272º/34º	0.287	Karadağ Conglomerate of Aksu Fm Conglomerate
41	$0306^{053}/4159^{624}$	245º/0º	155º/31º	335º/59º	0.362	Karpuzçay Fm turbidites
42	$0308^{176}/4163^{332}$	057º/27º	156º/18º	275º/57º	0.680	Aksu Fm Conglomerate
43	$0306^{264}/4130^{291}$	2º/71º	126º/10º	219º/15º	0.126	Aksu Fm Conglomerate — basement

Karacaören Fault

The NW-trending Karacaören Fault is approximately 15 km long and is situated between Karacaören and Mustanlar villages (Fig. 3). It is characterized by NE-dipping normal fault planes that are observed in the Bucak Conglomerate of the Aksu Formation, Quaternary tufa and Karpuzçay Formation to the north. The similar strike and dip measurements are also determined between the Karadağ Conglomerate of the Aksu Formation and Karpuzçay Formation to the south.

Field observations on this fault which cuts the Bucak Conglomerate of the Aksu Formation clearly represent a two-stage movement history. The former slickenlines indicate reverse faulting with a minor dextral component (Table 1, station #17-2) where the superimposing ones show normal faulting (Table 1, station #17-1).

Aksu Thrust

The Aksu Thrust, first defined by Poisson (1977), constitutes the eastern boundary of the Aksu Basin (Akbulut 1977; Poisson et al. 1984, 2003a, 2011; Akay et al. 1985). This NNW-trending fault is approximately 100 km long and lies between the Aşağıgökdere village to the north and town of

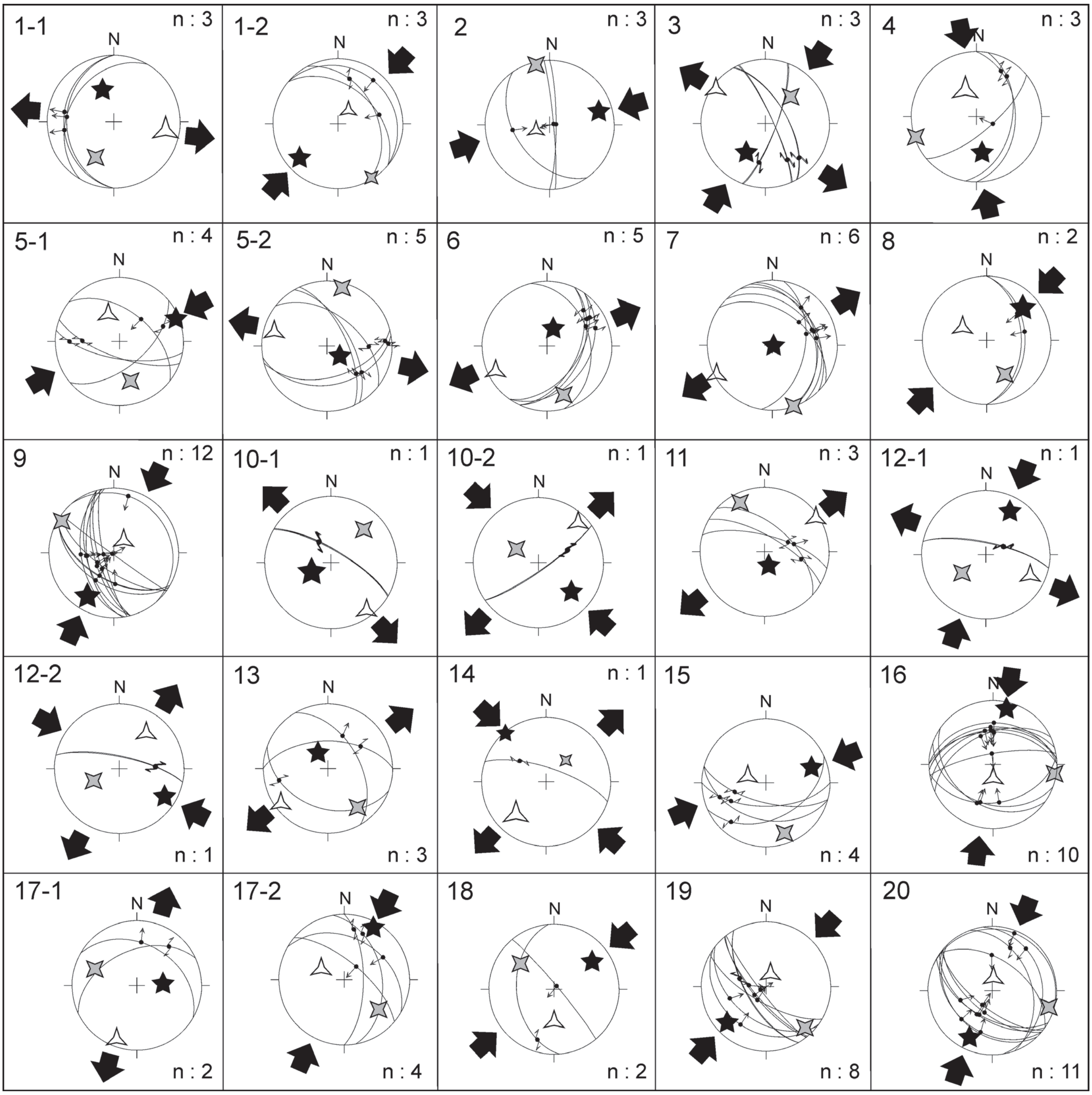

Fig. 4. Stereographic plots of fault slip plane data of each station on Schmidt lower hemisphere, σ_1, σ_2, σ_3 are maximum, intermediate and least stress axes, respectively.

Gebiz to the south (Fig. 1c). The carbonates of the Antalya Nappe unit and ophiolites are thrusted onto the Kapıkaya and Kozan conglomerates of the Aksu Formation to the north and south. Additionally, in the central part of the basin, Antalya Nappe units are thrust onto sandstones of the Karpuzçay Formation.

Position of bedding planes and folds

Most of the bedding plane measurements were obtained from fan delta deposits of the Aksu Formation well exposed in the study area. Since the bedding planes are gentler than 30 in inclination, it is difficult to determine whether the de-

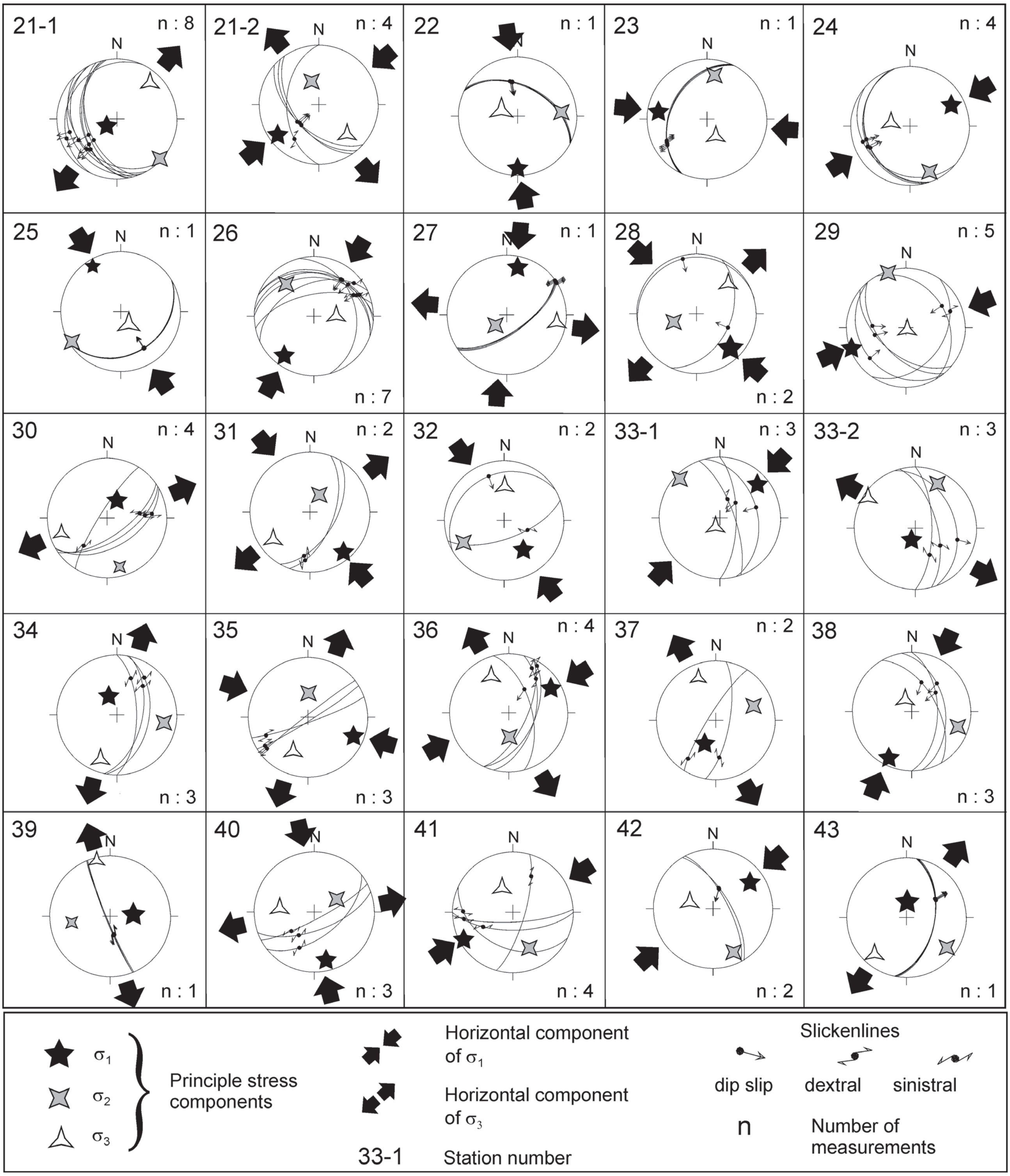

Fig. 4. *Continued.*

posits are in their original position or inclined by tectonism. Bedding planes with greater inclination than this should be related to tectonism rather than initial setting. Because of this ambiguity, bedding plane measurements from the Aksu Formation were not taken into account for the determination and interpretation of the folding. To the southwest of Kozan town, bedding measurements from the Karpuzçay Formation clearly indicate several NW-trending anticlines and synclines showing a NE-SW compressional tectonic regime (Fig. 3).

Fault-slip analysis

Compressional stress regimes

The first data set characterizes a NW–SE compressional stress regime. At stations #4, 22, 23, 25 and 32, σ_3 is vertical and according to the ϕ value the type of deformation differs between pure and radial compression, while at stations #10–2, 12–2, 28, 31, 35 and 40, σ_2 is vertical and the ϕ value represents pure strike-slip regime. Station #14 also has vertical σ_2 and shows transtension with the ϕ value (Fig. 4, Table 1). In the field, macro-scale features linked to this stress regime are primarily characterized by NE-trending thrust faults with minor sinistral components. NNE-trending sinistral strike-slip faults are observed on reactivated fault planes or linkage fault planes of two reverse faults.

The second data set indicates a NE-SW compressional stress regime. At stations #1–2, 2, 5–1, 8, 9, 15, 16, 18, 19, 20, 24, 26, 33–1, 38, 41 and 42, σ_3 is vertical and the stress regime is determined as pure and radial compression. Stations #3 and 36 have vertical σ_2 and the ϕ value indicates pure strike-slip, while stations #12–1, 17–2, 21–2, 27, 29 present transpression (Fig. 4, Table 1). In the field, NNW- to NW-trending thrust faults with minor dextral components are the dominant elements of this stress regime. E-W trending sinistral faults constitute a second group, pertaining to this deformation phase.

Tensional stress regimes

The third data set represents the NW-SE extensional stress regime. At stations #5–2, 10–1, 33–2, 37 and 39, σ_1 is vertical and according to the ϕ values the deformation type is determined as pure and radial extension where station #1–1 shows transtension (Fig. 4, Table 1). Macro-scale features are dominantly demonstrated by NNE-trending (NNW-dipping) normal faults with dextral components. NNW- to NW-trending (both NE- and SW-dipping) dextral strike-slip faults with normal components constitute the second major group that represent this tensional stress regime.

The last data set indicates the NE-SW extensional stress regime. At stations #7, 11, 13, 21–1, 30, 34 and 43 σ_1 is vertical and the ϕ values refer to a pure and radial extensional stress regime. Stations #6 and 17–1 also have vertical σ_1 with higher ϕ values and show transtension (Fig. 4, Table 1). Macro-scale structures are NE-trending (NW- and SE-dipping) normal faults and NNE-trending (ESE-dipping) sinistral faults with a normal component.

Results of structural analysis

NW-SE compression

The oldest tectonic phase is NW-SE compression as the faults of this stress regime are only observed in the oldest rocks of the basin fill turbidites (Karpuzçay Formation and base of the Karadağ Conglomerate (Aksu Formation)).

NW-SE extension

Several pieces of evidence clearly show that the NW-SE compressional stress regime is followed by a NW-SE extensional phase. The first data is related to the position and situation of deposits of the Aksu Formation. The Karadağ and Kargı Fan Delta deposits of this formation are located in the western part of the Aksu Basin with a N-S trend (Fig. 3a–b). Paleocurrent analyses of these two units clearly show that the source rock of these units are the Beydağları Platform Carbonates located on the western margin. The Tortonian Karadağ Fan Delta deposits are separated from their source area (Karabıyıkoğlu et al. 2004; Üner et al. 2011). The space between the Beydağları Platform Carbonates and the Karadağ Fan Delta deposits is filled with Kargı Fan Delta deposits (Fig. 3b). The age of the Kargı deposits is determined as Tortonian according to the corals/patch reefs (Tuzcu & Karabıyıkoğlu 2001; Karabıyıkoğlu et al. 2005b). Taking the gap and positions of these units into account, an extensional period is inferred for the separation of the Karadağ Fan Delta deposit from the source and deposition of the Kargı Fan Delta deposits in the Tortonian (Fig. 5a). Additionally, upward decrease of bedding plane inclination of the Karadağ Fan Delta deposits supports this extensional period. A 40 dip angle is measured from the lower part of this unit, but it gradually decreases to 16 at the top (Fig. 5b). This decrease of dip angle and rhythmic sedimentation are the clues to extension.

Another clue is the syn-sedimentary normal faults observed in the Kargı Fan Delta deposits (Fig. 5c). The upward displacement decrease on the fault planes and undeformed bedding covering the faults represents the syn-sedimentary tectonism. Analyses of these faults clearly indicate NW-SE extension.

NE-SW compression

This tectonic regime, named the "Aksu Phase" by Poisson (1977) in previous studies, formed and reactivated both the marginal and inner faults of the Aksu Basin. With this activity, the Antalya Nappe units were thrusted onto the Karpuzçay Formation at the eastern margin of the basin (Fig. 6a), while thrust faults between the Aksu and Karpuzçay Formations are observed in the basin fill (Fig. 6b). The most important data for the transition from NW-SE extension to NE-SW compression are the two superimposed slickenline sets, determined on the fault plane in the sandstones of the Karpuzçay Formation, to the south of Kargı village. The slickenlines with a 50 (from SE) rake cut by the ones with an 86 (from SE) rake, show that the NE-SW compression is

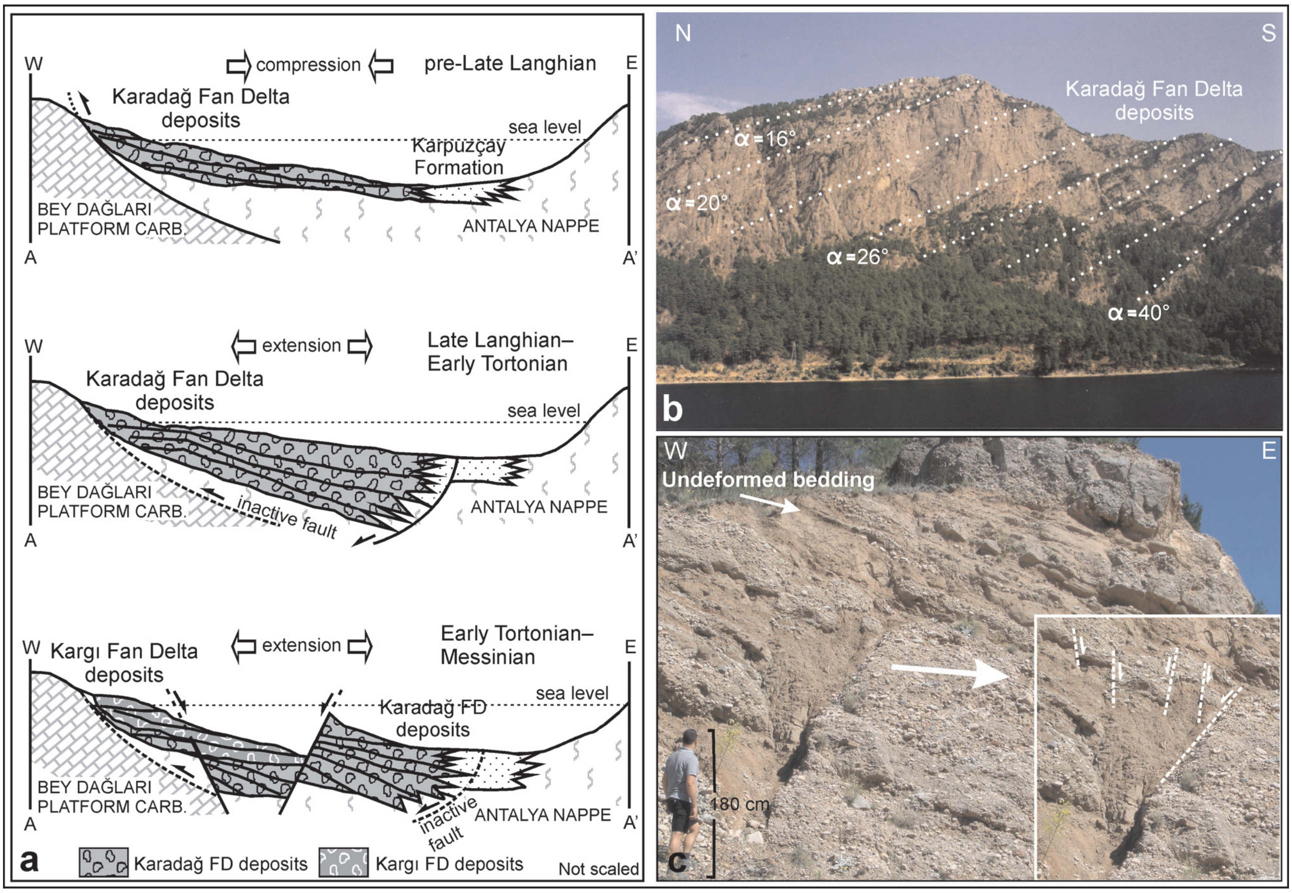

Fig. 5. a — Simplified cross-section showing the sedimentation process of the Kargı Conglomerate into a new depression, formed by the separation of the Karadağ Conglomerate from their source; **b** — Upward decrease of the dip of bedding planes in the Karadağ Conglomerate; **c** — Syn-sedimentary faulting on the Tortonian Kargı Conglomerate.

younger than the NW-SE extension (Fig. 6c). In addition, NW-trending folds observed in the Karpuzçay Formation indicate a NE-SW oriented compressional tectonic regime, which can be correlated with the Aksu Phase that prevailed between the Late Messinian and Late Pliocene.

NE-SW extension

Because the Quaternary Antalya tufa is the youngest rock group exposed in the study area, faults that cut these units are ascribed to the youngest tectonic phase (Fig. 7a). The transition from NE-SW compression to NE-SW extension is also observed in two locations near Karacaören village. At the first location two faults are observed in Bucak Conglomerate of Aksu Formation. The reverse fault with sinistral strike-slip component that is formed by NE-SW compression is cut by the sinistral strike-slip fault with normal component formed due to NE-SW extension (Fig. 7b). At the latter location, two superimposed slickenline sets are observed in Bucak Conglomerate of Aksu Formation (Fig. 7c). The older slickenline set shows NE-SW compression while the younger represents NE-SW extension. These examples indicate that the basin experienced NE-SW extension after NE-SW compression.

Discussion and conclusions

The Aksu Basin is an important archive for all temporal and spatial changes produced by the African-Eurasian contraction, which have affected both the basin's geometry and depositional systems since its formation. Structural and sedimentological data, collected from the basin fill and margins, indicate a complex tectonic evolution that deformed the Aksu Basin from the Langhian to Recent. According to these data four different deformation phases are defined.

The first phase is a NW-SE compressional stress regime. There are two different views for the origin of this regime. The first group suggests that this regime occurred because of the southeastern movement of the Lycian Nappe units which played an important role in the formation and initial deformation of the Aksu Basin (Flecker 1995; Flecker et al. 1998, 2005; Glover & Robertson 1998a,b; Karabıyıkoğlu et al. 2005a). According to these authors, the Aksu Basin was formed as a foreland basin due to the emplacement and lithospheric load of the Lycian Nappe units. The second group claims that the N-S trending Aksu Basin occurred as a half-graben related to the pre-Neogene paleogeographical setting of the basin (Poisson et al. 2011). Our study concludes that the first deformation of the basin fill is connected with a

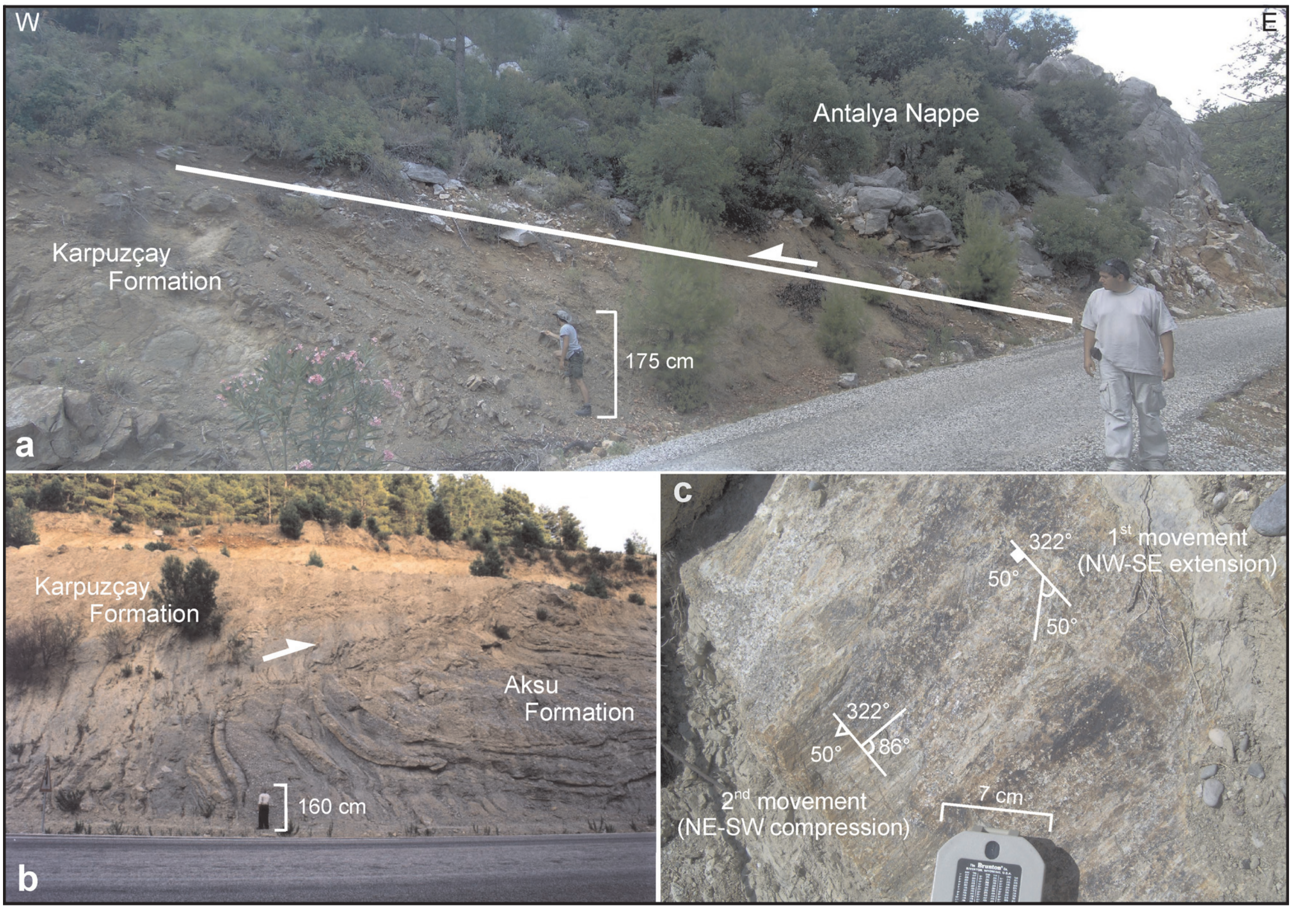

Fig. 6. a — Thrust of the Antalya Nappe units onto the basin fill, **b** — Thrust fault located to the NW of the village of Karacaören (Karpuzçay Formation units thrusted onto Aksu Formation units), **c** — Close-up view of superimposed slickenline sets showing the order of the NW-SE extension and the NE-SW compression.

compressional tectonic regime which is compatible with the first group of authors. NE-SW oriented reverse faults observed only in the oldest basin fill (Karpuzçay Formation) support this suggestion. This phase prevailed until the emplacement of the Lycian Nappe units at the end of the Langhian (Gutnic et al. 1979; Hayward 1984; Poisson et al. 2003a,b).

NW-SE extension (Serravalian to Messinian) is the second phase. There are few studies mentioning that there might be an extensional phase in the Aksu Basin during this time interval. Glover & Robertson (1998b) proposed that a transtensional tectonic regime might have prevailed in the Tortonian, but that the dominant extensional regime developed after the late Pliocene. Poisson et al. (2003a) indicated the formation of the Eskiköy graben, located in the central part of the Aksu Basin during the Messinian. Poisson et al. (2011) proposed three normal fault systems within the basin. These are the Kapıkaya (middle Langhian), Kargı and Antalya (Quaternary) Faults. The only fault system that corresponds to this period is the Kargı Fault which was not clearly defined and was associated with the compressional Aksu Phase by the authors.

This regime is defined in this paper for the first time with its prevailing time interval, sedimentological and kinematic data. These are the separation of the Karadağ Fan Delta from the Bey Dağları Platform Carbonates, the angular decrease of bedding planes, rhythmic sedimentation in the Karadağ Fan Delta conglomerates, the deposition of the Tortonian Kargı Conglomerate between the Karadağ conglomerates and their source (Bey Dağları Platform Carbonates) and syn-sedimentary normal faulting in the Kargı Conglomerate clearly indicating a post-Langhian extension. Because the Eskiköy graben was formed in the Messinian (Poisson et al. 2003a), the prevailing period of extension probably continued until the end of the Messinian. The possible reason for this extension is the regional subduction and slab retreat of the remnant Neotethys (Flecker et al. 2005; Kelling et al. 2005; Koçyiğit & Deveci 2007).

After the extensional regime, a NE-SW compressional stress regime (Aksu Phase) was initiated in the basin. NNW- to NW-trending thrust faults and reactivations of existing fault planes are the major indicators for this changeover. Several interpretations exist for the time interval of the Aksu Phase. Former studies suggest that the Aksu Phase influenced the basin in the Late Miocene (Poisson 1977; Flecker et al. 1998; Glover & Robertson 1998a,b). Recent studies propose this time interval to be between the latest Tortonian to early Messinian (Poisson et al. 2011) and late Pliocene (Poisson et al. 2003a, 2011). This contraction period is associated with the western tectonic escape of the Anatolian Plate due to the con-

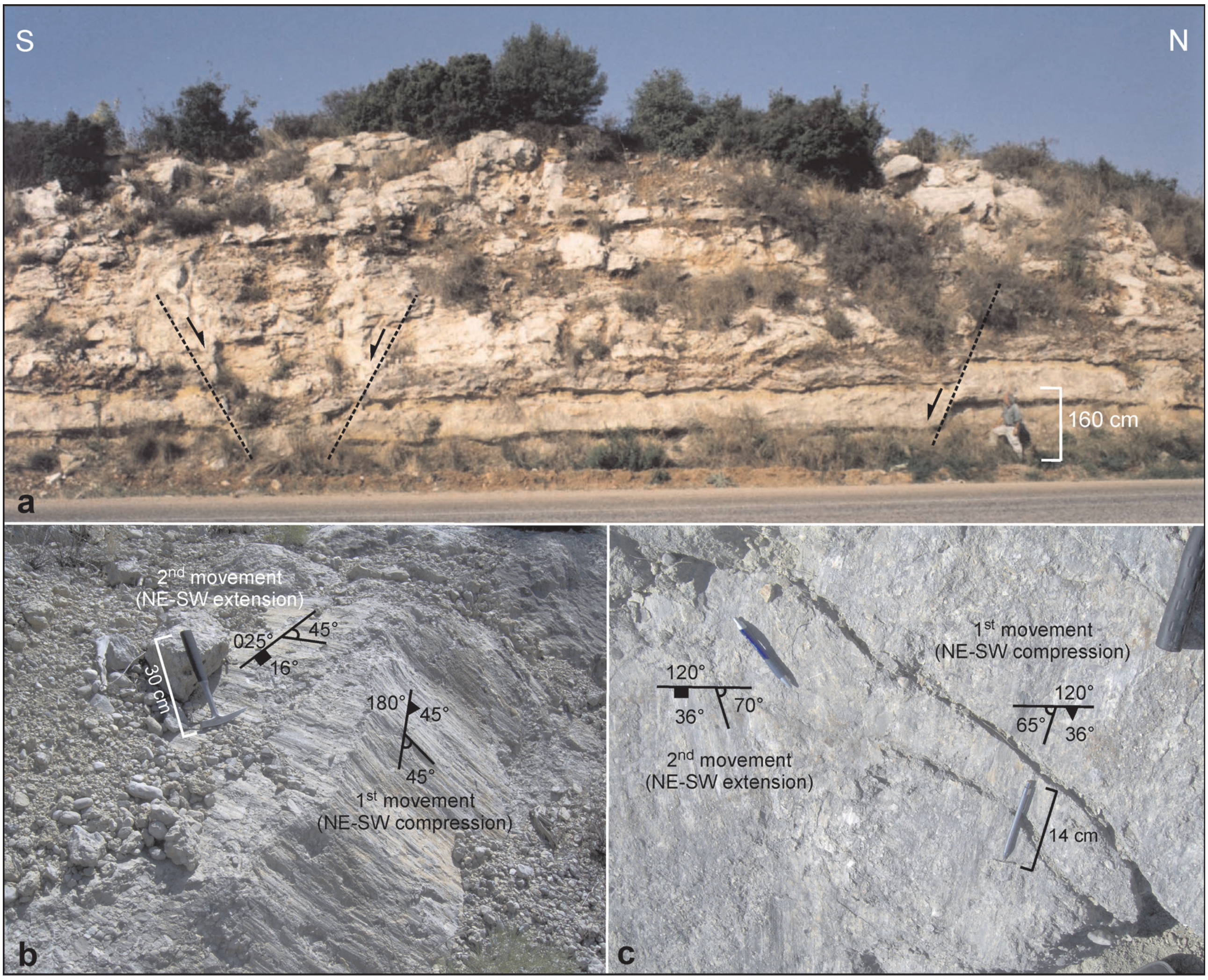

Fig. 7. a — Normal faults observed in the Quaternary Antalya tufas, **b**— Photo showing the order and the cutting relationship between the faults that arose from NE-SW compression and NE-SW extension, **c** — Close-up view of superimposed slickenline sets showing the order of the NE–SW compression and the NW-SE extension.

tinental collision between the Arabian Plate and the Eurasian Plate (McKenzie 1972, 1978; Şengör & Yılmaz 1981; Şengör et al. 1985; Glover & Robertson 1998a; Poisson et al. 2011).

Stress in the neotectonic period is NE-SW tension characterized by NW-SE oriented normal faults observed within the youngest rocks (Antalya Tufa) of the Aksu Basin. The direction of extension in the Isparta Angle and surrounding regions differ locally (Temiz et al. 1997; Koçyiğit & Özacar 2003; Robertson et al. 2003; Verhaert et al. 2006; Koçyiğit & Deveci 2007; Özsayın & Dirik 2007, 2011). Several researchers agree on the idea that roll-back of the slab, which was initiated in the Late Pliocene, is the reason for this extension in the Isparta Angle and the Aksu Basin (Glover & Robertson 1998a; Koçyiğit et al. 1999; Kelling et al. 2005; Özsayın et al. 2013). Furthermore, GPS data also indicate that a NE-SW extension is still prevailing within the Isparta Angle (Reilinger et al. 1997; McClusky et al. 2000).

Although orientations of extension and compression differ locally, the order of deformational phases presented in this paper is relevant not only for the Aksu Basin but also for the entire Isparta Angle area.

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