Neotectonic aspects of the northern margin of the Adana–Cilicia submarine basin, NE Mediterranean

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The sedimentary basins that dominate the north-eastern Mediterranean (Adana–Cilicia basins in the west and Iskenderun basin in the east) are located on the flanks of a partly submerged positive structure (a part of the Africa–Eurasia convergence zone) along which strike-slip faults are evident. This study summarizes the findings of two seismic surveys carried out in the Alanya–Mersin offshore region. Some 850 km of geophysical survey lines were compiled on these cruises. Based on the results determined from these surveys, the north and central part of Adana–Cilicia basin can be subdivided into eastern, central and western structural sub-basins separated by the Ecemiş fault complex in the east and the Anamur–Kormakiti structural high in the west at the same time. Results of this study also indicate that Ecemiş and Anamur–Kormakiti faults are active. Late Miocene regional compression was responsible for the compartmentation of this complex into the present arrangement and has initiated the rotational regime which has governed subsequent tectonic developments, notably the extensional behaviour of the NE–SW trending Ecemiş and Anamur–Kormakiti faults and the transpressive behaviour of the NNE–SSW trending border fault complex.

1. Introduction

The Cyprus Arc comprises several distinct morphological domains: The Florence Rise and part of the Anaximander Mountains to the west, the island of Cyprus and the Kyrenia Rise in the east. From the Pliocene to Recent, it has been mainly viewed as a convergence zone where the African plate is consumed beneath the Anatolian microplate (Robertson 1998a). The Cyprus Arc segment is considered to be almost blocked now by the collision of Eratosthenes Seamount there (e.g., Robertson 1998b; Glover and Robertson 1998; Veen *et al* 2004). The eastern part of the Cyprus Arc is a typical transpressional feature (Ben-Avraham *et al* 1995; Vidal *et al* 2000), where the subduction stopped before the Messinian period. The structural settings are different on the two sides of the Kahramanmaraş triple junction which is the junction of the Dead Sea Transform Fault, the Kyrenian–Misis Zone and

the East Anatolian Fault (figure 1). On the east, structures controlled by strike-slip and compression coexist, whereas on the west compression is less conspicuous. Here, deep basins which are the Cenozoic depocentres of the Adana–Cilicia and Iskenderun Basin complexes, Antalya and Latakia Basins separated by a partly submerged ridge, are prominent (Kempner and Garfunkel 1994). Kempner and Garfunkel (1994) have interpreted this ridge (the Kyrenia–Misis Thrust) as a large flower structure which extends from southeastern Turkey to Cyprus. The Adana–Cilicia and the Iskenderun–Latakia Basins on its flanks were interpreted as being due to extension (Aksu *et al* 1992, 2005; İşler *et al* 2005).

The Misis–Kyrenia fault zone (figure 1) links the Misis Mountains of southern Turkey and the Kyrenia Range of northern Cyprus (Anastakis and Kelling 1991; Aksu *et al* 1992, 2005; İşler *et al* 2005).

Keywords. Cilicia basin; seismic data; active faults; Ecemiş fault; NE Mediterranean.

Figure 1. General geotectonic setting of the NE Mediterranean, showing location of the Adana–Cilicia trough with respect to adjacent Neogene and neotectonic basins and structural features (modified from Şengör and Yılmaz 1981; Hancock and Barka 1980 and Dewey *et al* 1986; Veen *et al* 2004; Aksu *et al* 2005).

The Adana–Cilicia Basin which is located between the early Cenozoic Tauride belt and the narrow late Cenozoic Misis–Kyrenia (Cyprus) lineament, is a Neogene extensional structure formed within the broadly convergent setting of the north-east Mediterranean. It was influenced by the Arabian–Eurasian collision (to the east), Hellenic–Cyprian subduction (to the west and south) caused by the northward movement of the African plate and westward tectonic ‘escape’ of the Anatolian microplate along the N and E Anatolian Faults (Şengör *et al* 1985; Dewey *et al* 1986; Bozkurt 2001).

The Adana–Cilicia Basin is actually a portion of the former, much larger, Çukurova Basin complex, which also includes the Iskenderun–Latakia trough and the intervening Misis–Kyrenia structural high (figure 1), which demarcates the southern boundary of the Adana–Cilicia structural depression. The western boundary of Çukurova basin is represented by a steep, dissected internal slope (underlined by the Anamur–Kormakiti basement high), separating the Cilicia trough from the deeper Antalya Basin. Morphologically defined by the boundaries specified above, the Cilicia Basin has a submerged area extent of some 15,000 km². It is characterised by relatively narrow shelves to the north and south, with the wide Seyhan delta-front platform to the east. The slope sectors (commencing at around 200 m water depth) are comparatively wide and constitute around 20% of the total area.

The Turkish slope appears to be significantly more dissected and transected by canyons and gullies, compared to the relatively smoother slope of northern Cyprus (Evans *et al* 1978; Hooker 1981). The basin floor lies generally around 800–1000 m depth. The offshore Cilicia Basin continues north-eastwards under the plains of the Seyhan Delta which represents the youngest part of the fill of the Adana Basin, the subsidence history of which appears to have been initiated in the late Oligocene or earliest Miocene (Kelling *et al* 1987). At present, Adana Basin is separated from the broadly coeval Mut Basin to the west (figure 1) by the important Ececi Fault lineament.

The nature and origin of the Adana–Cilicia Basin has evoked some recent debate, mostly based upon the assessment of regional seismicity or plate kinematic consideration. Recent geodetic measurements in the region (e.g., Le Pichon *et al* 1995; McClusky *et al* 2000; Kahle *et al* 2000) indicate (a) that there is a relatively small convergence rate between Anatolia and Africa along the Cyprus Arc (e.g., rates of about 7 mm/yr according to McClusky *et al* 2000), (b) that the plate interaction occurring there is more oblique ENE–WSW than normal to the boundary and (c) that the pole of rotation describing this interaction is relatively near (possibly as close as 600 km to the south), in keeping with the apparent deformation rates. This confirms marine observation (Woodside *et al* 2002) from the eastern Cyprus Arc which indicates

Figure 2. The figure above is general bathymetry of the study area (Aksu *et al* 2005). In the figure below, track-lines for seismic reflection profiling programmes on 1988 and 1989 cruises of R/V K. Piri Reis are shown.

broad, relatively undeformed (Vidal *et al* 2000) zones separated by narrow corridors of transpressive shearing (Ben Avraham *et al* 1995). Adana–Cilicia Basin has been described as a marginal trough associated with plate collision (Biju-Duval and Montadert 1977; Vidal *et al* 2000), as part of forearc-basin complex (Jackson and McKenzie 1984). This basin is a possible major pull-apart associated with an extension of the East Anatolian Transform (Dewey *et al* 1986) or as an incongruous feature in the region, generated after formation of the Kahramanmaraş Triple junction and related to westwards tectonic escape of Anatolia (Sengor *et al* 1985). Onshore studies of the Misis Complex (Kelling *et al* 1987; Gokcen *et al* 1988) have suggested a complex geotectonic evolution for the Adana Basin, involving an early phase of peripheral foreland basin development succeeded in the late Miocene/early Pliocene by a transtensional regime generated during the westward tectonic escape of Anatolia and following inception of the Kahramanmaraş triple junction (Sengor *et al* 1985).

However, the role of the offshore Adana–Cilicia Basin in these geotectonic scenarios remains

poorly defined and therefore a marine geological research programme has been designed to address this question, and specifically, to investigate the tectono-stratigraphic framework and neotectonic processes which have governed the evolution of the Adana–Cilicia Basin, especially the northern and western margins of that trough. The data reported here are derived from the two cruises undertaken by the R/V K. Piri Reis belonging to the Institute of Marine Science and Technology of Dokuz Eylül University, Izmir, in 1988 and 1989. Some 850 km of geophysical survey lines were compiled on these cruises (figure 2).

Position locations were achieved using satellite navigation. Single channel seismic reflection profiling was undertaken with the aid of an EEG PAR-600 airgun (40 cubic inch) with a pulse-rate of 2 seconds, towed at a depth of 2–3 m. Signals were received with a Benthos 460 streamer, which is single channel with 6 parallel hydrophone and 10 m length, and processed through a Khron-Hite 3700 band-pass filter into an EPC Graphic/tape recorder.

Figure 3. Line number 3 single-channel seismic profile (a) and interpreted line drawing (b) through the distal pro-delta region of the Seyhan Delta (see figure 2 for location), showing the upper part of the thick Plio-Quaternary sequence developed in this region. Note the array of faults and general progradational (divergent) character of Plio-Quaternary reflectors here.

2. Seismic stratigraphy

Within the relatively shallow-penetration profiles obtained in this study, three main reflector groups can be distinguished on the basis of relative depth, the nature and attitude of mutual contacts. These profiles indicate one-way travel time.

The shallowest reflector group (A) is characterised by close-spaced, sub-parallel reflectors, essentially concordant with the seafloor but locally

(especially in shelf and upper slope profiles) displaying internally divergent reflector geometry of progradational type (figure 3). Discrete slump-masses up to 50 ms (= 80 m) thick occur in this zone at several places near the base of the continental slope. The meniscoid pattern of near-seafloor reflectors described by Hooker (1981) as ‘giant ripples’ is patchily developed within the reflector group A on the Turkish shelf and uppermost slope south of Anamur. The thickness of the reflector group is highly variable. The average thickness

Figure 4. Line number 6 single-channel seismic profile across outer shelf, south of Silifke (see figure 2 for location), illustrating the condensed sedimentary succession seen below much of the Turkish shelf. E – erosional surface, probably separating unit A from unit B.

observed is around 80 ms on shelf profiles. The thickness diminishes in the morphologically rough inner shelf, immediately south of Silifke (figure 4). Unusually thick developments of group A occur: on the shelf and lower slope south of Anamur (northeast flank of the Anamur–Kormakiti structural high), the slope south of Ovacık, and the prodelta slope of the Seyhan Delta, south of Mersin (figures 3 and 4).

Reflector group B also comprises close-spaced, sub-parallel reflectors, sometimes disposed in alternating bundles of prominent and less distinct reflectors, a few tens of milliseconds thick.

These reflectors are everywhere warped or folded or affected by faulting, including faults and more brittle, through-going fractures (figures 4–7). The upper surfaces of this reflector group is usually in discordant contact with the base of group A, although a near-gradational passage between the two groups is observed in some slope-base and basin-floor profiles from the easternmost Antalya Basin, the deep Cilicia Basin south of Ovacık (figure 6) and from the diapiric zone in front of the Seyhan Delta (figure 5).

The geometry and dimensions of the folds affecting group B vary greatly, from gentle warps with

Figure 5. Single-channel seismic profile line number (4) across base of Seyhan Delta (see figure 2 for location), showing halokinetic deformation of upper Plio-Quaternary, including an emergent diapir and some faults.

Figure 6. Line number 7 single-channel seismic profile across upper Turkish slope south of Ovacık (see figure 2 for location). Note the several faults affecting the entire Plio-Quaternary (P–Q); tight folds locally developed in the older P–Q sequence; the discordant truncation of most of these folds against the substantial thickness of the post-Messinian succession here.

wavelengths in excess of 10 km and amplitudes of 60–70 ms (= 80–90 m) to relatively small, tight plications, a few hundreds of metres in wavelength and with amplitudes of average 12.5 ms (~ 20 m).

These folds appear to be associated mainly with the Seyhan diapir field (figure 5). Asymmetry of the major folds is not conspicuous but, where detectable, limbs of the larger folds generally face

Figure 7. Line number 5 single-channel seismic profile across major fault-complex (extension of Ecemiş lineament) SE of Silifke. Downslope thickening of the Plio-Quaternary (P-Q) and Quaternary (Q) is also evident.

to the north or northeast, and thus contrast with the south-facing comparable structures reported by Evans *et al* (1978) from the eastern part of the basin.

Reflector group C cannot be observed very clearly because of the insufficient acoustic energy of the seismic system performed for this study (figure 8). From this observation, the boundary between Group B and Group C is displaced by normal and reverse or thrust faults. In the deeper sectors of the western part of the study area (Antalya Basin and Anamur region) the geometry of the folded boundary is broadly concordant with the folds within reflector group B in the same region. However, further east of the shelf, slope profiles reveal some discordance between the deformation features observed in the two groups.

2.1 Stratigraphic correlation

The reflector group A (plio-Quaternary sediments) is discordant contact with the underlying group B. Both onshore and offshore boreholes in the vicinity of the Ceyhan and Goksu deltas have yielded Quaternary succession (Aksu *et al* 1992, 2005). Therefore, B reflector group must extend into

the Pliocene age. The Deep Sea Drilling Project (DSDP) and onshore exploration wells have determined that the age of the reflector correlatable to the top of unit C is of Messinian age (e.g., Hsü *et al* 1973; Ryan and Cita 1978; İşler *et al* 2005) and has demonstrated that in most of the Mediterranean region this reflector marks the top of a thick sequence. Group B in the Cilicia Basin is similar to the seismic signature of sequences encountered above the Messinian reflector in adjacent areas of the eastern Mediterranean, and generally ascribed to the main part of the Pliocene succession (Yalçın and Görür 1984).

Strata attributed to the Pliocene attain thicknesses of as much as 1600 m in oil exploration boreholes from the front of the Seyhan Delta (Rigassi 1971; Evans *et al* 1978), comparable to the 1070 m maximum thickness of Group B encountered in the same area during the present study.

As indicated above, the Messinian reflector indicates the upper limit of group C sequence. The group C sequence is represented by discontinuous reflector and scattered echoes (figure 8). The discontinuous reflector and scattered echoes may be because of the lower resolution of signal at greater penetration depth.

Figure 8. Line number 8 single-channel seismic profile across the northern end of the Anamur–Kormakiti buried structural high (see figure 2 for location). The Mes reflector (Mes reflector is the Messinian reflector and the top of unit C) at the southeast end of this profile can be traced below the floor of the adjacent Antalya Basin, but appears to be imbricated and stacked further east.

2.2 Structural aspects

The northern and central parts of the Adana–Cilicia Basin can be subdivided into three main regions, on the basis of shallow and intermediate structural features, which differ from east to west. These can be termed as the western, central and the eastern subregions. A major fault complex attributed to an offshore extension of the Ecemiş Fault separates the eastern portion from the

central, while the Anamur–Kormakiti structural high demarcates the western portion (figures 1 and 9).

2.2.1 Eastern sector

The eastern sector lies between the Misis–Kyrenia system and the Ecemiş Fault. Aksu *et al* (1992) described the Inner Cilicia Basin as the E–W trending structure that comprises of a complex array of

Figure 9. Map of geological and structural study area and adjacent areas. Sub-basins of Adana–Cilicia Basin. The general geology of the adjacent part of Turkey is also indicated (compiled from Gokcen *et al* 1988).

north- and south-dipping synthetic and antithetic listric normal faults where the detachment surface coincides with the base of the Messinian salt. They interpreted that the deeper outer Cilicia Basin is mainly controlled by salt diapirism, drawing from the Messinian evaporate sequence which was estimated to be at a thickness of 500 m (Bridge *et al* 2005).

This is characterised by:

- Deltaic sediments. This sector is described by a prograding wedge of deltaic sediments of the Seyhan river. These deltaic sediments can be observed over 100 ms in seismic lines 4 and 6. In this sector, a predominantly transparent sub-unit represents with weak and discontinuous parallel reflections (figure 5). This subunit is correlated to the early Pliocene Formation (Aksu *et al* 2005). The northern slope of the Cilicia Basin is mantled by Plio-Quaternary sediments resting upon a Messinian horizon. However, the Plio-Quaternary cover is thin to absent on the Turkish shelf.
- Prominent Diapirs and growth faults. This sector became emergent during the Messinian salinity crisis, and up to 1000 m of evaporates were deposited (Aksu *et al* 2005). Also in the eastern sector, Messinian displays erosional character and is probably represented by shallow marine

to terrestrial clastic facies. The folding and faulting (growth faults) in this sector are possibly related to the salt movement caused by loading by Seyhan sediments (figure 5).

2.2.2 Central sector

This sector lies between the marine extension of the Ececiş fault complex and the Anamur–Kormakiti buried structural high. The Messinian horizon can be traced throughout this region. In the Turkish shelf area, the thickness contours for the Plio-Quaternary sequence are generally E–W trending with only a thin development beneath, but rapidly thickening down slope and accompanied by large slump masses both at the present sea floor and buried in the older part of the sequence.

The fracture system in the eastern part of central sector is observed on the seismic sections (figures 6 and 7). The location and clear tectonic importance of the fracture system strongly suggests that it represents an offshore extension of the well known Ececiş Fault complex, which marks the present western limit of the onshore Adana Basin. This fault is considered to have been active since Palaeogene times (Yetiş 1984). However, the location and behaviour of the southwestern extension of this lineament is not very obvious (Demirtaşlı and Genc 1986; Akay and Uysal 1988).

Figure 10. Distribution of epicentre locations recorded during the period 1990–2006 in the vicinity of the Cilicia Basin ($M \geq 3$) (data obtained by Yakup Gezdirici, earthquake monitor-<http://www.gezdirici.net/eqmon>).

Regional seismic activity (figure 10) indicates that the Ecemiş lineament extends as a presently active seismo-tectonic feature in the area around Mersin and in the offshore area to the southeast of Silifke (Doyuran *et al* 1989). The major submarine fracture system identified in the present study is plausibly regarded as an offshore extension of the Ecemiş lineament. Its recent history confirms the continuing tectonic activity of this feature, at least in the southeastern portion (see figures 6 and 7).

2.2.3 Western sector

This comprises the northeastern portion of the Antalya Basin, including the intrabasinal slope connecting with the Cilicia Basin, which is underlined by the roughly N–S trending Anamur–Kormakiti basement high. This feature is buried beneath a significant thickness of P–Q sediments (it can be observed up to 180 m in seismic section in figure 8).

However, the overlying sediments display signs of folding in the area immediately east of the Anamur–Kormakiti high. Thus, the western boundary of the Cilicia Basin probably was related

to Mio-Pliocene compression, which was subsequently blanketed by Plio-Quaternary sediments, and later deformed by re-activation of this feature. It is noteworthy that the older structures of the Anamur–Kormakiti high appear to be truncated by the important E–W trending normal fault system, which at least locally affects the Plio-Quaternary sequences along much of the Turkish slope of the Cilicia Basin. West of Anamur the thick Plio-Quaternary sediments underlying the strongly dissected slope have been affected by N–S trending normal faults and display a block and graben morphology. According to İşler *et al* (2005), below the Antalya Basin the present-day structural framework of the Anamur–Kormakiti high is characterized by an imbricate fold-thrust system.

3. Conclusion

The Cyprus Arc comprises several distinct morphological domains: The Florence Rise and part of the Anaximander Mountains to the west, the island of Cyprus and the Kyrenia Rise in the east. From

the Pliocene to Recent, it has been mainly viewed as a convergence zone where the African plate is consumed beneath the Anatolian microplate. The Adana–Cilicia Basin which is located between the early Cenozoic Tauride belt and the narrow late Cenozoic Misis–Kyrenia (Cyprus) lineament, is a Neogene extensional structure formed within the broadly convergent setting of the northeast Mediterranean.

From the one-way travel time seismic section, three main seismic sequences can be distinguished within the northern submerged margin of the Cilicia Basin. These are separated by regional discordances, and three main structural domains can be distinguished:

- the eastern sector corresponding to the offshore Adana Basin dominated by halokinetic and growth-fault tectonics resulting from interaction of Seyhan delta progradation with a Messinian depocentre characterised by neotectonic extension;
- the central sector demarcated to the east and north by major fault complexes, both of which appear to be still active. The eastern fault system appears to be an offshore extension of the Ecemiş lineament. The NE–SW trending northern fault complex is associated with locally more intense deformation of the Plio-Quaternary, suggesting a transpressive kinematic regime here;
- the western sector comprises the northeastern portion of the Antalya Basin and includes a prominent NS-oriented structural high (Anamur–Kormakiti high) with a thick cover of Plio-Quaternary sediments. Below the Turkish shelf and slope this high appears to be formed by extensional/transensional faults of Early-Pliocene age (İşler *et al* 2005) and is truncated by the younger E–W trending border faults. Further west, the basin floor and northern slopes of Antalya Basin reveal halokinetic deformation, apparently related to N–S trending faults and local thrusts, indicating continued compressive deformation in this sector.

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